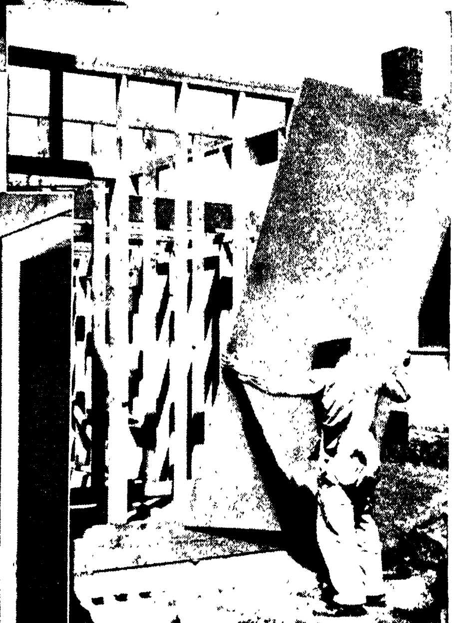
APPLICATION OF FILL INSULATION—GRANULATED ROCK WOOL (*Left*)

Courtesy of Celotex Corp., Chicago, Ill.

APPLICATION OF INSULATING BOARD (*Right*)

Courtesy of Insulite Division of M. & O. Paper Co., Minneapolis, Minn.



APPLICATION OF ROCK WOOL BATTS TO CEILING (*Left*)

Courtesy of Celotex Corp., Chicago, Ill.

PICTURE SHOWS APPLICATION OF CELL-U-BLANKET (*Right*)

Courtesy of Masonite Corp., Chicago, Ill.

BUILDING INSULATION

A Treatise on the Principles and Application of Heat and Sound Insulation for Buildings

By PAUL DUNHAM CLOSE, B.S.

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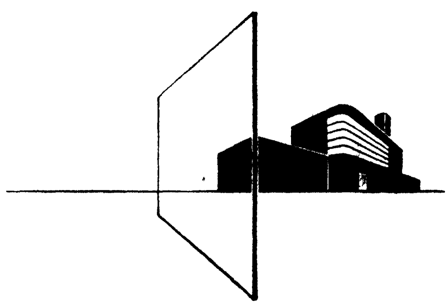

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PREFACE

HERE is a book to serve as a reference volume for those interested in the subject of heat and sound insulation for buildings. An effort has been made to cover the subject in such a manner that it will be useful and of practical value to the architect or engineer, to the manufacturer, to the dealer, to the insulation salesman and to the consumer who may be contemplating the construction of a new house or the remodeling of an old one. The scope of the subject matter is sufficiently broad that this book can be used in conjunction with architectural and engineering courses in colleges and universities, for the training of insulation salesmen, and by lumber and building supply dealers.

Perhaps no other phase of building construction involves so many controversial problems as insulation. The prospective home owner, with no previous knowledge of or experience with insulating materials used in conjunction with building construction, will invariably want to know what is considered to be the best insulation, or the best type, how much to use, where to apply it, what the saving in fuel will be, and many other facts.

If he asks six "authorities" he may get as many answers to each question. One reason for this is that there is no universally accepted method of rating insulations. Obviously there are many factors and conditions which must be taken into consideration in endeavoring to establish a preference as to the type of insulation; to determine the best there must be a measuring stick. The answers may be influenced by the experience (or lack of it) of the individual, by his likes and dislikes, by commercial interests, and by hearsay. The information given in this book should enable the prospective user of insulation to determine the type and thickness best adapted to his requirements, based on the specific conditions under which the material will be used. A sincere effort has been made to avoid discrimination, to treat all products fairly and without bias and to state the facts as they are known.

A brief history of the development of commercial insulations is given in Chapter I. Chapter II contains information regarding the various types of insulation now in use as well as the trade names and descriptive data of specific products. The general methods of application of these various types of insulation are given in Chapter III.

The theory of thermal insulation and the economics thereof begin with the fundamentals of heat transfer discussed in Chapter IV. The next logical step in the study of this subject is that of the all-important heat-loss coefficients of insulating and building materials, and compound wall and roof structures which will be found in Chapter V. The practical application of these coefficients is illustrated in Chapter VI dealing with the calculation of heat losses from buildings.

Chapters VII, VIII and IX treat with the economic phases of insulation such as the fuel saving derived from the use of insulating materials and the reduction in the size of the heating plant. The subject of insulating efficiencies discussed in Chapter X should be of particular interest, as it affords a percentage basis for evaluating the results obtained with various types and thicknesses of insulation. An important use of insulating materials is that of preventing sweating on interior wall and ceiling surfaces. This subject is treated in Chapter XI, which also includes information on the prevention of condensation within walls.

In many localities, particularly in warm climates, human comfort is the primary incentive for using insulation, and Chapter XII, on insulation and comfort, should be of interest to everyone concerned with this problem. Pipe and duct insulation is discussed in Chapter XIII. The deleterious effects of unwanted sound are well known. Chapters XIV, XV and XVI deal with three important phases of the sound-insulation problem and contain practical information for the solution of them.

During the more than four years the author served as Technical Secretary of the American Society of Heating & Ventilating Engineers, New York, he taught heating, ventilating and air conditioning at the Polytechnic Institute of Brooklyn. He was associated with the Celotex Corporation for more than ten years and the Johns-Manville Company for two and one-half years in various technical and sales capacities on building and refrigerating insulation, architectural acoustics and noise quieting. Since 1929 he has contributed numerous articles on insulation and heating to technical and trade publications including *Heating, Piping & Air Conditioning* and the American Society of Heating & Ventilating Engineers' Journal Section thereof, *Heating & Ventilating, American Architect, American Builder & Building Age,* and *American Artisan.* These articles have included various papers presented before the American Society of Heating & Ventilating Engineers.

The author served as a member of the American Society of Heating & Ventilating Engineers' Guide Publication Committee for five consecutive issues of the Guide. The heat transmission tables in the Guide 1944 were calculated by him. He is Chairman of the American Society of Heating & Ventilating Engineers' Technical Advisory Committee on Heating Load and is a member of the A.S.H.V.E. Technical Advisory Committee on Weather Design Conditions. He is also a member of the American Society for Testing Materials Committee C-16 on Thermal Insulating Materials, of which he is a sub-committee chairman.

The author is indebted to Mr. E. C. Lloyd of the Armstrong Cork Co., Lancaster, Pa., for his valuable comments and suggestions, to the various manufacturers who have supplied photographs, and to Mr. A. E. Burke for the art work on illustrations.

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LIVING ROOM FINISHED IN AN ATTRACTIVE DESIGN USING INSULATING BUILDING BOARD AND PANELLING

CHAPTER I

INTRODUCTION

Since the beginning of time one of the most important problems faced by man has been that of protecting himself against the extremes of weather. Primitive man learned to clothe himself in the skins of animals; he found shelter in caves or in crude huts; he learned to control fire and to put it to his own uses. From the very start man utilized some of the principles of insulation in his battles with the elements.

Derivation of the Word "Insulate". The verb "insulate" is derived from the Latin word *insula* meaning island. As defined in most dictionaries, to *insulate* means to isolate or place in a detached state, and an *insulation* or *insulator*, therefore, is a material that insulates—a non-conductor.

Heat and Sound Insulations. Insulating materials are commonly employed to insulate against electricity, heat, "cold" and sound. This book deals primarily with heat, "cold" and sound insulation as used in building construction. However, it is not technically correct to speak of *cold* insulation, since cold is simply the absence of heat. Therefore "cold" insulation is more correctly designated as *low temperature insulation* and will hereafter be referred to as such. Heat or thermal insulations, then, are divided into three classes, namely, (1) low temperature, (2) medium temperature, and (3) high temperature insulation.

The temperature of the space or substance to be insulated is the governing factor as to the classification of the insulation. There is no exact line of demarcation between these classes of heat insulation, but in general the distinguishing element is whether or not the temperature of the space (or substance) is suitable for human occupancy. In other words, if the room or space to be insulated is to be used for human occupancy, the type of insulation to be employed would be termed *medium temperature insulation,* more commonly known as *thermal building insulation,* or *building insulation,* or just *insulation.* On the other hand, if the space or substance is to be maintained at a temperature below that suitable for human occupancy, such as a cold storage building or a cold water pipe, the insulation employed would then be known as *low temperature insulation.* If the temperature to be maintained is above that suitable for human beings, as for an oven or a steam pipe, the insulation employed would be termed *high temperature insulation.* Aside from these three classifications based on the temperatures involved, heat or thermal insulations are classified according to their uses, such as wall insulation, roof insulation, pipe insulation, refrigerator insulation, oven insulation, etc.

Practical Definition of Heat Insulation. The dictionary definition, already given, of the verb "insulate" does not apply strictly to thermal or heat insulating materials, since no material will completely *isolate* heat. In other words, no known substance is an absolute heat stop, for no matter how efficient the substance may be there will always be some transfer of heat through it if there is a difference in temperature on the two sides. If the substance were several feet thick and were extremely efficient from the standpoint of heat resistance, there would be very little heat flow through it, but this heat flow would never be stopped 100% as long as it was warmer on one side than on the other.

Any solid material, however, will retard the flow of heat to some extent if it is sufficiently air-tight to prevent the air from actually blowing through it. Heavy, dense substances such as metals and certain masonry materials are usually inefficient, and do not retard the passage of heat effectively unless used in prohibitive thicknesses. On the other hand, lightweight substances containing a high percentage of air voids or interstices are, as a rule, efficient heat resistors and are, therefore, classified as insulating materials. These materials possess "concentrated heat resistance". A *thermal insulating material, therefore, is a material having a high degree of heat resistance per unit of thickness.* This definition applies to all commercial heat insulations, provided that with the reflective type, the necessary air space, which must always be associated with this material, is considered part of the thickness.

Purpose of Heat Insulation. The question is sometimes asked, "How much insulation is required to maintain a certain temperature, say 70°, when it is 0° outside?" The answer, of course, is that no insulation is required if enough heat is supplied, regardless of how poorly constructed the building may be. To heat such a building during cold weather may require an exorbitant quantity of fuel, and even then the heating results may be unsatisfactory because of drafts and lack of uniformity of temperature. But the fact remains that the building can be "heated" whether the structure is insulated or not, provided enough heat is supplied. *The primary function of the insulation in such cases is to permit the maintenance of the desired temperature economically.* This reasoning, of course, also applies to artificial cooling by refrigeration.

On the other hand, in the case of buildings which cannot be properly heated with existing heating equipment, the use of insulation in the walls, attic and other places may reduce the heat loss sufficiently to make it possible to maintain the desired temperature during the coldest weather. In retarding the passage of heat, thermal insulating materials also perform certain other functions such as the prevention of surface condensation (discussed in the chapter on Condensation) and the reduction in expansion and contraction of concrete, steel and other types of roof slabs.

Examples in Nature. There are many examples of insulation in nature (Fig. 1). Light, porous or fluffy materials such as fur, feathers, cotton, wool and straw, are efficient insulating materials. Dry snow is a good insulation. These substances have been used as natural insulating materials since the beginning of creation. The fur covering of the polar bear enables him to withstand the cold blasts of the Arctic regions and sleep on icy floes. Feathers and blubber similarly provide protection for birds and mammals.

Aside from purposes of modesty, the main reason for wearing clothing is for insulation. The purpose of clothing, of course, is to retard the loss of heat from the body. The proper amount of clothing from the insulation standpoint is that amount which will permit heat to be dissipated from the body at the rate at which it is produced. In warm weather the problem is to dispose of body heat and the less insulation (clothing) the better.

Insulated Dwellings Not New. Even insulated dwellings are not new. Natural substances have been used by primitive peoples for ages to keep the heat in or out. For example, the thatched hut of northern Europe with a roof of two feet of straw woven together, and with thick walls of clay and straw, was well insulated. The south sea islander keeps cool in a thatched hut constructed of dried sea grass. The hollow fiber of the grass, which is a natural insulation, protects him from the sun.

Similarly the Spanish Mission houses of the southwest desert, where the temperature sometimes rises to 140° in the daytime, were always comparatively cool because the walls were constructed of

Fig. 1. Examples of Insulation

several feet of clay and straw. While clay is not regarded as an insulating medium, if used in a sufficient thickness it will provide a well-insulated structure, especially when straw is used as a binder. In contrast, the Eskimo constructs his winter dwelling of snow blocks because snow, which contains millions of entrained air cells, is an excellent insulation. While these people had no knowledge of the principles of insulation, they became aware by trial and error of the value of certain materials to keep the heat in or out of their dwellings.

There are also many recorded instances of the application of cork for insulating purposes prior to the development of commercial insulations. Pliny in the first century of the Christian era referred to the use of cork as a covering for roofs. The peasants of Spain lined their stone houses with cork bark to make them easier to heat and to prevent the precipitation of moisture on the masonry walls. North African natives used cork mixed with clay for the walls of their dwellings, and slabs of cork as roof tiles. Powdered cork was used in Europe as the basic heat-resisting element of a plastic composition applied to steam pipes and hot surfaces in general to prevent the escape of heat. Molded cork pipe covering is still used extensively, especially for low temperature insulation. In tropical countries, cork-lined hats and helmets have long served as protection against the intense heat of the sun.

Development of Commercial Insulations. While physical scientists have been aware of the advantages of heat and sound insulation for centuries, it has been only within the past 20 or 25 years that civilized people generally have begun to realize the importance of insulation. Much of this has been due to the promotional and advertising activities of manufacturers of commercial insulations. It has likewise been during this period that the greatest development in insulating materials has taken place. The cold storage field also had a profound influence on the development of commercial insulations, as the materials originally used for cold storage purposes, such as sawdust, shavings and air-space construction, were found to be unsatisfactory when mechanical refrigeration was introduced and lower temperatures maintained.

Obviously the crude materials used by our ancestors were not suitable for modern construction; nor was it feasible or economical to use excessive thicknesses of noninsulating materials to obtain adequate insulation. Materials had to be developed which were not only highly efficient from the standpoint of heat resistance, but which could readily be adapted to conventional methods of construction.

While the early facts concerning the commercial developments of insulating materials are somewhat obscured, it appears that the so-called blanket type of insulation was one of the first of these products to be manufactured in the United States. This product—Cabot's Quilt—was introduced by Samuel Cabot, Inc., of Boston, Mass., in the year 1891 and is still extensively used. It consists of a matting of Zostera Marina, a marine plant, stitched between two layers of kraft paper. The old Pierce House in Dorchester, Mass., built in 1635 and one of the oldest houses in America, was insulated with Zostera Marina stuffed between the studding.

According to the National Mineral Wool Association, the first mineral wool was produced commercially in Wales in 1840 and was used largely at that time as an insulator for boilers and steam pipes. Later, according to this source, it was produced in Germany as a tinsel for Christmas trees and for other decorative purposes. The following statement on the development of this type of insulation appears in a catalog of the General Insulating & Manufacturing Co., Alexandria, Ind., (now owned by the National Gypsum Co., Buffalo, N.Y.):

> In about the year 1901 a plant operating in Alexandria, Ind., produced, among other things, an unrefined form of rock wool material. Ultimately, all other lines of manufacture were discontinued at this plant and its entire facilities were devoted to the production of insulating materials made from rock wool. Originally known as the American Insulating Company, it was some few years later changed to the General Insulating & Manufacturing Company, at which time rock wool exclusively was produced at this plant under the direction of C. C. Hall. Mr. Hall produced the first such material made in Indiana in about 1897. At this time he was a chemical engineer for a steel plant at Alexandria, Ind. The General Insulating & Manufacturing Company began manufacturing rock wool under its trade name of Gimco Rock Wool in about 1912 and has been in practically continuous operation since that date.

According to *Cork Insulation*, by P. E. Thomas, the manufacture of corkboard was started about the year 1890 when the German firm of Grunzweig & Hartmann acquired patents in Germany and in the United States for impregnated corkboard which was used mainly for cold storage purposes. The United States patent rights for this insulation were acquired by the Armstrong Cork Company, about the year 1900, following which a plant was established in Beaver Falls, Pa., for the manufacture of this product. Subsequently the manufacture of impregnated or composition corkboard was superseded largely by pure corkboard.

Much of the early development of the insulation industry in the United States took place in Minnesota. The cold winters of that area, together with the fact that many enterprising individuals identified with the early development of the insulation industry came from this locality, served to develop an appreciation and demand for proper insulation which preceded such demands in other localities.

Structural Insulating Board had its inception in Minnesota in 1914 with the production of a wood pulp product known as *Universal Insulite* (later re-named *Insulite*), made at International Falls by the International Insulation Company (now the Insulite Company). The Homasote Company of Trenton, New Jersey, however, marketed a somewhat similar product in 1908. In 1920, the Celotex Company introduced an insulating board made from bagasse or sugar cane fiber. Four years later, the Wood Conversion Company entered the field, followed in rapid succession by other large concerns.

One of the most recent types of insulation to be developed is the reflective. The first patents on the use of bright metallic surfaces for thermal insulation were issued in 1804 and although patents have been issued periodically since that time, this type of material has been developed commercially only within the past few years. Aluminum is the most widely used metallic reflective material on the market at the present time. The Aluminum Company of America has been largely instrumental in sponsoring the utilization of this insulating principle, aided, however, by the Reynolds Metal Corporation, the Alfol Company and others.

The individuals and concerns referred to in the preceding historical outline have for the most part been those identified with the early development of the various types of products discussed. There are, of course, many other American and foreign companies and scientific laboratories which have had an active part in this matter, but it would obviously be impossible to take cognizance of every factor entering into the historical development of insulating materials in America and abroad. However, information regarding many of the products now on the market is given in the chapter on Thermal Building Insulations.

RECREATION ROOM FINISHED WITH INSULATING BOARD INTERIOR FINISH PRODUCTS
Courtesy of Insulite Division of M. & O. Paper Co., Minneapolis, Minn.

CHAPTER II

TYPES OF THERMAL BUILDING INSULATIONS

This chapter deals with descriptive information relative to commercial heat-insulating materials used primarily for wall, floor, ceiling, and roof insulation in all types of buildings. Many of the heat-insulating materials discussed in this chapter also have a satisfactory degree of sound-insulation and some are also efficient sound-absorbing materials. Therefore, they are suitable for acoustical correction and noise quieting. The subjects of Sound Insulation and Architectural Acoustics and Noise Quieting are covered in later chapters.

Definition of Thermal Building Insulation. In considering the subject of commercial thermal building insulation, the question naturally arises as to what constitutes an insulation, or how such a material is defined. As stated in the previous chapter, a thermal-insulating material is such because it possesses concentrated heat resistance or has a high degree of heat resistance per unit of thickness. These statements are general and do not permit an exact differentiation between insulating materials and noninsulating materials.

Two requirements are necessary in order for a material to rate as an insulation, namely: (1) it must have a low heat conductivity; that is, a high degree of heat resistance per unit of thickness, and (2) it must be installed in an adequate thickness. To comply with the first requirement the material should have a conductivity not to exceed 0.50 B.t.u. per hour per square foot per degree Fahrenheit temperature difference per inch thickness. To comply with the second requirement the material must be installed in a thickness sufficient to provide a total heat resistance of the material (as installed) of not less than 1.0. Therefore, for the purpose of this discussion a *thermal insulation is defined as a proprietary (owned) manufactured building material having a rate of heat flow (conductivity) not to exceed 0.50 B.t.u. per hour per square foot per degree Fahrenheit per inch thickness as tested by an authoritative laboratory and which, when installed, shall have a total heat resistance of not less than 1.0.* The terms *conductivity* and *heat resistance* and *authoritative laboratory* are defined and explained in the chapter on Transmission Coefficients and Tables.

The exact meaning or interpretation of the foregoing definition may not be apparent until a study has been made of other chapters. Not all of the materials referred to by trade name in this chapter necessarily conform to this definition inasmuch as essential data on all materials sold as insulations are not available. Some materials on the market would definitely not qualify as an insulation either because the conductivity is too high or the commercial or installed thickness is insufficient. However, many materials having slightly higher con-

Fig. 1. Loose Rock Wool

ductivities than 0.50 are customarily used in a sufficient thickness so that a heat resistance of 1.0 or greater is obtained. Therefore, such materials in effect meet the requirements of an insulation but are not classified as such because of the higher conductivity. A material having a conductivity of 0.50 (per inch) requires a ½-inch thickness as installed to meet the minimum requirements of the definition.

Reflective insulations which depend entirely upon surface characteristics and not upon thickness may be embraced within this definition provided the necessary air space with which reflective insulations must be associated (as explained elsewhere in this book) is considered a part of the thickness. An air space bounded on one or both surfaces with a reflective insulation and having a conductance of 0.50 or less meets the requirements of this definition.

Insulation Classification. Commerical thermal building insulations as defined previously may be classified as: (1) loose fills; (2) blanket insulations; (3) bats; (4) structural insulating board; (5) slab, or block, insulations; (6) reflective insulations; and (7) miscellaneous.

LOOSE FILL INSULATIONS

Bulk materials, which are generally sold in bags and poured in place (or hand packed) between the structural framing members, are known as *loose fill insulations*. This type of material may also be applied mechanically by a pneumatic or *blown-in* process, the latter method being that commonly used in the case of old buildings. Details of application of all types of insulating materials are given in the chapter on Methods of Application.

Fig. 2. Granulated Rock Wool

Loose fill insulations are of three types, namely: (1) fibrous; (2) granular; and (3) powdered. These may be subdivided further as follows:

1. Fibrous Loose Fill Insulations
   a) Mineral wool
      1) Rock wool
      2) Glass wool
      3) Slag wool
   b) Vegetable—Wood fiber wool
2. Granular Loose Fill Insulations
   a) Mineral—Vermiculite
   b) Vegetable—Granulated cork
3. Powdered Loose Fill Insulations
   a) Mineral—Gypsum, diatomaceous earth, and various other types

1. Fibrous Loose Fill Insulations. Loose fill insulations are made from either mineral or vegetable substances. Mineral wool insulations in fibrous loose fill form include *rock wool*, *glass wool*, and *slag wool*.

The vegetable wool insulations in fibrous loose fill form include lightweight fleecy materials made primarily from wood fiber.

Rock Wool. The basic rock used in the manufacture of a typical rock-wool product is known technically as an *argillaceous limestone* or *calcareous shale.* This material is composed usually of silica, aluminum, calcium, magnesium, and other miscellaneous substances. The quarried rock is conveyed to a rock-wool cupola which is a cylindrical furnace, about 5 feet in diameter and 10 feet high, cooled by means of a water jacket. The cupola is charged with alternate layers of rock

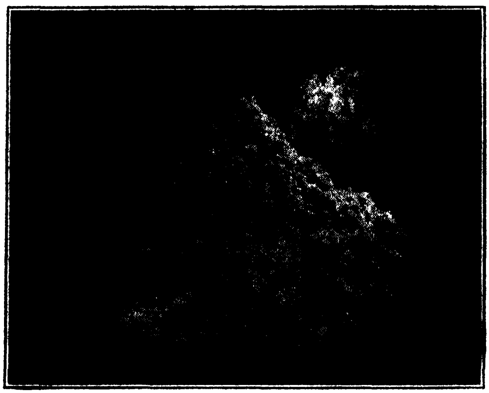

Fig. 3. Nodulated Glass Wool
Courtesy of Owens-Corning Fiberglas Corp., Toledo, Ohio

and coke, introduced at the top of the cupola. The rock is melted by the intense heat generated by the coke, which is burned under a forced draft, the melting temperature of the rock being approximately 2800° F. The molten rock flows from a port near the bottom of the furnace. As it leaves the furnace the molten rock is shredded by a blast of steam which also carries the beads or shot and streamers of wool (similar to a comet and its tail) into large annealing chambers. The rock-wool fibers are formed as they pass through the air from the steam blast into the annealing chamber, which is a long narrow room, the floor of which is an endless belt. A felting process is used in the production of blankets and bats, and in some cases certain additional special treatments are employed.

Rock wool is supplied in the natural fibrous state as loose wool, Fig. 1. It is supplied also in granulated or nodulated (pellet) forms,

Fig. 2. Loose rock wool is commonly used for hand packing, and granulated rock wool is poured from the bag between the framing members or applied pneumatically. According to one manufacturer, a 35-pound bag of loose rock wool covers an average of about 17 square feet, applied about 4 inches thick; and a 35-pound bag of granulated rock wool covers about 20 square feet, applied to the same thickness. To prevent settling, rock wool should be applied in side walls to a density of at least 6 pounds per cubic foot. Rock wool is also fabricated into blankets and bats.

Fig. 4. Glass Wool Being Applied by Blowing Process
Courtesy of Owens-Corning Fiberglas Corp., Toledo, Ohio

Glass Wool. Another insulating fill, known as *glass wool,* is made from silica and other ingredients by the Owens-Corning Fiberglas Corp., Toledo, Ohio (plant at Newark, Ohio) and sold for industrial uses under the trade name of *Fiberglas Insulating Wool.* It is distributed for domestic use by the United States Gypsum Co., Chicago, Illinois, under the trade name of *Red-Top Insulating Wool.* It is sold in bags in nodulated (granulated) and shredded forms. The nodulated wool (Fig, 3) is hand applied by pouring it from the bags and the shredded wool is applied mechanically, by the blowing or pneumatic process, as shown in Fig. 4. Glass wool is also fabricated into blankets and bats.

Slag Wool. This type of mineral wool is manufactured principally from lead, blast-furnace, or copper slag. A typical lead-slag wool is that made by the Eagle-Picher Lead Co., Cincinnati, Ohio, and sold under the trade name of *Eagle*, Fig. 5. The Baldwin-Hill Co., Trenton, New Jersey, uses lead slag in the manufacture of a mineral wool sold under the trade name of *B-H*. Blast-furnace and copper slags are also used to some extent. Slag wools are commonly designated as *mineral wools* and although this general term applies also to both rock

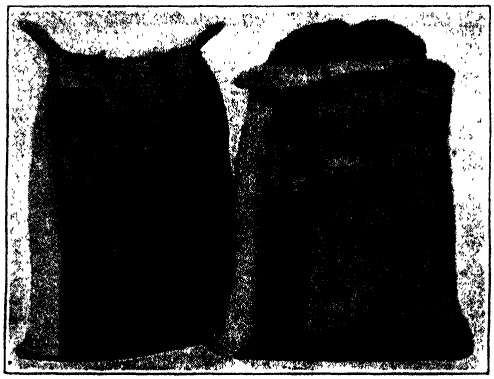

Fig. 5. Eagle Insulating Wool
Courtesy of Eagle-Picher Lead Co., Cincinnati, Ohio

and glass wool, the latter materials are usually designated specifically as *rock wool* or *glass wool* rather than by the general term *mineral wool.* Slag wools also are fabricated into other products such as bats and blankets.

Wood Fiber Wool Insulation. One of the principal materials in this classification is *Palco Wool* made from redwood bark by the Pacific Lumber Company, San Francisco, California. Another wood-fiber fill insulation is *Insul-Wool* made by Insul-Wool Insulation Corp., Wichita, Kansas. This type of insulation is generally advertised as nonsettling, odorproof, vermin-repellent, moisture-resistant, and durable. Some wood-fiber insulations are fabricated into blankets.

2. Granular Loose Fill Insulations. Fill insulation in this classification are of two principal types: (1) expanded vermiculite and (2) granulated cork.

Vermiculite. An inert, lightweight, granular insulating material known as *vermiculite* is manufactured by exploding an aluminum magnesium silicate mineral. This mineral, a form of mica, is composed of individual layers numbering approximately one million per inch. A minute amount of water separates the layers. When flakes of aluminum magnesium silicate are suddenly exposed to a high temperature in a furnace specially designed for the purpose, the water between the layers of material changes into steam causing the flakes of mineral to explode into cellular granules of vermiculite insulation about fifteen times their original size. The final product, graded into different sizes for various uses, includes building insulation, and lightweight concrete and plaster aggregates. This type of product is sold under various trade names, such as: *Masterfil, mica pellets, Unifill, Vermiculite, Wyolite,* and *Zonolite.* The Vermiculite Research Institute, an association of producers and manufacturers of vermiculite products, is located in Evanston, Illinois. Vermiculite granular-fill insulation is poured in place between the framing members as illustrated in the chapter on Methods of Application (Fig. 12). Expanded vermiculite or similar insulations are produced by various manufacturers or exfoliators listed below.*

Granulated Cork.[1] Although seldom used in ordinary building construction, granulated cork is used to a limited extent as a low-temperature insulation.

3. Powdered Loose Fill Insulations. The principal type of building insulation in this classification is composed of finely ground gypsum and is known as *dry fill insulation.* This is poured from bags into the spaces between the ceiling joists and wall studs. This product is sold under various trade names, such as *Gold Bond Dry Fill Insulation* (National Gypsum Company, Buffalo, N.Y.) and *Thermofill* (United States Gypsum Company, Chicago, Ill.). The trade names of many common loose fill insulations of various types are given in the following list.

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*Armco International Corporation, Middletown, Ohio; Dodson Manufacturing Co., Wichita 2, Kans.; Gladding, McBean & Co., Los Angeles 26, Cal.; Hutchison Lbr. Co., Oklahoma City 4, Okla.; F. Hyde & Company, Ltd., Montreal 29, Que., Canada; Insulation Industries, Ltd., Calgary, Alberta, Canada and Vancouver, B.C., Canada; Insulation Service Company, Albuquerque, N.M.; Intermountain Insulation Co., Salt Lake City 9, Utah; G. A. MacArthur Co., Minneapolis, Minn.; Mineral Products, San Antonio 5, Texas; B. F. Nelson Mfg. Co., Minneapolis, Minn.; Northwest Insulations Company, Spokane 12, Wash.; Robinson Insulation Co., Great Falls, Mont.; Universal Insulation Company of Northern California, Sacramento 1, Cal.; Universal Zonolite Insulation Co., Chicago 3, Ill. and Detroit 27, Michigan; Vermiculite Products Corporation, Washington 7, D.C.; Houston 2, Texas, and Kansas City 7, Mo.; Webster & Sons, Ltd., Montreal 2, Que., Canada; Western Mineral Products Co., Minneapolis 13, Minn.; Omaha 1, Nebr., and Milwaukee 4, Wisc.; Western Vermiculite Co., Denver 4, Colo.; and Zonolite Insulation Co., St. Louis 10, Mo.

LOOSE FILL INSULATIONS—TRADE NAMES

Trade Name	Manufacturer or Distributor	Basic Material
Airseal Mineral Wool...	Insulation Products, Ltd., Toronto, Canada	Mineral wool
Banroc...............	Johns-Manville, N.Y.C.	Rock wool
Barrett Rock Wool.....	The Barrett Co., N.Y.C.	Rock wool
B-H Rock Wool.......	Baldwin-Hill Co., Trenton, N.J.	Rock wool
Capitol Rock Wool.....	Standard Lime & Stone Co., Baltimore, Md.	Rock wool
Carey Rocktex........	Philip Carey Co., Cincinnati, Ohio	Rock wool
Carney..............	Carney Rock Wool Co., St. Paul 4, Minn.	Rock wool
Celotex Rock Wool....	The Celotex Corp., Chicago, Ill.	Rock wool
Century Mineral Wool..	Keasbey & Mattison Co., Ambler, Pa.	Mineral wool
Columbia Mineral Wool	United States Mineral Wool Co., Chicago, Ill.	Mineral wool
Denesen..............	The Denesen Co., Minneapolis, Minn.	Rock wool
Eagle Type H-1....... (Granulated)	The Eagle-Picher Co., Cincinnati, Ohio	Mineral wool
Eagle Type H-2 (Loose)	The Eagle-Picher Co., Cincinnati, Ohio	Mineral wool
Ehret Rock Wool Home Insulation...........	Ehret Magnesia Mfg. Co., Valley Forge, Pa.	Rock wool
Flintkote............	The Flintkote Company, N.Y.C.	Rock wool
Gimco...............	The National Gypsum Company, Buffalo, N.Y.	Rock wool
Gold Bond Rock Wool..	The National Gypsum Company, Buffalo, N.Y.	Rock wool
Gold Bond Dry Fill Insulation...........	The National Gypsum Company, Buffalo, N.Y.	Finely ground gypsum
Gyproc...............	Gypsum, Lime & Alabastine, Ltd., Toronto, Ontario, Canada	Rock wool
Homart Loose Rock Wool...............	Sears-Roebuck & Co., Chicago, Ill.	Rock wool
Homart Mineral Fill....	Sears-Roebuck & Co., Chicago, Ill.	Vermiculite
Insul-Fibre............	The Celotex Corporation, Chicago, Ill.	Rock wool
Insulroc..............	Rock Products Co., Nashville, Tenn.	Rock wool
Insul-Wool............	Insul-Wool Corp., Wichita, Kans.	Wood fibers
Johns-Manville Rock Wool...............	Johns-Manville, N.Y.C.	Rock wool
Masterfil..............	B. F. Nelson Mfg. Co., Minneapolis, Minn.	Vermiculite
Mica Pellets...........	F. E. Schundler & Co., Inc., Joliet, Ill.	Vermiculite
Mico.................	Mineral Insulation Co., Chicago, Ill.	Mineral wool
Nat Roc..............	National Rock Wool Sales, Inc., Lagro, Ind.	Rock wool
Palco Wool...........	The Pacific Lumber Co., San Francisco, Calif.	Shredded redwood bark
Pal-O-Pak............	Palmer-Wittkopp Co., Hartland, Wisc.	Chipboard and paper
Perfection.............	Riverton Lime & Stone Co., Riverton, W.Va.	Rock wool
Poeco................	C. W. Poe Co., Cleveland, Ohio	Rock wool
Porosil...............	Harris Bros. Co., Chicago, Ill.	Vermiculite
Red-Top Insulating Wool...............	United States Gypsum Co., Chicago, Ill.	Glass wool
Rocktex..............	Philip Carey Co., Cincinnati, Ohio	Rock wool
Ru-ber-oid Rock Wool Insulation...........	The Ruberoid Co., N.Y.C.	Rock wool
Salisco...............	Salem Lime & Stone Co., Salem, Ind.	Rock wool
Spun Rock Wool.......	Spun Rock Wools, Ltd., Thorold, Canada	Rock wool
Summit Rock Wool....	Ohio Valley Rock Asphalt Co., Louisville, Ky.	Rock wool
Therminsul...........	The Therminsul Corp., Kalamazoo, Mich.	Rock wool
Thermofill............	United States Gypsum Co., Chicago, Ill.	Powdered gypsum
Therm-O-Proof........	Therm-O-Proof Insulation Co., Chicago, Ill.	Mineral wool
Tomhave.............	Northern Home Improvement Co., Sandstone, Minn.	Rock wool
Unifil................	G. A. MacArthur Co., St. Paul, Minn.	Vermiculite
Union Rock Wool......	Union Rock Wool Corp., Wabash. Ind.	Rock wool
United States Wool....	United States Mineral Wool Co., Chicago, Ill.	Mineral wool
Ward Brand..........	Montgomery Ward & Co., Chicago, Ill.	Rock wool
Waukesha............	Waukesha Lime & Stone Co., Waukesha, Wis.	Rock wool
Western Rock Wool....	Western Rock Wool Corp., Huntington, Ind.	Rock wool
Wyolite..............	Wyolite Insulating Products Co., Cleveland, Ohio	Vermiculite
Zonolite..............	Universal Zonolite Insulation Co., Chicago, Ill.	Vermiculite

BLANKET INSULATIONS

Blanket insulations are a flexible type of insulation usually supplied in rolls, strips, or panels. These are made from various processed mineral and vegetable fibers, including mineral wool (rock, glass, and slag), wood fiber, cotton, eel grass (Zostera Marina), and cattle hair. The fibers in most cases are either naturally fire, moisture, and vermin-resistant, or are treated to render them so.

Fig. 6. Balsam Wool, a Blanket-Type Insulation
Courtesy of Wood Conversion Co., St. Paul, Minn.

Because of variation in these different products, the manufacturing processes vary considerably. However, blanket insulation may be considered as being of felted or wool-like mattings which are of two general types: (1) those having the fibers completely encased on all sides with kraft or other paper, one side of which is a vapor barrier, and (2) those which have no paper covering, the interlaced fibers having sufficient strength with or without stitching, to hold the material into a coherent matting or blanket.

Materials in the first classification often are provided with a nailing flange to conform to standard spacings of wood framing. Typical blanket insulations in this classification are shown in Figs. 6,

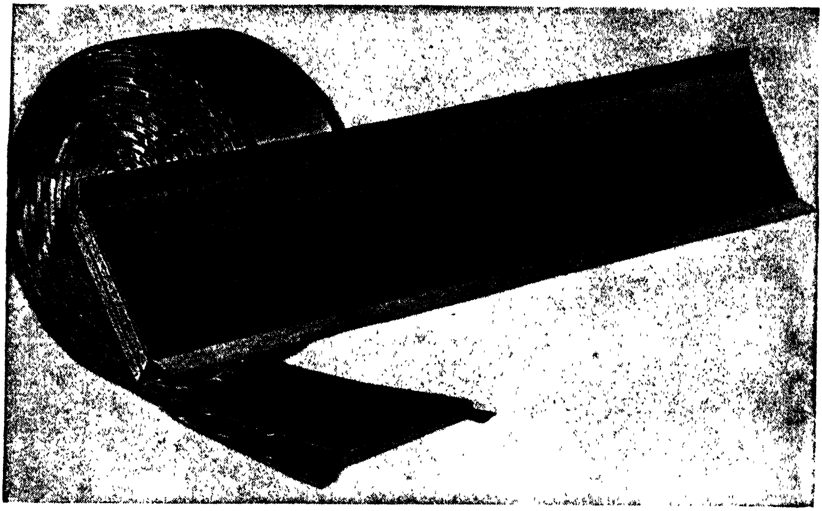


Fig. 7. Masonite Cell-U-Blanket; Ordinary Cell-U-Blanket in Roll; Double Efficiency Cell-U-Blanket in Panel Form
Courtesy Masonite Corporation, Chicago, Ill.

7, and 8. The most common thicknesses of blanket insulations are approximately 1 inch and 2 inches, although the nominal thickness is

Fig. 8. Red Top Insulating Blanket
Courtesy of United States Gypsum Co., Chicago, Ill.

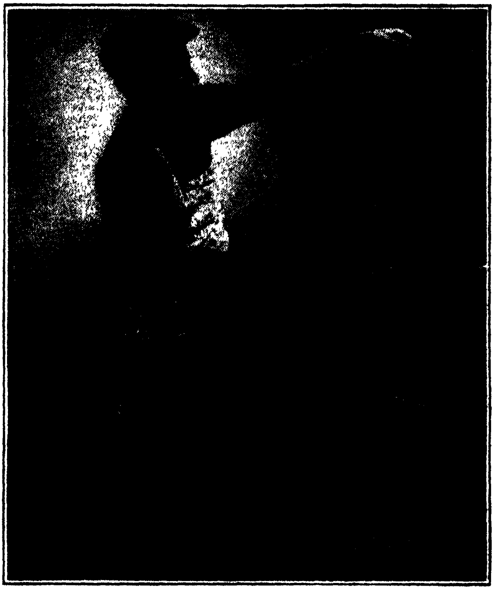


Fig. 9. Kimsul, a Blanket-Type Insulation
Courtesy of Kimberly-Clark Corp., Neenah, Wis.

not always specified but instead is referred to as *standard, commercial, double,* or by some other designation which is defined in each case. Blanket insulations of the second classification, which have no paper covering, are shown in Figs. 9 and 10. Trade names of many of the blanket insulations on the market are given in the list on page 20.

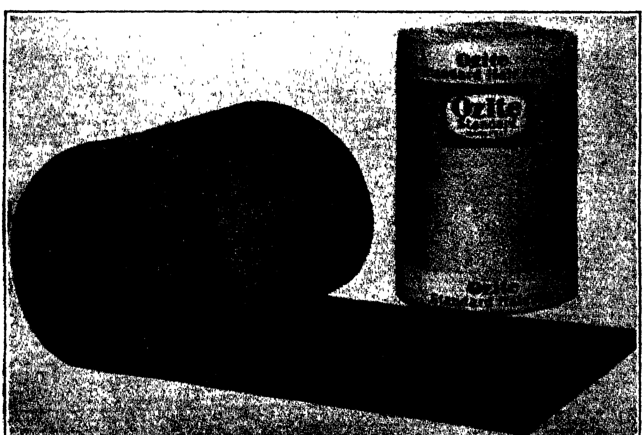


Fig. 10. Ozite All-Hair Building Blanket
Courtesy of American Hair and Felt Co., Chicago, Ill.

BLANKET INSULATIONS—TRADE NAMES

Trade Name	Manufacturer or Distributor	Basic Material
Anti-Pyre Quilt....	Samuel Cabot, Inc., Boston, Mass.	Eelgrass (a marine plant)
Asbestos Quilt.....	Samuel Cabot, Inc., Boston, Mass.	Eelgrass (a marine plant)
Balsam Wool......	Wood Conversion Co., St. Paul, Minn.	Wood fiber
B-H..............	Baldwin-Hill Co., Trenton, N.J.	Rock wool
Blan-Kets	Blandin Paper Co., Grand Rapids, Mich.	Layers of paper
Cabot's Quilt......	Samuel Cabot, Inc., Boston, Mass.	Eelgrass (a marine plant)
Cardinal Insulating Felt..........	American Hair & Felt Co., Chicago, Ill.	50% cattle hair—50% jute
Cell-U-Blanket....	Masonite Corporation, Chicago, Ill.	Wood fiber
Cellulite.......	Gilman Bros. Co., Gilman, Conn.	Cotton
Dry-Zero.........	American Hair & Felt Co., Chicago, Ill.	Kapoc
Eagle Blanket.....	Eagle-Picher Co., Cincinnati, Ohio	Mineral wool
Fiberglas.........	Owens-Corning Fiberglas Corp., Toledo, Ohio	Glass wool
Gold Bond Sealed Blanket.........	National Gypsum Co., Buffalo, N.Y.	Rock wool
Hairinsul.........	American Hair & Felt Co., Chicago, Ill.	Cattle hair or hair and jute
Insl-Cotton.......	Taylor Bedding Mfg. Co., Taylor, Texas	Cotton
Jiffy Blanket......	Jiffy Mfg. Co., Hillside, N.J.	Macerated paper between kraft paper
Kimsul...........	Kimberly-Clark Corp., Neenah, Wis.	Wood fiber
Lo-K	Lockport Cotton Batting Co., Lockport, N.Y.	Cotton
Multicell..........	Multicell Sales Corp., Minneapolis, Minn.	Layers of newspapers
Natur-temp.......	Barnhardt Mfg. Co., Charlotte, N.C.	Cotton
Ozite All-Hair Building Blanket.....	American Hair & Felt Co., Chicago, Ill.	Cattle hair
Palcozite Insulating Blanket.........	American Hair & Felt Co., Chicago, Ill.	Cattle hair—redwood bark fiber
Partemp..........	Firestone Tire & Rubber Co., Akron, Ohio	Cotton
Red Top Blanket..	United States Gypsum Company, Chicago, Ill.	Glass wool
Reyn-O-Cell.......	Reynolds Metals Co., Richmond, Va.	Cotton
Salisco............	Salem Lime & Stone Company, Salem, Ind.	Rock wool
Standard Cotton Insulation.......	Standard Cotton Products Co., Flint, Mich.	Cotton
Stonefelt..........	Johns-Manville, N.Y.C.	Rock wool
Tankinsul Insulating Blanket.....	American Hair & Felt Co., Chicago, Ill.	Cattle hair
Thermofelt........	American Hair & Felt Co., Chicago, Ill.	Cattle hair and asbestos fiber

BAT INSULATIONS

Bat insulations are similar to blankets except that the bats are usually smaller in size and thicker than blankets. Also, bats are made principally of mineral fibers. The most common thicknesses of bat insulations are approximately 2 inches and 3 inches although some blanket insulations, completely encased on all sides with paper, are available also in these thicknesses. Bats are commonly produced in small units in widths suitable for inserting between framing—usually about 15 inches wide for 16-inch framing centers and 23 inches for 24-inch framing centers—and of various convenient lengths ranging from about 8 inches to 48 inches. They may be plain (without paper on either side) as illustrated in Fig. 11, or with paper (vapor barrier) on

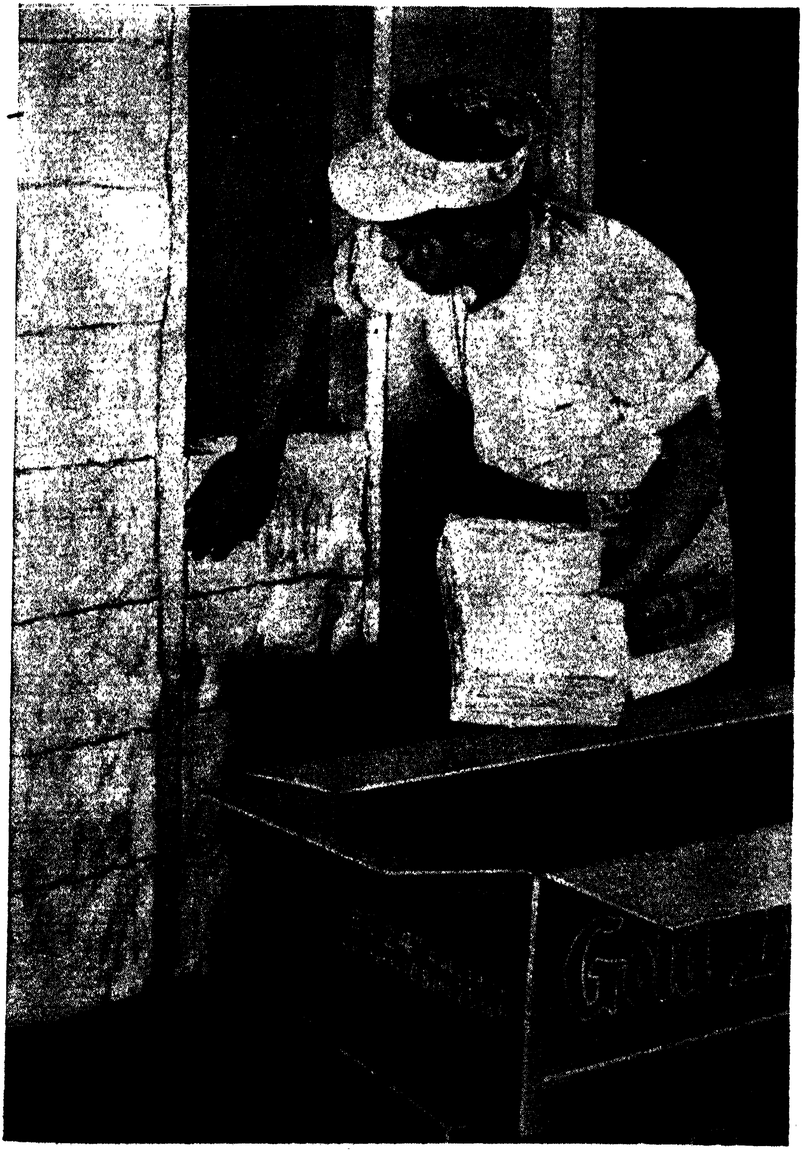


Fig. 11. Gold Bond Handi-Batts (Wall-Thick) Without Paper Liner
Courtesy of National Gypsum Co., Buffalo, N.Y.

one side only, as illustrated in Fig. 12. Bats with vapor barriers are recommended in preference to plain bats where vapor barriers are required. An exception to this rule is where the vapor barrier is likely to

Fig. 12. Rock Wool Bat with Vapor Barrier
Courtesy of National Gypsum Co., Buffalo, N.Y.

be in a position in the wall where it will be below the dew-point temperature at certain times, in which case a separate barrier as near the warm surface as possible should be installed. Trade names of many of the common bat insulations are given in the following list:

BAT INSULATIONS—TRADE NAMES

Trade Name	Manufacturer or Distributor	Basic Material
Airseal Mineral Wool	Insulation Products, Ltd., Canada	Mineral wool
Barrett Rock Wool Bats	The Barrett Co., N.Y.C.	Rock wool
B-H Rockwool Bats	Baldwin-Hill Co., Trenton, N.J.	Rock wool
Canasco Bats	Canadian Asbestos Co., Montreal, Quebec, Canada	Mineral wool
Carney Brand	Carney Rockwool Co., St. Paul 4, Minn.	Rock wool
Celotex Rock Wool Bats	The Celotex Corporation, Chicago, Ill.	Rock wool
Denesen	The Denesen Co., Minneapolis, Minn.	Rock wool
Dura Bats	The Flintkote Company, N.Y.C.	Rock wool
Eagle Bats	Eagle-Picher Co., Cincinnati, Ohio	Mineral wool
Ehret Rock Wool Bats	Ehret Magnesia Mfg. Co., Valley Forge, Pa.	Rock wool
Five-Point Mineral Wool	R. Laidlaw Lumber Co., Ltd., Toronto, Ontario, Canada	Mineral wool
Gimco	National Gypsum Company, Buffalo, N.Y.	Rock wool
Gold Bond Bats	National Gypsum Company, Buffalo, N.Y.	Rock wool
Gyproc Wool	Gypsum, Lime & Alabastine, Ltd., Toronto, Ontario, Canada	Rock wool
Handi-Bats	National Gypsum Co., Buffalo, N.Y.	Rock wool
Homart Rockwool Bats	Sears-Roebuck & Co., Chicago, Ill.	Rock wool
Insulroc	Rock Products Co., Nashville, Tenn.	Rock wool
Nat Roc	National Rock Wool Sales, Inc., Lagro, Ind.	Rock wool
Perfection Bats	Riverton Lime & Stone Co., Riverton, W.Va.	Rock wool
Red Top	United States Gypsum Co., Chicago, Ill.	Glass wool
Rocktex	Philip Carey Mfg. Co., Lockland, Cincinnati, Ohio	Rock wool
Salisco	Salem Lime & Stone Company, Salem, Ind.	Rock wool
Spun Rock Wool Bats	Spun Rock Wools, Ltd., Thorold, Ontario, Canada	Rock wool
Stud-Pak Wool	United States Mineral Wool Co., Chicago, Ill.	Mineral wool
Super-Felt	Johns-Manville, N.Y.C.	Rock wool
Tomhave	Northern Home Improvement Co., Sandstone, Minn.	Rock wool
Wal-Pac Pads	Ruberoid Co., N.Y.C.	Rock wool
Ward Brand	Montgomery Ward & Co., Chicago, Ill.	Rock wool
Waukesha	Waukesha Lime & Stone Co., Waukesha, Wis.	Rock wool

STRUCTURAL INSULATING BOARD

Produced in large units without knots or grain, *structural insulating board,* as the name implies, is a synthetic or manufactured insulating *lumber,* commonly known by the shorter term *insulating board.*

Insulating board is made by reducing wood, cane, or other vegetable fibers to a pulp and then re-assembling the fibers into boards. The methods of manufacture vary somewhat, but in general the first step is to reduce the raw material to a pulp, after which the fibers are washed and then waterproofed, or otherwise treated. Some manufacturers also introduce a cooking process. The next step is the felting process by which the loose fibers are formed into large cohesive boards, Fig. 13. The final steps are the drying and the removal of the water and the cutting and trimming of the board to the finished size. The natural interlacing and weaving of the fibers and their subsequent drying knit them firmly together and form a grainless board of relatively high tensile and compressive strength and stiffness.

The distinguishing characteristic of insulating boards is that they combine strength with heat and sound insulating properties. The

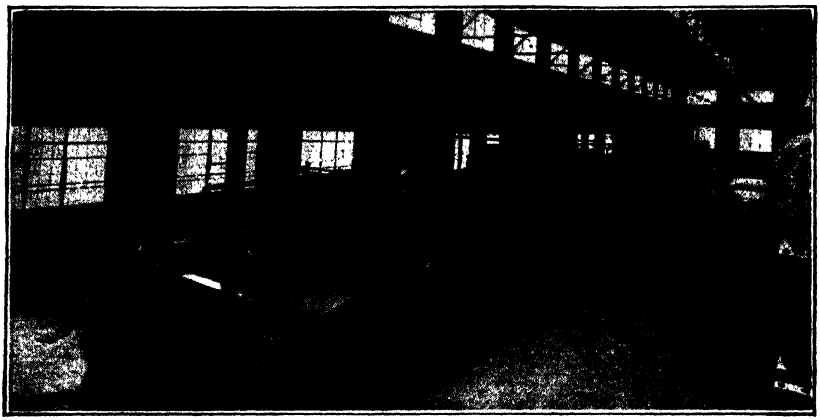


Fig. 13. Insulating Board Manufacturing Machine
Courtesy of Celotex Corp., Chicago, Ill.

properties of various structural insulating board products as reported in B.M.S.-13* of the United States Department of Commerce, National Bureau of Standards, are given in Table 1. Other B.M.S. publications of the Department of Commerce dealing with structural insulating board products are as follows:

B.M.S.-3 Suitability of Fiber Insulating Lath as a Plaster Base.

B.M.S.-4 Accelerated Aging of Fiber Building Boards.

B.M.S.-17 Sound Insulation of Wall and Floor Construction (plus supplement issued December 20, 1940).

B.M.S.-31 Structural Properties of "Insulite" Wall and "Insulite" Partition Construction Sponsored by the Insulite Company.

B.M.S.-42 Structural Properties of Wood-Frame Wall and Partition Construction with "Celotex" Insulating Boards Sponsored by the Celotex Corporation.

*Building Materials and Structure, Bulletin No. 13.

B.M.S.-50 Stability of Fiber Building Boards as Determined by Accelerated Aging.

B.M.S.-69 Stability of Fiber Sheathing Boards as Determined by Accelerated Aging.

Table I. Properties of Structural Insulating Board†

Board	Thickness, In.	Density, Lbs. per Cu. Ft.	Thermal Conductivity B.T.U. per Hr. per Sq. Ft. °F per In.	Flexural Properties[a] Breaking Load Lbs. Across Long Direction	Flexural Properties[a] Breaking Load Lbs. Across Short Direction	Flexural Properties[a] Deflection at Rupture, In. Across Long Direction	Flexural Properties[a] Deflection at Rupture, In. Across Short Direction	Water Absorption, by Volume (2-Hr. Immersion) per Cent	Water Permeability (Time of Penetration Through the Board), Hr.	Air Permeability (Rate of Flow Through the Board)[b]	Linear Expansion (for Increase from 50 to 95% Relative Humidity) per Cent	Nail-holding Strength (Lateral), Lbs.
Class I—½-inch Insulating Boards without Special Finish												
A....	0.49	16.9	0.35	14.3	11.3	0.72	0.76	5.7	25	454	0.15	74
B....	.50	16.2	.34	16.5	13.0	.60	.72	12.5	6	1084	.20	72
I....	.52	16.9	.36	25.4	18.0	.54	.64	5.5	30	505	.15	95
J....	.53	16.6	.34	20.6	15.6	.52	.68	7.9	21	498	.20	87
L..	.49	19.5	.37	12.7	12.4	.30	.31	6.0	26	3780	.10	64
M...	.51	15.7	.37	17.2	11.3	.52	.57	6.3	5	383	.10	67
N...	.47	16.5	.33	9.7	10.5	.50	.48	5.4	22	1215	.10	57
O...	.55	17.0	.33	12.2	11.4	.55	.50	6.8	25	2665	.20	87
R....	.48	18.2	.36	15.3	14.5	.98	1.05	5.3	5	479	.40	83
K...	.51	16.5	.37	10.5	12.1	.54	.57	4.2	5	700	.30	64
Class II—½-inch Interior-Finish Insulating Boards												
C....	0.47	21.0	0.39	14.4	14.0	0.61	0.89	5.1	26	676	0.35	72
D...	.48	16.9	.36	15.1	11.4	.83	.89	9.0	18	207	.30	79
P....	.46	20.7	.35	12.0	12.1	.77	.97	9.3	21	704	.40	94
R....	.49	18.3	.36	16.4	14.1	.98	1.10	5.6	5	339	.40	87
Class III—Insulation Sheathing												
E....	0.83	20.0	0.39	48.0	45.0	0.48	0.45	[c]	72	125	0.10	171
C....	.81	17.0	.38	37.8	28.2	.72	.69	[c]	168	0.001	.30	103

†Extracted from B.M.S.-13, U.S. Dept. of Commerce, Bureau of Standards, issued Feb. 23, 1939.
[a]Tests made under standard atmospheric conditions of 65% relative humidity and 70° F.
[b]Cu. cm. per sq. m. per sec.

Grams per sq. cm.

[c]Test not applicable to this class of boards.

The minimum average tensile strength of the building board as specified in Federal Specification LLL-F-321b and Department of Commerce Commercial Standard CS42-43 is 150 pounds per square inch. This product also effectively resists compression loads as well as

Table 2. Sizes, Thicknesses and Uses of Insulating Board Products

Product	Sizes	Thicknesses	Type of Edge	Major Uses
Building Board*	4 x 6 ft., 4 x 7 ft. 4 x 8 ft., 4 x 9 ft. 4 x 10 ft., 4 x 12 ft.	½", ¾", 1"	Square	General purpose structural insulating board; interior finish, base for plastic paints, wall coverings and other interior decorative finishes.
Sheathing	4 x 8 ft., 4 x 8½ ft. 4 x 9 ft., 4 x 9½ ft. 4 x 10 ft., 4 x 12 ft.	½", 25/32"	Square	Wall sheathing under siding, brick veneer, shingles or stucco, also as roof sheathing on pitched roofs under various types of roofing. Also to insulate floors of basementless houses.
	2 x 8 ft.	25/32"	Long edges fabricated†, short edges square	
Lath	16" x 48" 18" x 48" 24" x 48"	½", 1"	Long edges fabricated†	Insulating plaster base for walls, partitions and ceilings.
Roof Insulation	23" x 47" Note ‡	½", 1", 1½", 2"	Square edges on ½" thickness. Square edges and/or offset on 1", 1½" and 2" thickness	For roof insulation under built-up roofing on flat roofs and under certain types of roofing on pitched roofs. Floor insulation for masonry floors.
Tileboard (Panels)	8" x 8" 12" x 12" 12" x 24" 16" x 16" 16" x 32"	½", ¾", 1"	Fabricated edges†	Decorative, insulating wall and ceiling panels. Frequently used in conjunction with building board and plank.
Plank	Widths: 8", 10", 12" and 16" Lengths: 6', 8', 10', 12'	½"	Fabricated long edges†	Decorative, insulating wall and ceiling finish. Frequently used in conjunction with building board and tileboard (panels).

*Standard colors and finishes of Building Board are (1) natural finish on both surfaces and (2) one surface natural and the other with light colored finish such as white, ivory, cream or buff.

†Fabricated edges means any type of edge treatment other than square edges without reinforcement.

‡Also available in a 22" x 47" and other sizes.

transverse stresses. The sound-absorbing qualities render insulating boards valuable for acoustical correction and sound quieting as well as for reducing machinery noises.

The principal insulating board products are the building board, sheathing, lath, tileboard (panels), plank and roof insulation. The standard sizes and thicknesses of these products and their principal

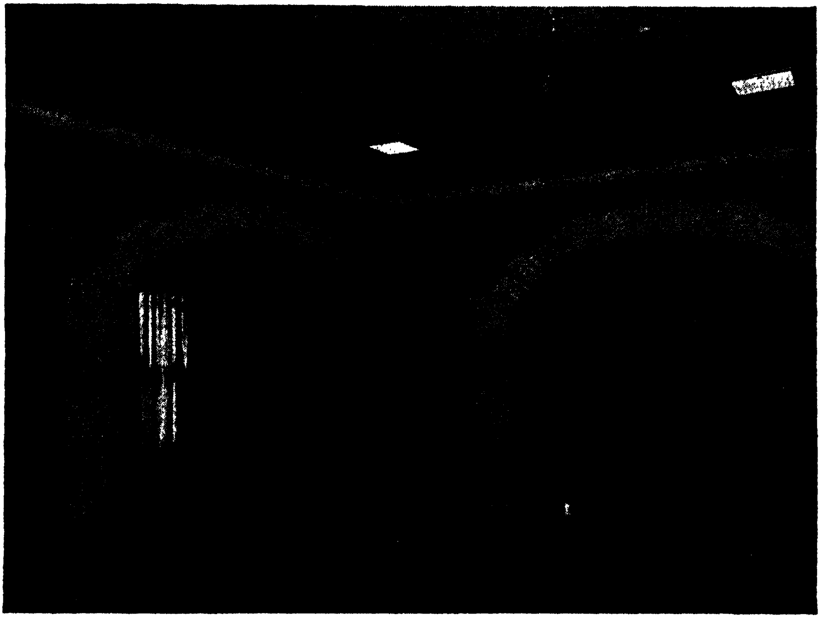


Fig. 14. Living Room Finished with Structural Insulating Board
(Courtesy of Wood Conversion Co., St. Paul, Minn.

uses are given in Table 2. The sizes and thicknesses in this table are those specified in the United States Government simplified practice recommendation R179–42.

Insulating Building Board. A general purpose product, insulating building board is produced in 4-foot widths and in various lengths. Edges are plain and square. Ordinarily it is ½-inch thick, although greater thicknesses are also available. Building board is produced with the natural finish on both sides and also with the natural finish on one surface and a light-colored finish, such as white, ivory, cream, or buff on the other surface.

The edges of the board may be beveled with a simple cutting tool to form a V-joint before it is applied. Other interesting decorative designs may be produced by cutting additional grooves. An interior view of a living-room showing the use of insulating building board and other interior finish products is shown in Fig. 14.

Sheathing. As the name implies, *sheathing* is used mainly for wall and roof sheathing (on pitched roofs) and because of the large units

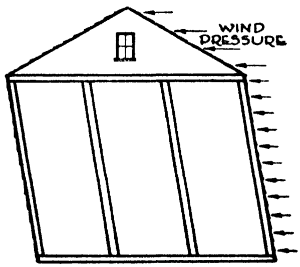


Fig. 15. Sheathing Removed from End; Building Distorted

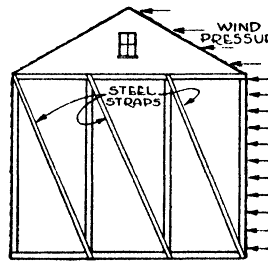


Fig. 16. Sheathing Removed from End; Diagonal Steel Bracing Straps under Tension; Building Not Distorted

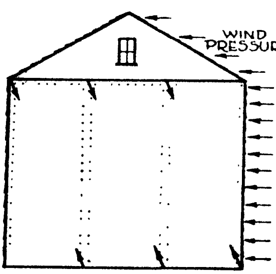


Fig. 17. Insulation Board Sheathing under Diagonal Tension. Same as Steel Straps in Fig. 16; Building Not Distorted

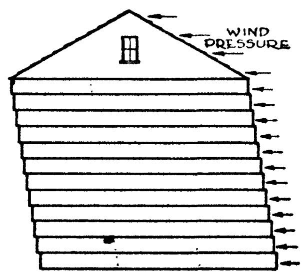


Fig. 18. Conventional Sheathing on Ends; Little Diagonal Bracing Obtained; Boards Tend to Slip Edge on Edge, Distorting Building

and tensile strength, provides a structure of exceptional strength and rigidity. According to tests conducted at the Forest Products Laboratory, Madison, Wisconsin, a wall sheathed with the 4-foot wide units of 25/32-inch insulating-board sheathing has a rigidity factor of 3.0 compared to a factor of 1.0 for a wall sheathed with lumber applied horizontally. The accompanying charts (Figs. 15, 16, 17, and 18) show why a wall sheathed with large units such as insulating board has such exceptional strength and rigidity. Many insulating-board sheathings are additionally waterproofed with asphalt by means of either a surface or an integral treatment.

The building board, tileboard (panels), and plank are used for interior finish. The tileboards are made from the same basic stock as the building board but they are produced in smaller square or rectangular patterns. The edges usually are beveled and so manufactured that they fit together smoothly and firmly.

Insulating board planks are long, narrow units produced in several widths and lengths. The long edges are beveled and, when applied in place, they fit together for greater rigidity. In addition to the regular bevel, the plank may be obtained with a narrow groove which produces a bead adjacent to each bevel. The planks may be applied either vertically or horizontally.

The lath, as the name implies, is used as a plaster base and is available in units 4 feet long and in 16-inch, 18-inch, and 24-inch widths. The thicknesses are ½ inch and 1 inch. Insulating-board lath is manufactured with special joints for reinforcing the plaster at the joints. The bond between insulating-board lath and plaster is about 1000 pounds per square foot or about 200 times the weight of the plaster. This type of lath eliminates lath marks (discussed in the chapter on Economics of Insulation) and minimizes plaster cracks.

Insulating-board products may be used to insulate roofs and may be installed in the ceiling or roof, or both. The interior finish products or the lath (and plaster) are used where the ceiling is insulated, whereas the sheathing or building board is used to insulate pitched roofs. The roof insulation board is used generally on flat roofs.

In addition to the standard insulating-board products listed in Table 2, there are also various specially fabricated materials using insulating board as a base or core. One of the most common of these is known as *insulated-brick siding*, which consists of insulating board with a facing which simulates brick and is made by embedding mineral granules in bitumen in the insulating board. Another product consists of an insulating-board core faced on both surfaces with asbestos-cement board.

Special products of various types, sizes, thicknesses, and densities are also fabricated for the automotive, refrigeration, and other industries.

The trade names of the insulating-board products of the members of the Insulation Board Institute appear in Table 3. A general alphabetical list of insulating-board products follows:

STRUCTURAL INSULATING BOARD—TRADE NAMES

Trade Name	Manufacturer or Distributor	Type of Fiber
Ankar Board	Ankarsviks Ångsågs A/B, Sundsvall, Sweden	Wood
Bildrite	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Bird	Bird & Son, Inc., East Walpole, Mass.	Wood
Canec	Hawaiian Cane Products, Ltd., San Francisco, Calif.	Cane
Celotex	Celotex Corporation, Chicago, Ill.	Cane
Colorkote	Fir-Tex Insulating Board Co., Portland, Ore.	Wood
Decoblend	Flintkote Company, N.Y.C.	Wood
Domster Board	Made in Sweden	Wood
Donnacona	Donnacona Paper Co., Donnacona, Quebec, Canada	Wood
Dubblseal Sheathing	Masonite Corporation, Chicago, Ill.	Wood
Enso Board	Enso-Gutzeit Company, Enso, Finland	Wood
Fiberlite	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Firkote Insulating Sheathing	Fir-Tex Insulating Board Co., Portland, Ore.	Wood
Fir-Tex	Fir-Tex Insulating Board Co., Portland, Ore.	Wood
Flintkote	Flintkote Company, N.Y.C.	Wood
Gold Bond	National Gypsum Company, Buffalo, N.Y.	Wood
Graylite	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
HiLite	United States Gypsum Company, Chicago, Ill.	Wood
Homasote	Homasote Co., Trenton, N.J.	Newsprint and vegetable fibers
Ins-Lite	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Insul-Board	Building Products, Ltd., Port Neuf, Ontario, Canada	Wood (laminated)
Insulite	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Ivrykote Building Board	Fir-Tex Insulating Board Co., Portland, Ore.	Wood
J-M Insulating Board	Johns-Manville Sales Corp., N.Y.C.	Wood
Kolorfast	Wood Conversion Co., St. Paul, Minn.	Wood
L-W Insulating Board	Ljusne-Woxna Company, Ljusne, Sweden	Wood
Lockaire (Formerly Maftex)	MacAndrews & Forbes, Camden, N.J. (sold by Plastergon Wall Board Co., Buffalo, N.Y.)	Licorice root
Lok-Joint	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Maftex	See *Lockaire*	Licorice root
Maizewood	Maizewood Insulation Co., Dubuque, Iowa	Corn stalks
Masonite	Masonite Corporation, Chicago, Ill.	Wood
Nu-Wood	Wood Conversion Co., St. Paul, Minn.	Wood
Palmatex	Palmatex Co., Pinellas Park, St. Petersburg, Fla.	Palm fiber
Satincote	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Smoothcote	Insulite Div. of M. & O. Paper Co., Minneapolis, Minn.	Wood
Sta-Lite Tile	Wood Conversion Company, St. Paul, Minn.	Wood
Temlok	Armstrong Cork Co., Lancaster, Pa.	Wood
Temseal	Armstrong Cork Co., Lancaster, Pa.	Wood
Ten Test	International Fiber Board, Ltd., Gatineau, Quebec, Canada	Wood
Thermasote	Homasote Company, Trenton, N.J.	Wood and others
Thermotex	A/B Varjag, Stockholm, Sweden	Wood
Torex	Torefors A/B, Tore, Sweden	Wood
Treetex	Mo and Domsjo Trading Co., Ornsköldsvik, Sweden	Wood
Weathertite	Johns-Manville Sales Corp., N.Y.C.	Wood
Weatherwood	United States Gypsum Company, Chicago, Ill.	Wood
Yamaska	Yamaska Mills, Inc., St. Pie, Quebec, Canada	Wood

Table 3. Structural Insulating Board

Trade Names by Type of Product*

Manufacturer	Building Board†	Sheathing	Lath	Plank	Tileboard (Panels)	Roof Insulation
Armstrong Cork Co., Lancaster, Pa.	1. Armstrong's Temlok Standard Insulating Board 2. Temlok DeLuxe	Armstrong's Temseal Insulating Sheathing	Armstrong's Temlok Insulating Lath	Armstrong's Temlok Plank DeLuxe	Armstrong's Temlok Panels DeLuxe	Armstrong's Temlok Roof Insulation
Bird & Son, Inc., East Walpole, Mass.	Bird Building Board	Bird 25/32" Sheathing				Bird Roof Insulation
Celotex Corporation, Chicago 3, Ill.	Celotex Building Board (No. 84)	1. Celotex Sheathing 2. Celotex Center Matched Sheathing 3. Celotex Asphalted Building Board	Celotex Lath	Celotex Finish Plank	Celotex Tile Board	1. Celotex Roof Insulation 2. Celotex Vapor-seal Roof Insulation
Flintkote Company, New York 20, N.Y.	Flintkote Building Board	1. Flintkote Sheathing Asphalt Sealed (25/32") 2. Flintkote Asphalt-Coated Sheathing (½")	Flintkote Insulation Lath	Flintkote Insulation Plank	Flintkote Insulation Tile Board	1. Flintkote Roof Insulation 2. Flintkote Cold Processed Roof Insulation
Hawaiian Cane Products, Ltd., San Francisco 5, Calif.	Canec Insulating Board	Canec Asphalt Sheathing	Canec Insulating Lath	Canec Insulating Plank	Canec Insulating Tile	Canec Roof Insulation
Insulite Div. M. & O. Paper Co., Minneapolis 2, Minn.	1. Ins-Lite Building Board 2. Graylite Building B'rd 3. Smoothcote Interior Board 4. Satincote Interior Board	Insulite Bildrite Sheathing	1. Ins-Lite Lok-Joint Lath 2. Graylite Lok-Joint Lath 3. Sealed Graylite Lok-Joint Lath	1. Ins-Lite Plank 2. Graylite Plank 3. Smoothcote Plank 4. Satincote Plank	1. Smoothcote Tileboard 2. Satincote Tileboard 3. Ins-Lite Tileboard 4. Graylite Tileboard 5. Fiberlite	1. Ins-Lite Roof Insulation 2. Graylite Roof Insulation
Johns-Manville Sales Corporation, New York 16, N.Y.	J-M Insulating Board	J-M Weathertite Sheathing	J-M Insulating Lath	J-M Bevel Plank	J-M Bevel Panels	J-M Rigid Roofinsul
Maizewood Insulation Co., Dubuque, Iowa	Maizewood Insulating Board	Maizewood Insulating Asphalt-Coated Sheathing	Maizewood Insulating Lath	Maizewood Insulating Plank	Maizewood Insulating Tile Maizewood Insulating Panel Strips	
Masonite Corporation, Chicago 2, Ill.	1. Masonite Insulating Board 2. Masonite Insulating Interior Finish Panels	1. Masonite Dubbleseal Sheathing 2. Masonite Asphalt Sheathing	1. Masonite Insulating Lath 2. Masonite Vapor-Barrier Lath	Masonite Insulating Beveled Plank	Masonite Insulating Beveled Tile	
National Gypsum Co., Buffalo 2, N.Y.	Gold Bond Standard Insulation	Gold Bond Fibre Insulation Sheathing	Gold Bond Fibre Insulation Lath	Gold Bond Insulation Plank	Gold Bond Insulation Tile	Gold Bond Insulation Roof Boards
United States Gypsum Co., Chicago 6, Ill.	Weatherwood Building Board	Weatherwood Asphalt-coated Sheathing	Weatherwood Plaster Base	1. Weatherwood HiLite Plank 2. Weatherwood Blendtex Plank	1. Weatherwood HiLite Tile 2. Weatherwood Blendtex Tile	Weatherwood Roof Insulation
Wood Conversion Co., St. Paul 1, Minn.	1. Nu-Wood Insulating Board 2. Nu-Wood Wainscot	Nu-Wood Insulating Sheathing	Nu-Wood Insulating Lath	1. Nu-Wood Sta-Lite Plank 2. Nu-Wood Kolor-Fast Plank	1. Nu-Wood Sta-Lite Tile 2. Nu-Wood Kolor-Fast Tile	Nu-Wood Roof Insulation

*Members of Insulation Board Institute, Chicago 2, Illinois. †Or interior board.

SLAB INSULATIONS

Slab insulations are small rigid units usually one inch or more in thickness and ranging in size up to about 24x48 inches or larger. Slabs are known also as *blocks* or *boards*. There are at present five general types of products in this classification, namely: (1) corkboard; (2) wood fiber and cement; (3) mineral wool with binder; (4) insulating board slabs; and (5) miscellaneous slab or board insulations which do not fall within any of these classifications.

Fig. 19. Stripping Bark from Cork Tree
Courtesy of Cork Insulation Co., New York, N.Y.

1. Corkboard Slabs. These slabs are made from the bark of the cork oak (*Quercus suber*) grown in the land contiguous to the western Mediterranean and comprising parts of Spain, Portugal, and Morocco. At periodic intervals, the trees are stripped of the bark, Fig. 19. After it is baled the bark is shipped to manufacturing centers in the United States and Europe.

In the manufacture of corkboard, the bark is first ground into ¼-inch to ¾-inch granules. These are placed in molds and hydraulically pressed to the required density. The molds are then placed in an oven for a period of time dependent upon the thickness of insulation involved, the cork granules being kept under compression during the baking process. The heat liquefies the gum or rosin which binds the granules together and also seals them, producing a solid slab of pure corkboard. No additional binding material is used nor is necessary.

The rough slab is then subjected to a finishing process which cuts it to commercial sizes, Fig. 20. The standard sizes of corkboard are 12x36, 18x36, 24x36, and 36x36 inches. The thicknesses are 1, 1½, 2, 3, 4, 5, and 6 inches.

Corkboard has a low conductivity and a high resistance to moisture and capillarity. It does not harbor vermin or germs and is free from offensive odors. It has sufficient structural strength so that it can

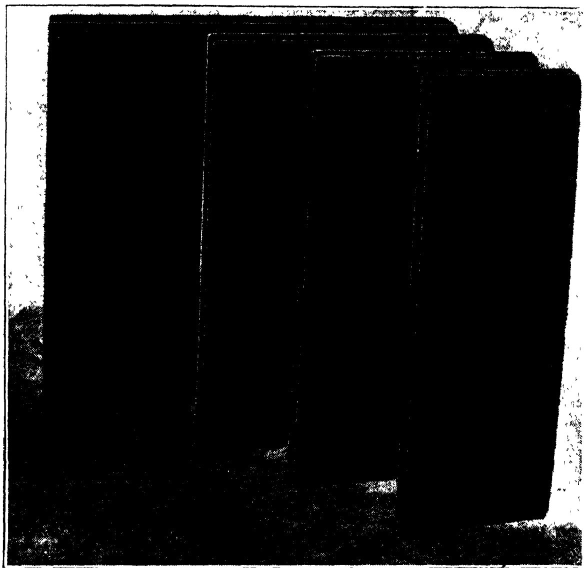


Fig. 20. Commercial Sizes of Corkboard
Courtesy of Armstrong Cork Co., Lancaster, Pa.

be handled and erected with ease, being sawed and nailed into place like lumber in frame construction, or set in Portland cement or hot asphalt against stone, brick, concrete, or hollow tile, on either walls or ceilings.

Corkboard is used for both heat and sound insulation but the primary use at present is for cold storage purposes. This type of insulation also is used extensively for roof insulation on flat roofs under built-up roofing, and to a limited extent as a plaster base. Special forms of corkboard are used for machinery insulation and acoustical correction. Molded cork is used for making pipe insulation.

The manufacturers of corkboard in the United States include the Armstrong Cork Company, Cork Import Company, Cork Insulation

Company, Inc., Mitchell & Smith, Inc., Mundet Cork Corporation, and the United Cork Companies. While the products of these concerns are similar, they vary somewhat as to their physical characteristics. Corkboard is purchased by the United States Government under Federal Specification HH-C-561a.

2. Wood-Fiber and Cement-Slab Insulations. Products of this type are made by combining long wood fibers or *excelsior* with either Portland cement or magnesite cement. They are produced in a single mechanical operation that shreds the timber into long fibers, passes these fibers through a binding solution of cement, then forms the mass into boards or slabs, 1, 2, or 3 inches thick and dries and cuts the product into various widths and lengths. The uses include roof deck insulation, floor and ceiling slabs, and nonbearing partitions.

A typical product of this type has an average density of 26.4 pounds per cubic foot and is said to be fire-resisting. The average ultimate load for a 3-inch thickness at a 24-inch spacing between supports is 345 pounds per square foot and for the 2-inch thickness on 16-inch centers is 500 pounds per square foot. The plaster bond is 316 pounds per square foot. Products in this category include *Thermax*, *Porex*, and *Porete*. A similar product sold under the trade name of *Heraklith* was made in Europe for many years.

3. Mineral Wool with Binder Slabs. Products of this type are made from both rock wool and glass wool. Rock wool slabs include Rock Cork (Johns-Manville) and Mineral Wool Board (Armstrong Cork Co.).

Rock Cork. Consisting of rock wool combined with wood pulp and an asphaltic binder, *Rock Cork* is furnished in standard sheets 18x38 inches and in thicknesses of 1, 1½, 2, 2½, 3, and 4 inches; also 18x18 inches in the 1-inch thickness. This product is used primarily for low-temperature insulation.

Glass Wool Slabs. This type of slab includes *Fiberglas PF Insulation* and *AE Board* (Owens-Corning Fiberglas Corp.). *PF Insulation* is used primarily for industrial requirements for temperatures up to 600° F. *AE Board* is made for use as a low-temperature insulation.

4. Insulating Board Slabs. Products of this type include low-density structural insulating board supplied plain; that is, without additional surface treatment, and with an impregnation, or coating, of asphalt. This type of insulation is sold primarily for low-temperature requirements and is made in sizes and thicknesses similar to those of corkboard.

5. Miscellaneous Slab or Block Insulations. These include Fesco Board, which is a slab made from vermiculite with an asphalt binder (F. E. Schundler & Co., Inc., Joliet, Ill.), Rubatex (Rubatex Corp., Richmond, Va.), and PC Foamglas (Pittsburgh Corning Corp., Toledo, Ohio). Trade names of some of the more common slab insulations are given in the following list:

SLAB INSULATIONS—TRADE NAMES

Trade Name	Manufacturer or Distributor	Basic Material
Airtite Corkboard (See Novoid)	Cork Import Co., N.Y.C.	Corkboard
Armstrong's Corkboard	Armstrong Cork Co., Lancaster, Pa.	Corkboard
Celo-Block	The Celotex Corporation, Chicago, Ill.	Cane fiber
Corkduc	Cork Import Co., N.Y.C.	Corkboard
Eagle Supertemp Block Insulation	Eagle-Picher Lead Co., Cincinnati, Ohio	Mineral wool
Fesco Board	F. E. Schundler & Co., Inc., Joliet, Ill.	Vermiculite-asphalt
Fiberglas AE Board	Owens-Corning Fiberglas Corp., Toledo, Ohio	Compressed glass fibers, asphalt enclosed
Fiberglas PF Insulation	Owens-Corning Fiberglas Corp., Toledo, Ohio	Compressed glass fiber with binder
Foamglas	Pittsburgh Corning Corp., Pittsburgh, Pa.	Glass
Jointite Corkboard	Mundet Cork Corp., Brooklyn, N.Y.	Corkboard
Mineral Wool Board	Armstrong Cork Co., Lancaster, Pa.	Rock wool, asphalt binder
Mitchell & Smith Corkboard	Mitchell & Smith, Inc., Detroit, Mich.	Corkboard
Naturzone	Wilson & Company, Chicago, Ill.	Hog hair and asphalt
Novoid	Cork Import Co., N.Y.C.	Corkboard
Porete	Porete Mfg. Co., North Arlington, N.J.	Wood fiber—Portland cement
Porex Slabs	Porete Mfg. Co., North Arlington, N.J.	Wood fiber—Magnesite cement
Rock Cork	Johns-Manville, N.Y.C.	Rock wool, asphaltic binder
Rubatex	Rubatex Corp., Richmond, Va.	Rubber
Thermax	The Celotex Corporation, Chicago, Ill.	Wood fiber—Magnesite cement
United BB Corkboard	United Cork Co., Kearny, N.J.	Corkboard
United States Royal Insulation Board	United States Rubber Company, Akron, Ohio	Rubber

REFLECTIVE INSULATIONS

Reflective insulations are distinguished from other types by the fact that they depend solely upon surface characteristics for their heat-resisting properties. Therefore, such materials to be effective must always be installed in conjunction with air spaces so that the reflective surface is exposed. An efficient reflective insulation must have a low emissivity (see chapter on Fundamentals of Heat Transfer), to be so classed. Bright metallic reflective surfaces such as aluminum foil have a lower emissivity (and therefore are more efficient) than nonmetallic reflective surfaces.

Reflective insulations are of four general types, namely: (1) aluminum foil; (2) aluminum foil-surfaced plaster board; (3) dull sheet steel; and (4) blanket or flexible insulations encased in paper with one or both exposed surfaces of reflective material.

Aluminum Foil. The aluminum-foil products include *Alfol,* Reynolds *Metallation,* and the various foil-surfaced plaster boards.

Alfol Insulating Blanket (Alfol Insulation Company, Inc., New York). This is a crimped blanket form of reflective insulation made in two types: Type 1 with a single layer and Type 2 with two *Alfol* layers. The widths of both types are 16, 20, and 24 inches. The net area per roll is 250 square feet, and the net weights are 17 and 19 pounds per roll respectively for Types 1 and 2.

Reynolds Metallation (Reynolds Metals Company, Inc., Richmond, Va.). Type *A* consists of heavy flat foil mounted with asphalt on both sides of kraft paper. Type *B* is similar to Type *A* but the foil is lighter in weight. Type *C* is similar to Type *B* but with foil on one side only. These products are supplied in rolls of 250 square feet in widths of 25, 33, and 36 inches. *Ecod Metal Lath,* which is a plaster base, consists of steel reinforcing wire backed with either plain kraft paper or "metalated" kraft paper.

Aluminum Foil-Surfaced Plaster Board. Several concerns supply aluminum-foil-surfaced gypsum wallboard, lath, and sheathing. Gypsum wallboard consists of a core of gypsum encased in a heavy waterproof building paper. It is furnished in large sizes, usually 36 and 48 inches wide by lengths ranging from 4 to 12 feet and thicknesses of ¼, ⅜, and ½ inch, and with various types of edges or joints. The insulating lath (plaster base) is a similar gypsum product with aluminum on one surface, which is available in two common sizes, 16x32 inches and 16x48 inches by 3/8-inch thick. The sheathing is generally 2 feet wide by either 6 feet 8 inches or 8 feet long by 1/2-inch thick, with or without tongue and groove along edges. Products of this type are supplied by various concerns, including Certain-teed Products Corporation, *Beaver Insulating Gypsum Lath* and *Metallized Bestwall Gypsum Board;* National Gypsum Company, *Gold Bond;* United States Gypsum Company, *Insulating Sheetrock*, *Insulating Rock Lath*, and *Insulating Gyplap;* and Mathieson Alkali Works, Inc.

Dull Sheet Steel. *Ferro-Therm* (American Flange & Manufacturing Co., Inc., N.Y.). This is a dull sheet-metal type of reflective insulation. The steel sheets are coated with an alloy of lead and tin for protection against corrosion. It is available in various sizes and weights or gauges. The sheets are packed 600 square feet to a box.

Some reflective-insulation trade names are given in the following list:

REFLECTIVE INSULATIONS—TRADE NAMES*

Trade Name	Manufacturer or Distributor	Description
Air-Met	H. D. Catty Corp., N.Y.C.	Air-Met Type IV consists of two sheets of aluminum. Air-Met Type II consists of one sheet of aluminum plus a sheet of heavy "vaporproof" paper.
Alfol	Alfol Insulation Co., Inc., N.Y.C.	Aluminum foil.
Beaver Insulating Lath	Certain-teed Products Corp., Chicago, Ill.	Reflective insulation consisting of Beaver gypsum lath with an aluminum-foil surface.
Ecod Metal Lath	Reynold Metals Co., Richmond, Va.	Plaster base consisting of steel reinforcing wire backed with metalated (aluminum foil) kraft paper.
Ferro-Therm	American Flange & Mfg. Co., Inc., N.Y.C.	Sheet steel reflective insulation.
Gold Bond Aluminum-Foil Insulation Board	National Gypsum Company, Buffalo, N.Y.	Standard Gold Bond Gypsum Board with aluminum-foil laminated to one side.
Gold Bond Aluminum-Foil Insulation Board	National Gypsum Company, Buffalo, N.Y.	Gold Bond Gypsum Lath on one side of which is laminated a sheet of aluminum foil.
Metallation	Reynolds Metals Co., Richmond, Va.	Aluminum foil mounted on heavy kraft paper.
Metallized Bestwall Gypsum Board	Certain-teed Products Corp., Chicago, Ill.	Reflective insulation consisting of gypsum board with metal foil on one side.
Reflect-O	Reflecto-O, Inc., Chicago, Ill.	Aluminum-colored paper similar to reflective insulation.
Rocklath, Insulating	United States Gypsum Company, Chicago, Ill.	Gypsum plaster board lath with aluminum foil laminated to one surface
Sheetrock, Insulating	United States Gypsum Company, Chicago, Ill.	Gypsum wallboard with aluminum foil laminated to one surface.
Silvercote	Silvercote Products, Inc., Chicago, Ill.	So-called reflective fabric consisting of two external sheets coated with oxide composition.

*Some of these products have been temporarily discontinued.

MISCELLANEOUS INSULATIONS

Sprayo-Flake (Sprayo-Flake Company, Chicago, Ill.). There are many insulating materials on the market which do not fall exactly within the scope of any of the classifications given, and others which might be included in two or more classifications. One of these is *Sprayo-Flake,* which consists of fibrous confetti-like flakes which are forcibly projected with a specially constructed air gun simultaneously

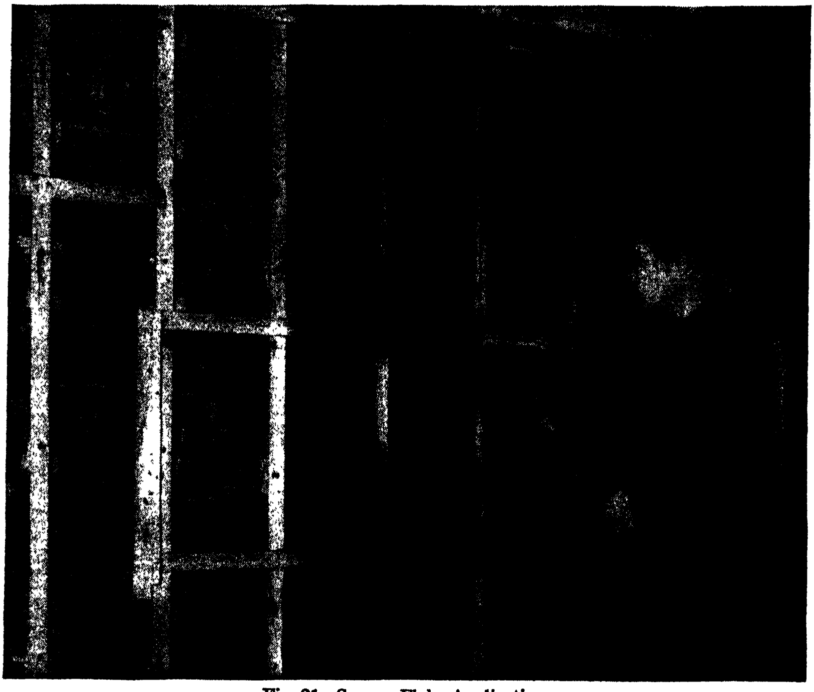


Fig. 21. Sprayo-Flake Application
Courtesy of Sprayo-Flake Co., Chicago, Ill.

with an atomized adhesive, Fig. 21. The manufacturers state that the flakes are inherently fireproof or have been impregnated with a fire-proofing agent. The atomized adhesive coats the fibers as they leave the nozzle of the air gun, causing them to build up in a cellular mass or blanket upon the surface against which the gun is directed. It is claimed that *Sprayo-Flake* can be applied to any surface (wood, masonry, or metal) in any thickness required.

Glass Blocks. These are hollow, partially evacuated blocks made of water-clear pressed glass. They are hermetically sealed at the time of manufacture and finished on mortar-bearing surfaces with a gritty mortar bond. This permits them to be laid in mortar to create attractive, light-transmitting panels. Glass blocks are translucent, but not transparent, and are resistant to sound transmission. Products in this category include *Insulux*, Fig. 22 (Owens-Corning Glass Company, Toledo, Ohio) and *P.C. Architectural Glass* (Pittsburgh Corning Corp., Pittsburgh, Pa.).

Aggregates. Cement and concrete products made from ordinary gravel and stone aggregates have a high conductivity; that is, a low heat resistance. By using special lightweight aggregates which are available, the conductivity of such cement or concrete products, including cement blocks, can be substantially reduced—in other words,

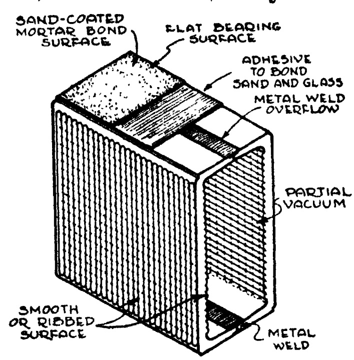


Fig. 22. Insulux Glass Block
Courtesy of Owens-Illinois Glass Co., Chicago, Ill.

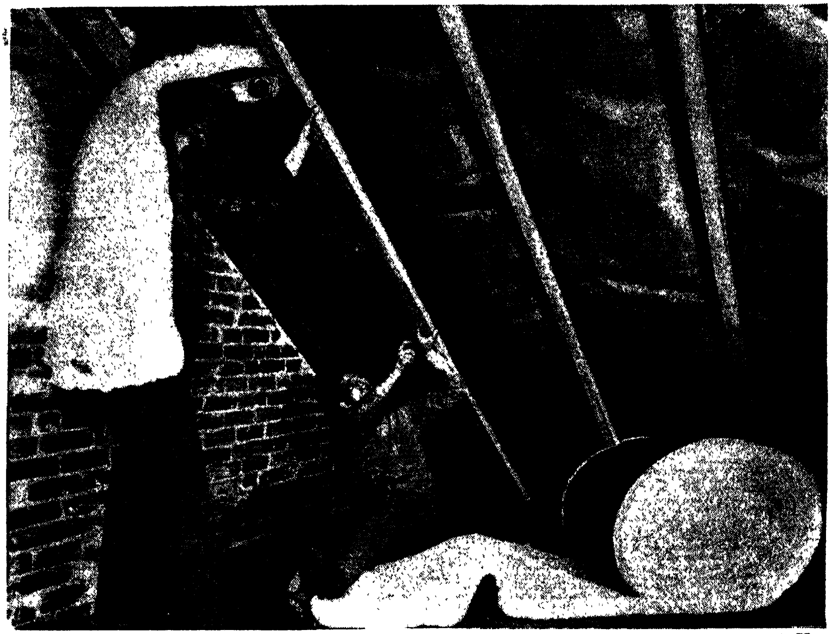
the heat resistance can be increased. The lightweight aggregates include: *Celocrete, Haydite, Superock, Vermiculite*, and *Waylite*.

Celocrete (Celotex Corporation, Chicago, Ill.). *Celocrete* is an aggregate made by converting molten blast-furnace slag into hard, cellular clinker which is crushed and screened to commercial sizes.

Haydite. This is a lightweight burned clay aggregate manufactured by various licensees under the Hays patents.

Superock (Birmingham Slag Co., Birmingham, Ala.) and *Waylite* (Waylite Co., Chicago, Ill.). *Superock* and *Waylite* are somewhat similar lightweight aggregates. The latter is made by passing molten blast-furnace slag through a processing machine where it is centrifuged and beaten in an atmosphere of steam.

Vermiculite. This aggregate has been described previously in this chapter.



Courtesy of Reynolds Metals Company, Richmond, Va.

APPLICATION OF COTTON INSULATION BETWEEN ROOF RAFTERS

Courtesy of Pittsburgh Corning Corp., Pittsburgh, Pa.

INSULATING MASONRY FLOOR WITH CELLULAR GLASS SLABS (PC FOAMGLAS)

INSULATION TRADE NAMES

Alphabetical list of trade names of all types of commercial insulations used primarily in residences.

KEY TO TYPES OF INSULATION

BL = Blanket insulation (other than mineral wool).
IB = Insulating board.
F = Loose fill insulation (other than mineral wool).
MW = Mineral wool.
R = Reflective insulation.
S = Slab insulation.
Mcl = Miscellaneous, including combinations of two or more types.

A

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Air-Cell-Board	Waldorf Paper Products Co., St. Paul, Minn.	Mcl	Corrugated board[a]
Air-Flo-Board	Waldorf Paper Products Co., St. Paul, Minn.	Mcl	Corrugated board[b]
Airlok	Plastergon Wall Board Co., Buffalo, N.Y.	MW	Rock wool
Air-Met	H. D. Catty Corporation, New York, N.Y.	R	Aluminum foil[c]
Airseal Mineral Wool	Insulation Products, Ltd., Toronto, Ont., Canada	MW	
Airtite Corkboard (See Novoid)	Cork Import Company, New York, N.Y.	S	Corkboard
Alfol	Alfol Insulation Co., Inc., New York, N.Y.	R	Aluminum foil blanket
Ankar Board	Ankarsviks Ångsågs A/B, Sundsvall, Sweden	IB	Wood fiber
Anti-Pyre Quilt	Samuel Cabot, Inc., Boston, Mass.	BL	Eelgrass[d]
Asbestos Quilt	Samuel Cabot, Inc., Boston, Mass.	BL	Eelgrass[e]

B

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Balsam Wool	Wood Conversion Company, St. Paul 1, Minn.	BL	Wood fiber[f]
Banroc	Johns-Manville, New York 16, N.Y.	MW	Rock wool
Barrett Rock Wool	Barrett Company, New York, N.Y.	MW	Rock wool
Beaver Insulating Lath	Certain-teed Products Corp., Chicago 3, Ill.	R	Gypsum lath with aluminum foil surface
B-H	Baldwin-Hill Company, Trenton, N.J.	MW	Lead slag
Bildrite Sheathing	Insulite Division of M. & O. Paper Co., Minneapolis 2, Minn.	IB	Wood fiber asphalt-treated sheathing

[a]Single layer of corrugated board with liner on both surfaces.
[b]Double layer of corrugated board with flat paper between and on both surfaces. Approximately ⅜-inch thick.
[c]Air-Met Type II consists of one sheet of aluminum plus a sheet of heavy "vapor-proof" paper. Air-Met Type IV consists of two sheets of aluminum.
[d]Eelgrass (a marine plant) between fire-resistant paper.
[e]Eelgrass between layers of sheet asbestos.
[f]Fleecy mat of wood fibers encased on both sides and edges with kraft liners.

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Bird Insulating Board (Building Board, Roof Insulation, and Sheathing)	**Bird & Son, Inc., East Walpole, Mass.**	IB	**Wood fiber**
Blan-Kets	**Blandin Paper Company, Grand Rapids, Mich.**	BL	**Layers of paper**
Blendtex	**See** ***Weatherwood***		

C

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Cabot's Quilt	Samuel Cabot, Inc., Boston, Mass.	BL	Eelgrass between layers of paper
Canasco	Canadian Asbestos Co., Montreal, Que., Canada	MW	
Canec[g]	Hawaiian Cane Products, Ltd., San Francisco 5, Calif.	IB	Cane fiber
Capitol Rock Wool	Standard Lime & Stone Co., Baltimore, Md.	MW	Rock wool
Cardinal Insulating Felt	American Hair & Felt Company, Chicago, Ill.	BL	Animal hair
Carney	Carney Rock Wool Company, St. Paul, Minn.	MW	Rock wool
Cell-U-Blanket	Masonite Corporation, Chicago 2, Ill.	BL	Wood fiber between layers of paper
Cellufoam	Masonite Corporation, Chicago 2, Ill.	Mcl	Semirigid wood-fiber product
Cellulite	Gilman Bros. Company, Gilman, Conn.	BL	Cotton
Celo-Block	Celotex Corporation, Chicago 3, Ill.	S	Cane fiber[h]
Celotex[i]	Celotex Corporation, Chicago 3, Ill.	IB	Cane fiber
Cemesto	Celotex Corporation, Chicago 3, Ill.	Mcl	Asbestos-cement board[k]
Century	Keasbey & Mattison Company, Ambler, Pa.	MW	Rock wool
Colorkote	See *Fir-Tex*		
Columbia	United States Mineral Wool Company, Chicago, Ill.	MW	
Corkduc	Cork Import Company, New York, N.Y.	S	Corkboard

D

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Decoblend	See *Flintkote Insulation Board*		
Denesen	The Denesen Company, Minneapolis, Minn.	MW	Rock wool products
Domster Board	Made in Sweden	IB	Wood fiber
Donnacona	Donnacona Paper Company, Donnacona, Que., Canada	IB	Laminated wood-fiber sheets
Dry Zero	American Hair & Felt Company, Chicago, Ill.	BL	Kapok
Dubbleseal Sheathing	Masonite Corporation, Chicago 2, Ill.	IB	Wood-fiber insulating board sheathing
Dura-Batts	Flintkote Company, New York 20, N.Y.	MW	Rock wool

[g]Canec insulating-board products include asphalt sheathing, insulating lath, insulating plank, insulating tile, and roof insulation.

[h]Cold storage insulation made from cane-fiber insulating board.

[i]Celotex insulating-board products include building board, center-matched sheathing, finish plank, roof insulation, vapor-seal roof insulation, sheathing and lath.

[k]Insulating board between layers of asbestos-cement board.

E

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Eagle[l]	Eagle-Picher Sales Company, Cincinnati 1, Ohio	MW	Lead slag
Ecod Metal Lath	Reynolds Metals Company, Inc., Richmond 19, Va.	R	Aluminum foil[m]
Ehret Rock Wool Batts	Ehret Magnesia Mfg. Company, Valley Forge, Pa.	MW	Rock wool
Enso Board	Enso-Gutzeit Company, Enso, Finland	IB	Wood fiber

F

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Ferro-Therm	American Flange & Mfg. Co., Inc., New York 20, N.Y.	R	Sheet iron with alloy coating
Fesco Board	F. E. Schundler & Company, Inc., Joliet, Ill.	S	Vermiculite with asphalt binder
Fiberglas	Owens-Corning Fiberglas Corp., Toledo, Ohio	MW	Glass wool
Fiberglas AE Board	Owens-Corning Fiberglas Corp., Toledo, Ohio	S	Compressed glass fibers, asphalt enclosed
Fiberglas PF Insulation	Owens-Corning Fiberglas Corp., Toledo, Ohio	S	Compressed glass fibers with binder
Fiberlite	Insulite Division of M. & O. Paper Company, Minneapolis 2, Minn.	IB	Wood fiber tileboard
Firkote	Fir-Tex Insulating Board Co., Portland, Ore.	IB	Wood-fiber insulating board sheathing
Fir-Tex[n]	Fir-Tex Insulating Board Co., Portland, Ore.	IB	Wood fiber
Five-Point Mineral Wool	R. Laidlaw Lumber Co., Ltd., Toronto, Ont., Canada	MW	
Flintkote Insulation Board[o]	The Flintkote Company, New York 20, N.Y.	IB	Wood fiber
Flintkote Rock Wool	The Flintkote Company, New York 20, N.Y.	MW	Rock wool
Flintlock Sheathing	The Flintkote Company, New York 20, N.Y.	IB	Asphalt and wood fiber[p]

G

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Gimco	National Gypsum Company, Buffalo 2, N.Y.	MW	Rock wool
Gold Bond Aluminum Foil Insulating Board and Lath	National Gypsum Company, Buffalo 2, N.Y.	R	Gypsum board and aluminum foil[q]
Gold Bond Dry Fill Insulation	National Gypsum Company, Buffalo 2, N.Y.	F	Powdered gypsum
Gold Bond Insulating Board[r]	National Gypsum Company, Buffalo 2, N.Y.	IB	Wood fiber

[l] Eagle products include bats, blankets, and loose and granulated wool.

[m] Plaster base of steel reinforcing wire backed with aluminum foil on kraft paper.

[n] Fir-Tex insulating-board products include building board, Colorkote interior finish, Ivrykote interior finish, insulating plaster base lath, plank, roof insulation, sheathing, and tile.

[o] Flintkote insulating-board products include asphalt-coated sheathing, building board, cold processed roof insulation, Decoblend plank and tile, insulating lath, and roof insulation.

[p] Asphalt-coated wood-fiber insulating-board sheathing (2′x8′x$\frac{25}{32}$″ thick) with T & G along edges.

[q] Gypsum board and lath with aluminum foil laminated to one surface.

[r] Gold Bond insulating-board products include standard insulation, fibre-insulation sheathing, fibre-insulation lath, insulation plank, tile, and roof boards.

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Gold Bond Rock Wool[a]	National Gypsum Company, Buffalo 2, N.Y.	MW	Rock wool
Graylite	See *Insulite*	IB	Wood fiber
Gyproc	Gypsum, Lime & Alabastine, Ltd., Toronto, Ont., Canada	MW	Rock wool
H			
Hairinsul	American Hair & Felt Company, Chicago, Ill.	BL	Cattle hair or hair and jute
Handi-Batts	National Gypsum Company, Buffalo 2, N.Y.	MW	Rock wool
HiLite	See *Weatherwood*		
Homasote	Homasote Company, Trenton, N.J.	IB	Newsprint and vegetable fibers
Homart Loose Rock Wool and Batts	Sears-Roebuck & Co., Chicago, Ill.	MW	Rock wool
Homart Mineral Fill	Sears-Roebuck & Co., Chicago, Ill.	F	Vermiculite
I			
Insl-Cotton	Taylor Bedding Mfg. Co., Taylor, Texas	BL	Cotton
Ins-Lite	See *Insulite*		
Insul-Fibre	Celotex Corporation, Chicago 3, Ill.	MW	Loose rock wool
Insulite[t]	Insulite Division of M. & O. Paper Co., Minneapolis 2, Minn.	IB	Wood fiber
Insulroc	Rock Products Company, Nashville, Tenn.	MW	Rock wool
Insul-Wool	Insul-Wool Corporation, Wichita, Kans.	F	Wood pulp
Isorel	Isorel, Paris, France	IB	Wood fiber
Ivrykote Building Board	See *Fir-Tex*		
J			
Jiffy Blanket	Jiffy Manufacturing Co., Hillside, N.J.	BL	Macerated paper between kraft paper
J-M Insulating Board[u]	Johns-Manville Sales Corp., New York 16, N.Y.	IB	Wood fiber
Johns-Manville Rock Wool	Johns-Manville Sales Corp., New York 16, N.Y.	MW	Rock wool
Jointite	Mundet Cork Corporation, Brooklyn 11, N.Y.	S	Corkboard
K			
Karlit	Made in Sweden	IB	Wood fiber
Kimsul	Kimberly-Clark Corporation, Neenah, Wis.	BL	Wood fiber
Kolorfast Tile	See *Nu-Wood*		

[a]Gold Bond rock-wool products include sealed blanket, Handi-Batts, and loose rock wool.

[t]Insulite insulating-board products include Bildrite sheathing; Ins-Lite building board, Lok-Joint lath, plank, TileBoard, and roof insulation; Graylite building board, Lok-Joint lath, plank, TileBoard, and roof insulation; Smoothcote interior board; plank and TileBoard; Satincote interior board, plank, and TileBoard; Sealed Graylite Lok-Joint lath and Fiberlite tile.

[u]J-M insulating-board products include Bevel plank and tile, insulating lath, rigid Roofinsul, and Weathertite sheathing.

L

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
L-W Insulating Board.	Ljusne-Woxna Company, Ljusne, Sweden	IB	Wood fiber
Lockaire.............	Plastergon Wall Board Co., Buffalo, N.Y. (Distributor), MacAndrews & Forbes, Camden, N.J. (Manufacturers)	IB	Licorice root
Lo-K................	Lockport Cotton Batting Co., Lockport, N.Y.	BL	Cotton
Lok-Joint............	See *Insulite*		

M

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Maftex..............	See *Lockaire*		
Maizewood, Insulating Board, Insulating Asphalt-Coated Sheathing, Insulating Lath; Insulating Plank, Insulating Tile, Insulating Panel Strips	Maizewood Insulation Co., Dubuque, Iowa	IB	Corn stalks
Masonite[v]...........	Masonite Corporation, Chicago 2, Ill.	IB	Wood fiber
Masterfil	B. F. Nelson Manufacturing Co., Minneapolis, Minn.	F	Vermiculite
Metallation..........	Reynolds Metals Company, Richmond 19, Va.	R	Aluminum foil
Mico................	Mineral Insulation Company, Chicago, Ill.	MW	
Mineral Wool Board...	Armstrong Cork Company, Lancaster, Pa.	S	Rock wool with asphalt binder
Mitchell & Smith Corkboard	Mitchell & Smith Company, Inc., Detroit, Mich.	S	Corkboard
Multicell.............	Multicell Sales Corp., Minneapolis, Minn.	BL	Layers of newspapers

N

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Nat Roc.............	National Rock Wool Sales, Inc., Lagro, Ind.	MW	Rock wool
Natur-temp..........	Barnhardt Mfg. Co., Charlotte, N.C.	BL	Cotton
Naturzone...........	Wilson & Company, Chicago, Ill.	BL,S	Hog hair and asphalt
Novoid..............	Cork Import Company, New York, N.Y.	S	Corkboard
Nu-Wood[w]...........	Wood Conversion Company, St. Paul 1, Minn.	IB	Wood fiber

O

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Ozite All-Hair Building Blanket	American Hair & Felt Company, Chicago, Ill.	BL	Cattle hair

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Palcozite Insulating Blanket	American Hair & Felt Company, Chicago, Ill.	BL	Cattle hair and redwood bark fibers
Palmatex............	Palmatex Corp., Pinellas Park, Fla.	IB	Palm fibers

[v] Masonite insulating-board products include asphalt sheathing, Dubbleseal sheathing, insulating interior finish panels, insulating lath, insulating beveled plank and tile, and vapor-barrier lath.

[w] Nu-Wood insulating-board products include insulating board, insulating sheathing, insulating lath, Kolor-Fast plank and tile, roof insulation, and Sta-Tite plank and tile.

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Pal-O-Pak	Palmer-Wittkopp Co., Hartland, Wis.	F	Chipboard and paper
Partemp	Firestone Tire & Rubber Co., Akron, Ohio	BL	Cotton
Perfection	Riverton Lime & Stone Co., Riverton, W.Va.	MW	Rock wool
Pliofoam	Goodyear Tire & Rubber Co., Akron, Ohio	Mcl	Rubber
Poeco	C. W. Poe Company, Cleveland, Ohio	MW	Rock wool
Porete	Porete Mfg. Company, North Arlington, N.J.	S	Wood fiber and Portland cement
Porex Slabs	Porete Mfg. Company, North Arlington, N.J.	S	Wood fiber and magnesite cement
Porosil	Universal Zonolite Insulation Co., Chicago, Ill.	F	Vermiculite
Pyrofill	United States Gypsum Company, Chicago 6, Ill.	F	Powdered gypsum

R

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Red Top Insulating Wool[x]	United States Gypsum Company, Chicago 6, Ill.	MW	Glass wool
Reflect-O	Reflect-O, Inc., Chicago, Ill.	R	Aluminum-colored paper
Reyn-O-Cell	Reynolds Metals Company, Richmond 19, Va.	BL	Cotton
Rock Cork	Johns-Manville Sales Corp., New York 16, N.Y.	S	Rock wool and asphalt binder
Rocklath, Insulating	United States Gypsum Company, Chicago 6, Ill.	R	Gypsum lath with aluminum foil laminated to one surface
Rocktex	Philip Carey Mfg. Company, Lockland, Cincinnati, Ohio	MW	Rock wool
Rubatex	Rubatex Corporation, Richmond, Va.	S	Rubber
Ru-ber-oid Rock Wool Insulation	Ruberoid Company, New York, N.Y.	MW	Rock wool

S

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Salisco	Salem Lime & Stone Company, Salem, Ind.	MW	Rock wool
Satincote	See *Insulite*		
Seal-O-Wool	United States Roofing Company, St. Paul, Minn.	MW	
Sheetrock, Insulating	United States Gypsum Company, Chicago 6, Ill.	R	Gypsum wallboard and aluminum foil[y]
Silvercote	Silvercote Products Company, Inc., Chicago, Ill.	R	Fabric coated with oxide composition[z]
Smoothcote	See *Insulite*		
Sprayo-Flake	Sprayo-Flake Company, Chicago, Ill.	Mcl	Fibrous flakes and adhesive[aa]
Spun Rock Wool	Spun Rock Wools, Ltd., Thorold, Ont., Canada	MW	Rock wool
Sta-Lite Tile	See *Nu-Wood*		

[x]Red Top insulating wool is available in its natural fibrous state and also in granulated and shredded forms. This product is also fabricated into blankets.

[y]Gypsum wallboard with aluminum foil laminated to one surface.

[z]Fabric consisting of two exterior sheets coated with oxide composition.

[aa]Fibrous flakes forcibly projected by an air gun simultaneously with an atomised adhesive against the surface which is to be insulated.

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Standard Cotton Insulation	Standard Cotton Products Company, Flint, Mich.	BL	Cotton
Stonefelt	Johns-Manville Sales Corp., New York 16, N.Y.	MW	Rock wool
Stud-Pak Wool	United States Mineral Wool Company, Chicago, Ill.	MW	
Summit	Ohio Valley Rock Asphalt Company, Louisville, Ky.	MW	Rock wool
Super-Felt	Johns-Manville Sales Corp., New York 16, N.Y.	MW	Rock wool
Supertemp Block Insulation	Eagle-Picher Sales Co., Cincinnati, Ohio	S	Mineral wool
T			
Tankinsul	American Hair & Felt Co., Chicago, Ill.	BL	Cattle hair
Temlok [bb]	Armstrong Cork Company, Lancaster, Pa.	IB	Wood fiber
Temseal Insulating Sheathing	Armstrong Cork Company, Lancaster, Pa.	IB	Wood fiber
Ten Test	International Fiber Board, Ltd., Gatineau, Que., Canada	IB	Wood fiber
Textolite Foam	General Electric Co., Pittsfield, Mass.	Mcl	Liquid resin [cc]
Thermasote	Homasote Company, Trenton, N.J.	IB	Wood and other fibers
Thermax	Celotex Corporation, Chicago 3, Ill.	S	Wood fiber and magnesite cement
Therminsul	The Therminsul Corp., Kalamazoo, Mich.	MW	Rock wool
Thermofelt	American Hair & Felt Co., Chicago, Ill.	BL	Cattle hair and asbestos fiber
Thermofill	United States Gypsum Company, Chicago 6, Ill.	F	Powdered gypsum
Therm-O-Proof	Therm-O-Proof Ins. Mfg. Co., Chicago, Ill.	MW	
Thermotex	A/B Varjag, Stockholm, Sweden	IB	Wood fiber
Tomhave	Northern Home Improvement Co., Sandstone, Minn.	MW	Rock wool
Torex	Torefors A/B, Tore, Sweden	IB	Wood fiber
Treetex	Mo and Domsjo Trading Co., Ornskoldvik, Sweden	IB	Wood fiber
U			
Unalit	Unalit Company, Brussels, Belgium	IB	Wood fiber
Union Rock Wool	Union Rock Wool Corporation, Wabash, Ind.	MW	Rock wool
United States Royal Insulation Board	United States Rubber Company, Akron, Ohio	S	Rubber
United States Wool	United States Mineral Wool Co., Chicago, Ill.	MW	

[bb] Temlok insulating-board products include standard insulating board, De Luxe insulating board, insulating lath, plank De Luxe, panels De Luxe, and roof insulation. Also Temseal sheathing.

[cc] Textolite Foam is made by activating a liquid resin so that it foams to a light, cellular mass many times its original volume.

W

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Ward Brand	Montgomery Ward & Company, Chicago, Ill.	MW	Rock wool
Waukesha	Waukesha Lime & Stone Co., Waukesha, Wis.	MW	Rock wool
Weathertite Sheathing	Johns-Manville Sales Corporation, New York 16, N.Y.	IB	Wood fiber insulating board sheathing
Weatherwood[dd]	United States Gypsum Company, Chicago 6, Ill.	IB	Wood fiber
Western Rock Wool	Western Rock Wool Corporation, Huntington, Ind.	MW	Rock wool
Wyolite	Wyolite Insulating Products Co., Cleveland, Ohio	F	Vermiculite

Y

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Yamaska	Yamaska Mills, Inc., St. Pie, Que., Canada	IB	Wood fiber

Z

Trade Name	Manufacturer or Distributor	Type of Insulation	Description or Basic Materials
Zonolite	Universal Zonolite Insulation Co., Chicago, Ill.	F	Vermiculite

[dd]Weatherwood insulating-board products include asphalt-coated sheathing, Blendtex plank Blendtex tile, building board, HiLite plank, HiLite tile, plaster base, and roof insulation.

CHAPTER III

METHODS OF APPLICATION

The importance of proper application of insulating materials cannot be over-emphasized. Improper application or inferior workmanship may reduce the effectiveness of an insulating material or may completely nullify its value. An example of improper application is that of a reflective material installed in such a manner that its reflective surface is covered or in contact with some other building material; whereas, to be effective as an insulating material, the reflective surface of the insulation must be exposed to an air space of appreciable width and not covered in any way.

The methods of application set forth in this chapter are typical for the various types of insulation. However, because of special characteristics or properties of certain patented materials the methods may deviate in some instances from those described herein. It is advisable, therefore, to consult the printed specifications of manufacturers of such patented products. Some insulating materials, such as the pneumatically applied mineral wool and *Sprayo-flake*, are installed exclusively by manufacturers or their contracting agents. This practice is due primarily to the fact that specially designed equipment which would not be available to the ordinary contractor is required for the application of such materials.

Practically all types of insulation except structural insulating board are used solely for insulating purposes, although in some instances the materials have certain other physical properties, such as wind and vapor resistance. Structural insulating board serves not only as an insulating material but may also be used for sheathing, replacing conventional lumber, or as a plaster base, replacing wood, metal or other types of lath; as an interior decorative material, or as a base for plastic paints, stains and wall coverings. It will be apparent that because of the many uses of this type of material the application instructions and details must necessarily be much more involved than those for products used solely as insulation.

TYPES OF CONSTRUCTION

A general knowledge of the types and methods of building construction is, of course, prerequisite to an understanding of the application of insulating materials.

Foundation. The foundation is one of the most important parts of a building, for without a firm base or support the best construction may be a failure. Where the basement is to be omitted, the least expensive type of foundation consists of piers of wood, concrete, brick or other materials which rest on the ground and support the

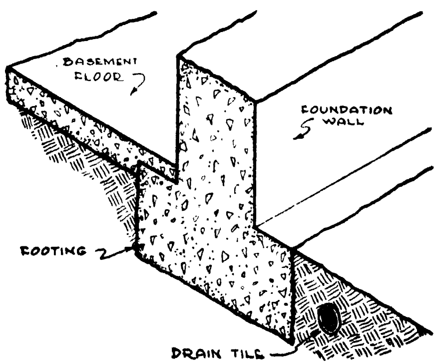


Fig. 1. Detail of Foundation Wall Showing Footing Properly Constructed

framework of the building. The use of piers to support the building is confined largely to one and two story dwellings located in moderate climates. In colder climates, where a more rigid or firm base is desired or necessary, and where the plumbing must be protected from freezing, the foundation usually consists of the footings and the foundation wall, Fig. 1. The footing is the base of the foundation where it is broadened to form a larger bearing surface against the soil beneath. The width of the footing varies with soil conditions and the size of the house, that is, the weight to be supported. In the average house with ordinary soil conditions, the footings should extend 4 inches to 8 inches beyond both sides of the foundation wall and to a depth of 8 inches beneath it.

Basement. If a basement is to be provided, the walls thereof may consist either of concrete blocks or reinforced concrete. The basement walls are usually completely or partly below grade (ground level) and are considered an integral part of the foundation inasmuch as the walls of the building rest on the top of the basement walls. For a permanently dry basement, the walls should not only be water-tight, but, under certain conditions of moisture and soil, drain tile should be provided as shown in Fig. 1, and the outside surface of the foundation waterproofed with a bituminous compound. The accumulation or deposition of moisture on the interior surface of basement walls may be due either to seepage of moisture through the walls or to condensation of the moisture or "humidity" in the air on the cold basement wall surfaces. Seepage of moisture through the walls will not take place if there are no cracks and the exterior surface has been properly waterproofed. "Green" concrete requires some time to cure and to become thoroughly dry to the touch. One method of eliminating moisture condensation on the surface of the basement walls is to install a layer of insulating board over the surface in accordance with the methods set forth in this chapter, leaving an air space between the wall and the insulation. (Further information on surface condensation will be found in the chapter on Condensation.) Basement floors should be provided with a drain connected with the sewer. Where there are excessive outside moisture conditions or a nearby body of water above the level of the basement floor which induces a hydrostatic pressure, the floor should also be waterproofed underneath by means of a membrane waterproofing course consisting of saturated roofing felt and hot asphalt.

Masonry Walls. If the structural or supporting part of the wall is of masonry materials such as concrete, cement or cinder blocks, brick or hollow clay tile, the wall construction is classified as masonry. Frame walls (see below) with a veneer of brick or other masonry material are not classified as masonry, although the exterior appearance may be the same in either case. In masonry construction, the total thickness of exterior walls usually is at least 8 inches and the individual units of brick, tile, or cement, or cinder blocks are laid in mortar in courses starting at the top of the foundation wall, or continuing with the same construction as the basement walls where the same material, such as cement or cinder blocks, is used for both the foundation walls and the above-grade walls. In some cases the masonry walls may consist of solid or monolithic concrete instead of individual units laid in mortar. In some instances in warm climates plaster is applied directly to the interior surface of the masonry material, but more often, especially in cold climates, an air space is provided between the masonry and the interior finish.

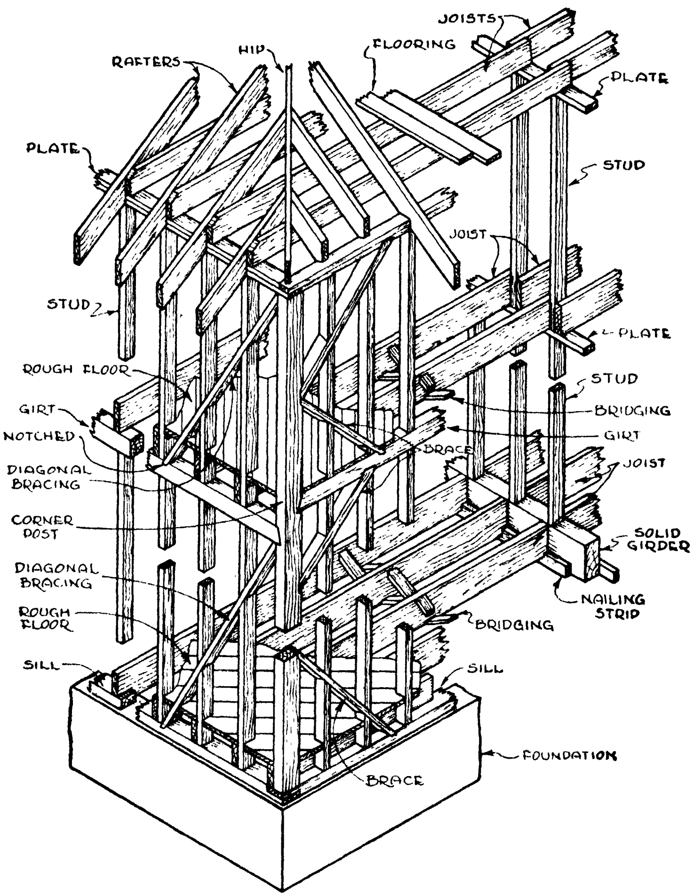


Fig. 2. Braced Frame Construction

An air space is advisable not only to prevent moisture from passing through the wall, but also to facilitate the application of the interior finish and/or insulating material. As is apparent from data elsewhere in this book, it is especially important that masonry walls be insulated.

Frame Walls. A frame building is one constructed of wood structural parts throughout, only the foundation and basement floor and walls being of masonry materials. See Figs. 2, 3 and 4. The frame wall consists of the *studs* (usually 2x4 or 2x6 inches), which are the upright or vertical framing members, covered on both sides with certain structural materials. The interior finish, applied to

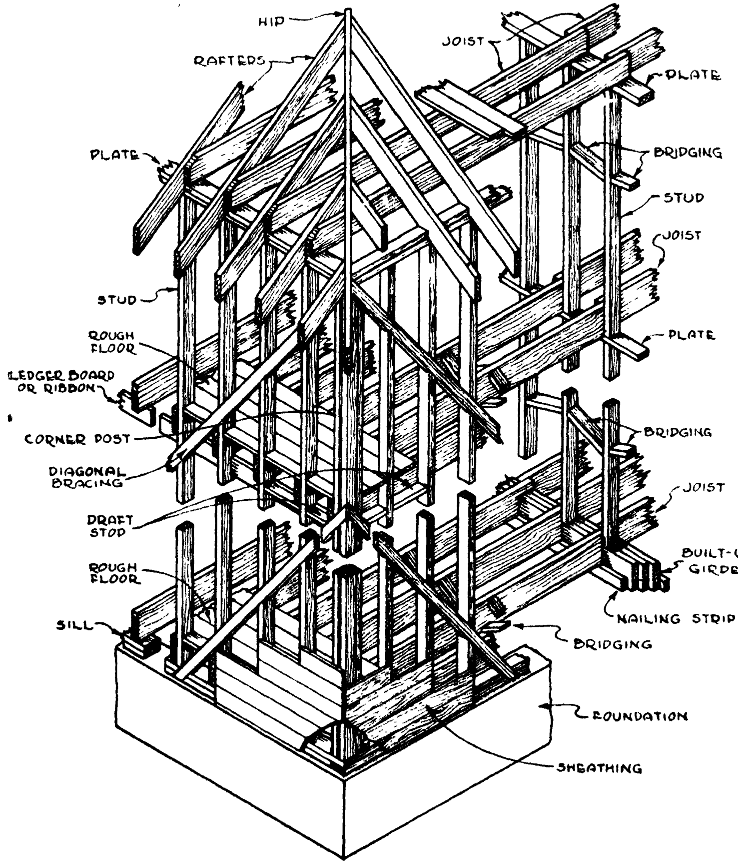


Fig. 3. Balloon Frame Construction

the interior edge or face of the studs, may consist of lath and plaster, insulating board, plywood, lumber, wall board or other material. The exterior face of the studs is covered first with sheathing and then with an exterior finish of weatherboarding, shingles, stucco or brick or stone veneer. The purpose of the *sheathing* is to lend strength and rigidity to the construction. The materials used for this purpose include lumber, applied either horizontally or diagonally, insulating board, plywood and plaster board. Sheathing in large units such as structural insulating board provides exceptional bracing strength and rigidity for reasons explained previously. In certain localities the sheathing is omitted in the less expensive houses and

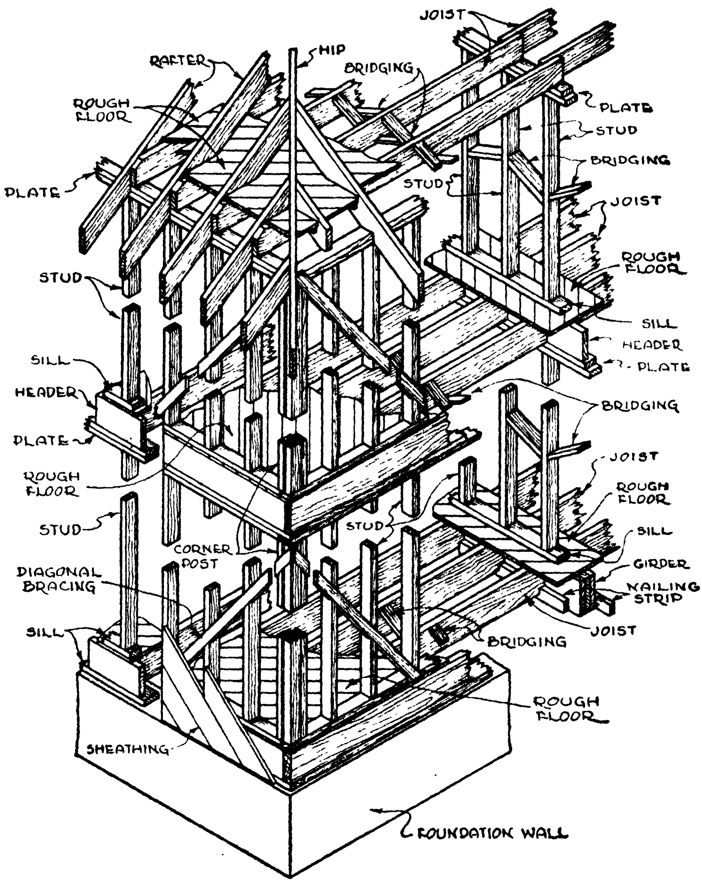


Fig. 4. Platform Frame Construction

the exterior finish is applied directly to the exterior face of the studs. The *weatherboarding* used for exterior finish is also known as *siding* or *clapboards* and is so shaped as to shed water by forming lapped joints with the boards above and below. Waterproof *building paper* to provide protection against the penetration of wind and rain usually is applied over the sheathing before the exterior finish is installed. This building paper may be omitted in most cases where structural insulating board is used, although its use is recommended in all cases under stucco.

Frame construction is the prevalent type in the United States except in certain sections where, due to local preference or building code requirements, masonry construction predominates. With frame construction the load of the house is carried by the wood framing, which must be strong enough to carry its own weight plus that of the roof, floors and walls, plus the contents of the building including the people who occupy it—all with a substantial factor of safety. It must resist wind and in some areas earthquakes and should be built so that there is a minimum of shrinkage or warping. There are three types of wood framing in general use; namely, (1) Braced Frame, (2) Balloon Frame and (3) Platform Frame.

The *Braced Frame Construction*, Fig. 2, is a modern adaptation of the framework used in the old New England houses. The distinguishing feature of the *Balloon Frame Construction*, Fig. 3, is the fact that the wall studs are continuous from the sill at the foundation to the top plate. The *Platform Frame Construction*, Fig. 4, is so named because the first floor is built on top of the foundation walls as though it were a platform.

The *sill* furnishes a means of securing the framing to the foundation and provides a nailing base for the joists. The *joists* are horizontal beams run from wall to wall to furnish support for the floors and for the ceiling below. Their size depends on the span and the load they must carry. The *bridging* are small braces that extend crosswise from the top of one joist to the bottom of the next and in a continuous line the length of the building. A *header* is a piece of lumber fitted between two studs, one purpose of which is to provide an intermediate nailing base or backing. The *rafters* are sloping timbers to support the roof.

Roofs may be broadly classified as *pitched* or *flat*. Pitched roofs are used with the various types of colonial architecture, Cape Cod, Georgian, English and others, whereas flat roofs are used on modern, Spanish, industrial and commercial types of construction.

Pitched Roofs. In the case of residences, pitched roofs are usually of frame construction similar to those illustrated in Figs. 2, 3 and 4, whether the walls are of frame or masonry. Where roll roofing or asphalt shingles are to be used, board sheathing is nailed to the roof rafters and the roofing applied to the sheathing. Where slate, Spanish tile or rigid shingles (such as wood shingles) are to be used, open wood strips (sometimes called *shingle lath* or *roofers*) are nailed to the rafters with a space between, the space depending upon the size of the shingle, tile or slate. Tile and slate, however, are also installed over, and nailed to, solid wood sheathing. A layer of waterproofing felt should always be used under slate or tile roofing.

Flat Roofs. The level surface of a flat roof is known as the *roof deck.* The materials used for flat roof decks include boards (lumber), monolithic or poured concrete, precast cement and gypsum tile, a composition of gypsum and wood fiber applied on the job over a base of insulating board or gypsum plaster board, and steel. Other proprietary insulated roof decks are used to a limited extent. The supporting roof structure depends largely on the type of roof deck. For example, wood structural members are most commonly used for supporting wood roof decks although steel joists are used in some cases. Steel joists or purlins are also generally used for precast tile and steel decks whereas for poured concrete the supporting structural members usually are of concrete, the under side of the roof deck being either of pan or flat slab construction. The roofing used on flat slab roofs is known as built-up roofing and consists of alternate courses of saturated roofing felt and either hot coal tar pitch or petroleum asphalt, the bituminous material (that is, the pitch or asphalt) used for applying it being the same as the saturant for the roofing felt.

Vapor Barriers. References regarding the application and use of vapor barriers in certain special cases will be found in this chapter and the chapter on Condensation. However, adequate vapor barriers are recommended in all cases in cold climates regardless of the type of insulation or whether or not insulation is used. Many types of insulation are provided with an efficient vapor barrier which also serves as an accessory in some cases for installing the insulation. The vapor barrier should be installed as near as possible to the warm side of the construction. If it is of the paper type it should be installed on the inside face of studs or the under side of ceiling joists. If the paint type barrier is used, it should be applied to the inside surface of the wall or the under side of the ceiling, using a sufficient number of coats of the material to insure satisfactory results.

APPLICATION OF FLEXIBLE INSULATIONS

In order to apply flexible insulations to *masonry walls* it is necessary first to install wood furring strips vertically and the proper distance apart, usually 16 inches on centers. The furring strips usually are either 1x2 or 2x2-inch wood strips and are attached to the masonry walls by nailing into the mortar joints. Where the wall is of solid concrete, it is necessary to drill holes in the concrete and to attach the furring strips by means of expansion bolts. The furring strips not only serve to level off the wall and provide a means

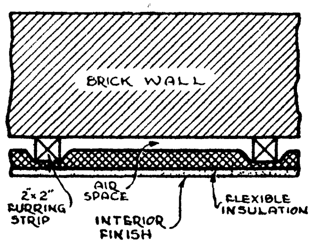


Fig. 5. Application of Flexible Insulation to Masonry Walls: Insulation Is Nailed to Furring Strips and Interior Finish Nailed to Same Furring Strips

of attachment for the flexible insulation, but also separate the insulation from the masonry by an air space, thus preventing any dampness from entering the insulation. Many flexible insulations are enclosed in a waterproof material which would protect them from such dampness, but the air space between the insulation and the masonry wall is considered good construction as well as facilitating the installation of the insulation.

Fig. 5 is a horizontal section through a masonry wall showing a common method of applying flexible insulation to 2x2-inch furring strips. The furring strips are attached to the wall vertically on 16-inch centers and shimmed plumb and true to provide an even surface. The insulation is then nailed or tacked in continuous strips to these furring strips. The ends of the insulation are fastened to sills, plates or headers in a similar manner. If an interior finish is to be installed, as is usually the case, the flexible insulation need only be tacked to hold it in place until the interior finish is applied. Flexible insulation having a nailing flange may be installed in a similar manner, the nails or tacks being driven through the flange into the furring strips. The *Balsam Wool* spacer flange provides an air space between the insulation and the interior finish.

Where the interior finish consists of plaster on open lath (such as wood or metal lath), an air space should be provided between the insulation and the plaster which forms the key in back of the lath. This prevents the wet plaster from coming in contact with the insulation. If the fabrication of the insulation is such that it does not provide for this air space, the method of application illustrated

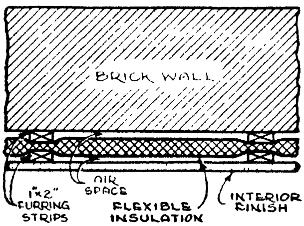


Fig. 6. Alternate Method of Applying Flexible Insulation to Masonry Walls Using Second Layer of Furring Strips over Insulation to Provide Air Space between Insulation and Interior Finish

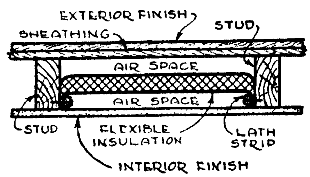


Fig. 7. Application of Flexible Insulation to Frame Construction by Means of Lath Strips Nailed through Insulation into Sides of Framing Members

in Fig. 6 is recommended. The two air spaces provided by this method are considered desirable whether or not the interior finish is of plaster on open lath. It will be noted that the method shown in Fig. 6 involves the use of two layers of 1x2 furring strips with the flexible insulation between and the interior finish applied to the outer layer. In some instances the two layers of furring strips are run at right angles to each other, the first layer horizontally and the second vertically, both on 16-inch centers. Insulations with a nailing flange may be installed in a similar manner, the nails or tacks being driven through the flange into the first layer of furring strips.

To Frame Walls. There are three general methods of applying flexible insulations to frame walls, namely: (1) between framing members, (2) over inside edges of framing members and (3) under or over sheathing.

Between Framing Members. When applied between framing members, the flexible insulation, for most effective results, should be installed in such a manner that two air spaces are formed. A method of application suitable in general for flexible insulations without the nailing flange is shown in Fig. 7. The insulation is held in place by means of lath strips nailed through the insulation into the sides of the framing members as illustrated. The ends are similarly fastened in place to the header or plate and sill by means of lath strips.

One type of flexible insulation (*Kimsul* blanket) is installed between studs by first securing the end with lath strips to the header, then stretching to the desired length and attaching to the sill plate in the same manner, after which the blanket is fastened along the

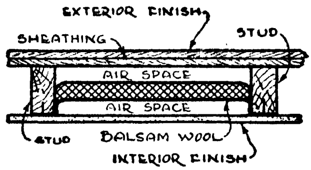


Fig. 8. Application of Flexible Insulation with Nailing Flange to Frame Construction; if Insulation has Spacer Flange Two Air Spaces Will Be Provided as Shown when the Interior Finish is Installed.

sides near the studs by driving nails at intervals of approximately 18 inches through the edges of the insulation into the sheathing.

Over Inside Edges of Framing Members. As previously stated, certain types of flexible insulation are provided with flanges for nailing to the framing members. A typical example is *Balsam Wool,* which also has a patented spacer flange which assures an air space between the insulation and the interior finish. A method of installing this product is shown in Fig. 8. The folded portion of the flange is lapped over the inside edge or face of the framing members and tacked or stapled through the flange for temporary fastening until held permanently by the plaster base or interior finish. If the interior is not to be finished, wood strips are applied over the edge of the framing and nailed securely through the flanges to form a continuous air-tight joint. The ends should be nailed to sills, plates or headers. Where the wall-thick *Balsam Wool* is used, a portion of the mat is removed to make fastening at ends easier. Where splicing is necessary, a header is installed between the framing members to which the two ends are attached.

Flexible insulations without the nailing flange may also be secured to the inside face of the framing members by cutting strips parallel to the studs to fit the space between the sills and plates. These strips may be nailed to the studs, sills and plates with large-headed nails, or held in place temporarily by means of tacks or

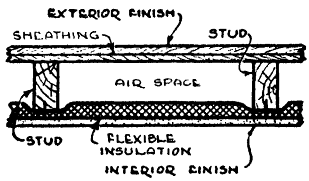


Fig. 9. Application of Flexible Insulation to Face of Studs with Interior Finish Applied Directly over Insulation

staples until the interior finish is installed as shown in Fig. 9. If the interior finish is to be plaster on open lath, an air space should be provided between the flexible insulation and the plaster base to prevent wet plaster from coming in contact with the insulation, but in any event, regardless of the type of interior finish, the air space is desirable. To provide this air space the flexible insulation may be installed by placing lath strips over the insulation and nailing through to the studs and then applying the plaster base or interior finish over the lath strips, nailing through to the studs, as shown in Fig. 10. The objection to this method of application is that the additional air space necessitates special window frames,

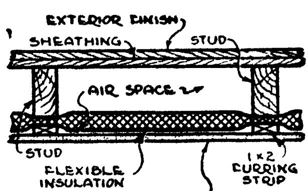


Fig. 10. Application of Flexible Insulation to Face of Studs with Furring Strips over Insulation for Attaching Interior Finish

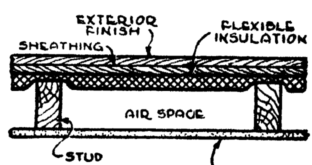


Fig. 11. Application of Flexible Insulation to Outside of Studs under the Sheathing

which can be avoided by installing the insulation between the framing members as shown in Fig. 7, so as not to increase the thickness of the wall.

Under Sheathing. Fig. 11 illustrates a method of applying flexible insulation directly to the outside of studs. The insulation and sheathing may be applied at the same time with the insulating material serving as a lining. The insulation is placed over and at right angles to the studs and the sheathing holds the insulation in place.

Over Sheathing. Flexible insulation may also be installed over wood sheathing. Starting from the foundation and working up, the insulation is applied at right angles to the framing members, and held in place by means of furring strips placed over the horizontal edges of the insulation and nailed into the sheathing. Vertical strips are also placed over the insulation at the studs and between the horizontal furring strips. The strips serve as a nailing base for wood siding for the lath used for stucco and for other exterior finishes.

It should be emphasized that the methods of application of flexible insulations between framing members and over the inside edges of framing members illustrated respectively in Figs. 7 and 8 are the preferred methods, and the others are shown only as possibilities.

To Ceilings and Roofs. The preceding discussion relative to the application of flexible insulations between and over the edges of framing members and illustrated in Figs. 7, 8, 9 and 10 has referred primarily to walls. These methods, however, are generally applicable to ceilings, the only difference being that the ceiling joists are horizontal whereas the wall studs are vertical. These methods are also applicable to roof rafters, the essential difference being that the interior finish is often omitted, especially where the attic is unused. Where the flexible insulation is applied to roof rafters and the interior finish is to be omitted over the insulation, the simplest method is to nail the flexible insulation to the lower edge of the rafters in a manner similar to that used for nailing the insulation to the inside face of the studs, shown in Figs. 8, 9 and 10, except, of course, that the interior finish shown in these figures is omitted.

APPLICATION OF FILL INSULATIONS

The application of granulated and powdered types of insulation, such as expanded vermiculite (mica pellets), loose and granulated rock wool and powdered gypsum, is comparatively simple. The material is simply poured from the bags in which it is sold or hand packed (in the case of loose fill) between the framing members. Mica pellets are generally used between ceiling joists only.

To Walls. When installed in outside walls, granulated or powdered fill insulations should be poured from the bags between the studs after the outside sheathing is in place and as the walls to be insulated are receiving the plaster base or interior finish. The fill insulation should be poured in place in sections not over 48 inches in height at a time as the work of applying the plaster base or interior finish progresses. Loose rock wool and similar fluffy fibrous fill materials should be hand packed between the studs to the proper density as recommended by the manufacturer. If open lath such as wood or metal lath are used, this type insulation cannot be installed

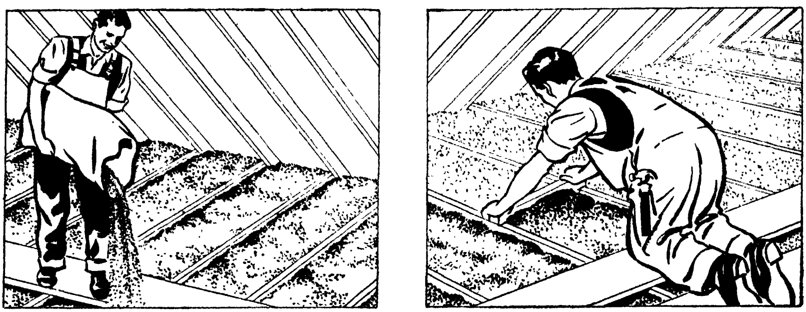


Fig. 12. Mica Pellets (Vermiculite) Poured from Bags between the Ceiling Joists; Note the Use of a Template to Gage the Depth or Thickness of the Insulation

until the plaster has been applied and has thoroughly dried. The application must therefore be made by taking off sheathing boards at regular intervals and placing the insulation from the outside between the stud spaces. The pneumatic type of installation referred to below is the most satisfactory under this condition.

Density. Packing to the proper density is important in the case of certain types of fill insulation not only to minimize or preclude settling, but to obtain the maximum efficiency of the insulation. Granulated or nodulated mineral wool has a somewhat higher density than the longer fiber loose wool as used in bats or blankets. The density of glass wool is about 1½ to 2 pounds per cubic foot. The density of mica pellets installed in ceilings is about 5½ or 6 pounds per cubic foot. Further information on the relation between insulating efficiency and density will be found in the chapter on Fundamentals of Heat Transfer through Building Materials under the heading Subdivision or Density. Data on the optimum density of fill insulations often can be obtained from the manufacturer.

Vapor Barrier in Walls. If a vapor barrier is to be provided it should be installed on the warm side of the wall, that is, on the inside face of the studs, and nailed thereto. The barrier should be installed as the work progresses, starting at the bottom of the wall, and applying first the vapor barrier and then the plaster base or

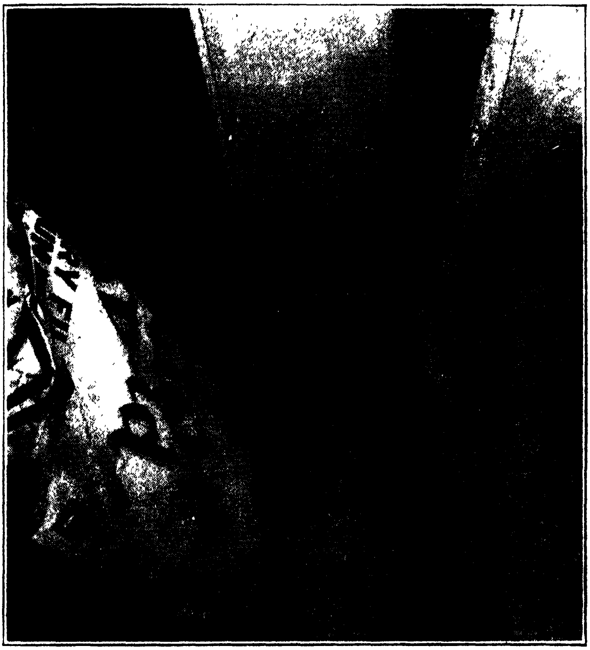


Fig. 13. Powdered Gypsum Being Poured from Bags between Ceiling Joists
Courtesy National Gypsum Company, Buffalo, N. Y.

interior finish over it to a height not to exceed 48 inches. The fill insulation may then be poured from the bags, or hand packed in the case of loose rock wool, to this height, and the procedure repeated until the stud spaces are filled to the top.

Application of Fill Insulations to Ceilings. Loose fill insulations of the granular, powdered or fibrous types may also be poured from bags into the spaces between the ceiling joists to the desired depth, usually 2 to 4 inches. The fill insulation may be poured in place as soon as the plaster base or interior finish is installed, except where open lath are used, in which case it is necessary to wait until the plaster has been applied and has thoroughly dried. Fig. 12 shows the application of mica pellets (vermiculite) between the ceiling joists and Fig. 13 shows the application of powdered gypsum. If a *vapor barrier* is to be provided it should be installed on the underside of the ceiling joists before the interior finish is applied. The fill insulation will, when installed in accordance with the foregoing procedure, rest directly on the upper surface of the barrier.

Pneumatic Application. The problem of insulating existing buildings with fill insulations is more intricate, due to the lack of access to the hollow spaces in walls and roofs. This is accomplished successfully by blowing nodulated or granulated mineral wool between these spaces. The wool is blown through a hose under pneumatic pressure, the installation being done by applicators equipped with the special apparatus for doing this work. Fig. 14 shows the manner of insulating the walls of existing structures by the mineral wool pneumatic process, and Fig. 15 shows how mineral wool may be blown into the top floor ceiling area. The vapor barrier for existing structures can best be provided by applying two or three coats of an efficient vapor-resisting paint to the interior plaster surface or other interior finish, unless the interior finish is to be removed and replaced, in which case the barrier may be installed before the new interior finish or lath and plaster are applied.

APPLICATION OF BATS AND PADS

Bats or pads are small units made from mineral wool, usually 15 or 23 inches wide to fit between standard stud spacings of 16 and 24 inches on centers and produced in various lengths and thicknesses. Plain bats without a paper backing are installed simply by inserting between the framing members, and are held in place in walls by fitting them tightly against the sheathing and between the studs. Adjoining bats should be butted snugly together to avoid leaving heat-leaking crevices. Odd-shaped spaces are filled by breaking the bats to the proper size. When plain bats are installed between roof rafters and no interior finish is planned, nails should be driven into the sides of the rafters staggered on 8-inch centers and a soft annealed, galvanized wire laced between the nails to support the bats as they are put in place. When the bats are installed between ceiling joists from above, the ceiling, if previously installed, supports the bats. If the ceiling joists are inaccessible from above, the bats may be installed from the

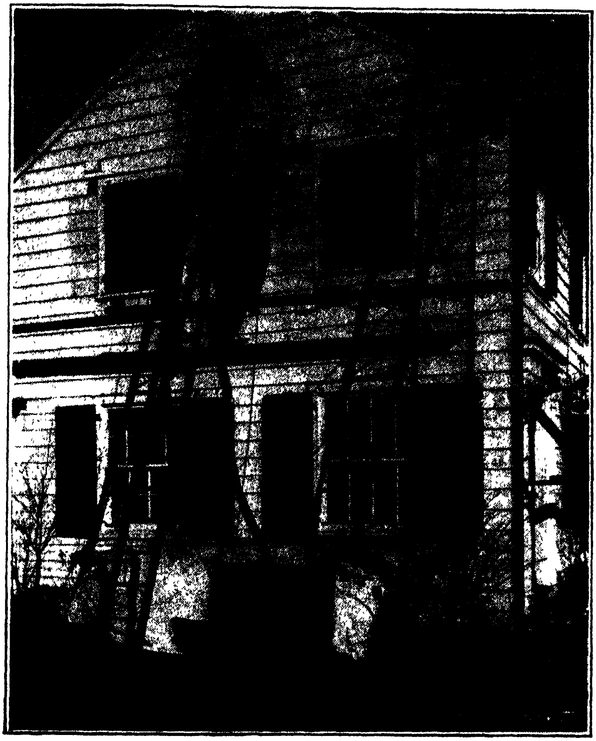


Fig. 14. Pneumatic Method of Insulating Existing Walls with Mineral Wool
Courtesy of Johns-Manville, New York, N. Y.

Fig. 15. Mineral Wool Being Blown into the Top Floor Ceiling Area by the Pneumatic Method
Courtesy of Johns-Manville, New York, N. Y.

under side and a vapor barrier immediately nailed to the under side of the joists to hold the bats in place until the interior finish is installed. A vapor barrier is recommended where plain bats are used and should be installed on the warm side of the wall or other construction as soon as the bats are in place. A vapor barrier should similarly be used when bats are installed between roof rafters, but it is advisable to hold the bats in place by means of a lacing of soft annealed wire as described above rather than to depend on the vapor

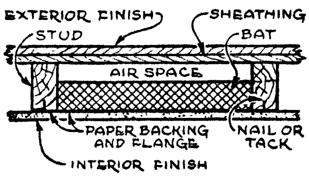


Fig. 16. Application of Flanged Paper Backed Bats Less Than Wall Thickness

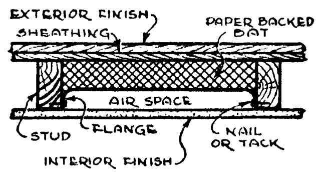


Fig. 17. Alternate Method of Application of Flanged Bats Less Than Wall Thickness

barrier to do so, unless an interior finish is to be applied over the vapor barrier.

Most manufacturers now furnish bats with a vapor-proofed paper backing which serves as a vapor barrier and is also used for installing the bats. This backing usually is wider than the bat and serves as a flange by which the insulation may be nailed to the framing member. If the bat is less than standard wall thickness based on 4-inch studding (3⅝ inches between the sheathing and interior finish) it may be installed as shown in Fig. 16, the flange of the bat being nailed to the studs as illustrated. Flanged bats less than wall thickness may also be installed as shown in Fig. 17 by nailing through flange into the studding. Both of the methods shown in Figs. 16 and 17 are suitable for so-called wall-thick bats installed between 6-inch or wider studs. Wall-thick bats may be installed between 4-inch studs as shown in Fig.18. These methods of application also apply in general to roof rafters. Fig. 19 shows the installation of vapor-proofed bats between ceiling joists.

APPLICATION OF SLAB INSULATIONS

The slab form insulation, as before stated, includes the various types of corkboard and Rock Cork which are used largely for cold storage and other low temperature insulation requirements. Corkboard is also used for roof insulation on flat roofs and as a plaster base, but the methods of application are similar to those for structural insulating board products as described in this chapter.

Shredded Wood and Cement Slab Insulations. Materials of this type include *Thermax* and *Porex* slabs and the methods of application are typical only of these or any similar products. Therefore, the detailed instructions of the manufacturers should be followed. The

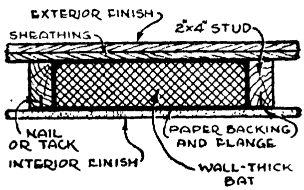


Fig. 18. Application of Wall-Thick Flanged Bats Between 4" Studding

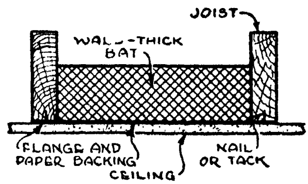


Fig. 19. Application of Wall-Thick Flanged Bats Between Ceiling Joists; Bats Are Installed before Ceiling Is Applied

uses include wall sheathing, exterior stucco base, interior plaster base and roof boarding for frame construction, lightweight floor slab, structural floor and ceiling slabs, industrial roof deck insulation and non-bearing partitions, the latter serving also as plaster base. In many cases, special clips or other appurtenances are required as indicated in the manufacturers' specifications. Cutting and fitting are accomplished with ordinary tools.

APPLICATION OF STRUCTURAL INSULATING BOARD

Many typical uses of structural insulating board products in a frame dwelling with a pitched roof are shown in Fig. 20. The uses illustrated include wall and roof sheathing, insulating board lath as plaster base, building board as base for plastic paint and various applications of the interior finish products—tileboard (panels), plank and building board.

Structural Insulating Board Wall Sheathing. The procedure for applying insulating sheathing is in general the same as that for wood sheathing, there being a few minor respects in which the methods differ. Studs should be erected as in ordinary frame construction on 12 or 16-inch centers and two by four headers inserted between framing members at the ends of all insulation boards to serve as a nailing base. Use 2-inch galvanized nails with $\frac{7}{16}$-inch heads for $\frac{25}{32}$-inch insulating board and $1\frac{1}{2}$-inch galvanized roofing nails with $\frac{7}{16}$-inch heads for $\frac{1}{2}$-inch board. Eight-penny (8d) common nails

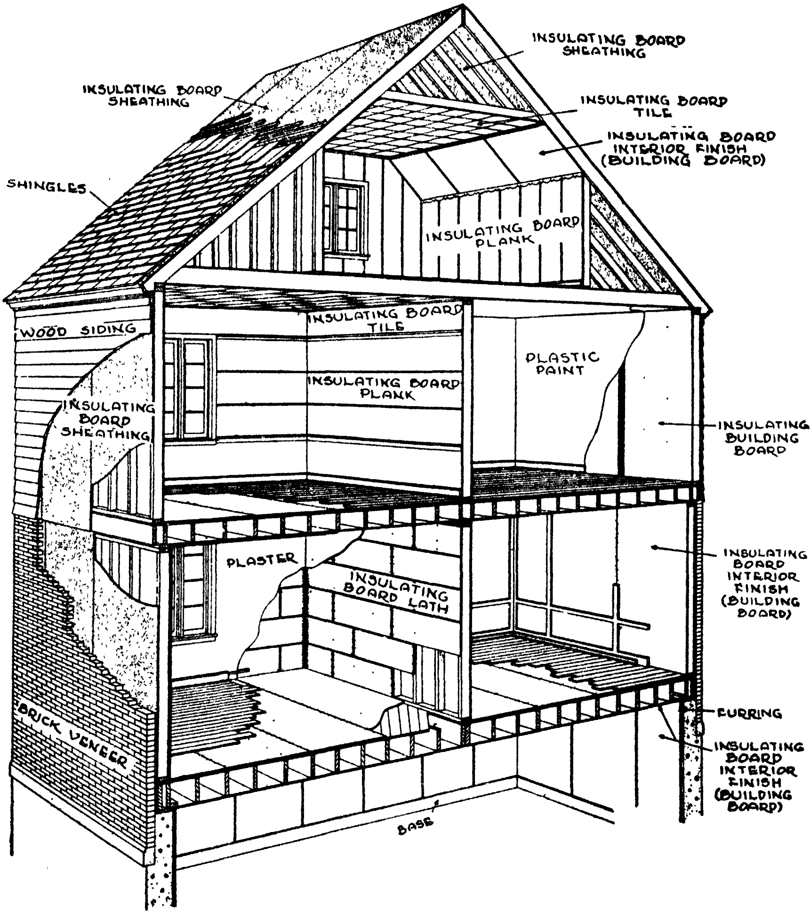


Fig. 20. Section of Building Showing Typical Uses of Structural Insulating Board

may be used for the $\frac{25}{32}$-inch sheathing if galvanized nails are not available. Tables 1 and 2 give the nails recommended for various structural insulating board products.

Apply the large insulating board units with long dimension vertical as shown in Fig. 21, and directly to all framing members, with ample bearing for nailing along the edges. Nail to intermediate framing members first, spacing nails 6 inches apart; and then along the edges, spacing nails 3 inches apart and 3/8 inch in from the edge. Drive nails so the heads are flush with the surface of insulating boards.

Table 1. Nails Recommended for Various Structural Insulating Board Products

Product	Thickness In.	Nails Recommended (See Table 2)
Sheathing	25/32	N
Sheathing	1/2	M
Lath	1/2	K
Lath	1	L
Building board (nails exposed)	1/2	A, C or E
Building board (nails exposed)	3/4 or 1	B, D or F
Building board (nails covered)	1/2	G, I, M or O
Building board (nails covered)	3/4 or 1	H, J, N or P
Tileboard (panels) (nails exposed)	1/2	A, C or E
Tileboard (panels) (nails exposed)	3/4 or 1	B, D or F
Plank (nails exposed)	1/2	A, C or E
Roof insulation	1/2	M
Roof insulation	1	N

Table 2. Description of Nails Used for Structural Insulating Board Products

No.	Name	Length In.	Size	Gage	Head	No. per Pound
A	Brad*	1 1/4	3d	14	11 ga.	568
B	Brad*	1 3/4	5d	12 1/2	9 1/2 ga.	271
C	Finishing	1 1/4	3d	15 1/2	12 1/2 ga.	807
D	Finishing	1 3/4	5d	15	12 ga.	500
E	Cadmium-plated "Insulation Board" nail diamond point	1 1/4	..	17	5/32"	1139
F	Cadmium-plated "Insulation Board" nail diamond point	1 3/4	..	17	5/32"	831
G	Box	1 1/2	4d	14	7/32"	473
H	Box	2	6d	12 1/2	17/64"	236
I	Common	1 1/2	4d	12 1/2	1/4"	316
J	Common	2	6d	11 1/2	17/64"	181
K	Blued plasterboard	1 1/4	..	13	5/16"	387
L	Blued plasterboard	1 3/4	..	13	5/16"	291
M	Galvanized roofing	1 1/2	..	11	7/16"	163
N	Galvanized roofing	2	..	11	7/16"	128
O	Galvanized shingle	1 1/2	4d	12	9/32"	274
P	Galvanized shingle	2	6d	12	9/32"	204

*Galvanized Brads should be used where available as the heads are less conspicuous.

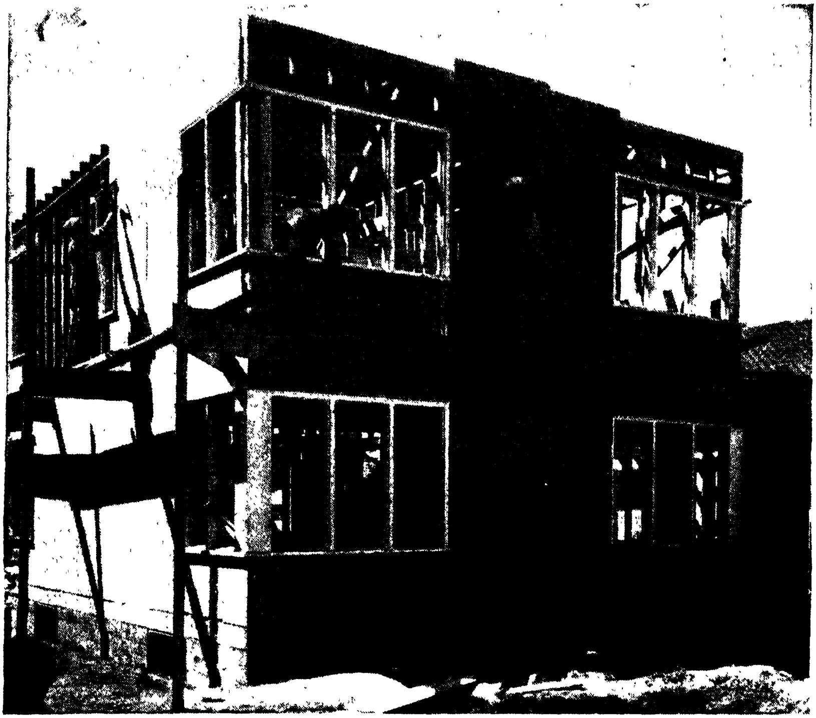


Fig. 21. Application of Large Units of Structural Insulating Board Sheathing
Courtesy of Insulite Division of M. & O. Paper Co., Minneapolis, Minn.

Fig. 22. Application of 2x8 Structural Insulating Board Sheathing
Courtesy of United States Gypsum Co., Chicago, Ill.

Never force insulating boards in place. Leave a ⅛-inch space between adjoining boards and at ends of boards. Most insulating boards are cut scant in width and length to allow for this space. Where 2x8-foot sheathing is used, it should be applied with long dimension horizontal, as shown in Fig. 22. The interlocking long edges should fit snugly with the tongues up. Headers are not required at the horizontal joints. Nail to intermediate framing members first

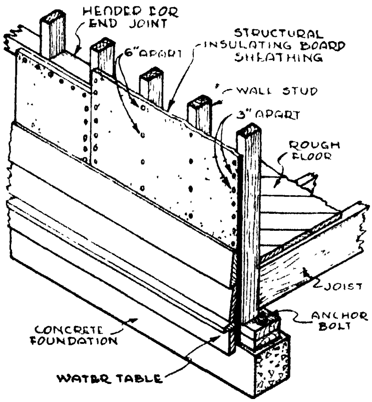


Fig. 23. Structural Insulating Board Used as Sheathing under Wood Siding

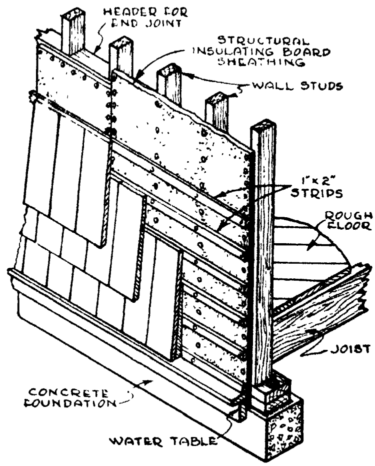


Fig. 24. Structural Insulating Board Used as Sheathing under Shingles

and then along edges, spacing nails 4 inches on centers and ⅜ inch in from the edge. Bring sheathing into close contact with frame around windows. Certain uncoated boards should be moistened lightly in dry weather, as directed by the manufacturer. Where the insulating board joins windows, doors, and other cased openings, the cracks should be sealed or "flashed" with strips of metal or prepared roofing.

Exterior Finish over Structural Insulating Board Sheathing. Wood siding may be applied directly over the insulating board, nailing to the studs. See Fig. 23. Siding boards should butt over studs. Where shingles are to be used, nail 1x2-inch furring strips horizontally over insulating board to studs, spacing to fit the shingles as shown in Fig. 24. Nail shingles to furring strips. For brick or stone veneer, space anchors properly and nail through the insulating board into the studs, as illustrated in Fig. 25. Lay the brick or stone in the usual manner. Allow not less than ½-inch space between the insulating board and the brick or stone. The building paper shown may be omitted if desired. If stucco is to be used as exterior finish, Fig. 26, it is generally considered good practice to apply a layer of building paper over all surfaces to receive stucco. Self-furring and

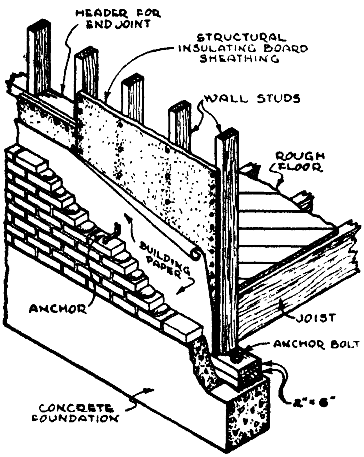


Fig. 25. Structural Insulating Board Used as Sheathing under Brick (or Stone) Veneer

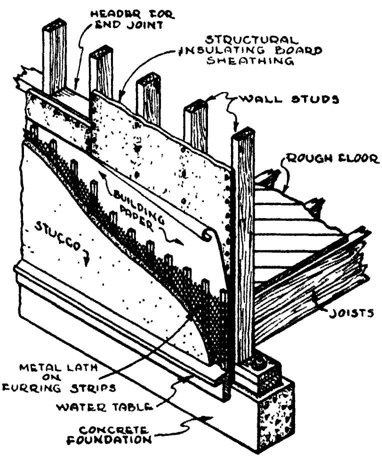


Fig. 26. Structural Insulating Board Used as Sheathing under Stucco

non-furring stucco bases should be applied in accordance with the manufacturers' specifications.

Pitched Roofs: Application of Structural Insulating Board Roof Sheathing. Where structural insulating board is to be applied directly to roof rafters of pitched roofs, either the 4-foot wide wall sheathing or building board may be used. The boards should be applied lengthwise and directly to all framing members with ample bearing for nailing along all edges. Nail to intermediate framing members first, spacing nails 6 inches apart, and then along all edges, spacing nails 3 inches apart and ⅜ inch from edges. Either solid wood sheathing or wood strips (shingle lath or roofers) depending on type of roofing to be used, should be applied directly over the insulating board, driving nails through to the rafters. If the roofing is to be shingles or slate, the wood strips are installed to receive the roofing as shown in Fig. 27. Other types of roofing such as asphalt shingles, roll or metal roofing and Spanish or French tile, require the installa-

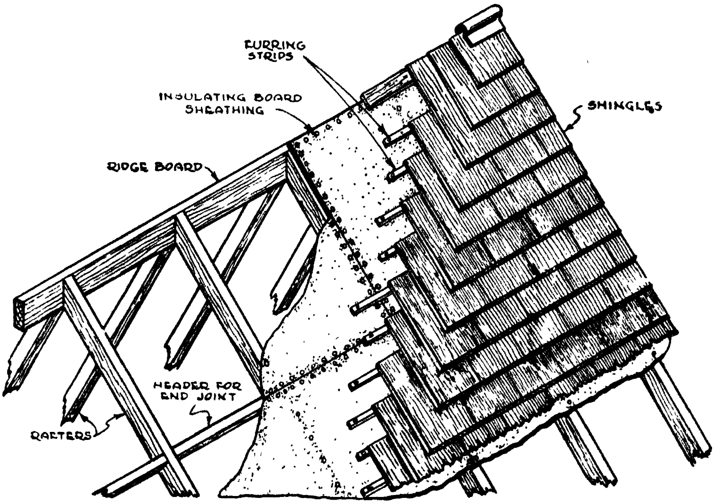


Fig. 27. Structural Insulating Board Used under Shingles (or Slate) on Roof

tion of the solid wood sheathing over which these types of roofing should be installed in accordance with manufacturers' specifications. Fig. 28 shows sections through roofs with both shingle lath and wood sheathing over the structural insulating board to receive the types of

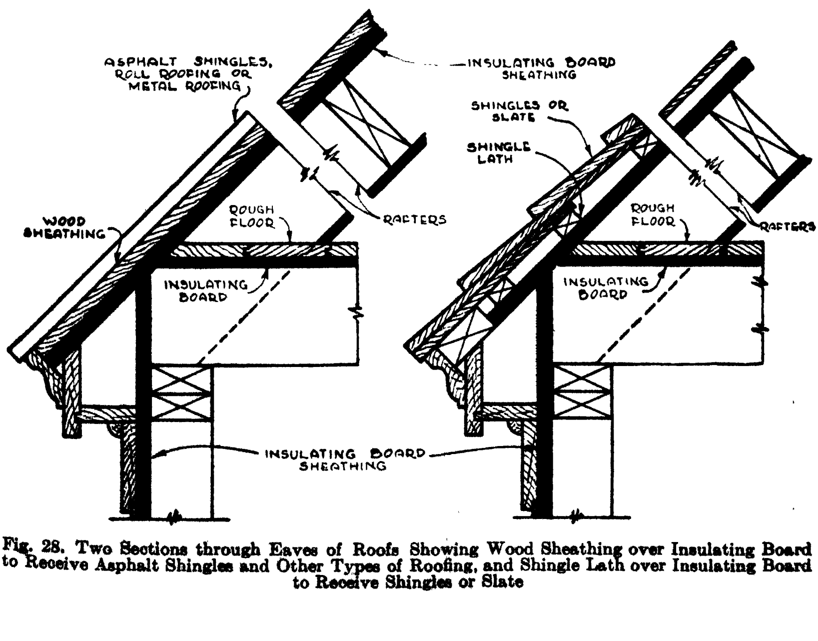


Fig. 28. Two Sections through Eaves of Roofs Showing Wood Sheathing over Insulating Board to Receive Asphalt Shingles and Other Types of Roofing, and Shingle Lath over Insulating Board to Receive Shingles or Slate

roofing indicated. Slate may also be installed over solid wood sheathing.

In some instances it is customary to install wood sheathing over the roof rafters and then to apply a layer of structural insulating board over the wood sheathing. Either the building board, wall sheathing or the smaller roof insulating board, size 23x47 inches, may be used. Each board should be secured in place by staggered nailing along the longitudinal center line, spacing nails 12 inches apart and along each edge, spacing nails about 6 inches apart. Roofing should be applied over the insulating board thus installed in accordance with manufacturers' specifications. The insulating board does not provide a nailing base and nails used to hold the roofing must therefore be driven into the wood sheathing underneath. Shingles or slate should be installed over wood strips as in Fig. 27.

Flat Roofs. Roof insulation board, a structural insulating board product, is designed especially for use on flat roofs under built-up roofing. It may also be used on pitched roofs over solid roof decks under various types of roofing. The most common size is 23x47 inches and the thicknesses are ½, 1, 1½, and 2 inches. This product is available in all thicknesses with square edges and is also available with offset (shiplapped) edges in one-inch or greater thicknesses. These shiplapped edges eliminate heat-leaking crevices at adjoining boards when applied in a single layer. This result can also be accomplished by applying two layers with the joints of the second layer parallel but offset (broken) with respect to those of the first layer.

Wood Roof Decks should be swept clean and free from dirt and loose material and should be thoroughly dry. All loose boards should be properly nailed before the insulation is laid. Where the insulation is to be applied in one layer, the entire roof area should be covered with two plies (lapped half) of rosin-sized building paper or coated roofing felt. Nail sufficiently to hold in place until the insulation is laid over it. Nails should be of sufficient length to pass through the insulation and penetrate the roof deck at least 1 inch, but should not pass through the under side of deck. See Tables 1 and 2. Space nails 12 inches apart. Each board should be secured in place by nailing along each edge and staggered along the longitudinal center line. Fig. 29 shows the application of a single layer of roof insulation board over a wood roof deck. Where two layers are to be used, nailing should be through the second or top layer only.

Vapor Barrier. Where high humidities are to be maintained in the building, a vapor barrier consisting of (a) building paper and roofing felt or (b) roofing felt only, should be installed over the roof deck before the insulation is applied. Although a vapor barrier is especially recommended whenever it is anticipated that high humidities will be encountered, its use is desirable in all cases; first,

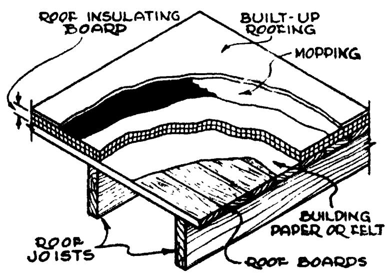


Fig. 29. Wood Roof Deck, Building Paper or Felt, Roof Insulation Board and Built-up Roofing

because the conditions of occupancy may change and second, because it is difficult in many instances to define the exact limits of relative humidity which do not require a vapor barrier. A detailed discussion of the conditions requiring the use of vapor barriers will be found in the chapter on Condensation.

(a) Where building paper and roofing felt are to be used, apply over the wood roof deck a layer of coated, rosin-sized, building paper lapped 2 inches at joints and nailed sufficiently to hold in position. Over the coated building paper lay two plies (lapped half) of 15-pound saturated roofing felt. Nail the back edge of each sheet with tin-capped, galvanized, barbed roofing nails spaced 12 inches apart. All laps should be mopped back with hot coal-tar pitch or asphalt, depending on the type of roofing used. The principal vapor resistance is obtained from the mopping of pitch or asphalt over the roofing felt in which the insulation is to be embedded. This mopping should therefore be continuous and liberal.

(b) If roofing felt only is to be used for the vapor barrier, apply over the wood roof two plies (lapped half) of heavy prepared roofing having one side coated. Lay coated side down. Nail the back edge of each sheet with tin-capped, galvanized, barbed roofing nails spaced 12 inches apart. All laps should be mopped back with hot bitumen just prior to the laying of the insulation.

Mop the exposed vapor barrier felt liberally with hot coal tar pitch or asphalt and embed each board firmly in the bituminous mopping. Only sufficient area to provide complete embedment of each board should be mopped at a time. Where two layers of roof insulation board are to be applied, mop the exposed surface of the first layer liberally with hot coal tar pitch or asphalt. Embed each board of the second layer firmly in the bituminous mopping.

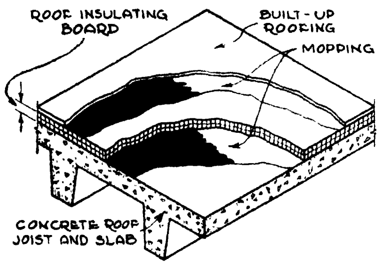


Fig. 30. Concrete Roof Deck (Pan Construction), Roof Insulation Board, and Built-up Roofing

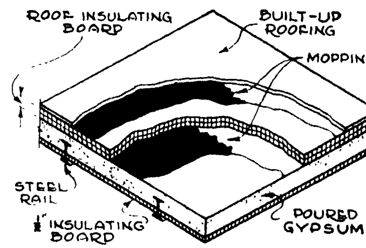


Fig. 31. Poured Gypsum on Structural Insulating Board Roof Deck, Roof Insulation Board, and Built-up Roofing

Concrete, Gypsum and Unit Tile Decks. The surface of the roof deck should be reasonably smooth without depressions, swept clean and free from dirt and loose material, and should be thoroughly dry. Where the roof deck is of cement, gypsum, book or other tile construction, the joints of all tiles should be properly pointed up.

If coal tar pitch is used, no primer is necessary. If asphalt is used, prime the deck with asphalt primer. If the deck is of monolithic construction such as poured concrete or gypsum, the subsequent mopping of the deck with pitch or asphalt should be continuous. If the deck is of precast tile units, coat the entire surface with a light and uniform mopping of asphalt; if coal tar pitch is used, spot or strip mop the individual units, keeping mopping back 4 inches from joints. This is to prevent the possibility of the pitch dripping through the joints. Only sufficient area to provide complete embedment of each board should be mopped at a time. Embed each board firmly in the bituminous mopping. Where two layers of insulation are to be used, mop the exposed surface of the first layer liberally with hot coal tar pitch or asphalt and embed each board of the second layer firmly in the bituminous mopping.

Figs. 30, 31, and 32 show poured concrete, poured gypsum on insulating board and precast cement tile roof decks respectively insulated with one layer of roof insulation board and covered with built-up roofing.

Vapor Barrier. If the rooms beneath the roof are to carry high humidities, a seal course should be included as follows: Mop the entire area with hot asphalt. Over the mopping, while hot, lay two plies, lapped half, of 15-pound saturated roofing felt. Wrap roofing

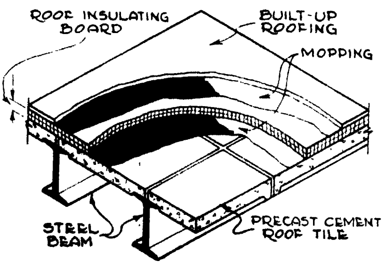


Fig. 32. Precast Cement Tile Roof Deck, Roof Insulation Board, and Built-up Roofing

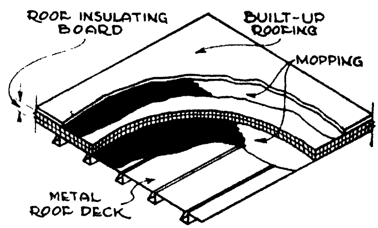


Fig. 33. Metal Roof Deck, Roof Insulation Board, and Built-up Roofing

felt around edges of insulation and mop back 6 inches at walls, skylight curbs and monitor skylight sash. Do not mop over this membrane until just prior to the laying of the insulation. The insulation should be applied in accordance with the second paragraph above, except that only asphalt roofing and asphalt should be applied over an asphalt vapor course. Coal tar pitch and asphalt should not be used together on the same job.

With this type of construction, as with others, a vapor barrier is desirable in all cases.

Steel Roof Deck. The steel deck, Fig. 33, should be securely anchored to the roof purlins and all joints should be made rigid. A vapor barrier should be installed in accordance with the preceding paragraph if a high humidity is to be maintained. Mop the roof deck or the vapor barrier with a liberal coat of hot asphalt. Only sufficient area to embed each board should be mopped at a time. Embed each board firmly in the bituminous mopping. Where two layers of insulation are to be applied, mop the exposed surface of the first layer liberally with hot asphalt and embed each board firmly in the asphalt.

Application of Roofing. In all cases, apply the roofing over the roof insulation board in accordance with the roofing manufacturer's specifications. Fig. 34 shows a typical roof deck with vapor barrier or seal course, two layers of roof insulation board, and built-up roofing.

Protection Course. An important use of roof insulation board is that of protection of waterproofing membranes. Waterproofing

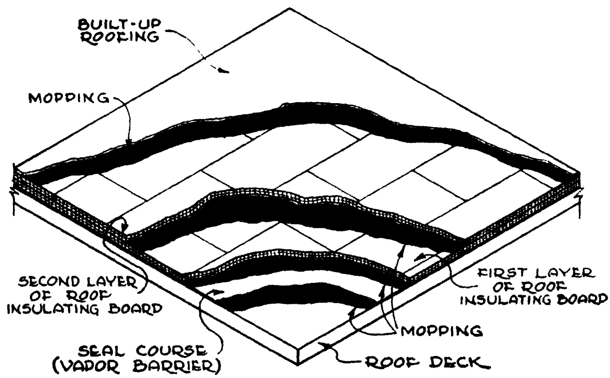


Fig. 34. Typical Roof Deck with Vapor Barrier, Two Layers of Roof Insulation Board, and Built-up Roofing

courses of saturated roofing felt and asphalt or pitch, similar to those used on flat roofs, are frequently used on the outside of foundation walls and under concrete floors to resist hydrostatic pressures. If they leak at any point water will penetrate them and their usefulness ceases. Consequently they must be safeguarded against mechanical injury until they are permanently enclosed by masonry or some other protective construction.

Where roof insulation board is to be used for this purpose, the waterproofing course should be applied to wall or floor areas in accordance with established practice. As the waterproofing treatment is given its final mopping, embed a layer of structural insulating board roof insulation, applied while the last mopping course is still hot and tacky, and with all edges in moderate contact. If a second layer of roof insulation board is to be applied, the surface of the first layer should be thoroughly mopped with bitumen into which while hot the second layer should be embedded with all joints broken. On vertical surfaces, use a wooden mallet to procure over-all contact. On horizontal surfaces press down on all units to insure intimate bond. After the roof insulation board is in place, mop exposed surfaces with bitumen, filling all joints. Where the floor areas are subjected to the sun or heat, dust the bitumen coating with sand or grit to prevent sticking under traffic, or preferably apply final bitumen coating just prior to laying of finished floor.

Application of Structural Insulating Board Lath. This type of product is available in commercial sizes—16, 18 or 24 inches wide by 48 inches long—and in thicknesses of ½ inch and 1 inch.

Insulating board lath is manufactured with special joints for reinforcing the plaster at the joints. The types available include the following: long edges shiplapped, galvanized wire reinforcing between framing supports; **V**-lap edge on the long sides, beveled on all edges; long edges tongued and grooved; beveled-shiplapped edges; and shiplapped on long edges with a 3-inch diamond mesh metal lath strip the full length of the long edge. There are also various modifications and variations of these edge treatments, but all are intended to perform the same function, namely, to reinforce the plaster at the joints between the individual lath units. Special vapor-resisting lath is also available.

The studs, joists and rafters should be erected as in ordinary frame construction on 12 or 16-inch centers. For exterior solid masonry walls install 1x2 furring strips vertically on 12 or 16-inch centers and shim to a true, level plane. Blued plasterboard nails are recommended for insulating board lath, 1¼-inch nails for ½-inch lath and 1¾-inch nails for 1-inch lath, as per Tables 1 and 2.

Insulating board lath should not be moistened prior to, during or after application. Lath should be applied with long edges at right angles to the framing or furring strips. Center all end joints on framing and stagger the vertical joints of each course of lath with the joints of the preceding course. Manufacturers' instructions should be followed where lath with special joints are used. Nail lath securely to framing, using five nails at each stud or furring strip; that is, twenty nails for each lath when framing is on 16-inch centers. Use strips of insulating board lath where piecing out is necessary; do not fill out with wood or wood strips. To cover arches, curves or sweeps, first nail lath at the end, bending it to the required contour and then nail to each successive stud, joist or furring strip.

All outside corners should be reinforced with metal corner beads. Reinforce all inside corners or re-entrant angles with standard expanded metal lath strips 6 inches wide bent into the angle and secured in place by nailing. Use 6-inch strips of expanded metal lath to reinforce all joints between frame and masonry construction.

Standard gypsum cement plaster or gypsum wood fiber plaster containing no lime should be used for the first two coats, the scratch and brown coats. Both coats should be mixed to a wet consistency to allow for application with light trowel pressure and to facilitate the use of the darby, the large plasterer's tool used for leveling the surface. Any standard plaster finish may be used over the brown coat, such as gypsum, lime or lime gauged with gypsum.

The plaster should be applied in three coats to full ½-inch thickness and the surface troweled to a true plane. All corners and angles should be plumb and true and darby strokes should be in the direction of framing members with the darby spanning two or more studs or joists.

Provide adequate ventilation for proper drying of the plaster in winter as well as in summer. Adequate heat should be provided in winter to prevent injury to fresh plaster by frost. Fig. 35 shows the application of plaster to insulating board lath.

Structural Insulating Board Interior Finish. The structural insulating board interior finish products include building board, plank and tileboard, the latter being also known as panels. The proper application of insulating board for interior finish purposes is important, and the specific instructions of the manufacturer of the product used should be followed for best results. The following details of application will, however, serve as a general guide.

Beveling and Grooving. By means of special tools which have been developed for the purpose, the large building boards may readily be beveled, grooved or hand carved. One of these tools—the Stanley Fiber Board Cutter, manufactured by Stanley Tools, New Britain, Conn.—is similar to a carpenter's plane and utilizes tool steel blades which may be used indefinitely if properly honed. This tool has adjustments for varying width and depth of cuts, and spacing for grooves. A supplementary tool or knife is used for freehand carving where the beveling and grooving would be unwieldy. Some of the operations possible with these tools include square and beveled edges, V-grooves of varying widths, diagonal grooves, and inside grooves "faded" by gradually lowering and raising the tool. Overlays and perfect circles can be obtained as well as freehand curves and sweeps; also V-grooves in fluted designs and miter and slip joints.

Applied to Framing or Furring. These products may be applied by nailing to framing or furring or by cementing to continuous,

Fig. 35. Application of Plaster to Structural Insulating Board Lath
Courtesy of the Celotex Corporation, Chicago, Ill.

smooth surfaces. When attached to a nailing base, the framing should correspond with the size or type of product used but in no case should be installed on greater than 16-inch centers. Furring strips for plank should be at right angles to plank on 9-inch centers up to a height of 3 feet and 12 or 16-inch centers above this height. It is especially important that the framing or furring for tileboard units should carefully conform to the size of units used. Headers are recommended in back of chair rail and all other heavy mouldings.

Where nailing is to be exposed, finishing nails, brads or cadmium-plated insulation board nails should be used. For ½-inch thick insulating boards use 1¼-inch nails and for 1-inch boards use 1¾-inch nails. Drive nails at an angle, setting below surface and tapping fiber over surface. Nails may be driven in beaded groove of plank. Where nails are to be covered with panel strips or mouldings, use 1½-inch nails for ½-inch board and 2-inch nails for 1-inch board as specified in Tables 1 and 2.

Concealed Nailing. Some manufacturers have developed special clip systems and interlocking joints for installing tileboard or panels and other interior-finish products, the object being to eliminate exposed nailing. Manufacturers of such systems should of course be consulted when their products are under consideration.

Over Smooth Surfaces. Insulating tileboard (panels) may also be applied to sound plaster, smooth wood, plaster board and other continuous surfaces by means of special adhesives available for this purpose, but for best results supplementary nailing is recommended where possible. Apply the adhesive to tileboard in spots 2 or 3 inches in diameter, one in each corner and additional spots on the larger sizes. The adhesive may also be applied over the entire surface to be bonded, if desired. It is particularly important that sufficient adhesive be used, especially in the case of rough surfaces, for which a heavy-bodied adhesive is preferable. Intimate bond is obtained by sliding the units in place, using a pressure sidewise and against the surface to be finished.

For application over metal ceilings, rough plaster or other irregular or unsound surfaces, furring strips should be installed and the insulating board nailed thereto in accordance with the instructions for application over framing or furring.

Fig. 36 shows various decorative wall designs using structural insulating board interior finish products. Fig. 37 shows various ceiling designs using insulating tileboard or panels.

Cleaning and Maintenance. Dust may be removed from the surface of insulating board by brushing lightly with a whiskbroom, by rubbing with another piece of insulating board, by vacuum cleaning with a brush attachment, or by means of wallpaper cleaner. Heavy smudges may be removed with fine sandpaper. Grease spots are removed by several treatments with a rag or sponge soaked in naphtha.

Structural Insulating Board as a Base for Paint and Wall Coverings. Insulating board may be used in the natural or in factory-finished colors, as described in the preceding paragraph or it may be used as a base for decorative finishes of various types, including paints, stains and wall coverings.

The framing or furring is installed in the usual manner on 12 or 16-inch centers. Headers are cut in between framing members at the

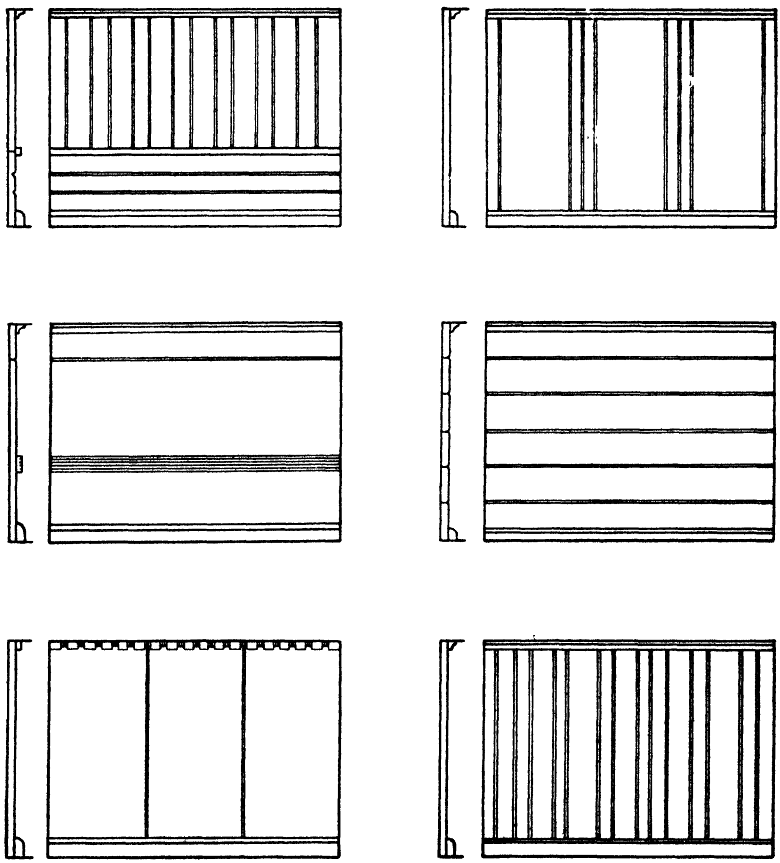


Fig. 36. Suggested Decorative Wall Designs Using Structural Insulating Board Interior Finish Products

ends of the insulating board to provide a nailing base and also in back of chair rails and other heavy mouldings. Where paints and stains are to be used, the insulating board is attached by means of finishing nails or brads driven at an angle and set flush with the surface of the board or slightly below. Otherwise 1½-inch box or common nails may be used, except where 1-inch insulating board is to be installed, in which case 2-inch nails are recommended, as per Tables 1 and 2.

The insulating board should be placed singly around the room for at least 24 hours prior to erection to allow adjustment to atmos-

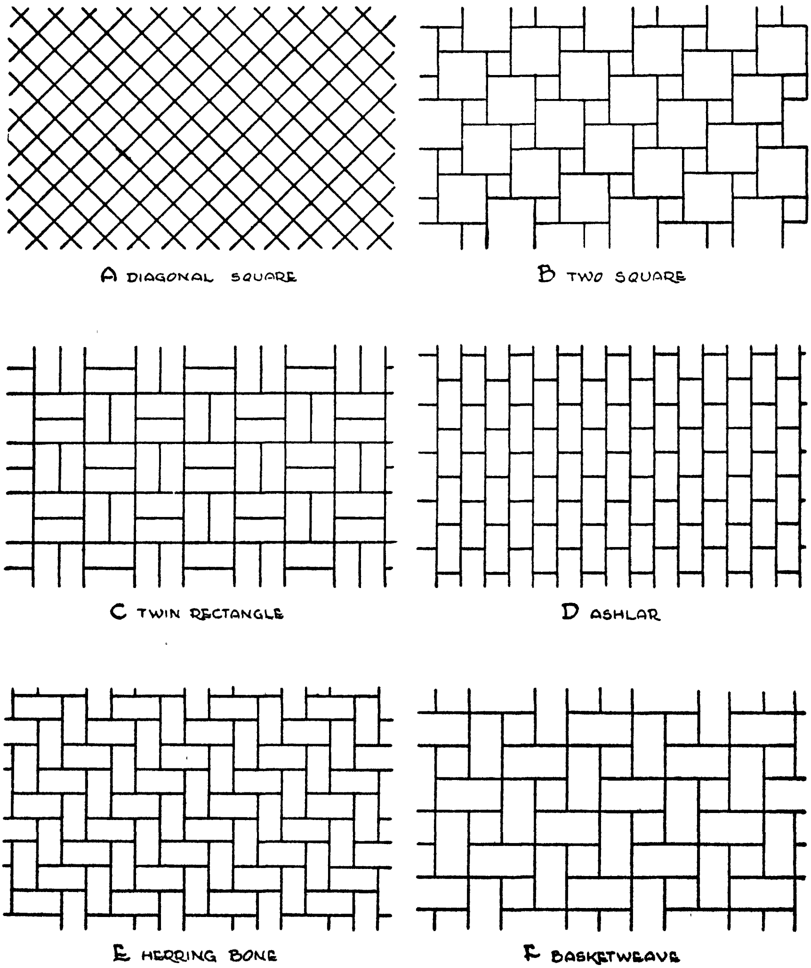


Fig. 37. Suggested Ceiling Designs Using Insulating Tileboard (Panels)

pheric conditions. Boards should be of sufficient length to span completely between sills and plates or other structural members. The insulating board is nailed first to intermediate framing members, and then the edges are nailed. On intermediate framing members, nails are spaced 6 inches apart. Nails are spaced 3 inches apart at edges and 3/8 inch away from edges and driven in until the heads are flush with the insulating board surface.

Calcimines, Casein and Water Paints. Calcimines and water paints may be applied directly to unsized insulating board, although calcimines may also be applied to varnish-sized surfaces to facilitate removal by washing. Water paints of the casein base class are washable to a certain degree but not quite so much so as oil or varnish paints.

A single coat of good casein-base water paint will usually give good coverage on insulating board, although two coats are recommended. Some of these paints are available tinted in a variety of attractive pastel shades. Others can be tinted from the white by the addition of dry colors in accordance with manufacturers' directions.

Stains may be used where the natural color of the insulating board is to be modified without destroying the texture and where its sound absorbing properties are of importance. While a variety of stains are available, glue stains usually give the best results on insulating board. A satisfactory glue stain may be made by dissolving 1/2 pound of flake or ground glue in a gallon of boiling water.

After the glue has been thoroughly dissolved, dry color is added in amounts depending on the depth of tone required. The dry colors are best added by mixing them with a small amount of water, stirring to a thin paste which is more easily taken up by the glue solution. Glue stains of this type must be used promptly after preparation. They should, if possible, be applied while they are still warm. Alcohol stains are not recommended—they dry too rapidly, leaving brush marks.

Oil or Varnish Paints. Structural insulating board must be properly sized before application of oil or varnish paints. A satisfactory glue size may be made by dissolving 1 1/2 pounds of chip or flake glue in a gallon of boiling water. Various prepared oil or varnish sizes, ready mixed and properly proportioned for direct application to insulating board, may be obtained but the size used should be that recommended by the manufacturer. The best results are obtained if the surface is sanded lightly after the size coat has dried thoroughly.

The paint may be applied to the surface thus prepared, using the desired number of coats for satisfactory results.

Covering Joints for Plastic Paints and Wall Coverings. Where plastic paints or wall coverings are to be applied over insulating board, some authorities recommend that all joints between boards be reinforced, using galvanized wire screen or buckram tape applied in Swedish putty or other suitable bonding cement. The wire mesh or tape should not be nailed or tacked in place except when starting a joint and occasionally on ceiling strips to hold in place while applying cement.

Hold one end of strip while the bonding cement is applied to the surface of the reinforcement and press through the mesh with a 4-inch painter's scraping knife. Spread the bonding cement beyond the edges of the reinforcement for not less than 1 inch so that the edge of the mesh will not show through the plastic paint finish. In bonding the reinforcement over the joints, press firmly against the insulating board and fill mesh well with the bonding cement applied in the consistency of putty. Apply, similarly, a strip of reinforcement bent around all corners and re-entrant angles.

Applying Plastic Paints and Wall Coverings. Plastic paints are thick paints which can be textured by manipulating the brush or various tools to produce various textures and effects. They are divided into two groups—those prepared by the addition of water to a powder and those having a linseed oil base furnished prepared for use. Water-base plastic paints, unless excessively alkaline, can usually be applied directly to unsized insulating board. For oil-base plastic paints, the insulating board should be sized in accordance with the instructions under the heading, *Oil or Varnish Paints.*

Wallpapers, canvas, fabrics such as *Sanitas,* leather and even thin plywoods and thin metal sheets may be applied to certain insulating boards. For best results, wallpaper may be applied over a 1-pound (per square yard) linoleum felt applied horizontally over the insulating board with joints butted, the felt cemented with paperhanger's paste. The surface of the linoleum felt should be sized with the paperhanger's paste before application of the wallpaper, the latter being applied in the usual manner. Where this method of application is used, the joint reinforcing over the insulating board may be omitted. Manufacturers should be consulted for specific recommendations as to this use of their product.

Stencil Decoration. Where a light touch of color is desired or where a means of accentuating a design is sought, stencils are recommended. Border stencils are particularly attractive on insulating board interiors and are approved by leading decorators.

Stencil designs may be cut in oiled paper or metal. They are held in position by hand or by thumb tacks while the color is applied with a stiff stencil brush. Colors ground in Japan are recommended. The Japan color paint should be thinned to the desired consistency with a mixture of six parts turpentine, three parts linseed oil and one part Japan drier.

Artistic decorative effects may be produced by carving the surface of insulating board, particularly in the case of large relief carving where detail is not required. A design is first laid out in pencil and razor blades or a sharp knife are then used to carve the insulating board.

Structural Insulating Board for Summer Cottages, Cabins and Camps. Simple structures such as summer cottages, tourist cabins and camps differ primarily from larger and more expensive residences in the fact that the exteriors of the walls are not usually finished with other facing, nor are the interiors generally plastered. Such houses are generally built at minimum cost consistent with satisfactory service for the particular use. Insulating board has been found by many users to be ideally suited to such types of buildings because when painted the material itself permits exposure to rain without injury and the side exposed to view on the interior makes an attractive interior finish. Where the least expensive structure is desired, only one thickness of insulating board is used, but in most cases two thicknesses are preferable, one on each side of the studding.

Figs. 38 to 48 show some of the more common methods of using structural insulating board for walls of such buildings as cottages, cabins and small bungalows. The most elementary type of wall is shown in Fig. 38 and consists of ordinary 2x4-inch studding placed 16 inches on center with one thickness of insulating board on the outside, painted on the exterior and with 1x4-inch strips over the joints. No insulating board is used on the interior. The 2x4 studs and the interior surface of the insulating board may be painted or stained or left in their natural colors. The construction shown in Fig. 38 may be modified by applying plaster to the inside surface between the studs with the plaster surface sand floated or painted, or by applying stucco to the exterior over reinforced steel fabric.

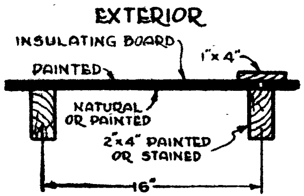


Fig. 38.

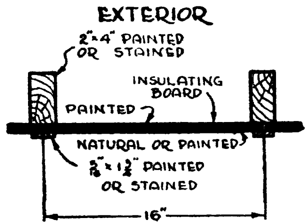


Fig. 39.

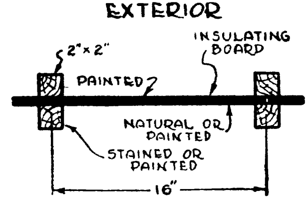


Fig. 40.

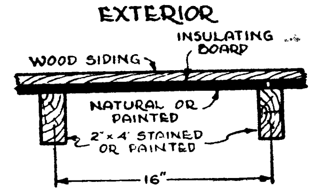


Fig. 41.

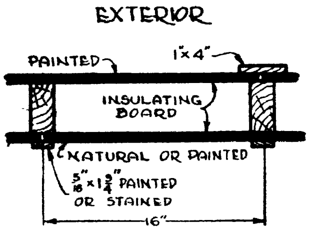


Fig. 42.

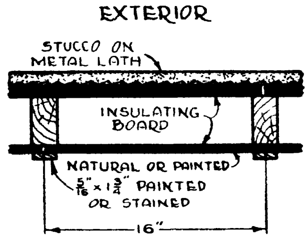


Fig. 43.

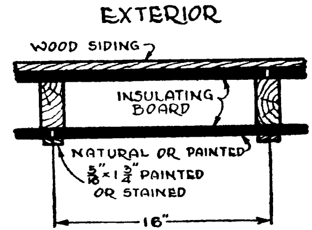


Fig. 44.

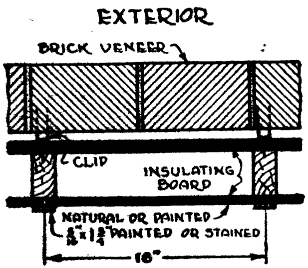


Fig. 45.

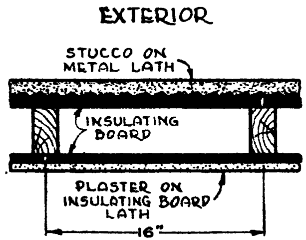


Fig. 46.

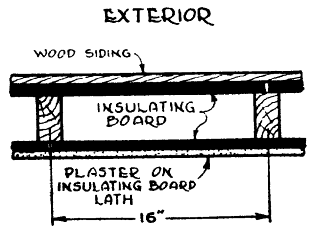


Fig. 47.

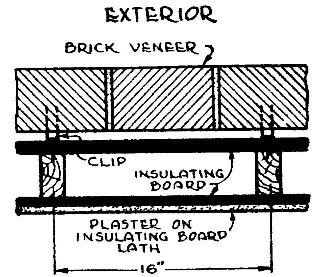


Fig. 48.

The construction shown in Fig. 39 differs from that in Fig. 38 only in that the 2x4-inch studding is exposed on the outside of the building. On the interior thin strips of wood are nailed vertically over the insulating board to each 2x4. When this is done all complications that arise in paneling the wall surface are eliminated. The narrow strips may extend from the baseboard to the picture moulding. A modification of this wall is to omit the strips and to apply plastic paint directly to the inside surface of the insulating board. Joints are reinforced with 4-inch strips of galvanized wire door screening. The construction shown in Fig. 40 has many advantages for simple houses. The 2x2-inch vertical members on each side of the insulating board make an attractive exterior as well as interior finish.

The wall in Fig. 41 differs from that shown in Fig. 38 by the addition of wood siding nailed through to the studding. The 2x4 studding is exposed on the interior of the building. Fig. 42 shows a frame wall using two thicknesses of insulating board. Figs. 43 to 48 inclusive are standard frame wall constructions which are included for comparison but which are also suitable for the more expensive summer cottages. Application details for these walls will be found elsewhere in this chapter.

Insulation of cottage or cabin roofs is important as such buildings are usually occupied in summer when the sun beats down on the roof, often making the rooms uncomfortably hot. There are three places in which insulating board is used to advantage in the tops of simple dwellings: (1) on top of the roof rafters, (2) under the roof rafters, and (3) on ceiling joists as a ceiling. For better insulating effect insulating board should be used in at least two of these places. It should not be used on top of roof rafters without wood sheathing in case of flexible roof covering, or without wood nailing strips in case of rigid roof covering such as wood shingles.

Any of the other types of building insulation suitable for ceilings or pitched roofs may also be used for cottage or cabin roofs, applied in accordance with the methods described in this chapter.

Application of Cement-Asbestos Covered Structural Insulating Board. Structural insulating board is furnished by several concerns surfaced on one or both sides with ⅛-inch asbestos cement. This product usually is 4 feet wide by lengths up to 12 feet and the thicknesses of the structural insulating board core are ½, 1, 1½ and 2 inches. This type of product is used as an insulated roof deck, for partitions and outside walls. It is frequently used to construct driers, kilns and other rooms or buildings in which temperatures and humidities above normal are maintained. This product may be nailed, sawed, or otherwise fabricated with carpenters' tools. In some cases special clips or other appurtenances are employed to install this material. Detailed specifications are furnished by the manufacturers.

APPLICATION OF REFLECTIVE INSULATIONS

Reflective insulations are generally installed in much the same manner as flexible insulations, that is, either between framing members and fastened to the sides thereof, or to the edges of framing

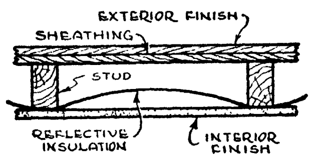


Fig. 49. Application of Reflective Insulation to Face of Framing Members

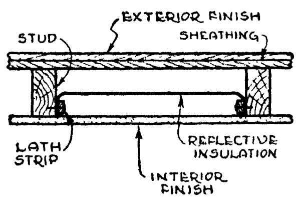


Fig. 50. Application of Reflective Insulation between Framing Members Using Lath Strips

members. It is important to remember that proper installation is particularly important with this type of insulation, because to be of value the reflective surfaces must always be exposed to an air space of appreciable size. To be of maximum value the air space should be an inch or more in width because the value of reflective insulation diminishes as the width of the air space decreases below one inch. As the width of the air space to which the reflective surface is exposed diminishes toward zero inches, the insulating value of the reflective material likewise diminishes toward zero, that is, no value. The reflective insulation should be installed in such a manner as to divide the air space into two air spaces, and when thus installed, the value will be greater if both sides of the material are reflective rather than only one.

Fig. 49 shows the application of a single curtain reflective insulation between wall studs, the insulation in this case being nailed to the face of the studs and later covered with the lath and plaster or other interior finish. Fig. 50 shows the installation of a single curtain

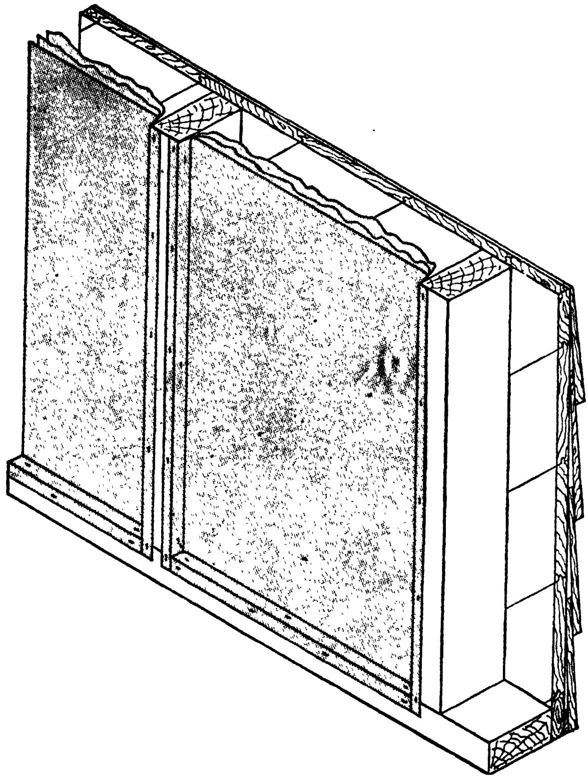


Fig. 51. Application of Type 2 Alfol Insulating Blanket
Courtesy of Alfol Insulation Co., Inc., New York, N. Y.

reflective insulation using lath strips and nailing through the strips to the sides of the studs. Fig. 51 shows the application of type 2 *Alfol* with two *Alfol* layers and a vapor barrier. Fig. 52 shows a method of application suitable for *Ferro-Therm* or *Reynolds Metal Insulation,* which have a flange for nailing or stapling to the sides of studs. These methods are generally suitable also for application of these materials to furring strips of masonry walls, to ceiling joists or to roof rafters. Insulating lath of the reflective types are installed in the same manner as insulating board lath, the reflective surface being exposed to the air space and plaster being applied to the other surface.

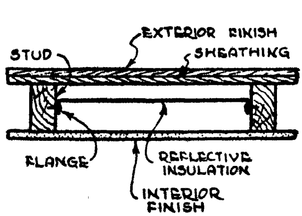
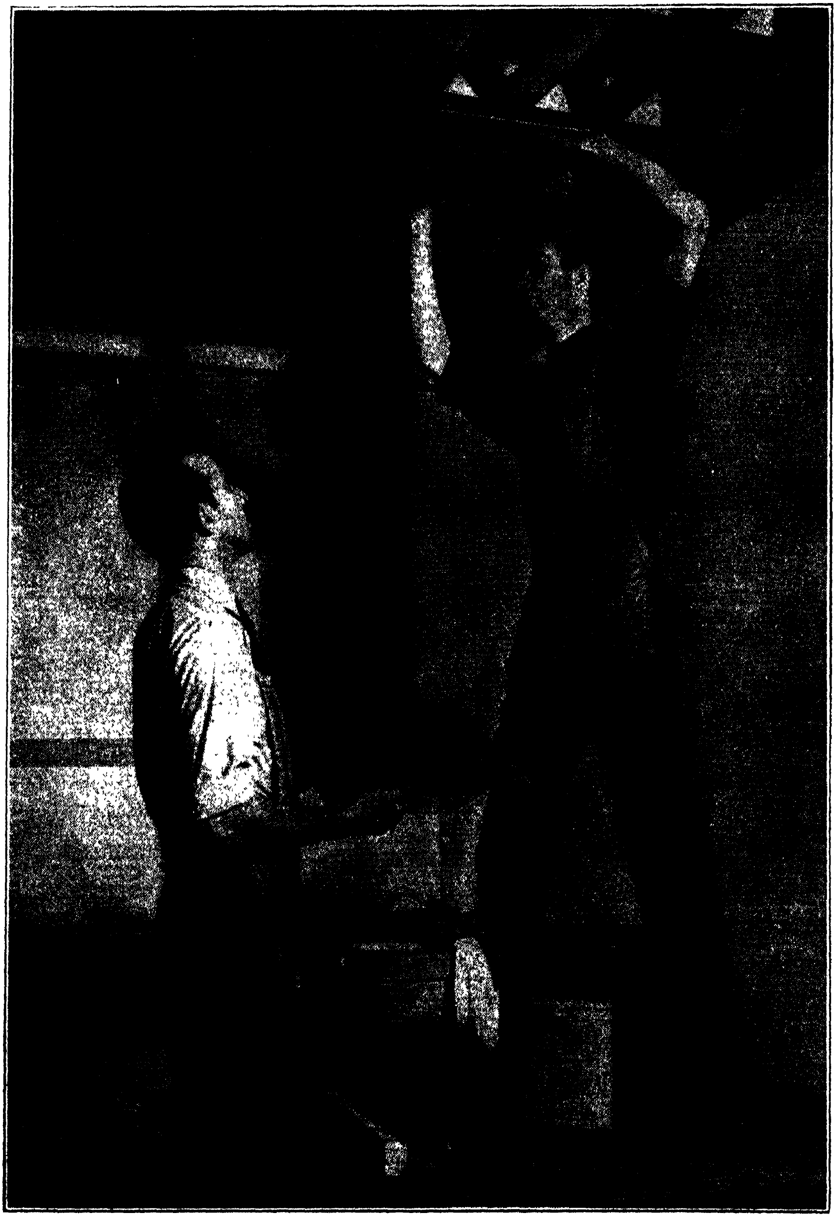


Fig. 52. Application of Reflective Insulations with Flanges between Framing Members



APPLICATION OF INSULATING TILEBOARD TO CEILING BY MEANS OF AN ADHESIVE

Courtesy of Armstrong Cork Products Co., Lancaster, Pa.

CHAPTER IV

FUNDAMENTALS OF HEAT TRANSFER THROUGH BUILDING MATERIALS

The study of the subject of insulation necessarily involves an understanding of certain fundamental principles. These principles include the theory of heat, the unit of heat, temperature, methods of heat transfer and the units of measure of the rate of heat transfer through individual materials and compound wall and roof structures.

What Is Heat? One of the first theories regarding heat was that it was a material substance, but one which could not be weighed or detected by any ordinary physical method. This substance was called *caloric,* the presence or absence of which accounted for differences or changes in temperature.

The second theory, which was generally accepted at the close of the eighteenth century and which contained the fundamental idea of the modern theory of heat, assumed that heat was due to a rapid motion of the molecules of a substance, and thus was a form of motion. Lord Bacon made a complete summary of the available information bearing on this theory and concluded that these facts indicated definitely that heat was a form of motion.

In 1798 Count Rumford conducted the first experiments dealing with the nature of heat. In boring out a cannon with a blunt tool, he observed that heat was developed so long as the boring was continued. This indicated that the supply of heat was inexhaustible and hence could not be a material substance. It also indicated that the development of heat must be due to some other cause than the forcing of the caloric out of one body by the boring process. Since the development of the heat accompanied the motion during the boring operation he concluded that the heat developed could not be a material substance but must be motion and hence energy.

Molecular Theory of Heat. From this time on the idea that heat is a form of energy was gradually accepted. According to the present day point of view, all substances are composed of infinitesimally small units or particles called *molecules,* which vibrate with great freedom when the matter is gaseous, and with less freedom when it is liquid or solid. The temperature of a body is due to the so-called kinetic energy of the molecules. In other words, the more rapidly the molecules vibrate, the higher the temperature. If it were possible to take away all of the heat from a substance, that is, to reduce its temperature to absolute zero (459.6 degrees below 0°F.), then theoretically there would be no motion of the molecules of this substance.

Temperature is not a quantity but simply an index of the intensity of heat of a substance, or of its thermal state, or of its heat level. Temperature scales and units are arbitrary. The Fahrenheit scale, the one in ordinary use in English-speaking countries, is obtained by giving the value 32 to the freezing point and 212 to the boiling point of water, and subdividing the fundamental interval, as it is called, into 180 degrees.

Absolute temperature is measured from absolute zero, which is the state in which a substance contains no heat, its molecules being at rest with respect to one another, as previously stated. On the Fahrenheit scale, a temperature of 0° corresponds to an absolute temperature of 459.6°. In technical computations a round figure of 460° is used, the absolute temperature being obtained by adding 460 to the temperature indicated by an ordinary Fahrenheit thermometer.

British Thermal Unit. The unit of heat in the English system is the British Thermal Unit (abbreviated B.t.u.), which is the amount of heat required to raise one pound of water one degree Fahrenheit, from 63° to 64°. This unit represents a definite and fixed quantity of heat, just as the foot is a unit of linear measure, the pound a unit of weight, and the second a unit of time.

Heat Content of Fuels. When a quantity of fuel is burned in the air, a definite number of heat units are given off. The heat content or the calorific value of fuel is the number of B.t.u. evolved when one pound of fuel is completely burned in air or oxygen.

Solid Fuels. The calorific value of various grades of coal varies considerably. The number of heat units given off when a pound of anthracite coal is completely burned in the air is in general greater than the number of heat units given off by complete combustion of a pound of bituminous coal. The average difference in heat value of anthracite and bituminous coal, however, is not as much as is generally supposed. Pennsylvania anthracite varies from 11,800 to 15,300 B.t.u. per pound of dry coal. Inasmuch as commercial coal contains a certain percentage of moisture, the actual calorific value of a pound of commercial coal is lower than the calorific value of a pound of dry coal.

Bituminous coals usually range between 11,000 B.t.u. per pound and 14,000 B.t.u. per pound of dry coal, but they generally contain a higher percentage of moisture. Coke contains from 12,500 B.t.u. per pound to 13,500 B.t.u. depending upon the ash content, which may vary from five to ten per cent. For estimating purposes heat values ranging from 12,000 to 13,000 B.t.u. per pound of fuel as fired are generally used for coal and coke.

Woods. The average calorific value of wood, according to Bureau of Standards Circular No. 70, is 8,000 B.t.u. per pound. This value probably applies to wood with considerably less than 20 per cent moisture. A cord of wood contains 128 cubic feet. Allowing 80 solid cubic feet of wood to an average cord of wood, and assuming the wood to be well seasoned, a cord of hickory or other heavy wood is equivalent in heat value to about one ton of coal. For the lighter woods, such as cedar, white pine, poplar and spruce, two cords are roughly equivalent to one ton of coal.

Liquid Fuels. Oil is the principal liquid fuel. Oil fuels are classified into six groups as shown in Table 1. The lighter oils designated as Nos. 1, 2 and 3 are used primarily for domestic heating,

Table 1. Fuel Oil Classifications[a]

Grade of Oil	Description	Approximate B.t.u. per Gallon[b]
1	A light distillate for domestic use	139,000
2	A medium distillate for domestic use	141,000
3	A distillate fuel oil for use in burners where a low viscosity oil is required	143,400
4	For use where a low viscosity industrial fuel oil is required	144,500
5	Bunker oil "B" for burners adapted to the use of industrial fuel oil of medium viscosity	146,000
6	Bunker oil "C" for burners adapted to oil of high viscosity	150,000

[a]Adapted from "Fuel Oils," U. S. Dept. of Commerce, Bureau of Standards, Washington, D. C.

[b]Government specifications do not give B.t.u. value.

whereas the heavier grades (Nos. 4, 5 and 6) are used largely for industrial purposes. The calorific value of No. 2 oil is about 141,000 B.t.u. per gallon, which is the value frequently used for estimating purposes.

Gaseous Fuels. Gas is broadly classified as natural and manufactured. Natural gas is a mechanical mixture of several combustible and inert gases rather than a chemical compound. Manufactured gas as distributed is usually a combination of certain proportions of gases produced by two or more processes, and is often designated as city gas.

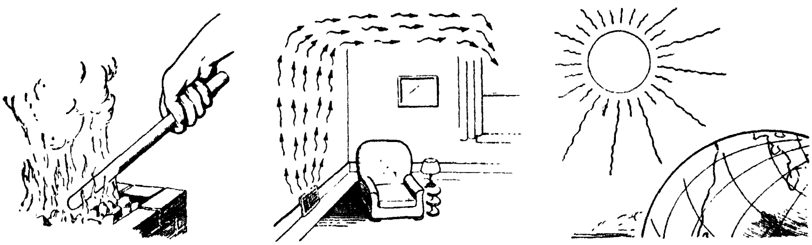
When gas is burned a large amount of water vapor is produced as one of the products of combustion. This ordinarily escapes up the chimney, carrying with it a certain amount of heat. The calorific value of a gas as determined in the laboratory usually includes this portion of the heat value of the fuel. The total value is termed the gross or higher heat value and this is what is ordinarily meant when the heat value of gas is specified. This heat value is usually stated in B.t.u. per cubic foot.

Natural gas is richer than city gas and ranges from 700 to 1,500 B.t.u. per cubic foot, the majority of natural gases averaging about 1,000 B.t.u. per cubic foot. The gross or higher calorific value of manufactured gas ranges between 520 and 545 B.t.u. per cubic foot, the average being 535. In many cases the heat value of manufactured gas is controlled by state legislation. Certain cities sell gas on the basis of the *therm* which is 100,000 B.t.u. of gross heat value.

Heat Seeks Lowest Temperature Level. Heat always seeks the lowest temperature level, just as water flows downward until it reaches the lowest point. Therefore, the transfer of heat always takes place, or is said to flow or pass, from a warmer to a colder body.

When fuel is burned in a furnace or under a boiler, the heat generated is finally dissipated to the outside air through the walls and roof of the building and through cracks and crevices and open doors and windows. There is a mistaken belief that only a part of the heat produced by combustion is transmitted to the outside atmosphere. The fact is that all of the heat—one hundred per cent of it—eventually finds its way through the structural materials of the building and through cracks, doors and windows.

Methods of Heat Transfer. The transfer of heat may take place by one or more of three methods, namely (1) conduction, (2) convection and (3) radiation. *Conduction* is the flow of heat through matter unaccompanied by any obvious motion of the matter, as for example, the passage of heat along an iron bar one end of which is held in a fire. *Convection* is the transfer of heat by moving



Conduction Convection Radiation

Fig. 1. Methods of Heat Transfer

matter, as for example, the heated air rising from a register of a warm air heating system. *Radiation* is the passage of heat through space without the presence of matter, as for example, the heat received from the sun. These methods of heat transfer are illustrated in Fig. 1.

CONDUCTION

When heat is transferred by conduction it passes from one part of a body to another part of the same body, or from one body to another body in contact with it without any relative displacement of the parts of the body or bodies with respect to each other. It is considered as being propagated by the warmer molecules, or those having the higher energy, to the cooler molecules having the lower energy. Thus the molecules or particles which are vibrating the more rapidly give up a portion of their energy to the less rapidly moving molecules. In this way the energy or heat is passed along during the collision process from one part of the body to another without any change in the exact position of the parts of the body. The result of this process is to increase the average energy and hence the temperature of the intermediate parts.

By placing one end of a metal bar or rod in a flame a gradual increase of the temperature of the bar will be noted at all points along the bar, the parts nearer the flame being warmer than the more remote parts. It is readily seen that the heat transferred by conduction along such a bar will depend upon the temperature difference that exists, the time involved, the dimensions of the bar, and the physical properties of the bar. If sufficient information is available to give the relation of these factors to each other, any problem of heat flow by conduction may be readily treated mathematically.

Heat Transfer through Building Materials. The transfer of heat through solid building materials takes place principally by conduction, the heat always flowing from the higher temperature side to the lower temperature side. The amount of heat which will pass through a material by conduction from one surface to the other, depends on the following factors:

1. *Temperature Difference.* The greater the temperature difference, the greater the amount of heat transferred, other things being equal.

2. *Thickness.* The greater the thickness, the less the amount of heat transferred.

3. *Area.* The greater the area, the greater the amount of heat transferred.

4. *Time.* The amount of heat transferred is proportional to the number of hours during which the heat flow takes place.

5. *Rate.* The amount of heat transferred depends on the rate of heat transfer (conductivity) of the material, which in turn depends on several factors which are discussed in the following paragraphs.

Conductivity. The characteristic of a material which determines the rate of flow of heat through it is called its *thermal conductivity*, usually referred to as its *conductivity*, and is expressed in terms of the number of B.t.u. which will pass through one square foot of a material one inch thick in one hour for a one degree Fahrenheit temperature difference. The conductivity of a material depends upon the following factors:

1. *Substance.* The rate of heat transfer (conductivity) through materials varies with the type of material. Materials are roughly classified as good conductors, such as metals of various kinds, brick and plaster and poor conductors, that is, insulators or insulations.

2. *Subdivision or Density.* For the same material, the rate of heat flow (conductivity) depends roughly on its condition of sub-

division or density. The conductivity of most insulating materials decreases as their densities decrease. For the same insulating material with all other conditions equal, this variation is usually a straight line. Certain other factors, however, such as moisture and arrangement and character of the fibers in a fibrous material may have a greater effect on the conductivity than density. For structural insulating board the conductivity value is usually improved

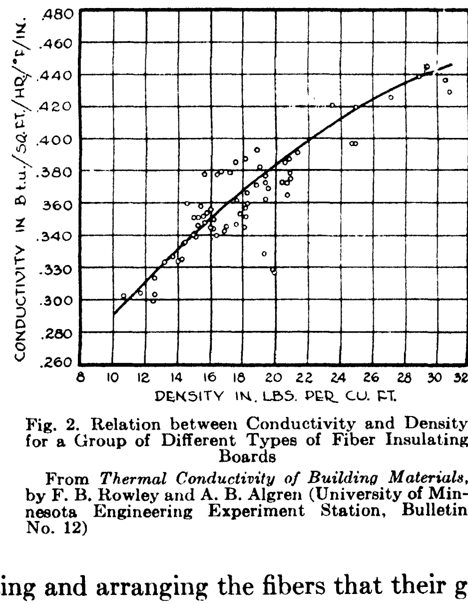


Fig. 2. Relation between Conductivity and Density for a Group of Different Types of Fiber Insulating Boards

From *Thermal Conductivity of Building Materials*, by F. B. Rowley and A. B. Algren (University of Minnesota Engineering Experiment Station, Bulletin No. 12)

by so laminating and arranging the fibers that their general direction is in a line perpendicular to the heat flow.[a] The points shown on the curve of Fig. 2 represent test results for a group of insulating boards made of the same type of fibrous materials, but of different densities.

Certain types of materials have what is known as an optimum density, that is, a density which will give the minimum rate of heat flow. Any increase or decrease from this optimum value will increase the conductivity. For example, although the rate of heat transfer through rock is extremely high, the rate of heat flow through the same material in an aerated or fluffy condition (rock wool) is greatly reduced, since the density of the rock is likewise reduced. On the other hand, if such a material is fluffed up to the extent that heat is

[a]See "Thermal Conductivity of Building Materials," by F. B. Rowley and A. B. Algren (University of Minnesota Engineering Experiment Station Bulletin No. 12).

transmitted through it by radiation or convection, the heat flow will be increased. Or if the material is packed or tamped to a high density, its rate of heat flow increases as the density increases. Fig. 3 shows the relation between density and conductivity for a typical loose fibrous material and illustrates the foregoing principle. This curve also shows that it is possible to have a decrease in conductivity with an increase in density, within certain limits.

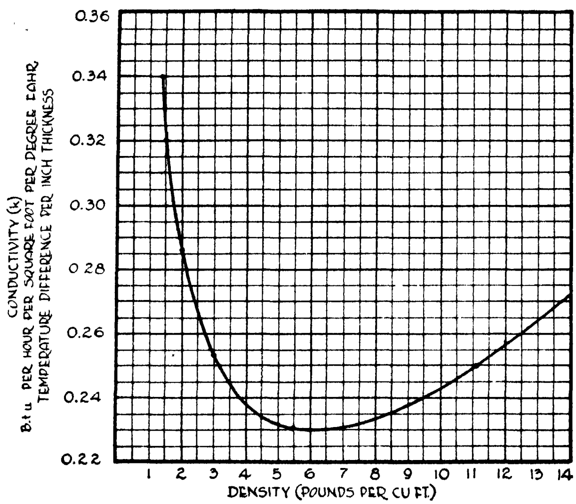


Fig. 3. Variation of Conductivity with Density for Typical Loose Fibrous Material

3. *Moisture* increases the rate of heat transfer through a material, because water, which fills the pores or voids, conducts heat more rapidly than air.

4. *Mean Temperature.* The conductivity or rate of heat transfer of most homogeneous insulating materials increases with the mean temperature, even for the same temperature difference, although this effect is usually small. According to the University of Minnesota, the rate of increase of conductivity is not the same for all materials even of the same type, but for structural insulating boards an average of 0.01 may be taken for each 30-degree F. increase in mean temperature, provided definite data are not available for specific materials. For example, if the temperature on one surface of a material is 60° and that on the opposite surface is 40°, the mean temperature will be 50°. On the other hand, if the temperature on one side is 90° and

that on the opposite side is 70°, the mean temperature will be 80°, or 30 degrees higher than in the first case, or an average conductivity of 0.01 B.t.u. higher in the second case. In many materials, particularly where the range of temperatures is great the mean temperature is an important factor and should be taken into consideration.

The conductivities of various building and insulating materials are given in the chapter on Transmission Coefficients and Tables.

Conduction Formula. The heat transferred per hour by conduction between the two surfaces of a material may be determined by means of the following formula:

$$q_c = (t_1 - t_2)\frac{Ak}{x} \qquad (1)$$

where

q_c = heat transferred by conduction, B.t.u. per hour

t_1 = temperature of hot surface, degrees Fahrenheit

t_2 = temperature of cold surface, degrees Fahrenheit

A = area perpendicular to heat flow, square feet

k = conductivity, B.t.u. per hour per square foot per degree Fahrenheit per inch thickness

x = thickness of material, inches

Example 1. Calculate the amount of heat transferred by conduction through 8 sq. ft. of a material 2 in. thick having a conductivity of 0.50, if the temperature of the hot surface is 100° and the temperature of the cold surface is 48°.

Solution. $t_1 = 100$, $t_2 = 48$, $A = 8$, $k = 0.50$ and $x = 2$. Substituting these values in Formula (1),

$$q_c = (100 - 48)\frac{8 \times 0.50}{2}$$

$$q_c = (52) \times (2)$$

$$q_c = 104 \text{ B.t.u. per hour}$$

CONVECTION

While the process of heat transfer by convection applies to practically all liquids and gases, the present discussion is confined to air, which is a mixture of gases. When air is heated it expands, with a resultant decrease in density. Then if air at a lower temperature and consequently a higher density exists adjacent to the heated air, the heated portion will rise, carrying its higher temperature with it. The heat has thus been transferred from one place to another by means of the actual transfer of a part of the air, and this process of heat transfer is known as convection or natural convection. If the heated air is transferred by mechanical means such as a fan, the process is known as forced convection. The heated air may give up its heat in the new position to objects with which it comes in contact by the process of conduction.

The important distinction between convection and conduction is that convection involves a physical movement of the medium (that is, the air) by which the heat is transferred. For this reason it follows very different laws and is much more complicated than either conduction or radiation. It has been demonstrated experimentally that heat transfer by natural or free convection varies approximately with the $5/4$ power of the temperature difference between the two surfaces on each side of an air space. Thus if the temperature difference across an air space were increased from 5 degrees to 40 degrees, the convection would be increased more than 12 times, rather than eight times, the ratio of 40 to 5.

The position of the air space (vertical, horizontal, etc.) has a marked effect on convection. The rate of heat transfer across a horizontal air space with heat flowing upward is roughly three times as great as it would be with the heat flowing downward. Convection also varies with the height of the air space up to approximately 2 feet and with the width up to about ¾ inch. It is seldom desirable or necessary to calculate separately the heat flow by convection across an air space in solving insulation problems.

Stratification. The convected heat not only circulates, but also has a tendency to cause the air to stratify, that is, to form in layers of different temperature, the warmest layers at the ceiling and the coolest at the floor. This stratification is due to the fact, as previously stated, that the warmer air is lighter or less dense and therefore rises. Thus in a room where there are surfaces of appreciable temperature difference, there will be not only a circulation of air due to convection, but also a stratification of air at different temperature levels. The amount of stratification, or the difference in temperature between the floor and ceiling, will depend on the type of heating system, the ceiling height and other factors. Information on the proper allowance to be made under various conditions is given in the chapter on Calculating Heat Losses.

Heat Rises. There is frequently some misunderstanding concerning the oft-repeated statement that heat rises. As will be apparent from Fig. 4, only the heat transmitted by convection rises.

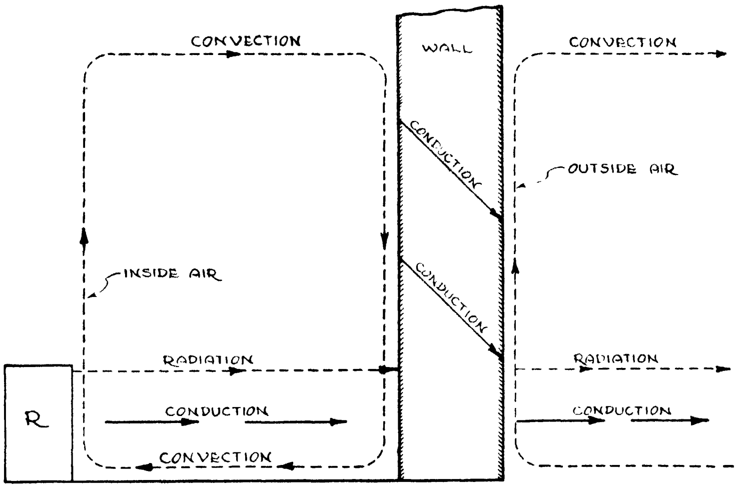


Fig. 4. Heat Transmission To, Through, and From a Wall

The heat transmitted by radiation travels in a straight line from the warm to the cold surface.

RADIATION

The process by which heat is transmitted through space with or without the presence of matter is called *Radiation.* While heat is being transmitted in this way it is called radiant energy and is not heat. This radiant energy is a form of electromagnetic wave motion and is similar to light and electrical (radio) waves, the essential difference being in the wave length. The wave length of heat radiation from a source at room temperature is approximately 10 microns, the micron being the thousandth part of a millimeter.

The transfer of heat by radiation is analogous to the transfer of sound by radio. Sound is produced in the broadcasting studio and changed to "radio waves" by means of the sending apparatus of the broadcasting station. While these radio or electrical waves are being transmitted, they are not sound but rather a form of radiant energy of various wave lengths. These waves are "caught" or absorbed by the aerial of the receiving set and reconverted to sound waves by means of the radio.

In a similar manner, heat is emitted from a hot surface or body in the form of radiant energy. This energy is then transmitted in waves until it comes in contact with colder surfaces or objects which the emitting surface can "see." The receiving surfaces or objects absorb a part of the radiant energy, converting it back to heat, and reflect the remainder. This process is called *thermal radiation* to distinguish it from light and radio or electrical radiation. The sending and receiving bodies may be millions of miles apart as in the case of the sun and earth, or they may be only a few inches apart as in the case of two wall surfaces separated by an air space. The width of air space has no appreciable effect upon the amount of radiation transfer. The rate of heat transfer by radiation would be essentially the same if the distance between surfaces were one inch, one foot, or one mile.

Emission is simply the starting of radiation waves. The conversion of these radiation waves into heat by the surface of a substance is called *absorption.* The waves not absorbed by a surface are *reflected.* The reason for the low temperature encountered in the stratosphere is that there are no opaque surfaces to absorb solar radiation and convert it to heat. The sun's "rays" are not absorbed until they strike the surface of the earth.

Emissivity, Absorptivity, Reflectivity. The transfer of heat by means of radiation across an air space is dependent upon the temperature of the two boundary surfaces and their respective emissivities. The *emissivity* of a surface is merely a factor indicating the relative amount of radiation absorbed by a surface as compared to an absolutely black body under the same conditions. An absolutely black body or surface absorbs all the radiation which strikes it and reflects or transmits none. Such a surface is said to have an emissivity of unity (1.0) and all other surfaces will have emissivities of less than 1.0.

The emissivities of various common surfaces used in building construction are given in Table 2. From the values given in this table it will be noted that most of the non-metals have high emissivities in the neighborhood of 0.9, while the metals when not oxidized

Table 2. Total Emissivity of Various Surfaces

Surface	Temp. Deg. F.	Emissivity	Authority
Aluminum			
Foil	70	0.05	Wilkes & Peterson
Oxidized	70	0.11	Wilkes & Peterson
Polished plate	73	0.040	E. Schmidt
Polished surface	68	0.045	E. Schmidt
Surface covered with 0.001 in. oil	68	0.27	E. Schmidt
Surface covered with 0.002 in. oil	68	0.46	E. Schmidt
Surface covered with 0.005 in. oil	68	0.72	E. Schmidt
Rough plate	78	0.055	E. Schmidt
Asbestos Board	74	0.96	E. Schmidt
Asbestos Paper	100–700	0.93–0.945	Heilman
Brass			
Hard rolled, polished	70	0.038	E. Schmidt
Rolled plate, natural surface	72	0.06	E. Schmidt
Rolled plate, rubbed with coarse emery	70	0.20	E. Schmidt
Brick, red, rough	70	0.93	E. Schmidt
Copper			
Oxidized black	70	0.78	Wilkes & Peterson
Polished	70	0.04	Wilkes & Peterson
Glass	70	0.9	Wilkes & Peterson
Glass, smooth	72	0.937	Heilman
Gypsum 0.02 in. thick on smooth, blackened plate	70	0.903	E. Schmidt
Iron and Steel			
Iron, freshly emeried	68	0.242	E. Schmidt
Iron, polished	70	0.06	Wilkes & Peterson
Iron, rough oxide layer	70	0.81	Wilkes & Peterson
Rolled sheet steel	70	0.657	E. Schmidt
Sheet steel, polished	...	0.20	A.S.R.E. Data Book
Sheet steel, rough oxide layer	75	0.80	E. Schmidt
Marble, light gray, polished	72	0.931	E. Schmidt
Oak, planed	70	0.895	E. Schmidt
Paint and Enamel			
Aluminum	70	0.4 –0.65	Wilkes & Peterson
Black	70	0.90	Wilkes & Peterson
Black shiny shellac on tinned iron sheet	70	0.821	E. Schmidt
Black shiny lacquer, sprayed on iron	76	0.875	E. Schmidt
White enamel on rough iron plate	70	0.906	E. Schmidt
Paper	70	0.90	Wilkes & Peterson
Plaster	70	0.93	Wilkes & Peterson
Roofing paper	69	0.91	E. Schmidt
Wood	70	0.9	Wilkes & Peterson

have very low emissivities—around 0.05. Aluminum and bronze paint that are a combination of metals and non-metallic vehicle have emissivities about half-way between the two values stated.

Heat radiation striking an opaque surface must either be absorbed or reflected, as previously indicated. Consequently, the radiation absorbed by a surface plus that reflected must equal in amount the radiation striking the surface. If a material is a good absorber of radiation, it is also an equally good emitter of radiation. For example, if a body is placed in a vacuum and allowed to come to temperature equilibrium, the radiation absorbed must equal that emitted. Consequently, if a = absorptivity, e = emissivity, and r = the reflectivity of a surface, then

$$a = e = 1 - r \tag{2}$$

As far as the rate of heat transfer across an air space by radiation is concerned, it makes no difference whether the reflective surface is on the cooler or warmer side of the space.

The emissivity coefficient varies with the *temperature of the surface,* while absorptivity may vary with the *temperature of the source of radiation* as well as the temperature of the receiving surface. For example, black and white paint have essentially the same emissivity at room temperature, but if exposed to solar radiation the black paint will absorb many times as much heat as the white paint.

Aluminum foil will emit at room temperature only about 5 per cent as much radiation as a white painted surface, but when exposed to radiation from the sun, the aluminum will not reflect as well as the white paint.

Every surface, regardless of its temperature, is radiating and receiving heat by radiation. In the case of the transfer of heat by radiation across an air space, only the net heat transfer between the two surfaces at different temperatures is significant.

Radiation Formula. The Stefan-Boltzmann equation for heat transfer by radiation between two parallel surfaces of the same area is as follows:

$$q_r = 0.172pA\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \tag{3}$$

where

q_r = heat transferred by radiation, B.t.u. per hour
A = area of surface, square feet
T_1 = absolute temperature of radiating surface
T_2 = absolute temperature of receiving surface
p = effective emissivity (frequently also designated by the letter e)

In calculating the net radiation between two parallel surfaces, the emissivity of each surface must be considered. The effective emissivity p used in Formula (3) is a combination of the two individual emissivities and can be calculated as follows:

$$p = \frac{1}{\frac{1}{p_1} + \frac{1}{p_2} - 1} \tag{4}$$

where

p_1 = emissivity of radiating surface
p_2 = absorptivity or emissivity of receiving surface

Formula (4) is based on infinite parallel surfaces, but there will be little error involved if it is applied to the ordinary air spaces found in building construction.

Example 2. Calculate the transfer of heat by radiation across an air space between studs if one surface is plasterboard (paper) at a temperature of 60° and the other surface is wood at a temperature of 30°, the area being 100 sq. ft.

Solution. $p_1 = 0.90$, $p_2 = 0.90$. From Formula (4),

$$p = \frac{1}{\frac{1}{0.90} + \frac{1}{0.90} - 1}$$

$$= \frac{1}{1.11 + 1.11 - 1} = \frac{1}{1.22} = 0.82$$

$$T_1 = 60 + 460 = 520$$
$$T_2 = 30 + 460 = 490$$
$$A = 100;$$

Substituting in Formula (3),

$$q_r = 0.172 \times 0.82 \times 100 \times \left[\left(\frac{520}{100} \right)^4 - \left(\frac{490}{100} \right)^4 \right]$$
$$= 0.172 \times 0.82 \times 100 \times (5.2^4 - 4.9^4)$$
$$= 0.172 \times 0.82 \times 100 \times (731 - 576)$$
$$= 0.172 \times 0.82 \times 100 \times 155$$
$$= 2186 \text{ B.t.u. per hour}$$

MECHANISM OF HEAT FLOW THROUGH WALLS

As previously stated, heat is received from the sun entirely by radiation. On the other hand, the transfer of heat through solid materials is almost entirely by conduction, except in the case of fluffy or highly attenuated substances in which case there may be some convection. The transfer of heat through air spaces, and from or to wall surfaces, involves all three processes, although the percentage of heat transferred by conduction through air is comparatively small. Therefore, the transfer of heat through walls from the air on one side to the air on the other side involves all three processes.

Fig. 4 illustrates the mechanism by which heat is transferred to, through and from a wall. Heat is transferred from the surface of a radiator, register, stove or other warm body, indicated in Fig. 4 by *R*, to the inside wall or roof surface by radiation, convection and conduction. The heat passes by radiation in a straight line from the surface of the warmer body (*R*) through the air without appreciably heating it, to the receiving colder wall or ceiling surface. The air in direct contact with the warmer body (*R*) will absorb heat, expand, rise and circulate by the process of convection, thus transferring its heat in turn to the colder wall or ceiling surfaces. When this heated air comes in contact with the colder wall or ceiling surfaces its temperature is of course lowered and the air drops to the floor and finally comes back to the warmer body (*R*) thus resulting in a continuous circulation of air and completing the convection process. A small amount of heat is also transferred by conduction from one particle of air to the next in the direction of the colder wall surface, but as previously stated, the percentage of heat transferred by conduction through air is comparatively small.

The transfer of heat from the inside surface of the wall or roof structure to the outside surface through the solid materials composing the wall or roof structures is entirely by conduction. If the wall contains an air space, the transfer of heat through this air space will take place by means of a combination of the three methods of heat transfer in a manner similar to the process by which heat is transferred from the warmer body (R) to the inside wall or ceiling surface. The heat transfer from the outer surface of the wall to the outer air takes place in the reverse order. The outside wall surface gives off heat not only by means of natural convection due to the tendency of the heated air in contact with this wall surface to rise, but also

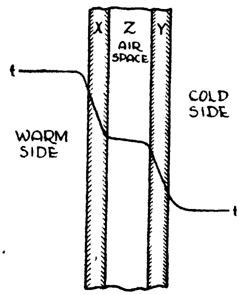


Fig. 5. Wall Containing Air Space

by forced convection caused by the wind blowing over the exterior surface. This outside surface also gives off heat by the process of radiation to the surrounding objects. In the removal of heat from the outside surface, there may also be a small amount of conduction of heat through the air particles, as in the case of the transfer of heat to the inside wall surface.

Conduction, Convection and Radiation Percentages. It is sometimes customary to refer to the percentages of heat transferred by one or more of the three processes. Unless properly qualified, such statements are meaningless. For example, to state that a certain percentage of heat is transferred by radiation is incorrect unless the statement refers to the heat transferred across an air space or from or to a wall or other surface under certain specific conditions.

Consider a wall, Fig. 5, consisting of two materials and with an air space between. Heat flows from the air on the warm side having a temperature t through the wall to the air on the cold side having a temperature t_o. Whatever heat passes through material X must also pass through the air space *Z* and through the outer material *Y*, just as water flowing through one channel of a stream must also flow through all other channels of varying widths of the same stream. The heat received by material *X* must be conveyed by all three methods of heat transfer as previously explained. The heat flowing through material *X*, however, will be transferred entirely—100 per cent—by conduction. The heat emerging on the other side of *X* will be transmitted across the air space *Z* to material *Y* by the three methods. For ordinary temperatures, from 55 to 70 per cent of the heat will be transmitted across this air space by radiation if the surfaces of materials *X* and *Y* are conventional building materials. The remainder will be transmitted by conduction and convection. Again, in passing through material *Y*, the heat flow is entirely by conduction, whereas in leaving material *Y* and passing to temperature t_o the heat flow will be by all three methods. The percentage of radiant heat received by the surface of material *X* or given off by the surface of material *Y* for still air conditions will ordinarily be substantially less than that transmitted through air space *Z* by radiation.

From the foregoing it is apparent that the heat flow by conduction may vary from a small percentage in the case of air spaces to 100 per cent in the case of solid materials, whereas the radiant heat transfer may vary from zero per cent in the case of solid materials up to 70 per cent or more in the case of air spaces. Likewise, convection may vary from zero per cent through solids to nearly 100 per cent in the case of surfaces exposed to forced convection. Thus it is evident that the percentage of heat transferred by the three processes varies greatly and depends on the conditions.

"Dead" Air Spaces. Large air spaces such as exist between studs of an ordinary frame wall, in hollow tile, in attics and in the core spaces of cement blocks are sometimes referred to as "dead" air spaces, implying that the air is still or motionless, whereas the fact is that there is always considerable air motion within these air spaces due to convection when a difference in temperature exists between the sides of the space. Thus the air in such spaces is not "dead" and because of the circulation a considerable amount of heat is transferred by this convection process, as well as by radiation when the bounding surfaces consist of ordinary building materials such as wood, plaster, brick, cement, tile and building paper.

Heat-Resisting Factors. If an obstruction such as a dam is interposed in the path of flow of a river, the rate of flow of water will be retarded. Similarly if an obstruction is interposed in the path of heat flow through a wall or other construction, the rate of heat flow will be retarded—in other words, less heat will pass through the same wall area in a given period of time. Such an obstruction to heat flow is known as an insulation which, as defined previously, "is a material having a high degree of heat resistance per unit of thickness."

Methods of Insulating. The use of an insulating material for retarding the heat flow through a wall or other construction may be accomplished by one or more of several methods:

1. By *replacing* materials of high conductivity such as X and Y of Fig. 5 with materials of low conductivity; that is, with insulating materials. Structural insulating board is commonly used for this purpose.

2. By *adding* insulating materials to the construction, such as by partially or completely filling the air space (or spaces) with an insulating material. Flexible insulations, fills, bats and pads are commonly used for this purpose.

3. By *replacing* one or both of the confining surfaces of an air space with a material of low emissivity; that is, with a reflective insulation such as aluminum foil. The reflective insulation may also be installed in such a manner as to divide the air space into two or more parts.

HOW INSULATIONS FUNCTION

Insulations are of two classes so far as the method of functioning is concerned; namely, (1) mass insulations and (2) reflective. *Mass insulations* are those which depend on a definite thickness of material to provide heat resistance and include all types except the *reflective*, which depend only on the character of the surface, that is, emissivity.

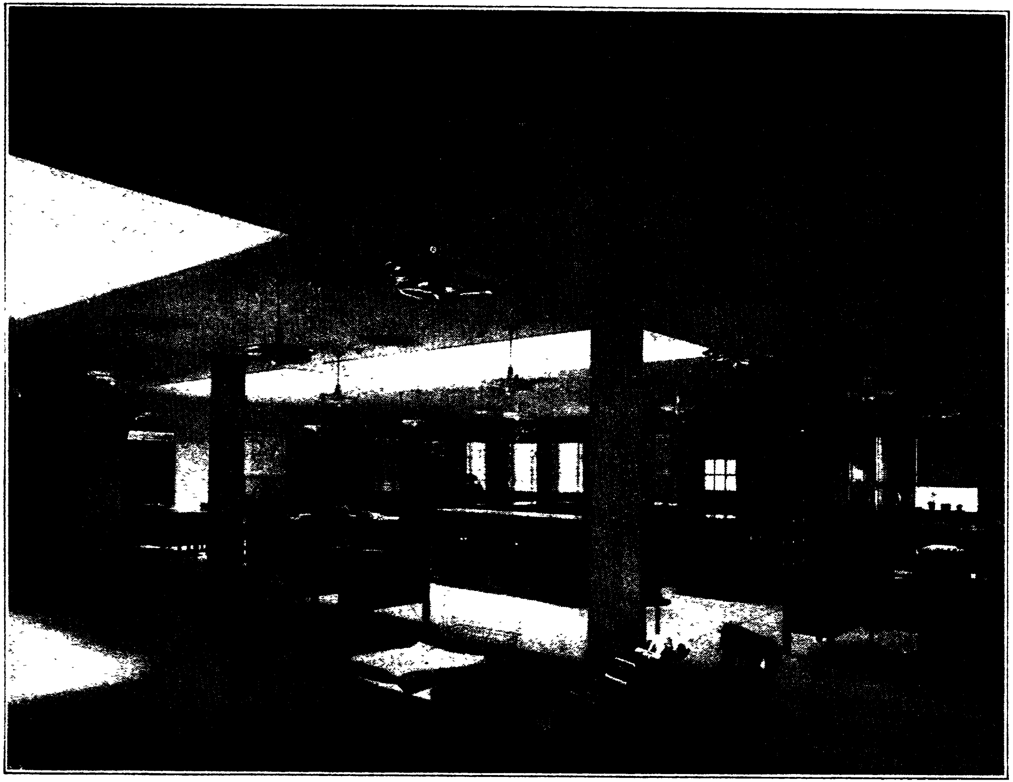
Principle of Mass Insulations. The effectiveness of a mass insulation in reducing heat transfer is due to the fact that such material has a low rate of heat conduction and practically no transfer of heat by convection and radiation, and these characteristics in turn are due to the condition of subdivision or density of the material. The minute air voids or interstices contain still or dead air because these air cells are too small to permit any circulation of air in or between them, thus eliminating convection. Radiation does not take place to any appreciable extent within these voids or interstices because there are no significant temperature differences between the infinitesimally small bounding surfaces—and radiant heat transfer requires appreciable temperature differences, in accordance with the Stefan-Boltzmann law.

The molecular theory explains why insulating materials have a lower rate of heat conduction than hard, dense materials such as steel, concrete and glass. If the molecules of a material are packed together more solidly as in the case of steel or concrete, any vibration or motion of the molecules is readily communicated from one part of the substance to the other. Thus in the case of a metallic rod, if heat is applied at one end of the rod, the motion of the molecules at this end is increased and, by impact with adjoining molecules, this increase of the motion of the molecules is rapidly passed down the rod to the cold end. With lighter and more porous materials any motion of molecules due to heat applied to one side is not readily transmitted through to the other side by impact with adjoining molecules because the molecules are less compact.

Factors Governing the Value of Mass Insulations include type of substance or material, subdivision or density, moisture and mean temperature, which were discussed earlier in this chapter, under Conductivity.

Principle of Reflective Insulations. As previously mentioned, reflective materials must always be associated with air spaces and they can be of value as insulating materials only when installed in the proper manner in conjunction with such air spaces. The reflective insulation, having a low emissivity, simply reduces the amount of heat transfer by radiation across the air space. Reflective materials, therefore, depend upon the retention of a surface of low emissivity value. If the surface becomes covered or coated in such a manner as to increase the emissivity, the insulating value diminishes proportionately. Thus should the emissivity increase from say 0.05, the average value of an aluminum foil surface, to say 0.90, the average value of the ordinary surface, the insulating value would be lost; that is, the surface would have no greater insulating value than that of ordinary building material surfaces. The visible brightness of a surface is not a gage of its emissivity, for a surface may appear to have lost its reflective value and yet have a comparatively low emissivity as tested by a radiometer or emissivity-testing instrument.

Factors Governing Value of Reflective Insulations. Certain conditions may seriously affect the heat-resisting properties of aluminum foil. Alkalis attack aluminum readily. The foil should always be protected from direct contact with wet plaster. If prolonged exposure to plaster is expected, it is possible to coat aluminum foil with a thin transparent lacquer as a protective agent. This coating should be applied only by the manufacturer, as an ordinary coat of transparent lacquer will usually ruin the reflective properties of aluminum for infrared (invisible) radiation, although it will still appear bright to the eye and will continue to be an effective reflector of visible radiation (light). A heavy coating of dust on a reflective surface will reduce the reflectivity materially. Proper allowance should therefore be made where the foregoing conditions are likely to be encountered. When in doubt as to the ultimate value of the air space under certain conditions, the safest procedure is to assume the value to be the same as that of air spaces bounded by ordinary materials, for which data are given in the chapter on Transmission Coefficients and Tables. In making installations of reflective insulation the partitions between air spaces should be tight, particularly at the top and bottom, so that air cannot circulate between spaces.



OFFICE CEILING OF DECORATIVE INSULATING TILEBOARD (PANELS)

Courtesy of Armstrong Cork Products Co., Lancaster, Pa.

CHAPTER V

TRANSMISSION COEFFICIENTS AND TABLES

Coefficient of Conductivity. Every building and insulating material has a certain heat transmission value which, as explained in the preceding chapter, depends on the nature or character of the substance of which it is composed, the condition of subdivision and density of the material, the moisture content, mean temperature and other factors. This heat transmission value is represented numerically in each case by a coefficient, namely, the *coefficient of thermal conductivity*, usually referred to as the *conductivity* of the material, for short. A coefficient of any material is simply a numerical quantity expressed in terms of certain units such as a unit of time, unit of length, unit of area, unit of thickness, etc. Thus the coefficient of thermal conductivity of a material is the number of heat units (B.t.u.) that will pass through *one* square foot of the material, *one* inch thick, in *one* hour for a *one* degree Fahrenheit temperature difference between the two surfaces. These of course are the English system units, which are employed throughout this book. If the metric system were used, the coefficient would be stated in terms of metric units such as meter, centimeter, Centigrade, etc. The coefficient of conductivity is designated by the letter k.

Coefficient of Conductance. Certain heterogeneous materials or combinations of materials are of such a character that it would not be feasible to give the coefficient in terms of an inch thickness. Materials of this type include hollow tile, cinder and concrete blocks, roofing, combinations of building materials and air spaces. The coefficients for these materials are termed *conductances* and are given in terms of the actual thickness or construction stated, such as 4-inch hollow tile or a combination of wood sheathing, building paper and stucco. In other words, conductivities are for an inch thickness of a material whereas conductances are for the thickness (other than one inch) or construction as stated. It should be understood, however, that the coefficients of conductivity and conductance represent the rate of heat transfer between the two bounding surfaces of the

Table A. Conductances of Vertical Air Spaces at Various Mean Temperatures*

Mean Temp. Deg. F.	Conductances of Air Spaces for Various Widths in Inches						
	0.128	0 250	0 364	0.493	0 713	1 00	1 500
20	2.300	1.370	1.180	1.100	1.040	1.030	1.022
30	2.385	1.425	1.234	1.148	1.080	1.070	1.065
40	2.470	1.480	1.288	1.193	1.125	1.112	1.105
50	2.560	1.535	1.340	1.242	1.168	1.152	1.149
60	2.650	1.590	1.390	1.295	1.210	1.195	1.188
70	2.730	1.648	1.440	1.340	1.250	1.240	1.228
80	2.819	1.702	1.492	1.390	1.295	1.280	1.270
90	2.908	1.757	1.547	1.433	1.340	1.320	1.310
100	2.990	1.813	1.600	1.486	1.380	1.362	1.350
110	3.078	1.870	1.650	1.534	1.425	1.402	1.392
120	3.167	1.928	1.700	1.580	1.467	1.445	1.435
130	3.250	1.980	1.750	1.630	1.510	1.485	1.475
140	3.340	2.035	1.800	1.680	1.550	1.530	1.519
150	3.425	2.090	1.852	1.728	1.592	1.569	1.559

*Thermal Resistance of Air Spaces by F. B. Rowley and A. B. Algren (A.S.H.V.E. TRANSACTIONS, Vol. 35, 1929).

material or combination of materials, not the heat transfer from the air on one side to the air on the other side. The conductance of a building or insulating material or a combination of materials is designated by the letter *C*.

Conductivities and Conductances Not Additive. Conductivities and conductances are not additive. In other words, two or more conductivities or conductances cannot be added together to obtain any rational or significant result. For example, if the conductivity of material A is 0.30 and the conductivity of material B is 0.40, the combined conductivities will *not* be the sum of these two quantities, or 0.70, which of course is greater than either conductivity value alone. It is obvious that a combination of two materials each an inch thick would have a lower total heat transfer than one inch of either material by itself. It is only by applying the proper formula in each case that the combined effect of two or more materials can be obtained. The formulas involved are described under the heading *Calculated Coefficients* in this chapter.

Air Space Conductances. The conductance of an air space is designated by the letter *a* and is the amount of heat transmitted by radiation, convection and conduction in one hour through an air space having an area of one square foot for a temperature difference of one degree Fahrenheit. The conductance of an air space depends on the mean temperature, temperature difference, width and position (whether horizontal, sloping or vertical), direction of heat flow, and the character of the materials enclosing it.

The conductances of vertical air spaces of various widths and at various mean temperatures and bounded by ordinary building materials based on tests conducted at the University of Minnesota, are given in Table A. According to this table, a vertical air space ¾ inch or greater in width and bounded by ordinary building materials has a conductance of about 1.10 B.t.u. per hour per square foot per degree Fahrenheit temperature difference, at a mean temperature of 40°, and this value is commonly used for heat transfer calculations. Vertical air space conductances compiled by M. S. Van Dusen are given in Table B. It should be noted that there is

Table B. Conductances of Vertical Air Spaces (Emissivity=0.90)*

These conductances are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference for the width stated.

Width of Air Space Inches	Mean Temp. Deg. F.	Temp. Dif. Deg. F.				
		1	5	10	20	100
⅛		1.82	1.82	1.82	1.82	1.82
¼		1.18	1.18	1.18	1.18	1.33
½	0	0.86	0.87	0.91	0.97	1.27
¾		0.76	0.81	0.87	0.94	1.23
1		0.72	0.80	0.86	0.94	1.23
2		0.69	0.79	0.85	0.94	1.23
5		0.69	0.79	0.85	0.94	1.23
⅛		2.08	2.08	2.08	2.08	2.08
¼		1.43	1.43	1.43	1.43	1.52
½		1.09	1.09	1.11	1.16	1.41
¾	50	0.98	1.01	1.06	1.11	1.41
1		0.92	0.99	1.04	1.11	1.41
2		0.89	0.98	1.04	1.11	1.41
5		0.88	0.98	1.04	1.11	1.41
⅛		2.38	2.38	2.38	2.38	2.38
¼		1.69	1.69	1.69	1.69	1.72
½		1.35	1.35	1.35	1.39	1.59
¾	100	1.23	1.25	1.28	1.32	1.59
1		1.16	1.22	1.27	1.32	1.59
2		1.12	1.21	1.27	1.32	1.59
5		1.11	1.21	1.27	1.32	1.59

*Compiled by M. S. Van Dusen, Bureau of Standards.

practically no decrease in the conductance of ordinary air spaces beyond about ¾ or 1 inch in width.

Tests conducted at the Massachusetts Institute of Technology resulted in conductances of 1.17 for a vertical air space, 1.32 for a horizontal air space, heat flow up, and 0.94 for a horizontal air space, heat flow down. These tests were based on 3⅝-inch air spaces bounded by 0.83 emissivity surfaces, the temperature difference being 15 degrees in all cases.

Conductances of air spaces bounded by aluminum foil are given in Fig. 1. It will be apparent from these curves that the position

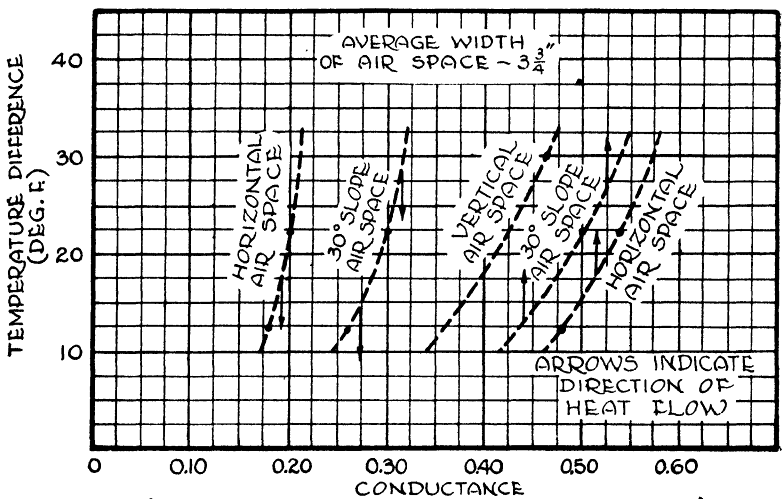


Fig. 1. Conductance Curves for Single Air Spaces in Various Positions, Bounded by One Reflective Surface Having an Emissivity of 0.05

These curves approximated from data in paper entitled *Thermal Heat Coefficients of Aluminum Insulation for Buildings*, by G. B. Wilkes and E. R. Queer (American Society of Heating & Ventilating Engineers Journal Section, Heating, Piping & Air Conditioning, January 1940), *Radiation and Convection across Air Spaces*, by G. B. Wilkes and C. M. F. Peterson (American Society of Heating & Ventilating Engineers Transactions, Vol. 43, 1937), and other sources.

of the air space, whether horizontal, sloping, or vertical, is particularly important. In the case of horizontal and 30-degree slope reflective air spaces, the direction of heat flow, whether up or down, is also important. The upward heat flow (winter) is much greater for the same temperature difference than the downward heat flow (summer). This is due to the effect of convection. Another important factor is the temperature difference. It will be noted that the conductance of the air space increases as the temperature difference increases.

Present available data indicate that conductances of reflective air spaces decrease to a greater extent with increase in width beyond 1 inch than vertical non-reflective air spaces which are practically unaffected by width beyond 1 inch, as indicated by Tables A and B.

The conductivity of air at room temperature with *no radiation or convection* is about 0.175 B.t.u. per hour per square foot per degree Fahrenheit per inch thickness. In practice, however, there is always some radiation and convection across air spaces of appreciable size.

Surface Conductances. Every material has a thin layer of air in contact with the surface which offers a certain resistance to the passage of heat. For this reason, the resistance of a material from one surface to the other is less than the resistance from the air on the one side to the air on the other side.

The surface conductance of a material is defined as the amount of heat (B.t.u.) transmitted from a surface to the air surrounding it, or vice versa, in one hour per square foot of the surface for a difference in temperature of one degree Fahrenheit between the surface and the surrounding air. This conductance is dependent upon the character of the surface, the velocity of air passing over it, the orientation or position, direction of heat flow, the temperature of the surface and the difference in temperature between the surface and surrounding air. To differentiate between inside and outside surfaces, f_i is used to designate the inside film or surface conductance and f_o the outside film or surface conductance. If the air is still (no wind), then for the same material, f_i and f_o are the same, and $f_i = f_o$; but if the outside air is in motion, then f_o is always greater than f_i and will increase as the wind velocity increases.

Values for f_i and f_o for various building material surfaces are given in Fig. 2. These coefficients were determined at the University of Minnesota, under a cooperative research agreement with the American Society of Heating and Ventilating Engineers. The zero-m.p.h. (still air) surface conductances are f_i values and the higher wind velocity surface conductances are f_o values. The range of surface conductances for ordinary building materials, however, is comparatively small and for practical purposes may be assumed constant for either still air or for any given wind velocity. The average value for f_i for ordinary building material surfaces and for still air is about 1.65. In determining basic heat transmission coefficients for building construction, it is customary to use that value of f_o which will occur when a 15-m.p.h. wind blows parallel to the outer surfaces considered. The average value of f_o for a wind velocity of 15 miles per hour is about 6.00 B.t.u. per hour per square foot per degree Fahrenheit difference in temperature between the surface and surrounding air.

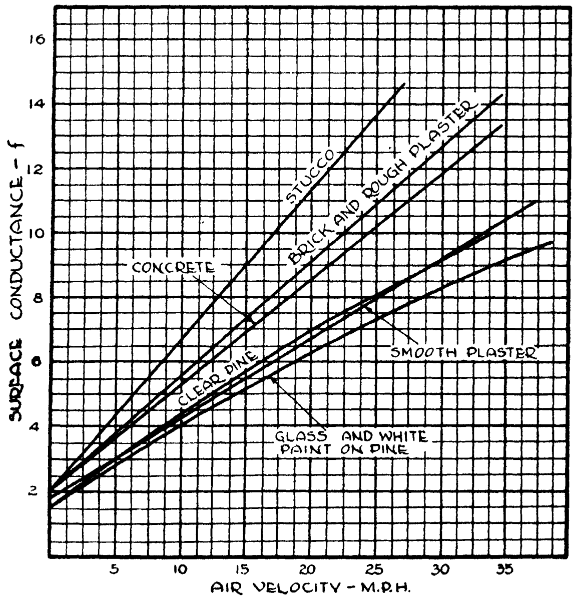


Fig. 2. Curves Showing Relation between Surface Conductances for Different Surfaces at 20°F. Mean Temperature

From *Thermal Conductivity of Building Materials*, by F. B. Rowley and A. B. Algren (University of Minnesota Engineering Experiment Station, Bulletin 12).

Conductances of reflective surfaces (emissivity = 0.05) and ordinary surfaces (emissivity = 0.83) for still-air conditions based on tests conducted at Massachusetts Institute of Technology are given in Table C.

Coefficient of Transmission. Conductivities and conductances of materials or conductances of air spaces and surfaces are not applied directly in estimating heat losses through the walls, floor, roof or other parts of a structure, but are used in the proper formula for deriving the over-all or air to air heat-transfer coefficient which is the ultimate objective. This is known as the coefficient of transmission designated by the letter U and is the amount of heat (B.t.u.) transferred through one square foot of the wall, floor, roof or glass

Table C. Still-Air Conductances of Surfaces Having Emissivities of 0.83 and 0.05 (Temperature Difference, 15 Degrees Fahrenheit)*

These coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference.

Position of Surface	Direction of Heat Flow	Emissivity	
		0.83	0.05
Horizontal	Down	1.21	0.44
Horizontal	Up	1.95	1.16
Vertical	....	1.52	0.74

*G. B. Wilkes and C. M. F. Peterson, Massachusetts Institute of Technology.

in one hour per degree Fahrenheit temperature difference between the air on the two sides. As with conductivities and conductances, coefficients of transmission are not additive.

Methods of Testing. The apparatus most commonly used for testing building materials, insulations and compound structures is of three types; namely, (1) the hot plate apparatus, (2) hot box apparatus and (3) the Nicholls heat meter. The *hot plate apparatus* is commonly used for determining the surface to surface conductivity or conductance of materials, the surfaces of which are smooth enough to give reasonably good contact between the test plates and the material. The *hot box apparatus* is employed for determining the over-all *air to air* coefficient of heat transmission (U) and is particularly adapted to testing built-up wall sections or structures whose surfaces are too rough for good contact with the plate used in the hot plate method. The *Nicholls heat meter* is used for testing actual walls or other structures in place.

Comparison of Hot Plate and Hot Box Results. The fundamental difference between the results of these two methods of testing is that in the hot plate method the conductivity or conductance is determined from surface to surface, thus eliminating the surface effects, whereas in the hot box method the coefficient determined is from air to air and includes the surface resistances. Therefore, the hot plate is usually employed to determine the conductivity (k) or conductance (C) of solid materials while the hot box is used to determine the over-all coefficient of transmission (U). However, the conductivity or conductance of a material from surface to surface can be obtained by the hot box method provided thermocouples for taking temperatures are properly placed on the surfaces of the material under test. On the other hand, the over-all coefficient of transmission may be calculated from the results of the hot plate test, if the surface conductances are known.

Conductivity and Conductance Tables. Conductivities and conductances of many common building materials and insulations are given in Tables 1 and 2. Table 3 gives the conductivities and conductances recommended for calculation. Most of these values were determined by means of the hot plate apparatus.

Authoritative Laboratories. It is obvious that heat transmission tests to be reliable must be made by an experienced and accredited laboratory; otherwise the results obtained may not be acceptable. There is a limited number of such laboratories in the United States. These include the following:

American Society of Heating & Ventilating Engineers Research Laboratory, Cleveland, Ohio.
Illinois, University of, Urbana, Ill.
Illinois Institute of Technology, Chicago (formerly Armour Institute)
Minnesota, University of, Minneapolis, Minn.
Pennsylvania State College, State College, Pa.
Mellon Institute, Pittsburgh, Pa.
Pittsburgh Testing Laboratory, Pittsburgh, Pa.
Massachusetts Institute of Technology, Cambridge, Mass.
U. S. Bureau of Standards, Washington, D. C.

For the purpose of this book, an "Authoritative Laboratory" is defined as "Any laboratory whose heat transmission data are accepted for inclusion in the American Society of Heating & Ventilating Engineers' Guide."

Comparison of Conductivities. It is common practice to compare the conductivities of various insulating materials. While it is true that a lower conductivity means greater heat resistance, conductivities alone do not necessarily afford a reliable basis of comparison. Other factors to be taken into consideration in making comparisons include the thickness installed, the manner of installation, materials replaced, if any, and increase or decrease in the number of air spaces in the construction due to the installation of the insulation. The only accurate basis for evaluating all of these factors is in terms of the over-all coefficients of transmission of the insulated construction under consideration as compared to the coefficients of transmission of a similar construction without insulation.

CALCULATED COEFFICIENTS

The coefficient of transmission of any type of construction can be determined by actual test in either the hot box apparatus or it can be determined by means of the Nicholls heat meter. From a practical standpoint, however, it is impossible to make individual tests of every conceivable type of wall or roof structure, with the hundreds of different materials and their varying thicknesses entering into construction. It is obvious that to attempt to test every type and thickness of wall structure would be an endless task. It is therefore necessary to determine the heat transmission coefficients of different types of construction by calculation, using the box test or the heat meter as a means of checking the calculated results.

Symbols. The symbols used in the heat transmission formulas in this chapter are as follows:

U = over-all coefficient of heat transmission and is the amount of heat expressed in B.t.u. transmitted in one hour per square foot of the wall, roof or ceiling for a difference in temperature of one degree Fahrenheit between the air on the inside and outside of the wall, floor or ceiling.

k = thermal conductivity and is the amount of heat expressed in B.t.u. transmitted in one hour through one square foot of a homogeneous material one inch thick for a difference in temperature of one degree Fahrenheit between the two surfaces of the material.

C = thermal conductance and is the amount of heat expressed in B.t.u. transmitted in one hour through one square foot of a non-homogeneous material or a combination of materials, for the thickness or type under consideration for a difference in temperature of one degree Fahrenheit between the two surfaces of the material.

f = film or surface conductance and is the amount of heat expressed in B.t.u. transmitted by radiation, conduction and convection from a surface to the air surrounding it, or vice versa, in one hour per square foot of the surface for a difference in temperature of one degree Fahrenheit between the surface and the surrounding air. To differentiate between inside and outside wall (or floor, roof or ceiling) surfaces, f_i is used to designate the inside film or surface conductance and f_o the outside film or surface conductance.

[*Continued on p. 126*]

Table 1. Conductivities (k) and Conductances (C) of Building

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference. Conductivities (k) are per inch thickness and conductances (C) are for thickness or construction stated, not per inch thickness.

Material	Description	Density (Lb. per Cu. Ft.)	Mean Temp. (Deg. Fahr.)	Conductivity or Conductance (k)	Conductivity or Conductance (C)	Resistance $\left(\frac{1}{k}\right)$ or $\left(\frac{1}{C}\right)$	Authority
BUILDING BOARDS (Non-Insulating)	Compressed cement and asbestos sheets	123	86	2.70	...	0.37	(1)
	Corrugated asbestos board	20.4	110	0.48	..	2.08	(2)
	Pressed asbestos mill board	60.5	86	0.84	..	1.19	(3)
	Gypsum board—gypsum between layers of heavy paper	62.8	70	1.41	....	0.71	(3)
	3/8 in. gypsum board	....	..	....	3.73	0.27	
	1/2 in. gypsum board	....	..	...	2.82	0.35	
	1/2 in. gypsum board	53.5	90	..	2.60	0.38	(1)
FRAME CONSTRUCTION COMBINATIONS	1 in. fir sheathing and building paper	...	30	..	0.86	1.16	(4)
	1 in. fir sheathing, building paper and yellow pine lap siding	.	20	.	0.50	2.00	(4)
	1 in. fir sheathing, building paper and stucco		20	. .	0.82	1.22	(4)
	Pine lap siding and building paper, siding 4 in. wide	.	16	....	0.85	1.18	(4)
	Yellow pine lap siding		..	. .	1.28	0.78	(4)
MASONRY MATERIALS Brick	Damp or wet	.	..	5.0[c]	....	0.20	(2)
	Common yellow clay brick[a]	.	..	4.8	...	0.21	(4)
	One tier yellow common clay brick, one tier face brick, approx. 8 in. thick[a]	....	..	.	0.77	1.30	(4)
Clay Tile, Hollow	2 in. tile, 1/2 in. plaster both sides.	120.0	110	...	1.00	1.00	(2)
	4 in. tile, 1/2 in. plaster both sides.	127.0	100	. .	0.60	1.67	(2)
	6 in. tile, 1/2 in. plaster both sides.	124.3	105	.	0.47	2.13	(2)
	8 in. tile, average of 8 types (Walls No. 59, 63, 64, 66, 67, 90, 91, 92[a])	.	..	....	0.52	1.92	(4)
	12 in. clay tile wall: 8 in. x 5 in. x 12 in. and 4 in. x 5 in. x 12 in.[a]		..	...	0.26	3.84	(4)
Concrete	Sand and gravel aggregate, various ages and mixes[d]		..	11.35 to 16.36	...	0.09 to 0.06	(5)
	Sand and gravel aggregate	142	75	12.6	.	0.08	(4)
	Limestone aggregate	132	75	10.8	..	0.09	(4)
	Cinder aggregate	97	75	4.9	...	0.22	(4)
	Steam treated limestone slag aggregate[a]	74.6	75	2.27	....	0.44	(4)
	Pumice (mined in California) aggregate[a]	65.0	75	2.42	....	0.41	(4)
	Expanded burned clay aggregate[a]	59.9	75	2.28	....	0.44	(4)
	Burned clay aggregate[a]	67.1	75	2.86	....	0.35	(4)
	Blast furnace slag aggregate	76.0	70	1.6	....	0.63	(3)
	Expanded vermiculite aggregate.	20	90	0.68	....	1.47	(3)
	Expanded vermiculite aggregate.	26.7	90	0.76	...	1.32	(3)
	Expanded vermiculite aggregate.	35	90	0.86	..	1.16	(3)
	Expanded vermiculite aggregate.	50	90	1.10	..	0.91	(3)
	Concrete plank	76	75	2.5	..	0.40	(3)
	Cellular concrete	40.0	75	1.06	...	0.94	(3)
	Cellular concrete	50.0	75	1.44	. .	0.69	(3)
	Cellular concrete	60.0	75	1.80	...	0.56	(3)
	Cellular concrete	70.0	75	2.18	...	0.46	(3)
8 In. Concrete Blocks 8x8x16 3-oval core concrete blocks	8 in. three oval core, sand and gravel aggregate[a]	126.4	40	....	0.90	1.11	(4)
	8 in. three oval core, crushed limestone aggregate[a]	134.3	40	....	0.86	1.16	(4)
	8 in. three oval core, cinder aggregate[a]	86.2	40	....	0.58	1.73	(4)
	8 in. three oval core, burned clay aggregate[a]	67.7	40	....	0.50	2.00	(4)
	8 in. three oval core, expanded blast furnace slag aggregate[a]	....	40	....	0.49	2.04	(4)

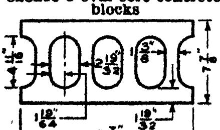


Table 1. Conductivities (*k*) and Conductances (*C*) of Building (*Concluded*)

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference. Conductivities (k) are per inch thickness and conductances (C) are for thickness or construction stated, not per inch thickness.

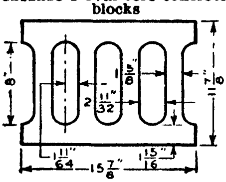
Material	Description	Density (Lb. per Cu. Ft.)	Mean Temp. (Deg. Fahr.)	Conductivity or Conductance (*k*)	Conductivity or Conductance (*C*)	Resistance $\left(\frac{1}{k}\right)$ or $\left(\frac{1}{C}\right)$	Authority
12 In. Concrete Blocks 8x12x16 3-oval core concrete blocks 	12 in. three oval core, sand and gravel aggregate[a]	124.9	40	....	0.78	1.28	(4)
	12 in. three oval core, cinder aggregate[a]	86.2	40	....	0.53	1.88	(4)
	12 in. three oval core, burned clay aggregate[a]	76.7	40	...	0.47	2.13	(4)
Gypsum	3 in. solid gypsum partition tile[a]	..	.	2.41	....	0.42	(4)
	3 in. three cell gypsum partition tile[a]	..	..	..	0.74	1.35	(4)
	4 in. three cell gypsum partition tile[a]	...	..	...	0.60	1.67	(4)
	87½ per cent gypsum, 12½ per cent wood chips	51.2	74	1.66	....	0.60	(4)
	Gypsum plaster	.	..	3.30	...	0.30	
PLASTERING MATERIALS	Gypsum plaster, ⅝ in. thick	...	73	..	8.80	0.11	(4)
	Cement plaster	..	..	8.00	...	0.13	(2)
	Wood, lath and plaster, total thickness ¾ in.	....	70	....	2.50	0.40	(4)
	Gypsum plaster and expanded vermiculite, 4 to 1 mix	39.9	75	0.85	....	1.18	(3)
	Insulating plaster 0.9 in. thick applied to ⅜ in. gypsum board	54.0	75	....	1.07	0.93	(3)
ROOFING	Asbestos shingles	65.0	75	..	6.0	0.17	(3)
	Asphalt, composition or prepared	70.0	75	...	6.5	0.15	(3)
	Asphalt shingles	70.0	75	....	6.5	0.15	(3)
	Built-up roofing, bitumen or felt, gravel or slag surfaced[a]	....	..	1.33	....	0.75	(2)
	Slate	....	..	10.00	...	0.10	
	Wood shingles	....	..	....	1.28	0.78	
WOODS	Balsa	20.0	90	0.58	..	1.72	(1)
	Balsa	8.8	90	0.38	..	2.63	(1)
	Balsa	7.3	90	0.33	...	3.03	(1)
	California redwood, 0 per cent moisture[a]	28.0	75	0.70	....	1.43	(4)
	Cypress	28.7	86	0.67	....	1.49	(1)
	Douglas fir, 0 per cent moisture[a]	34.0	75	0.67	....	1.49	(4)
	Eastern hemlock, 0 per cent moisture[a]	30.0	75	0.76	...	1.32	(4)
	Long leaf yellow pine, 0 per cent moisture[a]	40.0	75	0.86	....	1.16	(4)
	Mahogany	34.3	86	0.90	....	1.11	(1)
	Hard maple, 0 per cent moisture[a]	46.0	75	1.05	..	0.95	(4)
	Maple	44.3	86	1.10	.	0.91	(1)
	Maple, across grain	40.0	75	1.20	...	0.83	(3)
	Norway pine, 0 per cent moisture[a]	32.0	75	0.74	...	1.35	(4)
	Red cypress, 0 per cent moisture[a]	32.0	75	0.79	...	1.27	(4)
	Red oak, 0 per cent moisture[a]	48.0	75	1.18	....	0.85	(4)
	Short leaf yellow pine, 0 per cent moisture[a]	36.0	75	0.91	...	1.10	(4)
	Soft elm, 0 per cent moisture[a]	34.0	75	0.88	...	1.14	(4)
	Soft maple, 0 per cent moisture[a]	42.0	75	0.95	...	1.05	(4)
	Sugar pine, 0 per cent moisture[a]	28.0	75	0.64	....	1.56	(4)
	Virginia pine	34.3	86	0.96	....	1.04	(1)
	West coast hemlock, 0 per cent moisture[a]	30.0	75	0.79	...	1.27	(4)
	White pine	31.2	86	0.78	....	1.28	(1)
	Yellow pine	....	....	1.00	....	1.00	(3)
	Sawdust, various	12.0	90	0.41	....	2.44	(1)
	Shavings, various from planer	8.8	90	0.41	....	2.44	(1)
	Shavings, from maple, beech and birch (coarse)	13.2	90	0.36	....	2.78	(1)

Table 2. Conductivities (*k*) of Insulating Materials

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference.

Material	Description (For a more detailed description of these products, see chapter on Thermal Building Insulations)	Density (Lbs. per Cu. Ft.)	Mean Temperature Deg. Fahrenheit	Conductivity (*k*)	Resistance (*R*)	Authority
Balsam Wool..	Chemically treated wood fibers between layers of strong paper	3.6	70	0.25	4.00	(3)
Cabot's Quilt.	Zostera Marina (eel grass) between kraft paper	4.60	90	0.26	3.85	(1)
Cabot's Quilt.	Zostera Marina (eel grass) between kraft paper	3.40	90	0.25	4.00	(1)
Celotex	Insulating board made from sugar cane fiber	13.5	70	0.33	3.03	(3)
Cotton Seed	Loose Hulls	4.43	86	0.31	3.22	(1)
Corkboard	No added binder	10.6	90	0.30	3.33	(1)
Corkboard	No added binder	7.0	90	0.27	3.70	(1)
Corkboard	No added binder	5.4	90	0.25	4.00	(1)
Dry Zero	Flexible insulation of kapok.	1.00	90	0.24	4.17	(1)
Dry Zero	Flexible insulation of kapok.	1.90	75	0.23	4.35	(3)
Dry Zero	Flexible insulation of kapok.	1.60	75	0.24	4.17	(3)
Hairinsul	100% Cattle hair	13.0	90	0.26	3.84	(1)
Hairinsul	75% Cattle hair, 25% jute	6.30	90	0.27	3.70	(1)
Hairinsul	50% Cattle hair, 50% jute	6.10	90	0.26	3.85	(1)
Homasote	Insulating board of wood and other vegetable fibers	25.0	75	0.375	2.66	(3)
Housfil	Expanded vermiculite	5.62	75	0.38	2.63	(3)
Insulating Boards	½ in. insulating boards without special finish[f] (eleven samples)	16.5 to 21.8	90 ..	0.33 to 0.40	3.03 to 2.50	(1)
	1 in. insulating board[a]	13.2	..	0.34	2.94	(4)
Insulite	Insulating board made from wood fiber	16.0	70	0.33	3.03	(4)
Kimsul	Flexible insulation consisting of creped layers stitched together	1.5	70	0.27	3.70	(3)
Lockaire (Maftex)	Insulating board made from licorice root	16.1	81	0.34	2.94	(3)
Maizewood	Insulating board made from cornstalks	15.0	71	0.33	3.03	(3)
Masonite	Insulating board made from exploded wood fibers	15.0	75	0.33	3.03	(3)
Mineral Wool.	3 in. mineral wool bats, barrier lapped on warm side; horizontal position[b]	3.67	..	0.30	3.33	(4)
	3 in. mineral wool bats, barrier laid on warm side; horizontal position[b]	2.24	..	0.26	3.84	(4)
	3 in. mineral wool bats, barrier laid on warm side; vertical position[b]	2.24	..	0.25	4.00	(4)

Table 2. Conductivities (*k*) of Insulating Materials (*Concluded*)

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference.

Material	Description (For a more detailed description of these products, see chapter on Thermal Building Insulations)	Density (Lbs. per Cu. Ft.)	Mean Temperature Deg. Fahrenheit	Conductivity (*k*)	Resistance (*R*)	Authority
Mineral Wool.	4 in. mineral wool bats, barrier lapped on warm side; horizontal position[b].......	3.0	..	0.31	3.22	(4)
	4 in. mineral wool bats, barrier lapped on warm side; vertical position[b].........	3.0	..	0.33	3.03	(4)
	4 in. mineral wool bats, no barriers; horizontal[b]......	1.77	..	0.30	3.33	(4)
	Hand applied granular mineral wool 2 in. to 6 in. thick; horizontal position[b]. No covering.................	6.05 to 7.13	.. ..	0.30 to 0.33	3.33 to 3.03	(4)
	4 in. machine blown granular mineral wool, horizontal position[b]. No covering....	5.74	..	0.30	3.33	(4)
	Rock wool.......	10.0	90	0.27	3.70	(1)
Natur-Temp.	Cotton insulating batt.......	0.875	72	0.24	4.17	(3)
Natur-zone..	Treated hog hair covered with film of asphalt.......	10.0	75	0.28	3.57	(3)
Nu-Wood.. ..	Insulating board, wood fiber.	15.0	72	0.33	3.03	(3)
Palco Wool...	Fill insulation made from shredded redwood bark....	3.00	90	0.31	3.22	(1)
	Fill insulation made from shredded redwood bark...	5.00	75	0.26	3.84	(3)
Red Top Wool	Glass wool 0.0003 in. to 0.0006 in. in diameter............	1.5	75	0.27	3.70	(3)
Regranulated Cork.......	About 3/16" particles.........	8.10	90	0.31	3.22	(1)
Rock Cork....	Rock wool with a binding agent....................	14.5	77	0.33	3.03	(1)
Sprayo-Flake.	Paper and asbestos fibers with emulsified asphalt binder..	4.2	94	0.28	3.57	(1)
Temlok.......	Insulating board made from wood fiber................	15.0	70	0.33	3.03	(3)
Thermax.....	Slab insulation made from shredded wood and cement.	24.2	72	0.46	2.17	(3)
Thermofill....	Powdered gypsum fill.......	34.0	90	0.60	1.67	(1)
Thermofill....	Powdered gypsum fill.......	26.0	90	0.52	0.92	(1)
Thermofill....	Powdered gypsum fill.......	24.0	75	0.48	2.08	(3)
Thermofill....	Powdered gypsum fill.......	19.8	90	0.35	2.86	(1)
Thermofill....	Powdered gypsum fill.......	18.0	75	0.34	2.94	(3)
Vermiculite...	Expanded vermiculite.......	....	..	0.48	2.08	(1)
	Expanded vermiculite, particle size −3 +14.........	6.2	..	0.32	3.12	(4)
Weatherwood.	Insulating board, wood fiber.	15.2	70	0.33	3.03	(3)

Table 3. Conductivities (k) and Conductances (C) Used in Calculating Heat Loss Coefficients (U) in Tables 4 to 16

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference. Conductivities (k) are per inch thickness and conductances (C) are for thickness or construction stated, not per inch thickness.

Material	Description	Conductivity or Conductance		Resistance
		(k)	(C)	$\left(\frac{1}{k}\right)$ or $\left(\frac{1}{C}\right)$
AIR SPACES				
Bounded by ordinary materials	Vertical[h], ¾ in. or more in width	....	1.10	0.91
Bounded by Aluminum Foil	Vertical[h], ¾ in. or more in width	...	0.46	2.17
EXTERIOR FINISHES (Frame Walls)				
Brick Veneer	4 in. thick (nominal)	....	.	0.44
Stucco (1 in.)		12.50	.	0.08
Wood Shingles		....	1.28	0.78
Yellow Pine Lap Siding		...	1.28	0.78
INSULATING MATERIALS				
Aluminum Foil	See Air Spaces	....	.	....
Bats	Enclosed both sides	0.27	.	3.70
Blankets	Made from mineral or vegetable fibers or animal hair	0.27	.	3.70
Corkboard	Pure, no added binder	0.30	..	3.33
Insulating Board		0.33	.	3.03
Mineral Wool		0.27	.	3.70
Vermiculite		0.48	.	2.08
INTERIOR FINISHES				
Composition Wallboard	³⁄₁₆ in. to ⅜ in. thick	0.50	...	2.00
Gypsum Plaster		3.30	...	0.30
Gypsum Board (⅜ in.)	Plain or decorated	....	3.70	0.27
Gypsum Lath (⅜ in.) and Plaster	Plaster thickness assumed ½ in.	...	2.4	0.42
Insulating Board (½ in.)	Plain or decorated	...	..	1.52
Insulating Board Lath (½ in.) and Plaster	Plaster thickness assumed ½ in.	...	..	1.67
Insulating Board Lath (1 in.) and Plaster	Plaster thickness assumed ½ in.	....	....	3.18
Metal Lath and Plaster	Plaster thickness assumed ¾ in.	....	4.40	0.23
Plywood (⅜ in.)	Plain or decorated	....	..	0.47
Wood Lath and Plaster		....	2.50	0.40
MASONRY MATERIALS				
Brick	Adobe	3.56	....	0.28
Brick	Common	5.00[c]	...	0.20
Brick	Face	9.20	...	0.11
Cement Mortar		12.00	....	0.08
3 In. Clay Tile (Hollow)		....	1.28	0.78
4 In. Clay Tile (Hollow)		....	1.00	1.00
6 In. Clay Tile (Hollow)		....	0.64	1.57
8 In. Clay Tile (Hollow)		....	0.60	1.67
10 In. Clay Tile (Hollow)		....	0.58	1.72
12 In. Clay Tile (Hollow)		....	0.40	2.50
16 In. Clay Tile (Hollow)		...	0.31	3.23
Concrete	Light weight aggregate[m]	2.50	....	0.40
Concrete	Sand and gravel aggregate	12.00	....	0.08
3 In. Concrete Blocks	Hollow, cinder aggregate	....	1.28	0.78
4 In. Concrete Blocks	Hollow, cinder aggregate	....	1.00	1.00
8 In. Concrete Blocks	Hollow, gravel aggregate	....	1.00	1.00
12 In. Concrete Blocks	Hollow, gravel aggregate	....	0.80	1.25
8 In. Concrete Blocks	Hollow, cinder aggregate	....	0.60	1.66
12 In. Concrete Blocks	Hollow, cinder aggregate	....	0.53	1.88
8 In. Concrete Blocks	Hollow, light weight aggregate[m]	...	0.50	2.00
12 In. Concrete Blocks	Hollow, light weight aggregate[m]	....	0.47	2.13
Gypsum Fiber Concrete	87½ per cent gypsum and 12½ per cent wood chips	1.66	....	0.60
3 In. Gypsum Tile	Hollow	....	0.61	1.64
4 In. Gypsum Tile	Hollow	....	0.46	2.18
Stucco		12.50	....	0.08
Tile and Terrazzo	For flooring	12.00	....	0.08

Table 3. Conductivities (k) and Conductances (C) Used in Calculating Heat Loss Coefficients (U) in Tables 4 to 16 (*Concluded*)

These constants are expressed in Btu per hour per square foot per degree Fahrenheit temperature difference. Conductivities (k) are per inch thickness and conductances (C) are for thickness or construction stated, not per inch thickness.

Material	Description	Conductivity or Conductance (k)	Conductivity or Conductance (C)	Resistance $\left(\frac{1}{k}\right)$ or $\left(\frac{1}{C}\right)$
ROOFING MATERIALS				
Asbestos Shingles		...	6.00	0.17
Asphalt Shingles		...	6.50	0.15
Built-up Roofing	Assumed thickness ⅜ in.	...	3.53	0.28
Heavy Roll Roofing		...	6.50	0.15
Slate		10.00	...	0.10
Wood Shingles			1.28	0.78
SHEATHING				
Gypsum (½ In.)		....	2.82	0.35
Insulating Board (25/32 In.)		....	...	2.37
Plywood (5/16 In.)		...	...	0.39
Fir or Yellow Pine (1 In.)	Actual thickness 25/32 in.	..	...	0.98
Fir, Plus Building Paper	Actual thickness 25/32 in.	...	0.86	1.16
SURFACES				
Still Air	Ordinary non-reflective materials, vertical	...	1.65	0.61
15 Mph Wind Velocity	Ordinary non-reflective materials, vertical	.	6.00	0.17
WOODS				
Fir Sheathing (1 In.) Building Paper and Yellow Pine Lap Siding		....	0.50	2.00
Maple or Oak		1.15	....	0.87
Yellow Pine or Fir		0.80	....	1.25

NOTES FOR TABLES 1, 2, AND 3

AUTHORITIES:

(1) U. S. Bureau of Standards, tests based on samples submitted by manufacturers.

(2) A. C. Willard, L. C. Lichty and L. A. Harding, tests conducted at the University of Illinois.

(3) J. C. Peebles, tests conducted at Armour Institute of Technology, based on samples submitted by manufacturers.

(4) F. B. Rowley, et al, tests conducted at the University of Minnesota.

(5) A.S.H.V.E. Research Laboratory.

[a] See Thermal Conductivity of Building Materials, by F. B. Rowley and A. B. Algren (University of Minnesota *Engineering Experimental Station Bulletin* No. 12).

[b] Heat Transmission Through Insulation as Affected by Orientation of Walls, by F. B. Rowley and C. E. Lund (A.S.H.V.E. JOURNAL SECTION OF *Heating, Piping & Air Conditioning*, July, 1943).

[c] The Effect of Convection in Ceiling Insulation, by G. B. Wilkes and L. R. Vianey (A.S.H.V.E. JOURNAL SECTION OF *Heating, Piping & Air Conditioning*, February, 1943).

[d] See A.S.H.V.E. RESEARCH REPORT No. 915—Conductivity of Concrete, by F. C. Houghten and Carl Gutberlet (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 47).

[e] Recommended value. (See Heating, Ventilating and Air Conditioning, by Harding and Willard, revised edition, 1932).

[f] See BMS13, U. S. Department of Commerce, National Bureau of Standards, Washington, D. C.

[g] Roofing, 0.15 in. thick (1.34 lb per square foot), covered with gravel (0.83 lb per square foot), combined thickness assumed 0.25.

[h] Conductance values for horizontal air spaces depend on whether the heat flow is upward or downward, but in most cases it is sufficiently accurate to use the same values for horizontal as for vertical air spaces.

[m] Expanded slag, burned clay or pumice.

a = thermal conductance of an air space, and is the amount of heat expressed in B.t.u. transmitted by radiation, conduction and convection in one hour through an area of one square foot of an air space for a temperature difference of one degree Fahrenheit.

R = resistance or resistivity which is the reciprocal of transmission, conductance, or conductivity. This is explained under the heading *Resistances* in this chapter.

Formula for Simple Wall. The formula for calculating the overall coefficient of transmission for a simple wall or roof x inches thick is:

$$U=\frac{1}{\frac{1}{f_i}+\frac{x}{k}+\frac{1}{f_o}} \qquad (1)$$

Example 1. By means of Formula (1), calculate the coefficient of transmission (U) of a plain 10-in. concrete wall, Fig. 3.

Solution. The thickness $x=10$ in. and the conductivity (k) of concrete = 12.0, Table 3. The inside surface coefficient (f_i) for still air = 1.65 and the outside surface coefficient (f_o) for a wind velocity of 15 m.p.h. (the value used for heat transmission calculations) is 6.00. Substituting these values in Formula (1),

$$U=\frac{1}{\underset{\text{(Inside surface)}}{\frac{1}{1.65}}+\underset{\text{(Concrete)}}{\frac{10.0}{12.0}}+\underset{\text{(Outside surface)}}{\frac{1}{6.0}}}$$

$$=\frac{1}{0.61+0.833+0.17}$$

$$=\frac{1}{1.613}$$

= 0.62 B.t.u. per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides of the wall.

The coefficient of transmission of a simple roof structure would be calculated in a similar manner using the proper conductivity (k) for the roof material as well as the proper thickness (x). An inside partition next to an unheated space would also be calculated in a similar manner except that two still-air surface coefficients (f_i) would be used, each having a conductance of 1.65, instead of using one inside still-air surface conductance (f_i) of 1.65 and one outside surface conductance (f_o) of 6.00.

Formula for Compound Wall. The formula for the coefficient of transmission of a compound wall of several materials having thick-

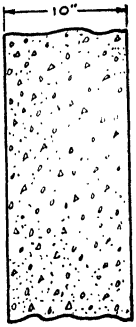


Fig. 3. Section through a Plain 10-inch Concrete Wall

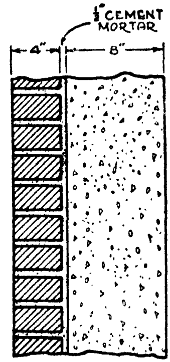


Fig. 4. Section through Wall Consisting of 8-inch Concrete, ½-inch Cement Mortar and 4-inch Face Brick

nesses in inches of x_1, x_2, x_3, etc., and conductivities of k_1, k_2, k_3, etc., is as follows:

$$U=\frac{1}{\frac{1}{f_i}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}+\frac{1}{f_o}} \tag{2}$$

For each homogeneous material in the construction there will be one x (thickness) and one k (conductivity). As in the case of the simple wall, f_i and f_o are always the inside and outside surface coefficients for the two materials in contact with the air, which for ordinary building materials are usually assumed to be 1.65 and 6.00 respectively.

Example 2. By means of Formula (2), calculate the coefficient of transmission (U) of an 8-in. concrete wall, having an exterior finish of 4-in. face brick. Assume ½ in. cement mortar between the concrete and face brick. Fig. 4.

Solution. The thicknesses (x_1, x_2, x_3) for the three materials are 8 in. for the concrete, ½ in. for the mortar and 4 in. for the face brick. The conductivities (k_1, k_2, k_3) of these materials respectively are 12.0, 12.0 and 9.2, Table 3. Substituting these values and the proper factors for f_i and f_o in Formula (**2**):

$$U=\frac{1}{\underset{\text{(Inside surface)}}{\frac{1}{1.65}}+\underset{\text{(Concrete)}}{\frac{8.0}{12.0}}+\underset{\text{(Cement) mortar)}}{\frac{0.5}{12.0}}+\underset{\text{(Face brick)}}{\frac{4.0}{9.2}}+\underset{\text{(Outside surface)}}{\frac{1}{6.0}}}$$

$$=\frac{1}{0.61+0.67+0.04+0.44+0.17}$$

$$=\frac{1}{1.93}$$

$=0.52$ B.t.u. per hour per square foot per degree Fahrenheit

Air-Space Construction. In the case of walls containing air spaces, an air-space coefficient (a) must be inserted in the equation for each air space. Thus for a wall containing two materials with an air space between, the formula would be:

$$U=\frac{1}{\frac{1}{f_i}+\frac{x_1}{k_1}+\frac{1}{a_1}+\frac{x_2}{k_2}+\frac{1}{f_o}} \tag{3}$$

and for a wall of three materials and two air spaces, the formula would be:

$$U=\frac{1}{\frac{1}{f_i}+\frac{x_1}{k_1}+\frac{1}{a_1}+\frac{x_2}{k_2}+\frac{1}{a_2}+\frac{x_3}{k_3}+\frac{1}{f_o}} \tag{4}$$

As previously stated, it is customary to use a conductance value (a) of 1.10 for each air space ¾ inch or more in width bounded by ordinary materials.

With certain special forms of construction which have irregular air spaces (such as hollow tile) or are otherwise non-homogeneous, it is necessary to use the conductance (C) for the unit construction, in which case $\frac{x}{k}$ is replaced by $\frac{1}{C}$.

Example 3. Calculate the coefficient of transmission (U) of an 8-in. hollow tile wall having an exterior finish of 1 in. of stucco and an interior finish of ½-in. insulating board lath, and ½-in. plaster furred out from the wall about 1 in., thereby creating an air space between the wall and the lath, as shown in Fig. 5.

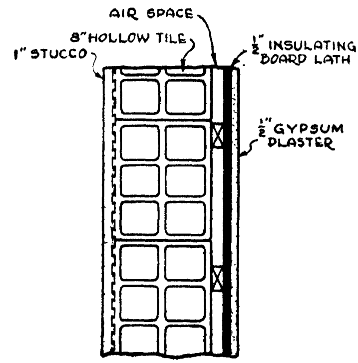


Fig. 5. Section through 8-inch Hollow Tile Wall with 1-inch Stucco Exterior Finish and ½-inch Gypsum Plaster (on ½-inch Insulating Board Lath), Interior Finish

Solution. The various conductivity and conductance values of the materials entering into this problem are given in Table 3; k (stucco) = 12.0, C (8-in. hollow clay tile) = 0.60, k (gypsum plaster) = 3.30, k (insulating board) = 0.33. Substituting these values in Formula (4):

$$U = \frac{1}{\underset{\text{(Inside surface)}}{\frac{1}{1.65}} + \underset{\text{(Plaster)}}{\frac{0.50}{3.30}} + \underset{\text{(Insulation)}}{\frac{0.50}{0.33}} + \underset{\text{(Air space)}}{\frac{1}{1.10}} + \underset{\text{(Hollow tile)}}{\frac{1}{0.60}} + \underset{\text{(Stucco)}}{\frac{1.0}{12.0}} + \underset{\text{(Outside surface)}}{\frac{1}{6.0}}}$$

$$= \frac{1}{0.61 + 0.15 + 1.52 + 0.91 + 1.67 + 0.08 + 0.17}$$

$$= \frac{1}{5.11}$$

= 0.196 or 0.20 B.t.u. per hour per square foot per degree Fahrenheit temperature difference

Resistances. As previously explained, conductivities and conductances are not additive; neither are coefficients of transmission. Resistances, however, can be added. These are simply the reciprocals of conductivities and conductances. In mathematics, the reciprocal of a number is simply one (unity) divided by the number.

For example, the reciprocal of 2 is ½ and the reciprocal of 6 is ⅙. Reciprocals of various numbers commonly used in calculating heat-transfer coefficients are given in Table D.

Table D. Reciprocals of Numbers

Coefficient	Resistance	Coefficient	Resistance	Coefficient	Resistance	Coefficient	Resistance
1.00	1.000	0.45	2.222	0.30	3.333	0.15	6.667
0.95	1.053	0.44	2.273	0.29	3.448	0.14	7.143
0.90	1.111	0.43	2.326	0.28	3.571	0.13	7.692
0.85	1.177	0.42	2.381	0.27	3.704	0.12	8.333
0.80	1.250	0.41	2.439	0.26	3.846	0.11	9.090
0.75	1.333	0.40	2.500	0.25	4.000	0.10	10.000
0.70	1.429	0.39	2.564	0.24	4.167	0.095	10.526
0.65	1.539	0.38	2.632	0.23	4.348	0.090	11.111
0.60	1.667	0.37	2.703	0.22	4.545	0.085	11.765
0.55	1.818	0.36	2.778	0.21	4.762	0.080	12.500
0.50	2.000	0.35	2.857	0.20	5.000	0.075	13.333
0.49	2.040	0.34	2.941	0.19	5.263	0.070	14.285
0.48	2.083	0.33	3.030	0.18	5.555	0.065	15.385
0.47	2.127	0.32	3.125	0.17	5.882	0.060	16.667
0.46	2.174	0.31	3.226	0.16	6.250	0.055	18.182
....	.....	....	.....	....	.....	0.050	20.000

The resistance of a 1-inch thickness of a building material or an insulation is equal to $\frac{1}{k}$ and the resistance of x inches is equal to $\frac{x}{k}$. If the conductivity of an insulating material is 0.33, the resistance will be $\frac{1}{0.33}$ or 3.03 per inch, and the resistance of two inches will be $\frac{2}{0.33}$ or 6.06. Likewise the conductance of 8-inch hollow clay tile is 0.60 and the resistance is $\frac{1}{0.60}$ or 1.67. The conductance of an average air space bounded by ordinary building materials is 1.10 and the resistance is $\frac{1}{1.10}$ or 0.91. The average still-air surface conductance (f_i) is 1.65 and the resistance is $\frac{1}{1.65}$ or 0.61. The average outside surface conductance (f_o) is 6.00 and the resistance is $\frac{1}{6.00}$ or 0.17.

Resistances of commercial thicknesses of insulating materials, based on conductivities ranging from 0.24 to 0.40, inclusive, are given in Table E. To use this table, locate the conductivity in the

Table E. Resistances of Commercial Thicknesses of Insulation

Conductivity per 1″	Thickness										
	¼″	⅜″	½″	⅝″	¾″	1″	1½″	2″	3″	3⅝″*	4″
0.24	1.04	1.39	2.08	2.78	3.125	4.17	6.25	8.33	12.50	15.10	16.66
0.25	1.00	1.33	2.00	2.67	3.00	4.00	6.00	8.00	12.00	14.50	16.00
0.26	0.96	1.28	1.92	2.57	2.89	3.846	5.77	7.69	11.54	13.95	15.38
0.27	0.93	1.23	1.85	2.47	2.78	3.704	5.56	7.41	11.11	13.43	14.62
0.28	0.89	1.19	1.79	2.38	2.68	3.57	5.36	7.14	10.71	12.94	14.28
0.29	0.86	1.15	1.72	2.30	2.59	3.448	5.17	6.90	10.34	12.50	13.79
0.30	0.83	1.11	1.67	2.22	2.50	3.333	5.00	6.67	10.00	12.08	13.33
0.31	0.81	1.08	1.61	2.15	2.42	3.226	4.84	6.45	9.68	11.69	12.90
0.32	0.78	1.04	1.56	2.08	2.34	3.125	4.69	6.25	9.38	11.33	12.50
0.33**	0.76	1.01	1.52	2.02	2.27	3.03	4.55	6.06	9.09	10.98	12.12
0.34	0.74	0.98	1.47	1.96	2.21	2.94	4.41	5.88	8.82	10.66	11.76
0.35	0.71	0.95	1.43	1.90	2.14	2.857	4.29	5.71	8.57	10.36	11.43
0.36	0.69	0.92	1.39	1.85	2.08	2.778	4.17	5.56	8.33	10.07	11.11
0.37	0.68	0.90	1.35	1.80	2.03	2.703	4.06	5.41	8.11	9.80	10.81
0.38	0.66	0.88	1.32	1.75	1.97	2.632	3.95	5.26	7.90	9.54	10.53
0.39	0.64	0.86	1.28	1.71	1.92	2.564	3.85	5.13	7.69	9.30	10.26
0.40	0.63	0.83	1.25	1.67	1.88	2.500	3.75	5.00	7.50	9.06	10.00

*Subtract resistance of air space (0.91) from figures in this column.
**Resistance of 25/32″, 2.37.

left-hand column, and then ascertain the required resistance under the proper thickness column. For example, to find the resistance of ¾ inch of an insulation having a conductivity of 0.31, first locate this conductivity in the left-hand column and then read the resistance under the "¾ inch" column, which is 2.42.

It will be noted that the quantities in the denominators of Formulas (1), (2), (3) and (4) $\left(\frac{x}{k}, \frac{1}{a}, \frac{1}{C}, \frac{1}{f_i}, \frac{1}{f_o}\right)$ are resistances which are additive, there being plus signs between each of these quantities.

The resistance of a building material or mass insulation is called its *internal resistance*, whereas the resistance of any exposed surface (except that of an air space) is called its *surface resistance*. The resistance of an air space is designated as an *air space resistance*. The sum of all the resistances is called the *total* or *over-all resistance* of the structure. The resistance of any material, surface, air space or compound structure is designated by the letter R and if R_1, R_2, R_3, etc., represent the various individual resistances and R_t represents the total or over-all resistance of a structure, then,

$$R_t = R_1 + R_2 + R_3 + \text{ etc. and} \tag{5}$$

$$U = \frac{1}{R_t} \tag{6}$$

Comparison of Resistances. Reference has been made in this chapter to the practice of comparing the conductivities of insulating materials. It is also customary to compare the resistances of two or more materials. For example, if material X has a conductivity of 0.30, the resistance per inch of thickness will be 3.33. On the other hand, the resistance of a non-insulating material Y having a conductivity of 10.0 is only 0.10. Therefore, it would require $\frac{3.33}{0.10}$ or 33.3 inches of material Y to provide the same amount of heat resistance as one inch of material X. While this is a legitimate comparison, it does not tell the complete story and, as in the case of conductivities, a true comparison of the actual functioning of these materials as installed can be obtained only by means of the coefficients of transmission of the constructions in which they are used.

The following example illustrates why an improper comparison of resistances may be misleading. Consider the wall shown in Fig. 4 of this chapter, having a coefficient of transmission of 0.52 and a resistance of 1.93. If one inch of material X having a resistance of 3.33 is added to this wall, the total resistance will be 1.93+3.33 or 5.26 and the coefficient of transmission will be 0.19. Now, if instead of adding one inch of material X, 3 inches of material Z having a conductivity of 0.25, are added; the resistance of material Z is 4.00 per inch or 12.00 for the 3 inches, which is 3.6 times as much as the resistance of one inch of material X. Adding the 3 inches of material Z to the wall of Fig. 4 makes the total resistance 1.93+12.00 or 13.93 and the theoretical coefficient of transmission will be 0.072. The one inch of material X will reduce the heat loss from 0.52 to 0.19 which is a reduction of 63.5 per cent and is obtained as follows:

$$100\times\frac{(0.52-0.19)}{0.52}=63.5 \text{ per cent}$$

The three inches of material Z will reduce the heat loss from 0.52 to 0.072, which is a reduction of 86.2 per cent and is obtained as follows:

$$100\times\frac{(0.52-0.072)}{0.52}=86.2 \text{ per cent}$$

Thus although three inches of material Z has 3.6 times (360 per cent) as much heat resistance as one inch of material X, the insulating effect in the case of the wall considered is only about a third greater, or

$$100\times\frac{(86.2-63.5)}{63.5}=36 \text{ per cent}$$

Determining the most desirable thickness of insulation to use is discussed in detail in the chapter entitled Economics of Insulation.

Resistance Method of Calculating Over-all Coefficients. The use of the various formulas for calculating the value of U may be simplified somewhat by tabulating the resistances of the component parts of the structure under consideration, adding these resistances, and then finding the reciprocal, Table D, to get the desired coefficient. Example 1 in this chapter may be solved by this method as follows:

Part of Structure	Thickness (x)	Coefficient	Resistance (R)
Outside Surface	...	6.00 (f_o)	0.17
Concrete	10″	12.00 (k)	0.833
Inside Surface	...	1.65 (f_i)	0.61
Total Resistance (R_t)			1.613

$$U=\frac{1}{R_t}=\frac{1}{1.613}=0.62$$

If Example 3 of this chapter were solved by the resistance method, the procedure would be as follows:

Part of Structure	Thickness (x)	Coefficient	Resistance (R)
Outside surface	...	6.00 (f_o)	0.17
Stucco	1″	12.00 (k)	0.08
Hollow Tile	8″	0.60 (C)	1.67
Air space	1″	1.10 (a)	0.91
Insulating board	½″	0.33 (k)	1.52
Plaster	½″	3.30 (k)	0.15
Inside surface	...	1.65 (f_i)	0.61
Total resistance (R_t)			5.11

$$U=\frac{1}{R_t}=\frac{1}{5.11}=0.196 \text{ or } 0.20$$

Minimum Practical Coefficient Value. Usually only two significant figures beyond the decimal point are shown, in which case the coefficient of transmission for this construction would be 0.20, as indicated. Where the coefficient is below 0.10, the result is usually carried out to three places, such as 0.092. However, it is the practice of many heating and insulation engineers to use minimum coefficients of 0.10 for calculating heat losses, even though the theoretical calculated coefficients may be substantially lower. This is to allow for possible defects in construction and defects in the application or functioning of the insulating material, uninsulated spaces caused by headers and other framing, and increase in emissivity of reflective materials, which might diminish the efficiency of the insulated construction. The lower the theoretical wall coefficient the greater will be the percentage of error due to failure of the insulating material to perform as rated.

At least two associations now recommend a minimum wall coefficient of 0.10 for frame walls, regardless of the theoretical calculated coefficient. This practice is further substantiated by a paper presented at the June 1941 semi-annual meeting of the American Society of Heating & Ventilating Engineers entitled, "Effect of Insulation on Heating Plant Performance in the Research Residence," by A. P. Kratz and S. Konzo (American Society of Heating & Ventilating Engineers Journal Section of Heating, Piping and Air Conditioning, May 1941). The theoretical insulated wall and ceiling coefficients in this case were 0.047 and 0.048 respectively and the estimated reduction in heat loss was 38.6 per cent. Actual fuel saving, however, averaged approximately 30 per cent.

Transmission Coefficient Tables. Heat-transmission coefficients (U) of many common types of construction are given in Tables 4 to 16 inclusive. These coefficients were calculated by the author from the conductivities and conductances given in Table 3 and are reprinted by permission from the Heating, Ventilating and Air Conditioning Guide, 1944, published by the American Society of Heating and Ventilating Engineers. These tables are revised to keep step with progress made in the testing of building and insulating materials.

It will be noted that each construction in Tables 4 to 16 inclusive is identified by a serial number. For example, the coefficient of transmission of a wall consisting of 12-inch brick with an interior finish of plaster on metal lath is 0.25 and the number assigned to a wall of this construction is 68-C, Table 6.

The coefficients in Tables 4 to 16 were calculated by the resistance method in a manner similar to the examples given in this chapter using the conductivities (k) and conductances (C) given in Table 3. An inside still-air surface conductance (f_i) of 1.65, and an outside surface conductance (f_o) of 6.0 were used in the calculations. An air space conductance (a) of 1.10 was used for air spaces ¾ inch or more in width bounded by ordinary building materials. Small air spaces or crevices were neglected as is customary practice.

Computed Transmission Coefficients. Computed heat transmission coefficients of many common types of building construction are given in Tables 4 to 17, inclusive, each construction being identified by a serial number. For example, the coefficient of transmission (U) of an 8-in. brick wall and ½ in. of plaster is 0.46, and the number assigned to a wall of this construction is *67-B*, Table 6.

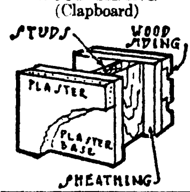
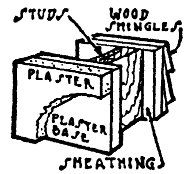
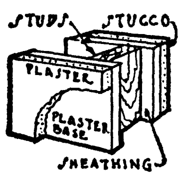
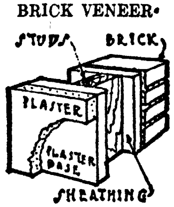
Example 4. Calculate the coefficient of transmission (U) of an 8-in. brick wall with ½ in. of plaster applied directly to the interior surface, based on an outside wind exposure of 15 mph. It is assumed that the outside course is of hard (high density) brick having a conductivity of 9.20, and that the inside course is of common (low density) brick having a conductivity of 5.0, the thicknesses each

[*Continued on p. 147*]

Table 4. Coefficients of Transmission (*U*) of Frame Walls

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on a wind velocity of 15 mph.

No Insulation between Studs[a] (See Table 5)

Exterior Finish	Interior Finish	Type of Sheathing: Gypsum (½ In. Thick) A	Ply-wood (5/16 In. Thick) B	Wood[f] (25/32 In. Thick) Bldg. Paper C	Insulating Board (25/32 In. Thick) D	Wall Number
WOOD SIDING (Clapboard) 	Metal Lath and Plaster[b]	0.33	0.32	0.26	0.20	1
	Gypsum Board (⅜ in.) Decorated	0.32	0.32	0.25	0.20	2
	Wood Lath and Plaster	0.31	0.31	0.25	0.19	3
	Gypsum Lath (⅜ in.) Plastered[c]	0.31	0.31	0.25	0.19	4
	Plywood (⅜ in.) Plain or Decorated	0.30	0.30	0.24	0.19	5
	Insulating Board (½ in.) Plain or Decorated	0.23	0.23	0.19	0.16	6
	Insulating Board Lath (½ in.) Plastered[c]	0.22	0.22	0.19	0.15	7
	Insulating Board Lath (1 in.) Plastered[c]	0.17	0.17	0.15	0.12	8
WOOD[d] SHINGLES 	Metal Lath and Plaster[b]	0.25	0.25	0.26	0.17	9
	Gypsum Board (⅜ in.) Decorated	0.25	0.25	0.25	0.17	10
	Wood Lath and Plaster	0.24	0.24	0.25	0.16	11
	Gypsum Lath (⅜ in.) Plastered[c]	0.24	0.24	0.25	0.16	12
	Plywood (⅜ in.) Plain or Decorated	0.24	0.24	0.24	0.16	13
	Insulating Board (½ in.) Plain or Decorated	0.19	0.19	0.19	0.14	14
	Insulating Board Lath (½ in.) Plastered[c]	0.19	0.18	0.19	0.13	15
	Insulating Board Lath (1 in.) Plastered[c]	0.14	0.14	0.15	0.11	16
STUCCO 	Metal Lath and Plaster[b]	0.43	0.42	0.32	0.23	17
	Gypsum Board (⅜ in.) Decorated	0.42	0.41	0.31	0.23	18
	Wood Lath and Plaster	0.40	0.39	0.30	0.22	19
	Gypsum Lath (⅜ in.) Plastered[c]	0.39	0.39	0.30	0.22	20
	Plywood (⅜ in.) Plain or Decorated	0.39	0.38	0.29	0.22	21
	Insulating Board (½ in.) Plain or Decorated	0.27	0.27	0.22	0.18	22
	Insulating Board Lath (½ in.) Plastered[c]	0.26	0.26	0.22	0.17	23
	Insulating Board Lath (1 in.) Plastered[c]	0.19	0.19	0.16	0.14	24
BRICK VENEER[e] 	Metal Lath and Plaster[b]	0.37	0.36	0.28	0.21	25
	Gypsum Board (⅜ in.) Decorated	0.36	0.36	0.28	0.21	26
	Wood Lath and Plaster	0.35	0.34	0.27	0.20	27
	Gypsum Lath (⅜ in.) Plastered[c]	0.34	0.34	0.27	0.20	28
	Plywood (⅜ in.) Plain or Decorated	0.34	0.33	0.27	0.20	29
	Insulating Board (½ in.) Plain or Decorated	0.25	0.25	0.21	0.17	30
	Insulating Board Lath (½ in.) Plastered[c]	0.24	0.24	0.20	0.16	31
	Insulating Board Lath (1 in.) Plastered[c]	0.18	0.18	0.15	0.13	32

[a] Coefficients not weighted; effect of studding neglected.
[b] Plaster assumed ¾ in. thick.
[c] Plaster assumed ½ in. thick.
[d] Furring strips between wood shingles and all sheathings except wood.
[e] Small air space and mortar between building paper and brick veneer neglected.
[f] Nominal thickness, 1 in.

Table 5. Coefficients of Transmission (*U*) of Frame Walls with Insulation between Framing[a, b]

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on a wind velocity of 15 mph.

COEFFICIENT WITH *NO* INSULATION BETWEEN FRAMING	COEFFICIENT WITH INSULATION BETWEEN FRAMING				Number
	BLANKET OR BAT INSULATION BETWEEN FRAMING [c] (Thickness below)			3⅝ IN. LOOSE MINERAL WOOL BETWEEN FRAMING	
	1 In.	2 In.	3 In.		
	A	B	C	D	
0.11	0.078	0.064	0.055	0.051	33
0.12	0.083	0.067	0.057	0.054	34
0.13	0.088	0.070	0.059	0.056	35
0.14	0.092	0.073	0.061	0.058	36
0.15	0.097	0.075	0.062	0.059	37
0.16	0.10	0.077	0.065	0.060	38
0.17	0.10	0.080	0.066	0.062	39
0.18	0.11	0.082	0.068	0.063	40
0.19	0.11	0.084	0.069	0.064	41
0.20	0.12	0.087	0.070	0.066	42
0.21	0.12	0.088	0.072	0.067	43
0.22	0.12	0.090	0.073	0.069	44
0.23	0.12	0.093	0.074	0.069	45
0.24	0.12	0.094	0.076	0.070	46
0.25	0.13	0.095	0.076	0.072	47
0.26	0.13	0.096	0.077	0.072	48
0.27	0.14	0.097	0.078	0.073	49
0.28	0.14	0.098	0.078	0.073	50
0.29	0.14	0.10	0.080	0.075	51
0.30	0.14	0.10	0.080	0.075	52
0.31	0.14	0.10	0.082	0.076	53
0.32	0.15	0.10	0.082	0.076	54
0.33	0.15	0.11	0.083	0.077	55
0.34	0.15	0.11	0.083	0.078	56
0.35	0.15	0.11	0.085	0.078	57
0.36	0.16	0.11	0.085	0.079	58
0.37	0.16	0.11	0.087	0.080	59
0.38	0.16	0.11	0.087	0.080	60
0.39	0.16	0.11	0.087	0.081	61
0.40	0.16	0.11	0.088	0.082	62
0.41	0.16	0.11	0.088	0.082	63
0.42	0.16	0.11	0.088	0.082	64
0.43	0.17	0.11	0.090	0.083	65
0.44	0.17	0.12	0.090	0.083	66

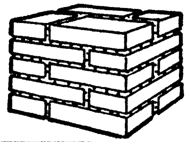
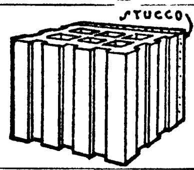
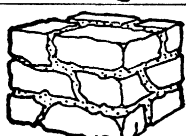
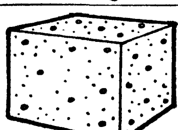
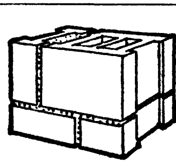
[a] This table may be used for determining the coefficients of transmission of frame constructions with the types and thicknesses of insulation indicated in Columns A to D inclusive between framing. Columns A, B and C may be used for walls, ceilings or roofs with only one air space between framing but are not applicable to ceilings with *no* flooring above. (See Table 10.) Column D is applicable to walls only. *Example:* Find the coefficient of transmission of a frame wall consisting of wood siding, 25/32 in. insulating board sheathing, studs, gypsum lath and plaster, with 2 in. blanket insulation between studs. According to Table 4, a wall of this construction with *no insulation* between studs has a coefficient of 0.19 (Wall No. 4D). Referring to Column B above, it will be found that a wall of this value with 2 in. blanket insulation between the studs has a coefficient of 0.084.

[b] Coefficients corrected for 2x4 framing, 16 in. o. c.

[c] Based on one air space between framing.

Table 6. Coefficients of Transmission (*U*) of Masonry Walls

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on a wind velocity of 15 mph.

Type of Masonry		Thickness of Masonry Inches	Plain Walls—No Interior Finish	Plaster (½ in.) on Walls	Metal Lath and Plaster[f] Furred	Gypsum Board (⅜ in.) Decorated—Furred	Gypsum Lath (⅜ in.) Plastered[g]—Furred	Insulating Board (½ in.) Plain or Decorated—Furred	Insulating Board Lath (½ in.) Plastered[g]—Furred	Insulating Board Lath (1 in.) Plastered[g]—Furred	Gypsum Lath[g] Plastered Plus 1 in. Blanket Insulation—Furred[h]	Wall Number
			Interior Finish (Plus Insulation Where Indicated)									
			A	B	C	D	E	F	G	H	I	
Solid[a] Brick		8	0.50	0.46	0.32	0.31	0.30	0.22	0.22	0.16	0.14	67
		12	0.35	0.34	0.25	0.25	0.24	0.19	0.19	0.14	0.13	68
		16	0.28	0.27	0.21	0.21	0.20	0.17	0.16	0.13	0.12	69
Hollow[b] Tile (Stucco Exterior Finish)		8	0.40	0.37	0.27	0.27	0.26	0.20	0.20	0.15	0.13	70
		10	0.39	0.37	0.27	0.27	0.26	0.20	0.19	0.15	0.13	71
		12	0.30	0.29	0.22	0.22	0.21	0.17	0.17	0.13	0.12	72
		16	0.25	0.24	0.19	0.19	0.19	0.16	0.15	0.12	0.11	73
Stone[c]		8	0.70	0.64	0.39	0.38	0.36	0.26	0.25	0.18	0.16	74
		12	0.57	0.53	0.35	0.34	0.33	0.24	0.23	0.17	0.15	75
		16	0.49	0.45	0.32	0.31	0.30	0.22	0.22	0.16	0.14	76
		24	0.37	0.35	0.26	0.26	0.25	0.20	0.19	0.15	0.13	77
Poured Concrete[d]		6	0.79	0.71	0.42	0.41	0.39	0.27	0.26	0.19	0.16	78
		8	0.70	0.64	0.39	0.38	0.36	0.26	0.25	0.18	0.16	79
		10	0.63	0.58	0.37	0.36	0.34	0.25	0.24	0.18	0.15	80
		12	0.58	0.53	0.35	0.34	0.33	0.24	0.23	0.17	0.15	81
Hollow Concrete Blocks			Gravel Aggregate									
		8	0.56	0.52	0.34	0.34	0.32	0.24	0.19	0.17	0.15	82
		12	0.50	0.46	0.32	0.31	0.30	0.22	0.22	0.16	0.14	83
			Cinder Aggregate									
		8	0.41	0.39	0.28	0.28	0.27	0.21	0.20	0.15	0.13	84
		12	0.38	0.36	0.26	0.26	0.25	0.20	0.19	0.15	0.13	85
			Light[e] Weight Aggregate									
		8	0.36	0.34	0.26	0.25	0.24	0.19	0.19	0.15	0.13	86
		12	0.34	0.33	0.25	0.24	0.24	0.19	0.18	0.14	0.13	87

[a] Based on 4 in. hard brick and remainder common brick.

[b] The 8 in. and 10 in. tile figures are based on two cells in the direction of heat flow. The 12 in. tile is based on three cells in the direction of heat flow. The 16 in. tile consists of one 10 in. and one 6 in. tile each having two cells in the direction of heat flow.

[c] Limestone or sandstone.

[d] These figures may be used with sufficient accuracy for concrete walls with stucco exterior finish.

[e] Expanded slag, burned clay or pumice.

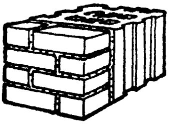
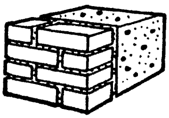
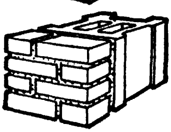
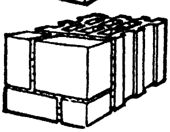
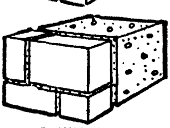
[f] Thickness of plaster assumed ¾ in.

[g] Thickness of plaster assumed ½ in.

[h] Based on 2 in. furring strips; one air space. These figures may also be used for wood or metal lath.

Table 7. Coefficients of Transmission (U) of Brick and Stone Veneer Masonry Walls

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on a wind velocity of 15 mph.

TYPICAL CONSTRUCTION	FACING	BACKING	INTERIOR FINISH (PLUS INSULATION WHERE INDICATED): Plain Walls—No Interior Finish	Plaster (½ in.) on Walls	Metal Lath and Plaster[e]—Furred	Gypsum Board (⅜ in). Decorated—Furred	Gypsum Lath (⅜ in.) Plastered[f]—Furred	Insulating Board (½ in.) Plain or Decorated—Furred	Insulating Board Lath (½ in.) Plastered[f]—Furred	Insulating Board Lath (1 in.) Plastered[f]—Furred	Gypsum Lath Plastered[f] Plus 1 in. Blanket Insulation—Furred[g]	Wall Number
			A	B	C	D	E	F	G	H	I	
	4 in. Brick Veneer[a]	6 in. Hollow Tile[b]	0.35	0.34	0.25	0.25	0.24	0.19	0.18	0.14	0.13	88
		8 in. Hollow Tile[b].	0.34	0.32	0.25	0.24	0.23	0.19	0.18	0.14	0.13	89
		6 in. Concrete.......	0.59	0.54	0.35	0.35	0.33	0.24	0.23	0.17	0.15	90
		8 in. Concrete.........	0.54	0.50	0.33	0.33	0.31	0.23	0.23	0.17	0.15	91
		8 in. Concrete Blocks[c] (Gravel Aggregate).	0.44	0.41	0.29	0.29	0.28	0.21	0.21	0.16	0.14	92
		8 in. Concrete Blocks[c] (Cinder Aggregate) .	0.34	0.33	0.25	0.24	0.24	0.19	0.18	0.14	0.13	93
		8 in. Concrete Blocks[c] (Light Weight Aggregate)[d]...... ..	0.31	0.29	0.23	0.23	0.22	0.18	0.17	0.14	0.12	94
	4 in. Cut Stone Veneer[a]	6 in. Hollow Tile[b]....	0.37	0.35	0.26	0.26	0.25	0.19	0.19	0.15	0.13	95
		8 in. Hollow Tile[b].....	0.36	0.34	0.25	0.25	0.24	0.19	0.19	0.15	0.13	96
		6 in. Concrete.........	0.63	0.58	0.37	0.36	0.34	0.25	0.24	0.18	0.15	97
		8 in. Concrete.........	0.57	0.53	0.35	0.34	0.33	0.24	0.23	0.17	0.15	98
		8 in. Concrete Blocks[c] (Gravel Aggregate)...	0.47	0.44	0.30	0.30	0.29	0.22	0.21	0.16	0.14	99
		8 in. Concrete Blocks[c] (Cinder Aggregate)..	0.36	0.34	0.25	0.25	0.24	0.19	0.19	0.15	0.13	100
		8 in. Concrete Blocks[c] (Light Weight Aggregate)[d]........	0.32	0.30	0.23	0.23	0.22	0.18	0.18	0.14	0.12	101

[a] Calculations based on ½ in. cement mortar between backing and facing except in the case of the concrete backing which is assumed to be poured in place.

[b] The hollow tile figures are based on two air cells in the direction of heat flow.

[c] Hollow concrete blocks.

[d] Expanded slag, burned clay or pumice.

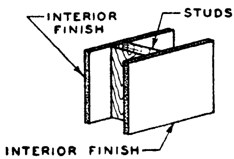
[e] Thickness of plaster assumed ¾ in.

[f] Thickness of plaster assumed ½ in.

[g] Based on 2 in. furring strips; one air space. The figures in this column may also be used for wood or metal lath.

Table 8. Coefficients of Transmission (U) of Frame Partitions or Interior Walls[a]

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on still air (no wind) conditions on both sides.

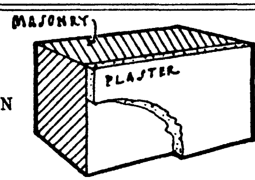


INTERIOR FINISH	SINGLE PARTITION (Finish on one side only of studs)	DOUBLE PARTITION (Finish on both sides of studs)		Partition Number
		No Insulation between Studs	1 In. Blanket between Studs. One Air Space.	
	A	B	C	
Metal Lath and Plater[b]	0.69	0.39	0.16	1
Gypsum Board (⅜ in.) Decorated	0.67	0.37	0.16	2
Wood Lath and Plaster	0.62	0.34	0.15	3
Gypsum Lath (⅜ in.) Plastered[c]	0.61	0.34	0.15	4
Plywood (⅜ in.) Plain or Decorated	0.59	0.33	0.15	5
Insulating Board (½ in.) Plain or Decorated	0.36	0.19	0.11	6
Insulating Board Lath (½ in.) Plastered[c]	0.35	0.18	0.11	7
Insulating Board Lath (1 in.) Plastered[c]	0.19	0.12	0.082	8

[a] Coefficients not weighted; effect of studding neglected.
[b] Plaster assumed ¾ in. thick.
[c] Plaster assumed ½ in. thick.
[d] For partitions with other insulations between studs refer to Table 5, using values in Column B of above table in left hand column of Table 5. *Example:* What is the coefficient of transmission (U) of a partition consisting of gypsum lath and plaster on both sides of studs with 2 in. blanket between studs? *Solution:* According to above table, this partition with no insulation between studs (No. 4B) has a coefficient of 0.34. Referring to Table 5, it will be found that a wall having a coefficient of 0.34 with no insulation between studs, will have a coefficient of 0.097 with 2 in. of blanket insulation between studs (No. 56B).

Table 9. Coefficients of Transmission (U) of Masonry Partitions

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on still air (no wind) conditions on both sides.

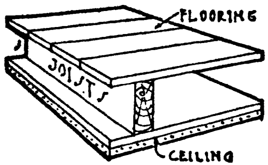


TYPE OF PARTITION		Thickness of Masonry (Inches)	TYPE OF FINISH			Partition Number
			No Finish (Plain Walls)	Plaster One Side	Plaster Both Sides[a]	
			A	B	C	
Hollow Clay Tile		3	0.50	0.47	0.43	9
		4	0.45	0.42	0.40	10
Hollow Gypsum Tile		3	0.35	0.33	0.32	11
		4	0.29	0.28	0.27	12
Hollow Concrete Tile or Blocks	Cinder Aggregate	3	0.50	0.47	0.43	13
		4	0.45	0.42	0.40	14
	Light Weight Aggregate	3	0.41	0.39	0.37	15
		4	0.36	0.34	0.32	16
Common Brick		4	0.50	0.46	0.43	17

[a] 2 in. solid plaster partition, U=0.53.
[b] Expanded slag, burned clay or pumice.

Table 10. Coefficients of Transmission (U) of Frame Construction Ceilings and Floors

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides and are based on still air (no wind) conditions on both sides.

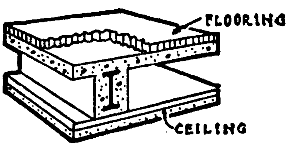


TYPE OF CEILING	INSULATION BETWEEN, OR ON TOP OF, JOISTS (NO FLOORING ABOVE)												WITH FLOORING[g] (ON TOP OF CEILING JOISTS)		NUMBER
	None	Insulating Board on Top of Joists		Blanket or Bat Insulation[f] between Joists[a]			Vermiculite Insulation between Joists			Mineral Wool Insulation between Joists			Single Wood Floor[b]	Double Wood Floor[c]	
		½ In.	1 In.	1 In.	2 In.	3 In.	2 In.	3 In.	4 In.	2 In.	3 In.	4 In.			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
No Ceiling		0.37	0.24										0.45	0.34	1
Metal Lath and Plaster[d]	0.69	0.26	0.19	0.19	0.12	0.093	0.18	0.14	0.11	0.12	0.092	0.066	0.30	0.25	2
Gypsum Board (⅜ in.) **Plain or Decorated**	0.67	0.26	0.18	0.19	0.12	0.092	0.18	0.14	0.10	0.12	0.092	0.066	0.30	0.24	3
Wood Lath and Plaster	0.62	0.25	0.18	0.19	0.12	0.092	0.17	0.14	0.10	0.12	0.091	0.065	0.29	0.24	4
Gypsum Lath (⅜ in.) **Plastered**[e]	0.61	0.25	0.18	0.19	0.12	0.092	0.17	0.14	0.10	0.12	0.091	0.065	0.28	0.24	5
Plywood (⅜ in.) **Plain or Decorated**	0.59	0.24	0.18	0.19	0.12	0.09	0.17	0.14	0.10	0.12	0.090	0.065	0.28	0.23	6
Insulating Board (½ in.) **Plain or Decorated**	0.37	0.19	0.15	0.16	0.11	0.082	0.15	0.11	0.092	0.11	0.082	0.060	0.22[h]	0.19[h]	7
Insulating Board Lath (½ in.) **Plastered**[e]	0.35	0.19	0.15	0.15	0.10	0.081	0.14	0.11	0.091	0.10	0.082	0.060	0.21	0.18	8
Insulating Board Lath (1 in.) **Plastered**[e]	0.23	0.15	0.12	0.12	0.089	0.072	0.12	0.097	0.080	0.089	0.072	0.055	0.16	0.14	9

[a] Coefficients corrected for framing.
[b] 25/32 in. yellow pine or fir.
[c] 25/32 in. pine or fir sub-flooring plus 13/16 in. hardwood finish flooring.
[d] Plaster assumed ¾ in. thick.
[e] Plaster assumed ½ in. thick.
[f] Based on insulation in contact with ceiling and consequently no air space between.
[g] For coefficients for constructions in Columns M and N (except No. 1) with insulation between joists, refer to Table 5. *Example:* The coefficient for No. 3-I of Table 10 is 0.24. With 2 in. blanket insulation between joists, the coefficient will be 0.094. (See Table 5.) (Column D of Table 5 applicable only for 3⅝ in. joists.)
[h] For 25/32 in. insulating board sheathing applied to the under side of the joists, the coefficient for *single* wood floor (Column M) is 0.18 and for *double* wood floor (Column N) is 0.16. For coefficients with insulation between joists, see Table 5.

Table 11. Coefficients of Transmission (*U*) of Concrete Construction Floors and Ceilings

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on still air (no wind) conditions on both sides.



Type of Ceiling	Thickness of Concrete[g] (Inches)	Type of Flooring: No Flooring (Concrete Bare)	Tile[a] or Terrazzo Flooring on Concrete	1/4 In. Battleship[b] Linoleum Directly on Concrete	Parquet[c] Flooring In Mastic on Concrete	Double Wood Floor on Sleepers[d]	Number
		A	B	C	D	E	
No Ceiling	3 6 10	0.69 0.59 0.50	0.65 0.56 0.48	0.45 0.41 0.36	0.45 0.41 0.36	0.25 0.23 0.22	1 2 3
1/2 in. Plaster Applied to Underside of Concrete	3 6 10	0.62 0.54 0.46	0.59 0.52 0.44	0.43 0.39 0.34	0.43 0.39 0.34	0.24 0.22 0.21	4 5 6
Metal Lath and Plaster[e]—Suspended or Furred	3 6 10	0.38 0.35 0.32	0.37 0.34 0.31	0.30 0.28 0.26	0.30 0.28 0.26	0.19 0.18 0.17	7 8 9
Gypsum Board (3/8 in.) and Plaster[f]—Suspended or Furred	3 6 10	0.36 0.33 0.30	0.35 0.32 0.29	0.28 0.27 0.24	0.28 0.27 0.24	0.19 0.18 0.17	10 11 12
Insulating Board Lath (1/2 in.) and Plaster[f] Suspended or Furred	3 6 10	0.25 0.23 0.22	0.24 0.23 0.21	0.21 0.20 0.19	0.21 0.20 0.19	0.15 0.15 0.14	13 14 15

[a] Thickness of tile assumed to be 1 in.
[b] The figures in Column C may be used with sufficient accuracy for concrete floors covered with carpet.
[c] Thickness of wood assumed to be 13/16 in.; thickness of mastic, 1/8 in. ($k = 4.5$).
[d] Based on 25/32 in. yellow pine or fir sub-flooring and 13/16 in. hardwood finish flooring with an air space between sub-floor and concrete.
[e] Thickness of plaster assumed to be 3/4 in.
[f] Thickness of plaster assumed to be 1/2 in.
[g] For other thicknesses of concrete, interpolate.

Table 12. Coefficients of Transmission (*U*) of Concrete Floors on Ground with Various Types of Finish Flooring

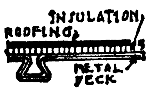
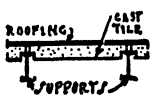
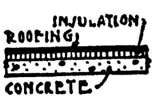
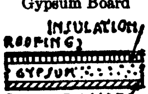
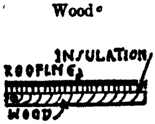
$U = 0.10^a$ Btu per hour per square foot per degree Fahrenheit temperature difference between the ground and the air over the floor.

[a] Until more complete data are available, based on tests now in progress, it is recommended that a coefficient of 0.10 be used for all types of concrete floors on the ground, with or without insulation. For basement wall below grade, use the same average coefficient (0.10). A lower ground temperature should, however, be used for walls than floors as explained in Chapter 6. For further data see A.S.H.V.E. Research Report No. 1213—Heat Loss Through Basement Walls and Floors, by F. C. Houghten, S. I. Taimuty, Carl Gutberlet and C. J. Brown (A.S.H.V.E. Transactions, Vol. 48, 1942, p. 369).

Table 13. Coefficients of Transmission (*U*) of Flat Roofs Covered with Built-up Roofing. No Ceiling—Under Side of Roof Exposed

(See Table 14 for Flat Roofs with Ceilings)

These coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on an outside wind velocity of 15 mph.

TYPE OF ROOF DECK	Thickness of Roof Deck (Inches)	No Insulation	Insulation on Top of Deck (Covered with Built-Up Roofing)							Number
			Insulating Board (Thickness Below)				Corkboard (Thickness Below)			
			½ In.	1 In.	1½ In.	2 In.	1 In.	1½ In.	2 In.	
		A	B	C	D	E	F	G	H	
Flat Metal Roof Deck[a] 		0.94	0.39	0.24	0.18	0.14	0.23	0.17	0.13	1
Precast Cement Tile 	1⅝ in.	0.84	0.37	0.24	0.18	0.14	0.22	0.16	0.13	2
Concrete 	2 in.	0.82	0.37	0.24	0.17	0.14	0.22	0.16	0.13	3
	4 in.	0.72	0.34	0.23	0.17	0.13	0.21	0.16	0.12	4
	6 in.	0.65	0.33	0.22	0.16	0.13	0.21	0.15	0.12	5
Gypsum and Wood Fiber[b] on ⅜ in. Gypsum Board 	2⅜ in.	0.40	0.25	0.18	0.14	0.12	0.17	0.13	0.11	6
	3⅜ in.	0.32	0.22	0.16	0.13	0.11	0.15	0.12	0.10	7
Wood[c] 	1 in.	0.49	0.28	0.20	0.15	0.12	0.19	0.14	0.12	8
	1½ in.	0.37	0.24	0.18	0.14	0.11	0.17	0.13	0.11	9
	2 in.	0.32	0.22	0.16	0.13	0.11	0.16	0.12	0.10	10
	3 in.	0.23	0.17	0.14	0.11	0.096	0.13	0.11	0.091	11

[a] Coefficient of transmission of bare corrugated iron (no roofing) is 1.50 Btu per hour per square foot of projected area per degree Fahrenheit difference in temperature, based on an outside wind velocity of 15 mph.

[b] 87½ per cent gypsum, 12½ per cent wood fiber. Thickness indicated includes ⅜ in. gypsum board.

[c] Nominal thicknesses specified—actual thicknesses used in calculations.

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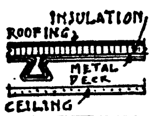
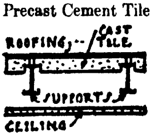
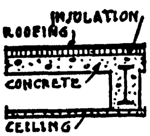
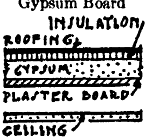
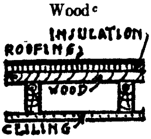
Table 14. Coefficients of Transmission (U) of Flat Roofs Covered with Built-up Roofing. With Lath and Plaster Ceilings[a]

(See Table 13 for Flat Roofs with No Ceilings)

These coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides, and are based on an outside wind velocity of 15 mph.

TYPE OF ROOF DECK	Thickness of Roof Deck (Inches)	No Insulation	Insulation on Top of Deck (Covered with Built-Up Roofing)							Number
			Insulating Board (Thickness Below)				Corkboard (Thickness Below)			
			½ In.	1 In.	1½ In.	2 In.	1 In.	1½ In.	2 In.	
		A	B	C	D	E	F	G	H	
Flat Metal Roof Deck 		0.46	0.27	0.19	0.15	0.12	0.18	0.14	0.11	12
Precast Cement Tile 	1⅝ in.	0.43	0.26	0.19	0.15	0.12	0.18	0.14	0.11	13
Concrete 	2 in.	0.42	0.26	0.19	0.15	0.12	0.18	0.14	0.11	14
	4 in.	0.40	0.25	0.18	0.14	0.12	0.17	0.13	0.11	15
	6 in.	0.37	0.24	0.18	0.14	0.11	0.17	0.13	0.11	16
Gypsum and Wood Fiber[b] on ⅜ in. Gypsum Board 	2⅜ in.	0.27	0.19	0.15	0.12	0.10	0.14	0.12	0.097	17
	3⅜ in.	0.23	0.17	0.14	0.11	0.097	0.13	0.11	0.091	18
Wood[c] 	1 in.	0.32	0.21	0.16	0.13	0.11	0.15	0.12	0.10	19
	1½ in.	0.26	0.19	0.15	0.12	0.10	0.14	0.11	0.095	20
	2 in.	0.24	0.17	0.14	0.11	0.097	0.13	0.11	0.092	21
	3 in.	0.18	0.14	0.12	0.10	0.087	0.11	0.096	0.082	22

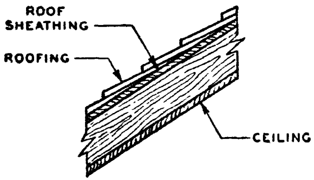
[a] Calculations based on metal lath and plaster ceilings, but coefficients may be used with sufficient accuracy for gypsum lath or wood lath and plaster ceilings. It is assumed that there is an air space between the under side of the roof deck and the upper side of the ceiling.

[b] 87½ per cent gypsum, 12½ per cent wood fiber. Thickness indicated includes ⅜ in. gypsum board.

[c] Nominal thicknesses specified—actual thicknesses used in calculations.

Table 15. Coefficients of Transmission (U) of Pitched Roofs

Coefficients are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides and are based on a wind velocity of 15 mph.



TYPE OF CEILING (APPLIED DIRECTLY TO ROOF RAFTERS)	WOOD SHINGLES (ON 1 x 4 WOOD STRIPS[c] SPACED 2 IN. APART)				ASPHALT SHINGLES OR ROLL ROOFING (ON SOLID WOOD SHEATHING)[c]				SLATE OR TILE[b] (ON SOLID WOOD SHEATHING)[c]				Number
	INSULATION BETWEEN RAFTERS				INSULATION BETWEEN RAFTERS				INSULATION BETWEEN RAFTERS				
	None	Blanket or Bat (Thickness Below)			None	Blanket or Bat (Thickness Below)			None	Blanket or Bat (Thickness Below)			
		1 In.	2 In.	3 In.		1 In.	2 In.	3 In.		1 In.	2 In.	3 In.	
	A	B	C[a]	D[a]	E	F	G[a]	H[a]	I	J	K[a]	L[a]	
No Ceiling Applied to Rafters	0.48[f]	0.15	0.11	0.083	0.53[f]	0.15	0.11	0.085	0.55[f]	0.16	0.11	0.085	1
Metal Lath and Plaster[d]	0.31	0.14	0.10	0.082	0.33	0.15	0.10	0.083	0.34	0.15	0.11	0.083	2
Gypsum Board (⅜ in.) **Decorated**	0.31	0.14	0.10	0.082	0.32	0.15	0.10	0.082	0.34	0.15	0.11	0.083	3
Wood Lath and Plaster	0.30	0.14	0.10	0.080	0.31	0.14	0.10	0.082	0.32	0.15	0.10	0.082	4
Gypsum Lath (⅜ in.) **Plastered**[e]	0.29	0.14	0.10	0.080	0.31	0.14	0.10	0.082	0.32	0.15	0.10	0.082	5
Plywood (⅜ in.) **Plain or Decorated**	0.29	0.14	0.10	0.080	0.30	0.14	0.10	0.080	0.31	0.14	0.10	0.082	6
Insulating Board (½ in.) **Plain or Decorated**	0.22	0.12	0.090	0.073	0.23	0.12	0.093	0.074	0.24	0.13	0.094	0.076	7
Insulating Board Lath (½ in.) **Plastered**[e]	0.22	0.12	0.090	0.073	0.22	0.12	0.090	0.073	0.23	0.12	0.093	0.074	8
Insulating Board Lath (1 in.) **Plastered**[e]	0.16	0.10	0.077	0.065	0.17	0.10	0.077	0.065	0.17	0.10	0.080	0.066	9

[a] Coefficients corrected for framing.
[b] Figures in Columns I, J, K and L may be used with sufficient accuracy for rigid asbestos shingles on wood sheathing. Layer of slater's felt neglected.
[c] Sheathing and wood strips assumed 25/32 in. thick.
[d] Plaster assumed ¾ in. thick.
[e] Plaster assumed ½ in. thick.
[f] No air space included in 1-A, 1-E or 1-I; all other coefficients based on one air space.

Table 16. Combined Coefficients of Transmission (U) of Pitched Roofs[a] and Horizontal Ceilings—Based on Ceiling Area[b]

Coefficients are expressed in Btu per hour per square foot of ceiling area per degree Fahrenheit difference in temperature between the air on the two sides, and are based on a wind velocity of 15 mph.

CEILING COEFFICIENT[f] (FROM TABLE 10)	TYPE OF ROOFING AND ROOF SHEATHING						Number
	WOOD SHINGLES ON WOOD STRIPS[d]			ASPHALT SHINGLES[c] OR ROLL ROOFING ON WOOD SHEATHING[e]			
	No Roof Insulation (Rafters Exposed) (U_r=0.48)	½ In. Insulating Board on Under Side of Rafters (U_r=0.22)	1 In. Insulating Board on Under Side of Rafters (U_r=0.16)	No Roof Insulation (Rafters Exposed) (U_r=0.53)	½ In. Insulating Board on Under Side of Rafters (U_r=0.23)	1 In. Insulating Board on Under Side of Rafters (U_r=0.17)	
	A	B	C	D	E	F	
0.10	0.085	0.073	0.066	0.087	0.074	0.067	19
0.11	0.093	0.078	0.07	0.094	0.079	0.071	20
0.12	0.099	0.082	0.074	0.10	0.083	0.075	21
0.13	0.10	0.087	0.077	0.11	0.088	0.079	22
0.14	0.11	0.092	0.080	0.11	0.093	0.083	23
0.15	0.12	0.096	0.084	0.12	0.097	0.086	24
0.16	0.12	0.10	0.087	0.13	0.10	0.089	25
0.17	0.13	0.10	0.090	0.13	0.10	0.092	26
0.18	0.13	0.11	0.093	0.14	0.11	0.095	27
0.19	0.14	0.11	0.096	0.15	0.11	0.098	28
0.20	0.15	0.11	0.098	0.15	0.12	0.10	29
0.21	0.15	0.12	0.10	0.16	0.12	0.10	30
0.22	0.16	0.12	0.10	0.17	0.12	0.11	31
0.23	0.17	0.12	0.10	0.17	0.12	0.11	32
0.24	0.17	0.13	0.11	0.18	0.12	0.11	33
0.25	0.17	0.13	0.11	0.18	0.13	0.11	34
0.26	0.18	0.13	0.11	0.19	0.13	0.11	35
0.27	0.18	0.13	0.11	0.19	0.13	0.12	36
0.28	0.19	0.14	0.11	0.19	0.14	0.12	37
0.29	0.19	0.14	0.12	0.20	0.14	0.12	38
0.30	0.20	0.14	0.12	0.20	0.14	0.12	39
0.34	0.21	0.15	0.12	0.22	0.15	0.13	40
0.35	0.21	0.15	0.12	0.22	0.15	0.13	41
0.36	0.22	0.15	0.12	0.23	0.15	0.13	42
0.37	0.22	0.15	0.13	0.23	0.16	0.13	43
0.45	0.25	0.17	0.13	0.26	0.17	0.14	44
0.59	0.29	0.18	0.14	0.30	0.19	0.15	45
0.61	0.29	0.18	0.14	0.31	0.19	0.15	46
0.62	0.30	0.18	0.15	0.31	0.19	0.15	47
0.67	0.31	0.19	0.15	0.33	0.20	0.16	48
0.69	0.31	0.19	0.15	0.33	0.20	0.16	49

[a] Calculations based on ⅙ pitch roof (n=1.2) using the following formula:

$$U = \frac{U_r \times U_{ce}}{U_r + \frac{U_{ce}}{n}}$$

U = combined coefficient to be used with ceiling area.
U_r = coefficient of transmission of the roof.
U_{ce} = coefficient of transmission of the ceiling.
n = the ratio of the area of the roof to the area of the ceiling.

[b] Use ceiling area (not roof area) with these coefficients.

[c] Coefficients in Columns D, E and F may be used with sufficient accuracy for tile, slate and rigid asbestos shingles on wood sheathing.

[d] Based on 1x4 in. strips spaced 2 in. apart.

[e] Sheathing assumed 25/32 in. thick.

[f] Values of U_{ce} to be used in this column may be selected from Table 10.

Table 17. Coefficients of Transmission (U) of Doors, Windows, Skylights and Glass Block Walls

Coefficients are based on a wind velocity of 15 mph, and are expressed in Btu per hour per square foot per degree Fahrenheit difference in temperature between the air inside and outside of the door, window, skylight or wall

Section A. Windows and Skylights		Single	Double	Triple
	U	1.13[a,c]	0.45[a,e]	0.281[a,e]

Section B. Solid Wood Doors[b,c]	Nominal Thickness Inches	Actual Thickness Inches	U Exposed Door	U[d] With Glass Storm Door
	1	25/32	0.69	0.42
	1¼	1 1/16	0.59	0.38
	1½	1 5/16	0.52	0.35
	1¾	1⅜	0.51	0.35
	2	1⅝	0.46	0.32
	2½	2⅛	0.38	0.28
	3	2⅝	0.33	0.25

Section C. Hollow Glass Block Walls	Description	U Still Air Both Sides	U Still Air Inside 15 mph Outside
	Smooth surface glass blocks 7¾ x 7¾ x 3⅞ in. thick.	0.40	0.49
	Ribbed surface glass blocks 7¾ x 7¾ x 3⅞ in. thick.	0.38	0.46

[a] See Heating, Ventilating and Air Conditioning, by Harding and Willard, revised edition, 1932.
[b] Computed using $C = 1.15$ for wood; $f_i = 1.65$ and $f_o = 6.0$.
[c] It is sufficiently accurate to use the same coefficient of transmission for doors containing thin wood panels as that of single panes of glass, namely, 1.13 Btu per hour per square foot per degree difference between inside and outside air temperatures.
[d] These values may also be used with sufficient accuracy for wood storm doors. Neglect storm doors if loose and use values for exposed doors.
[e] Air spaces assumed to be ¾ in. or more in width.

being 4 in. The conductivity of the plaster is assumed to be 3.3, and the inside and outside surface coefficients are assumed to average 1.65 and 6.00, respectively, for still air and a 15 mph wind velocity.

Solution. k (hard high density brick) $= 9.20$; $x = 4.0$ in.; k (common low density brick) $= 5.0$; $x = 4.0$ in.; k (plaster) $= 3.3$; $x = \frac{1}{2}$ in.; $f_i = 1.65$; $f_o = 6.0$. Therefore,

$$U = \frac{1}{\dfrac{1}{6.0} + \dfrac{4.0}{9.20} + \dfrac{4.0}{5.0} + \dfrac{0.5}{3.3} + \dfrac{1}{1.65}}$$

$$= \frac{1}{0.167 + 0.435 + 0.80 + 0.152 + 0.606}$$

=0.46 Btu per hour per square foot per degree Fahrenheit difference in temperature between the air on the two sides.

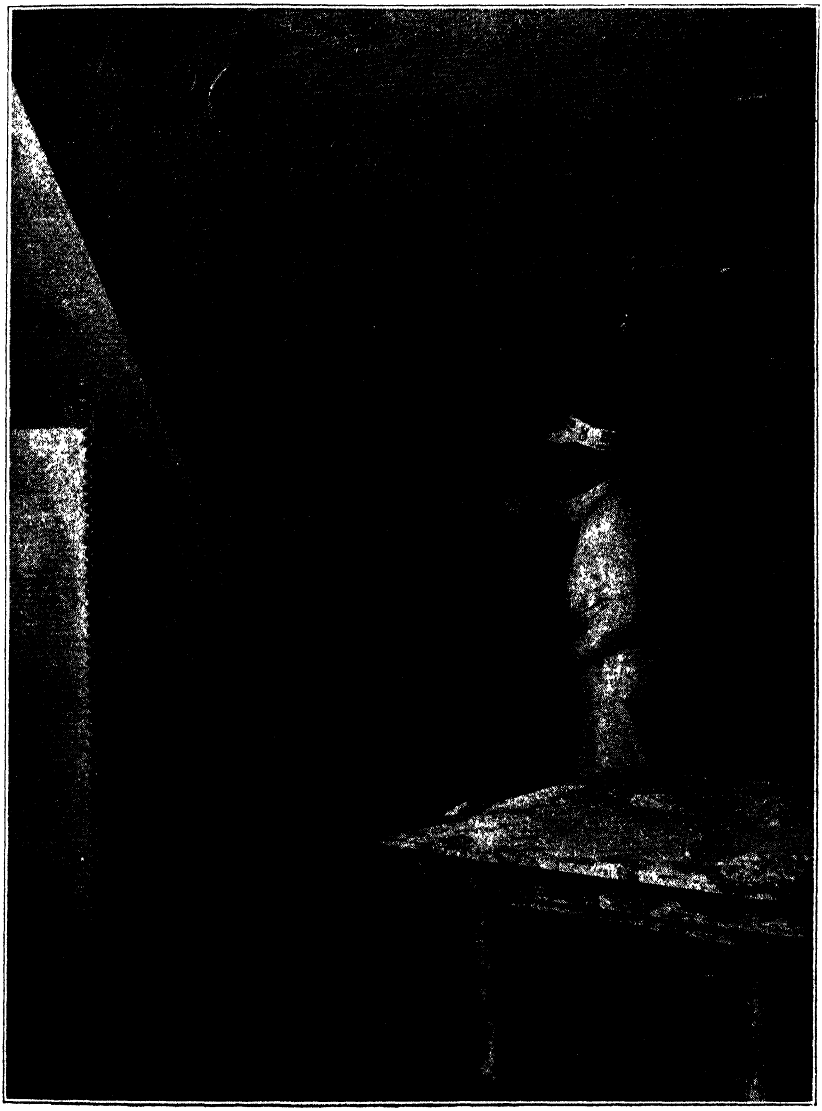
The thicknesses used for computing the coefficients in Tables 4 to 16 inclusive, were as follows:

Material	Thickness Inches
Brick veneer	4
Plaster on metal lath	¾
Plaster on gypsum lath or structural insulating board	½
Slate for roofing	½
Stucco	1
1-inch lumber (S2S)	25/32
1½ inch lumber (S2S)	1 5/16
2-inch lumber (S2S)	1⅝
3-inch lumber (S2S)	2⅝
4-inch lumber (S2S)	3⅝
Hardwood flooring (maple or oak)	13/16

Note that actual thicknesses of lumber were used in the calculations rather than nominal thicknesses. In accordance with customary practice, single thicknesses of building paper were neglected except where the conductance values used include building paper, such as 1-inch fir sheathing, building paper and lap siding for which the conductance is 0.50. Building paper is used primarily as a wind stop and the internal resistance of this material is almost nil.

In practice, the heat-resisting value of wood shingles and in some cases wood siding, is doubtful because of the cracks between boards which frequently allow the passage of air. This fact, however, is not usually taken into consideration in deriving theoretical heat-transfer coefficients of siding or shingle exterior walls or of shingle roofs of any type. In the case of poor construction the siding or shingles should be neglected in determining the coefficients of transmission of constructions involving these materials.

In computing these coefficients, solid brick walls were assumed to consist of 4-inch face brick and the remainder of common brick. Stucco was assumed to be 1 inch thick on masonry walls. Where metal lath and plaster are specified, the metal lath is neglected. There are many varieties of Spanish and French clay roofing tile, and since no reliable data are available pertaining to these products, roofs of this type were assumed to have the same heat-transmission coefficients as slate roofs. In cases where the tile are applied in such a manner as to permit air circulation underneath them, these tile



APPLICATION OF PLASTER TO INSULATING BOARD LATH

Courtesy of The Insulite Co., Minneapolis, Minn.

INSULATING BOARD USED IN PLACE OF WOOD SHEATHING
Courtesy of Dant & Russell, Inc., Portland, Ore.

should be neglected. Single plies of roofing felt used under slate and tile roofs were neglected in the calculations in accordance with customary practice, because of the negligible resistance of this material. The coefficient of transmission in Table 17 for single glass of 1.13 (resistance = 0.885) is equivalent to an outside surface resistance of 0.20, based on a wind velocity of 15 m.p.h., and inside (still air) surface resistance of 0.66 and an internal resistance of the glass of 0.025. The internal resistance of 0.025 is equivalent to that for a ⅛-inch thickness of glass having a conductivity (k) of 5.0.

Weighted Coefficients. The standard frame wall consists of 2x4 studding, usually on 16-inch centers, with the sheathing and exterior finish applied to the outside face of the studding and the interior finish applied to the inside face. The framing comprises about 15 per cent of the average wall and the area between framing about 85 per cent. In many cases the rate of heat flow through the 3⅝-inch wood studding and the materials on both sides thereof will be considerably different from that through the area between the studding, which may consist of an air space, instead of the 3⅝ inches of wood plus the enclosing materials. In most instances, the

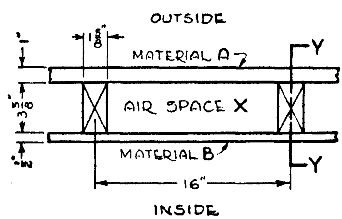


Fig. 6. Section through Typical Frame Wall

effect of the framing is neglected since as stated above it comprises only about 15 per cent of the total wall area. The coefficient of transmission through the wall is thus calculated as though there were no studding. If the effect of the studding is considered, the "weighted" coefficient may be calculated as shown in the following example.

Example 5. Consider a wall such as that shown in Fig. 6 consisting of material A on the outside of the studs and material B on the inside of the studs which are on 16-in. centers. Material A is 1-in. thick and is assumed to have a conductivity of 0.50. Material B is ½-in. thick and has a conductivity of 0.30.

Solution. The coefficient of transmission (U_x) through the materials in the area *between the studs* will be:

$$U_x = \cfrac{1}{\underset{\text{(Inside surface)}}{\frac{1}{1.65}} + \underset{\text{(Material } B)}{\frac{0.50}{0.30}} + \underset{\text{(Air space)}}{\frac{1}{1.10}} + \underset{\text{(Material } A)}{\frac{1}{0.50}} + \underset{\text{(Outside surface)}}{\frac{1}{6.00}}}$$

$$= \frac{1}{0.61 + 1.67 + 0.91 + 2.0 + 0.17}$$

$$= \frac{1}{5.36}$$

$$= 0.187$$

The coefficient of transmission (U_y) through the section in which the studding is located, based on a conductivity of the wood of 0.80, will be as follows:

$$U_y = \cfrac{1}{\underset{\text{(Inside surface)}}{\frac{1}{1.65}} + \underset{\text{(Material } B)}{\frac{0.50}{0.30}} + \underset{\text{(Studding)}}{\frac{3.625}{0.80}} + \underset{\text{(Material } A)}{\frac{1}{0.50}} + \underset{\text{(Outside surface)}}{\frac{1}{6.00}}}$$

$$= \frac{1}{0.61 + 1.67 + 4.53 + 2.0 + 0.17}$$

$$= \frac{1}{8.98}$$

$$= 0.11$$

To get the weighted or average coefficient of the wall, add 85 per cent of U_x to 15 per cent of U_y or

$$U = 0.85 \times 0.187 + 0.15 \times 0.11$$

$$= 0.176$$

The weighted or average coefficient, carried to three places is in this case about 5.9 per cent *lower* than the wall coefficient would be if the effect of the studs were neglected. If the air space is filled with an insulating material, the effect of the studs and other framing members is to *increase* the average rate of heat flow. For example, a frame wall containing 3⅝″ of insulation (conductivity 0.27) and having an assumed value of 0.065 between the framing would with this amount of insulation have an average coefficient of 0.0784 based on 15 per cent wood framing. Thus the framing *increases* the heat flow through the wall to the extent of 20.6 per cent in this case.

The majority of hollow frame walls range in value from 0.15 to 0.30 and the correction for these walls (based on 15 per cent framing) will range between about 5 and 8 per cent. However, this correction is comparatively small and may be neglected since to do so would be on the side of safety. On the other hand, the correction for walls containing more than 1 inch of insulation between the studs may be of somewhat greater magnitude and is in the opposite direction and particularly for the latter reason, the correction should be

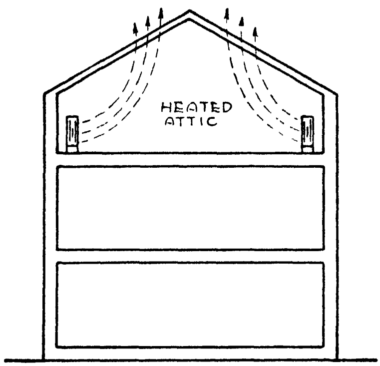


Fig. 7. Section through Building Showing Heated Attic: Heat Flow through Roof Structure; No Heat Flow through Top Floor Ceiling

made. The coefficients for frame construction in Tables 4 to 16 inclusive were corrected for the effect of the framing where such correction would increase the coefficients, but not where the correction would decrease the coefficient.*

Parallel and Series Heat Flow. Referring again to Fig. 6, materials *A* and *B* and the air space in Section *X* (the wall area between studs) are said to be in series heat flow. Similarly materials *A* and *B* and the studding in Section *Y* (the wall area through the studs) are likewise in series. These two sections, *X* and *Y*, however, are in parallel heat flow.

Upward and Downward Heat Flow. As stated before, the direction of heat flow through horizontal and inclined surfaces whether upward or downward has an important bearing on the air space coefficient, particularly when the surfaces are bounded by reflective

*For a further discussion of this subject, see "Effect of Studs and Joists on Heat Flow through Frame Walls and Ceilings," by Paul D. Close (Heating, Piping & Air Conditioning, October, 1943, page 529).

materials, as will be apparent from a study of Fig. 1. The coefficients in Tables 10 and 16 are for ordinary nonreflective surfaces and are based on upward heat flow through the structure and therefore are intended for use for calculating winter heat losses. For air spaces bounded by ordinary building materials the error resulting from the use of a value of 1.10 for either upward or downward heat flow will be small, but for surfaces bounded by reflective materials there may be an appreciable error resulting from the use of a single air-space

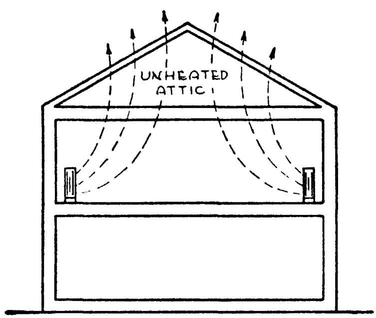


Fig. 8. Section through Building Showing Unheated Attic: Heat Flow through Top Floor Ceiling as Well as through Roof Structure

value for both upward and downward heat flow. Therefore, for constructions involving reflective insulations, the coefficients should be separately calculated using the proper conductance value obtained from Fig. 1 for the temperature difference involved and for upward or downward heat flow.

Heated and Unheated Attics. For heated attics under pitched roofs the coefficients given in Table 15 may be applied directly. See Fig. 7. If the attic is unheated, then the attic floor and the top floor ceiling as well as the roof of the building must be taken into consideration inasmuch as the heat must pass through both of these parts of the house to escape to the outdoors. See Fig. 8.

If the ceiling is parallel with the roof, as in the case of flat roofs covered with built-up roofing, Table 14, the combined coefficient of the roof and top floor ceiling may readily be determined by means of either Formula (3) or (4) in this chapter, depending upon the number of air spaces and materials entering into the construction. In the case of pitched roofs, the top floor ceiling including the attic floor is not parallel with the roof and consequently a special formula must be used to determine the combined coefficient of transmission. The formula for the combined coefficient of transmission of a pitched roof, an attic and a horizontal ceiling, *based on the roof area,* is as follows:

$$U_{rc} = \frac{U_r \times U_c}{nU_r + U_c} \tag{7}$$

where

U_{rc} = combined coefficient of transmission of roof and top floor ceiling, including attic floor and attic space, per square foot of *roof area.* (Multiply by roof area. See *Attic Temperature,* under Calculating Heat Losses.)

U_r = coefficient of transmission of roof.

U_c = coefficient of transmission of top floor ceiling, including attic floor, if any.

n = ratio of area of the roof to the area of the ceiling, Table 18.

In using this formula, it is sufficiently accurate in most cases to select the ceiling and roof coefficients from Tables 10 and 15 respectively. This procedure, however, is not strictly correct. Where maximum accuracy is desired the ceiling and roof coefficients should be recalculated, using the proper surface conductances from Table C for the surfaces enclosing the attic space and for the under surface of the ceiling. The surface conductance to use for the roof is 6.0, the average value for a 15 m.p.h. wind velocity.

Table 18. Values of *n* for Roofs of Various Pitches

Roof Pitch	Angle of Rise	Rise per Ft.	Area of Roof per 100 Sq. Ft. of Ceiling	*n*
¼	26°34′	6″	113.0	1.13
⅓	33°41′	8″	120.0	1.2
½	45°	12″	144.0	1.4
⅔	53° 8′	16″	166.8	1.7
1	63°27′	24″	223.4	2.2

Although the surface conductances in Table C are for emissivities of 0.83 and 0.05, it is sufficiently accurate to use the 0.83 emissivity conductances in this table for all ordinary building material surfaces, in recalculating the coefficients to be used in Formula (7). The 0.05 emissivity surface conductances in Table C may be used for reflective surfaces of this value, using the proper conductance for upward or downward heat flow.

Example 6. Calculate the combined coefficient of transmission (U_{rc}) of a one-third pitch roof consisting of asphalt shingles on wood sheathing, an unheated attic, and a top floor ceiling of wood lath and plaster based on upward heat flow (winter).

Solution. The value of n for a one-third pitch roof, according to Table 18 is 1.2. The ceiling and roof coefficients must be calculated separately, making the correction referred to above, that is, using a surface conductance of 1.95 from Table C for the surfaces enclosing the unheated attic. The roof coefficient (U_r) is therefore determined as follows, for a wind exposure of 15 m.p.h.

$$U_r = \frac{1}{\underset{\text{(Outside surface)}}{\frac{1}{6.00}} + \underset{\text{(Asphalt shingles)}}{\frac{1}{6.50}} + \underset{\text{(Roof sheathing)}}{\frac{0.781}{0.80}} + \underset{\text{(Under surface)}}{\frac{1}{1.95}}}$$

$$= \frac{1}{0.17 + 0.15 + 0.98 + 0.51}$$

$$= \frac{1}{1.81}$$

$$= 0.55$$

The ceiling coefficient is determined as follows:

$$U_c = \frac{1}{\underset{\text{(Upper surface)}}{\frac{1}{1.95}} + \underset{\text{(Wood lath and plaster)}}{\frac{1}{2.50}} + \underset{\text{(Under surface)}}{\frac{1}{1.95}}}$$

$$= \frac{1}{0.51 + 0.40 + 0.51}$$

$$= \frac{1}{1.42}$$

$$= 0.70$$

The combined coefficient of transmission of the ceiling, unheated attic and roof, based on the roof area, is as follows, using Formula (7):

$$U_{rc} = \frac{0.55 \times 0.70}{1.2 \times 0.55 + 0.70}$$

$$= \frac{0.385}{1.36}$$

$$= 0.283$$

This coefficient should be used in connection with the roof area and *not* the ceiling area. The formula for the coefficient of transmission expressed in terms of the *ceiling area* is given at the bottom of Table 16 in footnote *a*. The combined coefficients given in Table 16 are based on this formula and should always be used in conjunction with the ceiling area.

It is important to note that the formulas for determining the combined coefficient apply specifically to unheated attics under pitched roofs or without vertical wall surfaces, dormers or windows. If the unheated attic contains an excessive amount of vertical wall surfaces, dormers or windows, the procedure is to calculate or estimate the temperature in the attic space and then to calculate the heat loss through the ceiling in accordance with data in the chapter on Calculating Heat Losses. The formula for calculating the temperature in an unheated attic having vertical wall surface or dormers, based on specified inside and outside temperatures is given under the heading *Unheated Attics* in the same chapter.

Ventilated Attics, Coefficients to Use. Attic ventilation is intended to serve two purposes, first to permit the escape of accumulated heat in the summer and second, to prevent condensation on the underside of the roof in the winter, which condensation will drop onto the attic floor or the top of the ceiling below, if the attic is not floored.

The question arises as to the proper coefficient to use in arriving at the heat loss through vented or ventilated attics. The effect of attic ventilation is partially to nullify the heat resistance of the roof by lowering the attic temperature, but usually it is difficult to evaluate this effect with accuracy. Even if the exact amount of ventilation were known, it would be difficult to express the effect of this ventilation in terms of the effect upon the roof coefficient.

If, however, the attic temperature is known, it is only necessary to ascertain the ceiling coefficient from the tables in this chapter, and then multiply this coefficient by the temperature difference on the two sides of the ceiling, and by the ceiling area, to get the heat loss. The normal attic temperature without ventilation (disregarding the effect of the absorption by the roof of solar radiation) will range somewhere between the outside temperature and the attic temperature as calculated by means of Formula (3) of the next chapter.

The attic temperature without ventilation will depend on the ceiling and roof coefficients, the *lower* the ceiling coefficient and the *higher* the roof coefficient, the *lower* the attic temperature and the more nearly will it approach the outside temperature, disregarding the absorption by the roof of solar radiation. Conversely, the *higher* the ceiling coefficient and the *lower* the roof coefficient, the *higher* the attic temperature and the more nearly will the attic temperature approach the room temperature. As previously stated, the attic temperature without ventilation can be estimated, using Formula (**3**).

The degree to which the attic temperature is reduced by ventilation depends, of course, on the amount of ventilation, and this in turn depends on whether the ventilation is mechanical or natural. Mechanical ventilation is seldom used for ventilating attics in winter, but rather is confined largely to summer use. The amount of natural ventilation depends on the size and location of the openings and on wind velocity. Stack effect also may influence attic ventilation.

Data on the effect of natural and mechanical ventilation on attic temperatures will be found in the chapter on Fuel Saving under the heading, Estimated Fuel Saving with Ventilated Attics. From these data it will be apparent that venting or ventilation generally does not greatly reduce the attic temperature.

More often, instead of attempting to arrive at the ceiling heat loss by estimating the ventilated attic temperature, it is the practice either (1) to disregard the attic ventilation and to allow the full value of the roof, or (2) to disregard the roof entirely and to assume the attic temperature to be the same as the outside temperature, using *only* the ceiling coefficient in the calculations. The method to be employed would, of course, depend on which would result in the least error and this in turn would depend on the extent or effectiveness of the ventilation. However, in most cases, the first procedure would involve the least error. According to the data in the chapter on Fuel Saving, ordinary venting of the attic may have only a negligible effect on the attic temperature, in which case the full value of the roof may be taken into consideration without appreciable error. Moreover, where attic ventilation is intended mainly to exhaust summer heat and is not needed to prevent attic condensation (as explained in the chapter on Condensation), the ventilators may be sealed or closed in the winter so as to eliminate entirely the heat loss from this source.

CHAPTER VI

CALCULATING HEAT LOSSES

The heating plant must be of sufficient size or capacity to maintain the desired inside temperature during the coldest weather likely to be encountered in the locality of the building. Therefore, in order to select the heating plant, including all of the appurtenances thereof, an estimate must be made of the heat losses of the building during such extreme periods of cold weather; in other words, the heat losses must be calculated. These heat losses are calculated on a one-hour basis.

How Does Heat Escape? Obviously, to maintain the desired inside temperature heat must be supplied continuously, so long as it is colder outdoors. The heat supplied escapes to the outdoors in two ways, namely, (1) by *transmission* through parts of the structure which separate heated spaces from the outside air or from unheated colder spaces within the building, and (2) by air leakage or *infiltration* through cracks and crevices, through open doors and windows, and through fireplace chimneys. Under extreme conditions, air leakage also takes place directly through poorly constructed, porous walls. The air leakage through plastered walls, however, is negligible.

The calculation of the heat losses of a building is not an exact science because of the many factors involved which can only be approximated. The infiltration losses are particularly difficult to estimate with accuracy. Therefore, the calculated results should be regarded as an *estimate* of the probable heat losses under the conditions assumed.

TRANSMISSION LOSSES

Heat is lost by transmission through five parts of a building, as follows:

1. Outside walls.
2. Inside walls or partitions next to unheated spaces.

3. Ceilings of upper floors, either below a cold attic space or as the under side of a roof.

4. Floors of heated rooms above unheated spaces.

5. Outside glass.

Calculating Transmission Losses. The transmission losses are calculated by multiplying the area (A) by the proper coefficient (U) for such construction or material and by the temperature difference ($t-t_o$) between the two sides of the construction. This result is obtained by the following equation:

$$H_t = AU(t-t_o) \quad (1)$$

where

H_t = Heat transmitted through the materials of the wall, roof, floor or glass, in B.t.u. per hour.

A = Area of surface, in square feet (use inside room dimensions).

t = Room temperature, degrees Fahrenheit.

t_o = Outside temperature, degrees Fahrenheit.

U = Over-all coefficient of transmission, or the amount of heat transmitted in one hour per square foot of surface (wall, roof, floor or glass) for a temperature difference of one degree between the air on the inside and that on the outside. (See chapter on Transmission Coefficients and Tables.)

The heat transmitted through each surface is calculated separately and the total transmission loss for each room or space is equal to the sum of the individual transmission losses through each surface of the room or space. Such transmission losses are of course calculated for exterior surfaces or for surfaces adjacent to unheated spaces.

Example 1. Calculate the transmission heat loss per hour through an uninsulated 12-inch brick wall having a net area (exclusive of glass) of 1,000 square feet, based on an inside temperature of 70° and an outside temperature of zero.

Solution. The over-all coefficient of transmission (U) of a solid 12-inch brick wall (plain) is 0.35 (See Table 6, Transmission Coefficients and Tables). Therefore $U=0.35$; $A=1{,}000$; $t=70$ and $t_o=0$. Substituting these values in Formula (1),

$$H_t = 1{,}000 \times 0.35 \times (70-0)$$
$$= 24{,}500 \text{ B.t.u. per hour.}$$

Therefore the transmission loss (H_t) through this wall would be 24,500 B.t.u. per hour for an inside temperature of 70°F. and an outside temperature of zero. The transmission losses through the glass, ceiling (or roof) would be calculated in a similar manner and added to the wall transmission losses to obtain the total transmission losses.

INFILTRATION LOSSES

Every cubic foot of warm air lost through the cracks of a building by exfiltration is replaced by a cubic foot of outside cold air entering elsewhere by infiltration. The infiltration heat losses are determined by first estimating the volume of air in cubic feet which will enter the room or building by infiltration in a given period of time (usually one hour), and then calculating the amount of heat required to raise the temperature of this outdoor air to the inside temperature. The formula for estimating the heat required to warm the cold outside air which enters a room by infiltration to the temperature of the room is given by the following equation:

$$H_i = 0.018Q(t - t_o) = \frac{Q(t - t_o)}{55.6} \qquad (2)$$

where

H_i = B.t.u. per hour required for heating air leaking into building from outside temperature (t_o) to inside temperature (t).

0.018 is obtained by multiplying the specific heat of air (0.24) by the density of air at 70°F. which is 0.075 pounds per cubic foot.

Q = Cubic feet of air entering per hour.

Example 2. The estimated air leakage or infiltration (Q) for a certain room is 1100 cubic feet per hour. Calculate the amount of heat (H_i) required to raise the temperature of this air from 0° to 70°.

Solution. Substituting these values in Formula (2):

$$H_i = 0.018(70 - 0)1100$$
$$= 1386 \text{ B.t.u. per hour.}$$

Estimating Air Leakage. Using formula (2), it is necessary in each case to estimate the volume of air in cubic feet (Q) entering each room or space involved. There are two methods of estimating the volume of air infiltration; namely, (1) *the crack method* and (2) *the air-change method.*

Crack Method. In using the crack method, which is the more accurate, the type of windows and doors, width of crack, weather-stripping, storm sash and the wind velocity must be taken into consideration. Air leakage values for various types of windows and for various wind velocities are given in Table 1. The fit of double-hung wood windows is determined by crack and clearance. The crack thickness (*C*, Fig. 1) is one-half the difference between the inside window frame dimension (*D*) and the outside sash width (*E*). The difference between the width of the window frame guide (*A*)

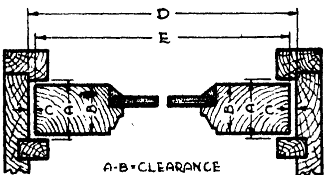


Fig. 1. Diagram Illustrating Crack and Clearance

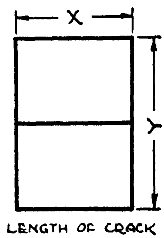


Fig. 2. Double-Hung Window, Length of Crack

and the sash thickness (*B*) is considered as the clearance. The length of the crack for a double-hung window is equal to three times the width plus two times the height, or in other words, it is the outer sash perimeter length plus the meeting rail length. Fig. 2.

The procedure to be followed in estimating the air leakage by the crack method is first to determine the average wind velocity from Table 2 and then from Table 1 to ascertain the leakage per foot of crack for the type of window or door under consideration. For example, if the average wind velocity is 15 m.p.h. and the windows are double-hung metal, the air leakage, according to Table 1, will be 70 cubic feet per hour per foot of crack, assuming non-weather-stripped, locked windows. If the average wind velocity were some value between any two wind-velocity figures in this table, it would be necessary to interpolate, that is, to calculate the leakage from the values given for the nearest two figures in the column at the top of Table 1. For example, if the average wind velocity were 12 m.p.h. and the same type of window were under consideration, the air leakage would be between the 10 and 15 m.p.h. values. The 10

Table 1. Infiltration through Windows

Expressed in Cubic Feet per Foot of Crack per Hour[a]

Type of Window	Remarks	Wind Velocity, Miles per Hour					
		5	10	15	20	25	30
Double-Hung Wood Sash Windows (Unlocked)	Around frame in masonry wall—not calked[b]	3.3	8.2	14.0	20.2	27.2	34.6
	Around frame in masonry wall—calked[b]	0.5	1.5	2.6	3.8	4.8	5.8
	Around frame in wood frame construction[b]	2.2	6.2	10.8	16.6	23.0	30.3
	Total for average window, non-weatherstripped, 1/16-in. crack and 3/64-in. clearance.[c] Includes wood frame leakage[d]	6.6	21.4	39.3	59.3	80.0	103.7
	Ditto, weatherstripped[d]	4.3	13.0	23.6	35.5	48.6	63.4
	Total for poorly fitted window, non-weatherstripped, 3/32-in. crack and 3/32-in. clearance.[e] Includes wood frame leakage[d]	26.9	69.0	110.5	153.9	199.2	249.4
	Ditto, weatherstripped[d]	5.9	18.9	34.1	51.4	70.5	91.5
Double-Hung Metal Windows[f]	Non-weatherstripped, locked	20	45	70	96	125	154
	Non-weatherstripped, unlocked	20	47	74	104	137	170
	Weatherstripped, unlocked	6	19	32	46	60	76
Rolled Section Steel Sash Windows[k]	Industrial pivoted, 1/16-in. crack[g]	52	108	176	244	304	372
	Architectural projected, 1/32-in. crack[h]	15	36	62	86	112	139
	Architectural projected, 3/64-in. crack[h]	20	52	88	116	152	182
	Residential casement, 1/64-in. crack[i]	6	18	33	47	60	74
	Residential casement, 1/32-in. crack[i]	14	32	52	76	100	128
	Heavy casement section, projected, 1/64-in. crack[j]	3	10	18	26	36	48
	Heavy casement section, projected 1/32-in. crack[j]	8	24	38	54	72	92
Hollow Metal, vertically pivoted window[f]		30	88	145	186	221	242

[a]The values given in this table, with the exception of those for double-hung and hollow metal windows, are 20 per cent less than test values to allow for building up of pressure in rooms, and are based on test data reported in the papers listed in the *Heating, Ventilating and Air Conditioning Guide, 1944*.

[b]The values given for frame leakage are per foot of sash perimeter as determined for double-hung wood windows. Some of the frame leakage in masonry walls originates in the brick wall itself and cannot be prevented by calking. For the additional reason that calking is not done perfectly and deteriorates with time, it is considered advisable to choose the masonry frame leakage values for calked frames as the average determined by the calked and not-calked tests.

[c]The fit of the average double-hung wood window was determined as 1/16-in. crack and 3/64-in. clearance by measurements on approximately 600 windows under heating season conditions.

[d]The values given are the totals for the window opening per foot of sash perimeter and include frame leakage and so-called *elsewhere* leakage. The frame leakage values included are for wood frame construction but apply as well to masonry construction assuming a 50 per cent efficiency of frame calking.

[e]A 3/32-in. crack and clearance represents a poorly fitted window, much poorer than average.

[f]Windows tested in place in building.

[g]Industrial pivoted window generally used in industrial buildings. Ventilators horizontally pivoted at center or slightly above, lower part swinging out.

[h]Architectural projected made of same sections as industrial pivoted except that outside framing member is heavier, and it has refinements in weathering and hardware. Used in semi-monumental buildings such as schools. Ventilators swing in or out and are balanced on side arms. 1/32-in. crack is obtainable in the best practice of manufacture and installation, 3/64-in. crack considered to represent average practice.

[i]Of same design and section shapes as so-called *heavy section casement* but of lighter weight. 1/64-in. crack is obtainable in the best practice of manufacture and installation, 1/32-in. crack considered to represent average practice.

[j]Made of heavy sections. Ventilators swing in or out and stay set at any degree of opening. 1/64-in. crack is obtainable in the best practice of manufacture and installation, 1/32-in. crack considered to represent average practice.

[k]With reasonable care in installation, leakage at contacts where windows are attached to steel framework and at mullions is negligible. With 3/64-in. crack, representing poor installation, leakage at contact with steel framework is about one-third, and at mullions about one-sixth of that given for industrial pivoted windows in the table.

m.p.h. velocity air leakage is 45 cubic feet per hour and the 15 m.p.h. air leakage is 70 cubic feet per hour and the difference is 25 cubic feet per hour. Therefore, the leakage per foot of crack for a 12 m.p.h. wind velocity, in this case, would be 45 plus $\frac{2}{5}$ of 25, or 55 cubic feet, since 12 m.p.h. is 10 plus $\frac{2}{5}$ the difference between 10 m.p.h. and 15 m.p.h. Note that this air leakage is per foot of window crack. To get the total air leakage for the window, the leakage per foot of crack must be multiplied by the total number of feet of window crack.

Formula (**2**) is modified somewhat to take into consideration the leakage per foot of crack, and the heat equivalent thereof per degree temperature difference. The modified infiltration formula for solving by the crack method is as follows:

$$H_i = B(t - t_o)L \qquad \textbf{(2a)}$$

where

B = Air leakage (cubic feet) per foot of crack, Table 1, for the wind velocity and type of window or door crack involved, multiplied by 0.018.

L = Length of window or door crack to be taken into consideration (feet).

In using Formula (**2a**), the air leakage per foot of crack may be determined by reference to Table 1 for the average wind velocity (during December, January and February) in the locality of the building and the coefficient B then calculated by multiplying this air leakage by 0.018, which is the heat equivalent per cubic foot of the entering air per degree of temperature rise.

The wind velocity ordinarily selected for estimating the air leakage through window and door cracks is the average during December, January and February. See Table 2.

Example. 3. By means of Formula (**2a**) estimate the amount of heat required for heating the air leakage through a 3x5 ft. double-hung, non-weatherstripped, unlocked wood sash window, assuming $\frac{1}{16}$-in. crack and $\frac{3}{64}$-in. clearance and an average wind velocity of 12.5 m.p.h. Inside and outside temperatures 70° and 0° respectively.

Solution. According to Table 1, the air leakage for this type of window for wind velocities of 10 and 15 m.p.h. are respectively 21.4 and 39.3 cubic feet per foot of crack per hour. The air leakage for a 12.5 m.p.h. velocity will of course be midway between these

Table 2. Temperature and Wind Velocities for Calculating Heat Losses

City	Recommended Design Temp.	Average Wind Velocity*—Dec., Jan., Feb.—Miles per hour	City	Recommended Design Temp.	Average Wind Velocity*—Dec., Jan., Feb.—Miles per hour
Birmingham, Ala....	10	8.5	Raleigh, N.C.......	15	8.2
Mobile, Ala.........	20	10.4	Wilmington, N.C...	20	8.5
Flagstaff, Ariz......	−10	7.8	Bismarck, N.D.....	−30	9.1
Phoenix, Ariz.......	25	6.4	Devils Lake, N.D...	−30	10.6
Fort Smith, Ark.....	5	8.1	Cleveland, Ohio....	−5	13.0
Little Rock, Ark....	10	8.7	Columbus, Ohio....	−10	12.0
Los Angeles, Calif...	30	6.3	Oklahoma City, Okla............	0	12.0
San Francisco, Calif..	30	7.6	Baker, Ore.........	−15	6.9
Denver, Colo.......	−15	7.5	Portland, Ore......	10	7.5
Grand Junction, Colo.	−10	5.3	Philadelphia, Pa....	0	11.0
New Haven, Conn....	0	9.7	Pittsburgh, Pa.....	−5	11.7
Washington, D.C....	0	7.1	Providence, R.I.....	0	12.8
Jacksonville, Fla....	25	9.2	Charleston, S.C.....	15	10.6
Atlanta, Ga........	10	12.1	Columbia, S.C......	10	8.1
Savannah, Ga.......	15	9.5	Huron, S.D........	−25	10.6
Lewiston, Idaho.....	−5	5.3	Rapid City, S.D....	−20	8.2
Pocatello, Idaho.....	−10	9.6	Knoxville, Tenn....	0	7.8
Chicago, Ill.........	−10	12.5	Memphis, Tenn....	0	9.7
Springfield, Ill.......	−10	10.1	El Paso, Tex.......	0	10.4
Evansville, Ind......	0	9.8	Ft. Worth, Tex....	0	10.4
Indianapolis, Ind....	−10	11.5	San Antonio, Tex...	10	8.0
Dubuque, Iowa.....	−20	7.1	Modena, Utah.....	−15	8.8
Sioux City, Iowa....	−20	11.6	Salt Lake City, Utah..........	−10	6.7
Concordia, Kan.....	−10	8.1	Burlington, Vt.....	−20	11.8
Dodge City, Kan....	−10	9.8	Lynchburg, Va.....	10	7.1
Louisville, Ky.......	−5	9.9	Norfolk, Va........	15	12.5
New Orleans, La....	20	8.8	Richmond, Va.....	10	7.9
Shreveport, La......	10	8.9	Seattle, Wash......	15	11.3
Eastport, Me.......	−10	12.0	Spokane, Wash.....	−15	7.1
Portland, Me.......	−10	9.2	Elkins, W.Va......	−10	6.6
Baltimore, Md......	10	7.8	Parkersburg, W.Va.	−10	7.5
Boston, Mass........	0	11.2	Green Bay, Wis....	−20	10.4
Alpena, Mich.......	−10	12.4	LaCrosse, Wis.....	−25	7.3
Detroit, Mich.......	−10	12.7	Milwaukee, Wis....	−10	11.5
Marquette, Mich....	−10	11.1	Lander, Wyo.......	−25	5.0
Duluth, Minn.......	−30	12.6	Sheridan, Wyo.....	−25	6.0
Minneapolis, Minn..	−20	11.3	Edmonton, Alta....	−20	6.5
Vicksburg, Miss.....	15	8.3	Vancouver, B.C....	15	4.5
St. Joseph, Mo......	−10	9.3	Victoria, B.C......	15	12.5
St. Louis, Mo.......	−5	11.6	Winnipeg, Man.....	−30	10.0
Springfield, Mo.....	−10	10.8	Fredericton, N.B....	−10	9.6
Billings, Mont......	−30	....	Yarmouth, N.S.....	0	14.2
Havre, Mont.......	−30	9.5	London, Ont.......	0	10.3
Lincoln, Neb........	−15	10.5	Ottawa, Ont.......	−10	8.4
North Platte, Neb...	−20	8.5	Port Arthur, Ont...	−15	7.8
Tonopah, Nev.......	5	10.0	Toronto, Ont......	−5	13.0
Winnemucca, Nev...	−15	8.7	Charlottetown,P.E.I	−5	9.4
Concord, N.H.......	−20	6.6	Montreal, Que.....	−10	14.3
Atlantic City, N.J...	5	15.9	Quebec, Que.......	−10	13.6
Albany, N.Y........	−5	8.1	Prince Albert, Sask.	−55	5.1
Buffalo, N.Y.........	0	17.2	Dawson, Yukon....	−50	3.7
New York, N.Y.....	0	17.1			
Santa Fe N.M.......	0	7.8			

*United States data from U.S. Weather Bureau. Canadian data from Meteorological Service of Canada.

figures or $21.4+\frac{39.3-21.4}{2}=30.4$. Therefore, $B=0.018\times 30.4$ or 0.55. The length of crack is $(2\times 5)+(3\times 3)$ or 19 feet; $t=70$ and $t_o=0$. Substituting these values in Formula (**2a**):

$$H_i=0.55\times(70-0)\times 19=732 \text{ B.t.u. per hour.}$$

The length of crack (L) per room to be used in Formula (**2a**) depends on the individual conditions, but in no case should the amount of crack used for the computations be less than half of the total window and door crack in the outside walls of the room. Thus, in a room with one exposed wall take all the crack; with two exposed walls, take the wall having the most crack; and with three or four exposed walls, take the wall having the most crack; but in no case take less than half the total crack. For a building having no partitions, such as a factory, whatever wind enters through the cracks on the windward side must leave through the cracks on the leeward side. Therefore, take one-half the total crack for computing each side and end of this type of building.

Air-Change Method. A quicker but not so accurate method of estimating the air leakage is to assume a certain number of air changes per hour for each room or space, depending on the number of exposures. The air changes assumed range from ½ to 2 per hour. A room with one side exposed is assumed to have one air change per hour, two sides exposed 1½ air changes per hour and three or four sides exposed, two air changes per hour. Entrance halls are assumed to have from two to three air changes per hour.

Example 4. By means of the air-change method, estimate the volume of air entering a room 10x15x9 feet high, with two sides exposed.

Solution. The volume of this room is $10\times 15\times 9$, or 1350 cubic feet. Based on 1½ air changes per hour for a room with two sides exposed, the air leakage (Q) would be 1350×1.5 or 2025 cubic feet per hour. This value of Q would be used in Formula (**2**) in order to arrive at the infiltration loss of the room.

The air-change method, as already intimated, is a rule-of-thumb method and does not take into consideration the type of windows, weatherstripping or wind velocity.

TEMPERATURES TO BE SELECTED

The inside or room temperature selected for calculating heat losses should be that near the wall, floor or ceiling surface under consideration. The nominal inside temperature for residences and apartments is 70°, although in many cases higher temperatures are maintained. The inside temperature for calculating the heat losses in other types of structures, such as factories and hospitals, may vary somewhat from this figure.

Heat-loss calculations are usually based on maintaining the desired temperature at the so-called *breathing line*, which is 5 feet above the floor. For ceiling heights up to about 10 feet it is customary to assume that the air temperature at the ceiling will be the same as at the breathing line in calculating the heat loss through the ceiling or roof. For higher ceilings, however, an allowance should be made for the fact that the temperature at the ceiling is higher than at the breathing line, due to the natural tendency of heated air to rise (convection). The allowances indicated in Table 2A are generally appli-

Table 2A. Approximate Temperature Differentials between Breathing Level and Ceiling, Applicable to Certain Types of Heating Systems[a]

Ceiling Height (Ft.)	Breathing Level Temperature (5 ft. above Floor)									
	60	65	70	72	74	76	78	80	85	90
10	3.0	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.3	4.5
11	3.6	3.9	4.2	4.3	4.4	4.6	4.7	4.8	5.1	5.4
12	4.2	4.6	4.9	5.0	5.2	5.3	5.5	5.6	6.0	6.3
13	4.8	5.2	5.6	5.8	5.9	6.1	6.2	6.4	6.8	7.2
14	5.4	5.9	6.3	6.5	6.7	6.8	7.0	7.2	7.7	8.1
15	6.0	6.5	7.0	7.2	7.4	7.6	7.8	8.0	8.5	9.0
16	6.1	6.6	7.1	7.3	7.5	7.7	7.9	8.1	8.6	9.1
17	6.2	6.7	7.2	7.4	7.6	7.8	8.0	8.2	8.7	9.2
18	6.3	6.8	7.3	7.5	7.7	7.9	8.1	8.3	8.8	9.3
19	6.4	6.9	7.4	7.6	7.8	8.0	8.2	8.4	8.9	9.4
20	6.5	7.0	7.5	7.7	7.9	8.1	8.3	8.5	9.0	9.5
25	7.0	7.5	8.0	8.2	8.4	8.6	8.8	9.0	9.5	10.0
30	7.5	8.0	8.5	8.7	8.9	9.1	9.3	9.5	10.0	10.5
35	8.0	8.5	9.0	9.2	9.4	9.6	9.8	10.0	10.5	11.0
40	8.5	9.0	9.5	9.7	9.9	10.1	10.3	10.5	11.0	11.5
45	9.0	9.5	10.0	10.2	10.4	10.6	10.8	11.0	11.5	12.0
50	9.5	10.0	10.5	10.7	10.9	11.1	11.3	11.5	12.0	12.5

[a] The figures in this table are based on an increase of 1 per cent per foot of height above the breathing level (5 ft.) up to 15 ft. and 1/10 of one degree for each foot above 15 ft. This table is generally applicable to forced-air types of heating systems. For direct radiation or gravity warm air, increase values 50 per cent to 100 per cent.

cable to forced-air types of heating systems. For direct radiation or gravity warm-air systems, add 50 to 100 per cent to the allowances indicated in Table 2A.

Outside Temperature. The recommended outside temperatures for calculating heat losses given in Table 2, range from about 5 to 15 degrees above the lowest recorded in the respective localities.

When estimating seasonal fuel consumption and fuel savings due to insulation, average instead of minimum outside temperatures are used. This is covered in detail in the chapter on Fuel Saving.

Attic Temperature. In some cases, as explained under the heading Unheated Attics, it is necessary to calculate the attic temperature in order to estimate the heat loss through the ceiling. The formula for estimating the attic temperature is as follows:

$$t_a = \frac{A_c U_c t + (A_r U_r + A_w U_w + A_g U_g) t_o}{A_r U_r + A_w U_w + A_g U_g + A_c U_c} \tag{3}$$

where

t_a = Attic temperature
t = Inside temperature near top floor ceiling
t_o = Outside temperature
A_c = Area of ceiling, square feet
A_r = Area of roof, square feet
A_g = Area of glass, square feet
A_w = Area of net vertical wall surface, square feet
U_c = Coefficient of transmission of ceiling
U_r = Coefficient of transmission of roof
U_w = Coefficient of transmission of vertical wall surface
U_g = Coefficient of transmission of glass

Example 5. Calculate the temperature in an unheated attic, assuming the following conditions: $t=75$; $t_o=-15$; $A_c=783$; $A_r=970$; $A_w=137$; $A_g=10$; $U_r=0.52$; $U_c=0.61$; $U_w=0.39$; $U_g=1.13$.

Solution. Substituting these values in Formula (3):

$$t_a = \frac{(783\times0.61\times75) + \{[(970\times0.52)+(137\times0.39)+(10\times1.13)]\times(-15)\}}{(970\times0.52)+(137\times0.39)+(10\times1.13)+(783\times0.61)}$$

$$t_a = \frac{(35822.25) + \{[(504.40)+(53.43)+(11.3)](-15)\}}{(504.40)+(53.43)+(11.3)+(478)}$$

$$t_a = \frac{(35822.25) + [569.13\times(-15)]}{1046.76}$$

Note: Multiplying a positive by a negative quantity produces a negative result.

$$t_a = \frac{(35822.25)+(-8536.95)}{1046.76}$$

Note: Adding a negative to a positive quantity is done by subtracting.

$$t_a = \frac{27285.3}{1046.76}$$

$$t_a = 26 \text{ degrees.}$$

Unheated Attics. The transmission loss through a ceiling, unheated attic, and *pitched roof* (Fig. 8, Transmission Coefficients and Tables) is estimated by substituting the proper values in Formula (1). These values depend somewhat on circumstances. If the unheated attic contains vertical wall surfaces, dormers, windows, etc., similar to the gable and gambrel types illustrated in Figs. 3 and 4 under Effect of Building Insulation on Heating Plant Size, the procedure in calculating transmission loss through the ceiling, attic and roof is first to estimate the attic temperature by means of Formula (3) of this chapter, then use this attic temperature as the outside temperature (t_o), and calculate the heat loss through the ceiling, substituting the proper values in Formula (1) for the ceiling area (A) and the ceiling coefficient of transmission (U). In other cases the combined coefficient of the roof and ceiling (U_{rc}), obtained by means of Formula (7) of the chapter Transmission Coefficients and Tables, should be used. The area (A) to be substituted in Formula (1) in this case, should be the roof area, and the temperature (t_o) should be the outside temperature. The same inside temperature (t) would be used in either case.

If the attic contains ventilators or open or loosely fitted windows which permit the entrance of outside air to such an extent that the attic temperature is appreciably reduced, proper allowance should be made therefor as explained in the preceding chapter under the heading Ventilated Attics, Coefficients to Use. Whether the probable attic temperature is calculated by means of Formula (3) of this chapter (which does not allow for ventilation) or is otherwise estimated or assumed, the ceiling heat transmission loss is calculated by means of Formula (1), substituting the calculated or assumed attic temperature for t_o, and using the inside room temperature (t), the ceiling area (A) for each room or space, and the ceiling coefficient of transmission (U).

For *flat roofs*, much the same reasoning applies. If the attic or space between the roof and ceiling is ventilated, allow for the reduction in air temperature in this space due to ventilation. Otherwise use the combined roof and ceiling coefficient for a flat roof from Table 14 under Transmission Coefficients and Tables.

Heated Attics. In estimating the transmission loss through the roof and ceiling over a heated attic where the ceiling is parallel with

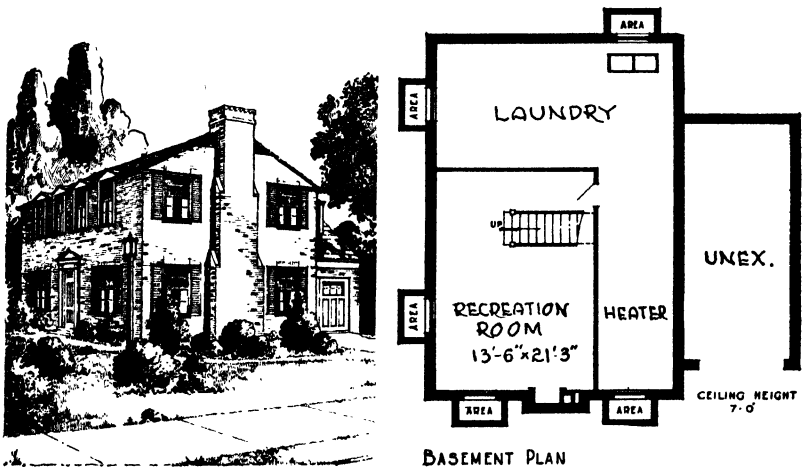


Fig. 3. Exterior View and Basement Plan of 7-Room Brick Veneer Residence

the roof (Fig. 7, Transmission Coefficients and Tables), the factors to be used in Formula (1) are the inside and outside temperatures (t and t_o), the ceiling (or roof) area (A) and the roof coefficient (U) including the ceiling finish applied to the under side of the roof rafters.

Typical Problem. The following is a typical example of the method of calculating the heat losses of a house:

Example 6. Calculate the heat loss of residence in Figs. 3 and 4 located in Kenilworth, Illinois, a Chicago suburb. Assume inside and outside design temperatures to be 70°F. and −10°F. respectively. The attic is unheated. Assume ground temperature to be 45°F. Estimate infiltration by crack method, assuming wind velocity to be 12.5 m.p.h. during December, January and February. No wall, ceiling, or roof insulation is to be figured in this problem, nor are the windows to have storm sash or weatherstrips. The building is constructed as follows, the transmission coefficients (U) in parentheses being obtained from the tables in the chapter on that subject or calculated:

Walls: Brick veneer, building paper, wood sheathing, studding, metal lath and plaster (0.28). Walls of dormer over garage, same except wood siding in place of brick veneer (0.28).

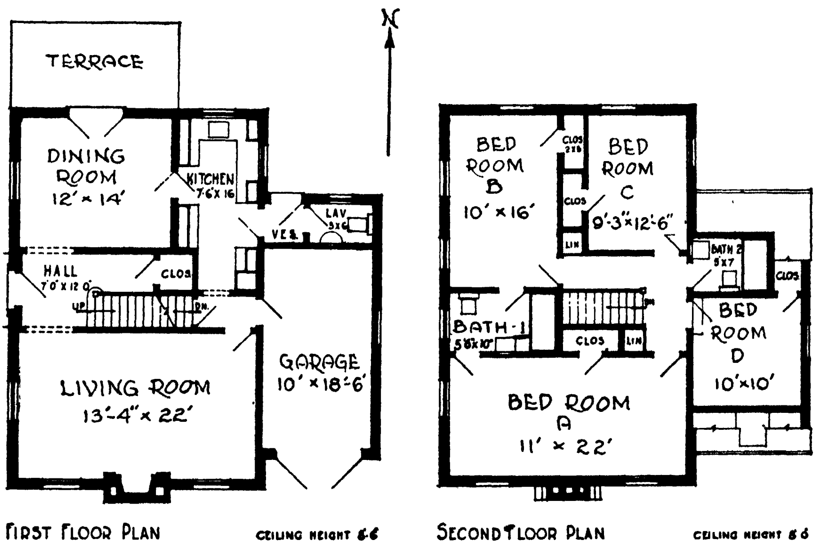


Fig. 4. First and Second Floor Plans of Residence

Attic Walls: Brick veneer, building paper, wood sheathing on studding (0.42).

Basement Walls: 10-in. concrete (0.10).

Roof: Asphalt shingles on wood sheathing on rafters (0.55).

Ceiling: (Second floor): Metal lath and plaster (0.69).

Windows: Double-hung wood windows, first and second floors (1.13). Steel casement sash in basement (1.13).

Floor (Bedroom D): Maple finish flooring on yellow pine subflooring; metal lath and plaster ceiling below (0.25).

Floor (Basement and Garage): 4-in. stone concrete on 3-in. cinder concrete (0.10).

Table 3. Heat Loss Calculation Sheet for Uninsulated Residence (Figs. 3 and 4)

Room or Space	Part of Structure	Net Area or Crack Length	Coefficient	Temp. Diff.[a]	Heat Loss (B.t.u. per Hour)	Totals (B.t.u. per Hour)
A	B	C	D	E	F	G
Bedroom *A* and Closet.	Walls	250 sq. ft.	0.28	80	5600	
	Glass	40 sq. ft.	1.13	80	3620	
	Crack	36 lin. ft.[b]	0.55[c]	80	1580	
	Ceiling[d]	254 sq. ft.	0.69	39.8	6970	17,770
Bedroom *B* and Closet.	Walls	168 sq. ft.	0.28	80	3760	
	Glass	40 sq. ft.	1.13	80	3620	
	Crack	36 lin. ft.[e]	0.55	80	1580	
	Ceiling[d]	170 sq. ft.	0.69	39.8	4660	13,620
Bedroom *C* and Closet.	Walls	114 sq. ft.	0.28	80	2560	
	Glass	27 sq. ft.	1.13	80	2440	
	Crack	18 lin. ft.[f]	0.55	80	790	
	Ceiling[d]	126 sq. ft.	0.69	39.8	3460	9,250
Bedroom *D* and Closet.	Walls	118 sq. ft.	0.28	80	2650	
	Glass	20 sq. ft.	1.13	80	1810	
	Crack	18 lin. ft.	0.55	80	790	
	Ceiling[d]	120 sq. ft.	0.69	39.8	3300	
	Floor over garage	110 sq. ft.	0.25	35[g]	960[m]	9,510
Bathroom 1..	Walls	30 sq. ft.	0.28	80	670	
	Glass	14 sq. ft.	1.13	80	1270	
	Crack	18 lin. ft.	0.55	80	790	
	Ceiling[d]	55 sq. ft.	0.69	39.8	1510	4,240
Bathroom 2..	Walls	79 sq. ft.	0.26	80	1770	
	Glass	9 sq. ft.	1.13	80	810	
	Crack	15 lin. ft.	0.55	80	660	
	Ceiling[d]	35 sq. ft.	0.69	39.8	960	
	Floor over garage	35 sq. ft.	0.25	35	310[m]	4,510
Living Room . .	Walls	267 sq. ft.	0.28	80	5980	
	Walls (adjoining garage)	94 sq. ft.	0.39[h]	35	1280[m]	
	Glass	50 sq. ft.	1.13	80	4520	
	Crack	40 lin. ft.	0.55	80	1760	13,540
Dining Room. . .	Walls	166 sq. ft.	0.28	80	3720	
	Glass (doors)	35 sq. ft.	1.13	80	3160	
	Glass (windows)	20 sq. ft.	1.13	80	1810	
	Crack[i]	31 lin. ft.	0.55	80	1360	10,050
Kitchen and Entrance to Garage..	Walls (outside)	96 sq. ft.	0.28	80	2150	
	Walls (adjoining garage)	51 sq. ft.	0.39[h]	35	700[m]	
	Crack	27 lin. ft.	0.55	80	1190	
	Glass	18 sq. ft.	1.13	80	1630	
	Door to garage	17 sq. ft.	0.51	35	300[m]	5,970

Room or Space	Part of Structure	Net Area or Crack Length	Coefficient	Temp. Diff.[a]	Heat Loss (B.t.u. per Hour)	Totals (B.t.u. per Hour)
A	B	C	D	E	F	G
Lavette and Vestibule	Walls (outside)........	82 sq. ft.	0.28	80	1840	
	Walls (adjoining garage)	85 sq. ft.	0.39[h]	35	1160[m]	
	Door................	19 sq. ft.	0.51	80	780	
	Glass................	9 sq. ft.	1.13	80	810	
	Crack...............	19 lin. ft.	0 55	80	840	5,430
Entrance Hall[p]...	Walls................	39 sq. ft.	0.28	80	870	
	Door................	21 sq. ft.	0 38	80	640	
	Crack...............	20 lin. ft.	1.55	80	880	
	Ceiling[d]............	87 sq. ft.	0.69	39.8	2490	4,880
Garage...	Walls................	167 sq. ft.	0.28	45	2110	
	Glass................	53 sq. ft.	1.13	45	2700	
	Doors................	44 sq. ft.	0.51	45	1010	
	Crack...............	37 lin. ft.	1.62[j]	45	2700	
	Floor (heat gain).....	185 sq. ft.	0.10[k]	—15[k]	−280	
	Heat gain............				−4710[m]	3,530
Recreation Room[n].	Floor................	287 sq. ft.	0.10	20	570	
	Walls................	235 sq. ft.	0.10	38	840	
	Glass................	8 sq. ft.	1.13	80	720	
	Crack...............	8 lin. ft.	0.76	80	490	2,620
Total........						104,920

[a] The inside-outside temperature difference is 70°−(−10°) or 80 degrees, except where noted.

[b] Only the south windows are used for arriving at the window crack for this room, on the assumption that whatever air enters through the south window cracks will leave through the west window cracks or elsewhere.

[c] The air leakage per foot of crack is determined by reference to Table 1. Refer to "Double-hung Wood Sash Windows (unlocked)" in this table and find the horizontal column under "Remarks" designated as "Total for average window, non-weatherstripped, etc." For 10 and 15 m.p.h. wind velocities the air leakages are 21.4 and 39.3 cubic feet per hour per foot of crack, respectively. For a 12.5 m.p.h. wind velocity, as in this problem, the air leakage would be the mean of these two values or 30.4 cubic feet per hour per foot of crack. The coefficient B will then be $0.018 \times 30.4 = 0.55$, as in Example 3 of this chapter.

[d] In this problem the ceiling heat losses are calculated by estimating the attic temperature and then calculating the loss through the ceiling, using the proper temperature difference. This unheated attic is not ventilated during the winter months. The attic temperature is estimated from Formula (1) to be 30.2 when the outside temperature is −10°F. and the room temperature is 70°F. The temperature difference is therefore 70−30.2 or 39.8 degrees F.

[e] The window crack in the west wall having two windows is used.

[f] One-half the total crack is used in these rooms.

[g] Temperature in garage assumed to be 35°F.

[h] Coefficient for wall adjoining garage calculated on basis of metal lath and plaster on both sides of studs. ($U = 0.39$.)

[i] The door crack is used for estimating the infiltration in this room and the infiltration coefficient is assumed to be the same as in Note b.

[j] The leakage for the garage doors is assumed to be twice that for poorly-fitted double-hung wood windows or about 90 cu. ft. per foot of crack for a wind velocity of 12.5 m.p.h. The infiltration coefficient is therefore 0.018×90, or 1.62.

[k] The ground temperature is assumed to be 50°F. and as the garage temperature is 35°F., the heat transfer will be from the ground to the garage, and this heat gain should therefore be subtracted from the heat loss.

[m] The heat losses from various rooms into the garage are heat gains for the garage.

[n] Heat is to be provided for the recreation room, and this space is therefore figured on the basis of a 70°F. temperature. Heat loss into the basement from the recreation room is neglected, the calculations being based only on losses through the outside walls, glass and floor. Ground temperature adjoining basement walls is assumed to be 32°F., and under floor 50°F.

[p] The upstairs hall ceiling is included with the downstairs entrance hall because these are connected by means of the stairway. The heat should be provided downstairs.

Solution. The calculations for this problem are given in Table 3, and a summary of the results in Table 4. The values in Column *F* of Table 3 were obtained by multiplying together the figures in Columns *C, D,* and *E*. The heat losses are calculated to the nearest 10 B.t.u.

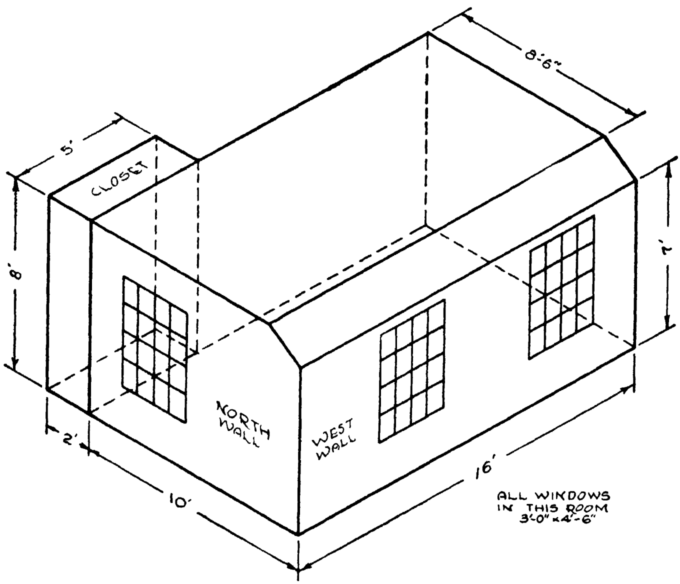


Fig. 5. Isometric Diagram of Bedroom *B*, Fig. 4

Areas. Fig. 5 is an isometric view of bedroom *B* showing the inside dimensions of this room. The figures in Column *C* for this room, including the closet, were determined as follows:

Window area (glass): 3×3×4.5 or 40+ or say		40 sq. ft.
Wall area:	West, 16 × 7 (gross area)	112 sq. ft.
	North, 10 × 8 (gross area)	80 sq. ft.
	Closet, 2 × 8	16 sq. ft.
	Gross wall area (including windows)	208 sq. ft.
	Window area	40 sq. ft.
	Net wall area	168 sq. ft.
Ceiling area: (10×16)+(5×2) (closet)		170 sq. ft.

(**Note:** The small sloping area is included with the flat area in arriving at the total ceiling area. The coefficients to be used for these two areas would be different but the coefficient for the flat area is used in the calculations as the difference will be small. Also the 10-ft. dimension of the ceiling would actually be slightly more than 10 ft. because of the slope but this small difference also is neglected, bearing in mind that minute accuracy in calculating heat losses is not justified.)

Crack Length (3×3)+(2×4.5) or 18 lin. ft. per window. For two windows (see Note *e* below Table 3) .... 36 lin. ft.

Table 4. Summary of Heat Losses of Uninsulated Residence

Heat losses given in B.t.u. per hour

Room or Space	Walls	Ceiling and Roof	Floor	Glass and Door	Infiltration (Crack)	Totals
Bedroom *A*	5600	6970	....	3620	1580	17,770
Bedroom *B*	3760	4660	....	3620	1580	13,620
Bedroom *C*	2560	3460	....	2440	790	9,250
Bedroom *D*	2650	3300	960	1810	790	9,510
Bathroom 1	670	1510	....	1270	790	4,240
Bathroom 2	1770	960	310	810	660	4,510
Living Room	7260	....	....	4520	1760	13,540
Dining Room	3720	....	....	4970	1360	10,050
Kitchen	2850	....	....	1930	1190	5,970
Lavette	3000	....	....	1590	840	5,430
Entrance Hall	870	2490	....	640	880	4,880
Garage	−1030[a]	....	−1550[b]	3410[c]	2700	3,530
Recreation	840	....	570	720	490	2,620
Totals	34,520	23,350	290	31,350	15,410	104,920
Percentages	32.9	22.2	0.3	29.9	14.7	100.0

[a] This negative heat loss of −1030 B.t.u. is the same as a heat gain of this amount and is equal to the wall heat loss of 2110 B.t.u. minus the wall heat gains from adjoining rooms of −700, −1160 and −1280: 2110 −700 −1160 −1280 = −1030.

[b] This negative heat loss of −1550 B.t.u. is a heat gain of this amount for the garage and is equal to the floor heat loss (−280) minus the heat received through the ceiling from the rooms above or: −280 −960 −310 = −1550 B.t.u.

[c] Heat received through door from kitchen to garage is 300 B.t.u. Therefore, the net heat loss = 3710 −300 = 3410 B.t.u.

Table 5. Summary of Heat Losses of Insulated Building

Heat losses given in B.t.u. per hour

Room or Space	Walls	Ceiling and Roof	Floor	Glass and Door	Infiltration (Crack)	Totals
Bedroom *A*	2800	2490	....	1440	1010	7740
Bedroom *B*	1880	1660	....	1440	1010	5990
Bedroom *C*	1280	1230	....	970	500	3980
Bedroom *D*	1320	1170	690	720	500	4400
Bathroom 1	340	540	....	500	500	1880
Bathroom 2	820	340	220	320	420	2120
Living Room	3580	....	....	1800	1120	6500
Dining Room	1860	....	....	3880	870	6610
Kitchen	1400	....	....	950	760	3110
Lavette	1460	....	....	1100	530	3090
Entrance Hall	440	850	....	640	560	2490
Garage	−400[a]	....	−1190[b]	3410[c]	2700	4520
Recreation	840	....	570	720	490	2620
Totals	17,620	8280	290	17,890	10,970	55,050
Percentages	32.0%	15.0%	0.5%	32.5%	20.0%	100.0%

[a] 1050 −590 −320 −540 = −400 B.t.u. (See Note *a*, Table 4)

[b] −690 −220 −280 = −1190 B.t.u. (See Note *b*, Table 4)

[c] 3710 −300 = 3410 B.t.u. (See Note *c*, Table 4)

The areas and crack lengths in Column *C* for all other rooms were determined from the plans in a similar manner. It should not be expected that the figures in Column *C* could be accurately determined from the small floor plan, Fig. 4, because of irregularities in the construction which cannot be shown on this small detail. The dimensions should be taken from either the plans or the actual job, if the building is completed.

Example 7. Calculate the heat loss of residence shown in Figs. 3 and 4 based on the same temperature and wind-velocity conditions as in Example 6, but with storm windows and weatherstrips on all first and second floor windows and insulated throughout as follows (coefficients in parentheses):

Walls: Brick veneer, $^{25}/_{32}$-in. insulating board sheathing, 1-in. insulating board lath and plaster (0.14). Walls of dormer over garage same except wood siding in place of brick veneer (0.13).

Attic Walls: Brick veneer, $^{25}/_{32}$-in. insulating board sheathing on studding (0.28).

Walls Adjoining Garage: Plaster on 1-in. insulating board, studding, metal lath and plaster (0.18).

Basement Walls (Recreation Room): 10-in. concrete, furring strips, ½-in. insulating board (0.10).

Roof: Asphalt shingles on wood sheathing on rafters (0.55).

Ceiling (Second Floor): 1-in. insulating board lath and plaster; ½-in. insulating board on top of ceiling joists (0.15).

Windows: Double-hung wood windows with storm sash (0.45) on first and second floors. Steel casement sash in basement (1.13).

Floor (Bedroom D): Maple finish flooring on yellow pine subflooring, ½-in. insulating board lath and plaster ceiling below (0.18).

Floor (Under Recreation Room): 4-in. concrete on 3-in. cinder concrete (0.10).

Solution. The procedure for calculating the heat losses is similar to that for Example 6. A summary of the results is given in Table 5.

Heat Saving. It should be noted from Examples 6 and 7 that the total heat loss is reduced from 104,920 B.t.u. per hour to 55,050 B.t.u. per hour as the combined result of the insulation, storm sash and weatherstrips. This is a percentage reduction of approximately 47.6 per cent. The fuel saving would of course be in this ratio. These percentage savings are divided as follows:

Insulation (B.t.u. saving = 31,970)	30.5%
Storm sash (B.t.u. saving = 13,460)	12.9%
Weatherstrips (B.t.u. saving = 4,440)	4.2%
Total	47.6%

The relative heat savings percentages due to insulation, storm sash and weatherstrips will of course vary with the building, the type and thickness of insulation and other conditions. For example, if 2-inch blanket or bat insulation is used in the outside walls and top floor ceiling, the saving due to insulation will be 33,170 B.t.u. or 31.6 per cent based on a wall coefficient of 0.095 and a ceiling coefficient of 0.10. Fuel savings due to insulation are fully discussed in another chapter.

University of Illinois Heat-Saving Tests. Tests were conducted in the Warm Air Heating Research Residence in Urbana, Illinois, to determine: (1) under actual service conditions over a wide range of outdoor temperatures, the percentage savings that could be effected by insulating a typical residence and by equipping it with storm windows and a storm door, and (2) to compare the actual savings so effected with those estimated from heat-loss calculations, employing commonly accepted values for the coefficients of heat transmission and air infiltration. Mineral wool insulation was selected to insulate the sidewalls and ceiling, using bats in accessible locations and nodulated wool elsewhere. The wall and ceiling insulation was 5⅝ inches thick and the insulation in sidewalls between heated and unheated spaces was 3⅝ inches thick.

The results of these tests are summarized in a University of Illinois bulletin.* The following paragraphs are quoted from this summary:

A seasonal fuel saving of the order of 20 per cent was obtained by completely equipping the uninsulated research residence with storm windows and a storm door. The actual saving effected by storm windows and a storm door, as determined by test, was about 0.81 of that estimated from the calculated heat losses.

The installation of insulation in the residence not equipped with storm windows resulted in an average saving of approximately 30 per cent in the actual fuel consumption, or about 0.78 of the estimated reduction based on calculated heat losses.

***Fuel Savings Resulting from Use of Insulation and Storm Windows*, by A. P. Kratz and S. Konzo, (Engineering Experiment Station, Bulletin No. 355).

The installation of both storm windows and insulation in the residence resulted in an average saving of approximately 45 per cent in the actual fuel consumption, or about 0.68 of the estimated reduction.

As the heat loss from the residence was progressively reduced, the deviation of the actual savings from the estimated reduction in heat loss became larger. This deviation was attributed to uncertainties accompanying the calculation of heat losses, particularly those for infiltration, and to the use of an oversized furnace as the heat loss was reduced.

It will be noted that the actual percentage savings were somewhat less than the theoretical for this particular residence and for the type of insulation used. This does not necessarily prove that such a discrepancy between the theoretical and actual results exists in all cases, but it may be assumed as stated that "the deviation of the actual savings from the estimated reduction" becomes larger as the heat loss is progressively reduced.

Heat Loss Percentages. The relative heat losses through various parts of a building are often regarded as more or less fixed percentages. For example, a recent publication states that 50 per cent of the heat is lost through the walls and roof, 25 per cent through the glass and 25 per cent through air leakage or infiltration at doors and windows. Actually, percentages vary considerably and depend on the type of building, the ratio of wall to roof area, the construction, and whether insulation, storm sash and weatherstrips are used.

For the building in Examples 6 and 7, without insulation, storm sash and weatherstrips, percentages are shown in Table 4 as follows:

Walls	32.9%
Ceiling and roof	22.2%
Floors	0.3%
Glass and door	29.9%
Infiltration (crack loss)	14.7%
Total	100.0%

If insulation, storm sash and weatherstrips are used as in Example 7, relative percentages for materials installed (Table 5) are:

Walls	32.0%
Ceiling and roof	15.0%
Floors	0.5%
Glass and door	32.5%
Infiltration (crack loss)	20.0%
Total	100.0%

CHAPTER VII

EFFECT OF BUILDING INSULATION ON HEATING PLANT SIZE

Central heating plants are of two general types, namely, (1) *steam, hot water* and *vapor systems* whereby radiators or convectors located in the rooms or spaces to be heated are connected to the *boiler* by means of supply and return piping and (2) *warm air systems* of the gravity and mechanical types, whereby the registers in the rooms or spaces are connected to the *furnace* by means of ducts or warm air pipes. Mechanical warm air systems usually have return ducts from major rooms as well as supply ducts. Mechanical warm air systems are also called winter air-conditioning systems if provision is made for humidifying and filtering the air. Either of these two general types of systems may be fired with coal, oil or gas.

The size of the heating plant required for any building is proportional to the heat loss. By reducing the heat loss through the use of insulation it may be possible to reduce the size of the heating plant, and the resulting monetary saving should be credited against the cost of the insulation. The actual saving in any given case depends on many factors, including the type of heating plant and the B.t.u. capacities of the various sizes involved.

There are three possible heating plant savings with steam, hot water and vapor systems, namely, (1) reduction in the amount of radiation required in each room or space to be heated, (2) reduction in the size of the boiler or furnace required, and (3) smaller-sized stoker, oil burner or gas burner where automatic fuel-burning equipment is used.

REDUCTION IN RADIATOR SIZES

All radiators emit heat by radiation to surrounding objects and by conduction to the air in contact with the surfaces. This heated air is in turn transmitted by convection to the rooms or spaces to be warmed.

The terms "radiator" and "radiation" were adopted when cast-iron heating units were introduced many years ago because such heating units gave off a large percentage of heat by radiation. Today these heating units frequently are enclosed in cabinets or concealed in the walls, in which case they give off heat to the room mainly by convection and are primarily convectors rather than radiators. The term "radiator," however, is generally applied to all heating units of this type whether they are exposed or enclosed. The heating elements of the enclosed or concealed radiators (convectors) often consist of finned copper tubing instead of cast-iron sectional units.

Rating of Radiators. Radiators, whether exposed or concealed, are rated on the equivalent square feet of radiation. This quantity usually has no direct relationship to the actual surface area of the heating element, as was originally the case, but means simply an output under certain standard conditions of 240 B.t.u. per hour per square foot for steam or vapor and 150[a] for hot water. Thus a 10 sq. ft. steam radiator has an output of 10×240 or 2,400 B.t.u. per hour.

In order to determine the square feet of equivalent radiation required for a room it is only necessary to divide the calculated heat loss for the room by 240 for steam or vapor and by 150 for hot water. Thus in the case of Bedroom *A* of Example 6, chapter on Calculating Heat Losses, the calculated heat loss is 17,770 B.t.u. per hour and the amount of steam radiation required would be $\frac{17,770}{240}$ or 74 square feet. The same room insulated as in Example 7, same chapter, has a heat loss of 7,740 B.t.u. per hour and therefore would require $\frac{7,740}{240}$ or 32.2 square feet of equivalent radiation for a steam or vapor system. The saving of $74 - 32.2$, or 41.8 square feet of radiation for this room has a direct monetary value which should be deducted from the *net*[b] cost of the insulation. It should be understood that radiators and convectors of all types come in sections or units and that the nearest commercial size must always be selected; consequently, the actual saving in any given case may

[a]An effort is being made at the present time to change the rating basis of hot water radiators from the square foot to the M.b.h. This unit is equal to a heat output of 1000 B.t.u. per hour. The square foot unit has led to some confusion because the capacity or rating varies with the temperature of the water in the radiator, and in certain types of hot water systems, the water temperature may be different in every radiator. This unit (the M.b.h.), however, is not universally in use as yet.

[b]The *net* cost of the insulation is the actual installed cost of the insulation minus the actual installed cost of materials replaced.

be slightly more or less than the theoretical saving, depending on the commercial sizes of the radiators under consideration.

Estimating Radiation Savings. The radiation saving may be determined by calculating the requirements with and without insulation, storm sash and weatherstrips, and subtracting the one from the other, as in the foregoing illustration. If only the saving due to insulation is being considered, the radiation saving for each surface insulated can also be calculated by means of the following formulas:

$$R_s = \frac{(U - U_i)A(t - t_o)}{240} \quad \text{(for steam)} \quad \textbf{(1a)}$$

$$R_w = \frac{(U - U_i)A(t - t_o)}{150} \quad \text{(for hot water)} \quad \textbf{(1b)}$$

where

R_s = Saving in steam or vapor radiation, equivalent square feet.
R_w = Saving in hot water radiation, equivalent square feet.
U = Coefficient of transmission of uninsulated surface.
U_i = Coefficient of transmission of insulated surface.
A = Net insulated surface area, square feet.
t = Inside temperature.
t_o = Outside design temperature.

Example 1. A room has a net wall area (exclusive of glass) of 300 square feet. The wall construction consists of wood siding, wood sheathing, studding, plasterboard lath and plaster. What will be the steam radiation saving for this room if the wall is insulated with 1-in. flexible insulation installed between the studs so as to provide one air space? The inside and outside design temperatures are 75° and 0°, respectively.

Solution. According to Tables 4 and 5 of the chapter on Transmission Coefficients and Tables, the wall coefficients are 0.25 without insulation (U) and 0.13 with insulation (U_i); $A = 300$; $t = 75$; $t_o = 0$. Substituting these values in Formula **(1a)**:

$$R_s = \frac{(0.25 - 0.13) \times 300 \times (75 - 0)}{240}$$

$$= \frac{0.12 \times 300 \times 75}{240}$$

$= 11.25$ sq. ft. of equivalent direct radiation

Pitched Roofs, Hip and Double Hip Types. If the ceiling or roof is to be insulated, the radiation saving resulting therefrom should be estimated in a similar manner and added to the saving obtained by insulating the walls, to get the total radiation saving due to insulation for the room or space under consideration. In the case of pitched roofs of the hip or double hip (mansard) types illustrated in Figs. 1 and 2, the combined coefficients of the roof and ceiling, with and without insulation, should be calculated in accordance with Formula (7) of the chapter on Transmission Coefficients and Tables

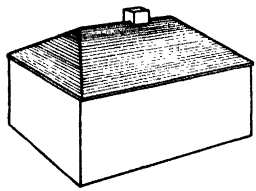


Fig. 1. Hip Roof

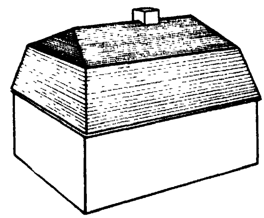


Fig. 2. Double Hip Roof (Mansard)

and substituted in Formula (**1a**) of this chapter if steam radiation is to be used and Formula (**1b**) if hot water radiation is to be used. The area (A) when using the combined roof and ceiling coefficients should be the roof area and the temperature should be the inside and outside design temperatures t and t_o, respectively, as was the case in Example 1.

Ventilated Attics. On the other hand, if the roof is of either of these types and the attic is winter ventilated, then the roof should *not* be taken into consideration. In this case the coefficients U and U_i to be used in Formulas (**1a**) and (**1b**) should be the ceiling coefficients with and without insulation, and the area (A) should be the ceiling area. The temperature should as heretofore be the inside and outside design temperatures, t and t_o. It is important to remember that if the attic is winter ventilated, the roof may have no appreciable heat resistance value whether it is insulated or not.

Pitched Roofs, Gable and Gambrel Types. Where the roof is of the gable or gambrel (Dutch Colonial) types, illustrated in Figs. 3 and 4, Formulas (**1a**) and (**1b**) may be applied directly when the attic is ventilated in the winter, as explained in the preceding paragraph, using the ceiling coefficients only, with and without insulation, the ceiling area (A) and the inside and outside design temperatures, t and t_o, respectively. But if the attic is not ventilated, the attic temperatures with and without insulation must be estimated by means of Formula (3) of the chapter on Calculating Heat Losses. The radiation required to supply the ceiling heat loss with and without insulation, should then be calculated and the difference between these two quantities will represent the radiation saving due to ceiling insulation.

Example 2. Refer to Examples 6 and 7, in the chapter headed Calculating Heat Losses. Estimate the hot water radiator saving

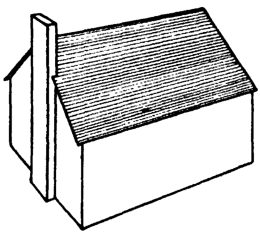


Fig. 3. Gable Roof

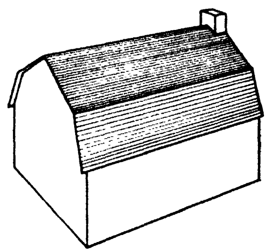


Fig. 4. Gambrel Roof (Dutch Colonial)

in Bedroom B resulting from the use of the ceiling insulation in this room as specified in Example 7.

Solution. According to Table 3, same chapter, the "ceiling and roof" heat loss is 4660 B.t.u. per hour. This is based on an estimated attic temperature of 30.2° (temperature difference $=70-30.2=39.8$ degrees) when the inside temperature is 70° and the outside temperature is $-10°$. The hot water radiation required to supply this heat loss will be $\frac{4660}{150}$ or 31 sq. ft. Now if the ceiling is insulated as in Example 7, same chapter, the estimated attic temperature will be 4.8° (temperature difference $=70-4.8=65.2$ degrees) and the "ceiling and roof" heat loss for Bedroom B, as shown in Table 5, same chapter, will be 1660 B.t.u. per hour. The hot water radiation required to supply this ceiling and roof heat loss will be $\frac{1660}{150}$ or 11 sq. ft. and the radiation saving due to ceiling insulation will be $31-11$ or 20 sq. ft.

Industrial Roofs. In the case of industrial buildings or other structures having high ceilings, the temperature at the ceiling will be somewhat higher than at the breathing line, as explained in an earlier chapter. In estimating the radiation *required*, proper allowance must be made for this increase in temperature in determining the inside temperature (t) at the ceiling, and this inside temperature should be used for estimating the radiation *saving*. Thus if the temperature near the ceiling is estimated to be 90° and the outside temperature is $-10°$, the temperature difference ($t-t_o$) is 100 degrees, and this temperature difference should be used in Formulas (**1a**) or (**1b**).

Value of Radiation. The cost of the radiation alone per square foot for any specific installation is usually determined by adding together all of the labor and material costs, including the piping to and from the boiler (but not the boiler itself), and dividing by the total square feet of equivalent radiation required. The allowance for any deduction in the radiation requirements as the result of the installation of an insulating material will not ordinarily be in the same proportion, because the labor and certain other material costs will be the same, regardless of the size of the radiators used. The allowance usually amounts to the actual value of the radiation saved, rather than a proportion of the total cost. Thus if the average cost of the radiation for a certain job is $1.50 per square foot, the allowance for any radiation saved may amount to say 50c per square foot in this particular case. In one large city, the cost of radiation at the present time for a steam or vapor system, including labor and accessories, ranges from about $1.30 for cast-iron radiation to $1.50 for copper radiation of the extended surface or finned type. The radiation alone averages from about 30c to 50c per square foot.

REDUCTION IN REQUIRED BOILER OR FURNACE AND STOKER CAPACITY

The boiler or furnace selected should be of sufficient capacity to supply the maximum heat demand. Practically all boiler manufacturers produce units of graduated sizes and capacities. The capacities or outputs of heating boilers are usually given in either B.t.u. per hour or in square feet of radiation, or both. Power boilers are rated in terms of horsepower. If the output is stated in terms of B.t.u. per hour, the equivalent steam radiation capacity is determined by dividing this B.t.u.-per-hour output by 240. For the equivalent hot water heating capacity, the divisor is 150.

If the calculated (maximum) heat loss of a certain building is 200,000 B.t.u. per hour without insulation, and 140,000 per hour insulated, this reduction in the heat loss would in many cases permit the use of a smaller-sized boiler, depending upon the various capacities of the type of boiler to be used. Considering the boiler only, the monetary value of the saving would be that due to the difference in the costs of the two boilers, and this saving should be credited against the cost of the insulation, as previously stated. If an oil burner or an automatic stoker were used for firing this boiler, there would be an additional saving if the reduction in the heating load were sufficient to permit the use of a smaller-sized unit.

The reduction in the size of the furnace for warm-air systems would be determined in a similar manner. Such furnaces are usually rated in B.t.u. output per hour and if in any given case the total heat loss of a building is reduced sufficiently to permit the use of a smaller unit, this saving should be deducted from the *net* cost of the insulation. Certain types of systems are now on the market which involve a combination of steam or hot water boilers, radiators and warm air ducts, but the savings in boiler size would be determined on the aforementioned basis.

Boiler Insulation. In many installations, particularly those in large buildings, boiler insulation is desirable or necessary. The materials used for cast-iron boilers are of two general types, namely (1) plastic material or blocks wired on and covered with canvas or duck and (2) sheets, blocks or plastic material covered with a metal jacket. Steel firebox boilers of the self-contained type usually are insulated with blocks, boiler cement and canvas or mineral wool blankets. Horizontal return tubular (H.R.T.) boilers are brick-set and do not require insulation other than that provided by the setting. Non-combustible materials are, of course, used for boiler insulation.

DECORATIVE INSULATING BOARD PLANK AND TILEBOARD (PANELS) USED TO FINISH THE WALLS AND CEILING OF A BEDROOM

Courtesy of Wood Conversion Co., St. Paul, Minn.

CHAPTER VIII

FUEL SAVING

An insulating material, as already explained, retards the passage of heat through any wall, roof or other structure in which it is installed. In the winter, therefore, less heat is required to maintain the desired inside temperature and this, of course, means less fuel. The difference between the amount of fuel required per heating season with and without insulation is the fuel saving for the conditions under consideration. This fuel saving can be predicted with considerable accuracy in any given case.

Basic formula. The fuel saving for any given wall or roof area is based on, and directly proportional to, the difference in the coefficients of transmission of the uninsulated and the insulated constructions. Thus if the coefficient of transmission (U) of a certain wall is say 0.30 B.t.u. without insulation, and 0.16 B.t.u. with insulation (U_i), the saving will be the difference between 0.30 and 0.16, or 0.14 B.t.u. for each square foot of surface insulated for each degree temperature difference, and for one hour. But the saving expressed in this manner—0.14 B.t.u. per hour per square foot per degree difference—would have little or no significance to the average person. It must be translated into terms understood by everyone, such as tons of coal, gallons of oil or cubic feet of gas per heating season.

It is emphasized that this 0.14 B.t.u. saving is for *one* square foot of wall area, *one* degree temperature difference and *one* hour of time. To get the total B.t.u. saving per heating season, the 0.14 must be multiplied by the total net surface area to be insulated, the average inside-outside temperature difference during the heating season, and the number of hours during the heating season. Thus if the net area to be insulated is 1,000 sq. ft., the average temperature difference during the heating season 35 degrees, and the number of hours 5,088, the total B.t.u. saving per heating season will be $0.14 \times 1000 \times 35 \times 5088$, or 24,900,000 B.t.u. per heating season. Now suppose coal is the fuel to be used and assume that this coal has a heat content of 13,000 B.t.u. per pound. Assume also that the heating efficiency is 50 per cent, in other words that one-half of the heat content value is available as explained under the heading, *Heating Efficiencies*. In this case only 6,500 B.t.u. will be available per pound of fuel. Dividing the 24,900,000 B.t.u. saving by the net heat value of the fuel, or 6,500, will result in a saving of $\frac{24,900,000}{6,500}$ or 3830 pounds of coal per heating season. To change to tons, divide by 2,000, or $\frac{3830}{2000} = 1.92$ tons of coal per heating season.

Thus in this example, the coefficient difference or saving $(U - U_i)$ was multiplied by the net insulated area (A) of the wall or other surface involved, by the average temperature difference during the heating season $(t - t_o)$ and by the number of hours during the heating season (N). This gave the total B.t.u. saving per heating season. Then in order to express the result in terms of the fuel used, this total B.t.u. saving was divided by the heat value of the fuel, and the heating efficiency. This entire procedure can be expressed as follows:

$$F = \frac{(U - U_i)(t - t_o)NA}{CE} \tag{1}$$

where

F = fuel saving
U = Coefficient of transmission of uninsulated structure
U_i = Coefficient of transmission of insulated structure
t = Inside temperature near surface under consideration
t_o = Average outside temperature during heating season (Table 1)
N = Number of hours during heating season
A = Net area of surface under consideration, square feet
C = Calorific value or heat content of fuel used = B.t.u. per pound for coal, B.t.u. per gallon for oil and B.t.u. per cubic foot for gas
E = Efficiency of utilization of fuel, expressed as a decimal fraction such as 0.70 for 70 per cent.

In using this formula, the result will of course be in terms of the fuel used such as pounds of coal, gallons of oil or cubic feet of gas. For coal, the result should be divided by 2000 to change to tons; for gas the result should be divided by 1000 to change to thousands of cubic feet.

Example 1. Estimate the fuel saving resulting from the installation of 1 inch of corkboard to a 4-inch concrete roof deck (to be covered with built-up roofing) and having a suspended metal lath and plaster ceiling. The roof area (A) is assumed to be 10,000 square feet, the inside temperature (t) at the ceiling 70°, the average outside temperature (t_o) during the heating season 35°, and the number of hours (N) during the heating season, 5088. The fuel is coal having a calorific value (C) of 13,000 B.t.u. per pound and the efficiency (E) is assumed to be 0.60.

Solution. The coefficients of transmission of the uninsulated and insulated roof structures are 0.40 (U) and 0.17 (U_i) respectively. (Table 14, Transmission Coefficients and Tables.) Substituting the proper values in Formula (1) and dividing by 2000 to change to tons:

$$F = \frac{(0.40-0.17)(70-35)5088 \times 10{,}000}{13{,}000 \times 0.60 \times 2000}$$

$= 26.2$ tons of coal saved per heating season.

Average Outside Temperatures. The *average* outside temperature (t_o) is used for estimating the fuel saving, that is, the average during the heating season. Average outside temperatures during the heating season for various cities in the United States are given in Table 1. These average temperatures are for a period extending from October 1 to May 1 or seven months or 5088 hours.

It will be noted that not only are the average outside temperatures given in Table 1, but also the average inside-outside temperature differences. For example, if the inside temperature is 70°F., the average inside-outside temperature difference in Boston would be located under the "70° Inside Temperature" column and is 31.9°F. If the inside temperature is 72°F. and the building located in Detroit, the average inside-outside temperature difference is 36.2°F.

The actual heating season may be of longer or shorter duration than seven months in some localities. However, if a seven-month period and the corresponding average temperature during this period is used, the result will be substantially the same in northern U. S. latitudes as it would be for a longer heating season and consequently a higher average outside temperature or a shorter heating season and a lower average outside temperature. Therefore, it is sufficiently accurate in most cases to base the calculations on a heating season

Table 1. Average Outside Temperatures and Temperature Difference ($t-t_o$) during Heating Season for Various Cities, Based on Various Inside Temperatures

City and State	Average* Outside Temperature (t_o)	Inside Temperature (t) 65	70	72	75	80	City and State	Average* Outside Temperature (t_o)	Inside Temperature (t) 65	70	72	75	80
Albany, N. Y.	35.2	29.8	34.8	36.8	39.8	44.8	Lincoln, Neb.	37.0	28.0	33.0	35.0	38.0	43.0
Alpena, Mich.	29.6	35.4	40.4	42.4	45.4	50.4	Little Rock, Ark.	51.6	13.4	18.4	20.4	23.4	28.4
Atlanta, Ga.	51.5	13.5	18.5	20.5	23.5	28.5	Louisville, Ky.	45.3	19.7	24.7	26.7	29.7	34.7
Atlantic City, N. J.	41.6	23.4	28.4	30.4	33.4	38.4	Lynchburg, Va.	46.8	18.2	23.2	25.2	28.2	33.2
Baker, Ore.	35.2	29.8	34.8	36.8	39.8	44.8	Marquette, Mich.	28.3	36.7	41.7	43.7	46.7	51.7
Baltimore, Md.	43.8	21.2	26.2	28.2	31.2	36.2	Memphis, Tenn.	51.1	13.9	18.9	20.9	23.9	28.9
Billings, Mont.	34.0	31.0	36.0	38.0	41.0	46.0	Milwaukee, Wis.	33.4	31.6	36.6	38.6	41.6	46.6
Birmingham, Ala.	53.8	11.2	16.2	18.2	21.2	26.2	Minneapolis, Minn.	29.4	35.6	40.6	42.6	45.6	50.6
Bismarck, N. D.	24.6	40.4	45.4	47.4	50.4	55.4	Modena, Utah	36.3	28.7	33.7	35.7	38.7	43.7
Boston, Mass.	38.1	26.9	31.9	33.9	36.9	41.9	New Haven, Conn.	38.4	26.6	31.6	33.6	36.6	41.6
Buffalo, N. Y.	34.8	30.2	35.2	37.2	40.2	45.2	New York, N. Y.	40.7	24.3	29.3	31.3	34.3	39.3
Burlington, Vt.	31.5	33.5	38.5	40.5	43.5	48.5	Norfolk, Va.	49.3	15.7	20.7	22.7	25.7	30.7
Chicago, Ill.	36.4	28.6	33.6	35.6	38.6	43.6	North Platte, Neb.	35.4	29.6	34.6	36.6	39.6	44.6
Cleveland, Ohio	37.2	27.8	32.8	34.8	37.8	42.8	Oklahoma City, Okla.	47.9	17.1	22.1	24.1	27.1	32.1
Columbia, S. C.	54.0	11.0	16.0	18.0	21.0	26.0	Parkersburg, W. Va.	42.6	22.4	27.4	29.4	32.4	37.4
Columbus, Ohio	39.9	25.1	30.1	32.1	35.1	40.1	Philadelphia, Pa.	42.7	22.3	27.3	29.3	32.3	37.3
Concord, N. H.	33.3	31.7	36.7	38.7	41.7	46.7	Pittsburgh, Pa.	41.0	24.0	29.0	31.0	34.0	39.0
Concordia, Kan.	39.8	25.2	30.2	32.2	35.2	40.2	Pocatello, Idaho	35.7	29.3	34.3	36.3	39.3	44.3
Denver, Colo.	38.9	26.1	31.1	33.1	36.1	41.1	Portland, Me.	33.8	31.2	36.2	38.2	41.2	46.2
Detroit, Mich.	35.8	29.2	34.2	36.2	39.2	44.2	Portland, Ore.	46.1	18.9	23.9	25.9	28.9	33.9
Devils Lake, N. D.	20.3	44.7	49.7	51.7	54.7	59.7	Providence, R. I.	37.2	27.8	32.8	34.8	37.8	42.8
Dodge City, Kan.	41.4	23.6	28.6	30.6	33.6	38.6	Raleigh, N. C.	50.0	15.0	20.0	22.0	25.0	30.0
Dubuque, Iowa	33.9	31.1	36.1	38.1	41.1	46.1	Rapid City, S. D.	33.4	31.6	36.6	38.6	41.6	46.6
Duluth, Minn.	24.3	40.7	45.7	47.7	50.7	55.7	Richmond, Va.	47.0	18.0	23.0	25.0	28.0	33.0
Eastport, Me.	31.5	33.5	38.5	40.5	43.5	48.5	St. Joseph, Mo.	40.7	24.3	29.3	31.3	34.3	39.3
Elkins, W. Va.	39.4	25.6	30.6	32.6	35.6	40.6	St. Louis, Mo.	43.6	21.4	26.4	28.4	31.4	36.4
El Paso, Tex.	53.5	11.5	16.5	18.5	21.5	26.5	Salt Lake City, Utah	40.0	25.0	30.0	32.0	35.0	40.0
Evansville, Ind.	45.1	19.9	24.9	26.9	29.9	34.9	San Francisco, Calif.	54.2	10.8	15.8	17.8	20.8	25.8
Flagstaff, Ariz.	35.8	29.2	34.2	36.2	39.2	44.2	Santa Fe, N. M.	38.3	26.7	31.7	33.7	36.7	41.7
Fort Smith, Ark.	50.4	14.6	19.6	21.6	24.6	29.6	Seattle, Wash.	44.8	20.2	25.2	27.2	30.2	35.2
Fort Worth, Tex.	55.2	9.8	14.8	16.8	19.8	24.8	Sheridan, Wyo.	30.7	34.3	39.3	41.3	44.3	49.3
Grand Junction, Colo.	38.9	26.1	31.1	33.1	36.1	41.1	Shreveport, La.	56.2	8.8	13.8	15.8	18.8	23.8
Green Bay, Wis.	30.0	35.0	40.0	42.0	45.0	50.0	Sioux City, Iowa	32.6	32.4	37.4	39.4	42.4	47.4
Havre, Mont.	27.6	37.4	42.4	44.4	47.4	52.4	Spokane, Wash.	37.7	27.3	32.3	34.3	37.3	42.3
Huron, S. D.	28.2	36.8	41.8	43.8	46.8	51.8	Springfield, Ill.	39.8	25.2	30.2	32.2	35.2	40.2
Indianapolis, Ind.	40.3	24.7	29.7	31.7	34.7	39.7	Springfield, Mo.	44.3	20.7	25.7	27.7	30.7	35.7
Knoxville, Tenn.	47.9	17.1	22.1	24.1	27.1	32.1	Tonopah, Nev.	39.4	25.6	30.6	32.6	35.6	40.6
LaCrosse, Wis.	31.7	33.3	38.3	40.3	43.3	48.3	Washington, D. C.	43.4	21.6	26.6	28.6	31.6	36.6
Lander, Wyo.	30.0	35.0	40.0	42.0	45.0	50.0	Wilmington, N. C.	54.2	10.8	15.8	17.8	20.8	25.8
Lewiston, Idaho	42.3	22.7	27.7	29.7	32.7	37.7	Winnemucca, Nev.	37.9	27.1	32.1	34.1	37.1	42.1

*October 1 to May 1; See Table 2, chapter on Calculating Heat Losses.

of seven months, even though the actual heating season may be of longer or shorter duration than seven months, provided the average outside temperature corresponding to the seven-month period is also used.

The inside temperature (t) should always be that near the surface involved, as previously explained. Thus in the case of high ceilings (over 10 feet), proper allowance should be made for the fact that the temperature at the ceiling will be higher than at the breathing line. The allowance to be made under various conditions is also given in the chapter on Calculating Heat Losses. See discussion under *Industrial and Commercial Buildings* in this chapter.

Heat Content of Fuel. The calorific value or heat content (C) of the fuel used may be determined from data in the chapter on Fundamentals of Heat Transfer under the heading, *Heat Value of Fuels.* The proper value of C so determined should be substituted in Formula (1) of this chapter. For average conditions, however, it is sufficiently accurate to use 13,000 B.t.u. per pound for coal or coke, 141,000 B.t.u. per gallon for oil, 535 B.t.u. per cubic foot for manufactured gas and 1,000 B.t.u. per cubic foot for natural gas. In some cities, gas fuel is sold on the basis of the *therm,* which is that amount of gas which would have a heat value of 100,000 B.t.u., rather than the cubic foot. Thus instead of so many cubic feet of gas, the consumer is charged for so many therms. Where the therm is the fuel unit, the value of C is 100,000.

Heating Efficiencies. Because of incomplete combustion, loss of heat in the flue gases and other inefficiencies, it is not possible to utilize all of the heat in a fuel. Heating efficiencies vary over a wide range depending on the type of fuel and the manner in which it is fired, that is, by hand or by automatic fuel burning devices such as coal stokers or oil burners, and the design of the heating plant. Even different grades of the same type of fuel will have different combustion efficiencies. Anthracite coal, for example, can usually be fired with a higher efficiency than bituminous or semi-bituminous coal, provided the heat-absorbing surfaces of the boiler or furnace are adequate. Where definite information is not available as to the heating efficiencies of installations, the following may be helpful in arriving at reasonable average efficiencies to be used for E in Formula (1).

Coal. Tests by Sherman and Cross* of Columbus, Ohio, fuel engineers of the Batelle Memorial Institute, indicate that for residential heating equipment over-all efficiencies ranging from 41.4 to 54.0 per cent may be expected with hand-fired bituminous and semi-bituminous coals and from 55.0 to 69.0 per cent for stoker-fired bituminous coal. According to these tests, an efficiency of about 75 per cent may be assumed with hand-fired coke. Where actual test data are not available, an average over-all efficiency of 50 per cent is recommended for coal for hand-fired residence heating plants, and 60 per cent for commercial or industrial installations. (See Column 4, Table 2.)

Efficiencies with stoker-fired installations are usually higher than hand-fired, as is apparent from the Sherman and Cross tests. Without actual test data, use an E value of 60 per cent in Formula (1) for coal-fired residence jobs with automatic stokers. For industrial or commercial jobs, use a heating efficiency of 70 per cent for coal-fired stoker installations.

Oil Fuel. With oil fuel heating efficiencies depend to a considerable extent on whether the installation is of the conversion type or of the oil-designed type. A *conversion* job is one involving the use of existing coal-burning equipment and an oil burner adapted to such equipment. The over-all heating efficiency may be very low with this type of installation—in some cases not over 40 or 45 per cent—whereas under favorable conditions it is possible to obtain an efficiency of 70 per cent or more. A reasonable average is 60 per cent where No. 3 oil is used, and this value is recommended for estimating fuel savings. Where an *oil-designed* furnace or boiler and oil burner are installed, higher heating efficiencies are obtained with this fuel, in some cases 85 or 90 per cent. For average conditions, 80 per cent is the efficiency recommended for use in computation. Carbon and soot deposits on the heating surfaces of oil-burning furnaces or boilers will reduce the over-all heating efficiencies.

Gas Fuel. With gas fuel heating efficiencies are comparable to those with oil. In some cases they may be somewhat higher, especially where the installation is of the *conversion* type involving a combination gas burner and coal-burning furnace or boiler and certain

*"Heat Losses in Residential Heating" by Sherman and Cross (American Society of Heating and Ventilating Engineers Transactions, Volume 43, 1937).

Table 2. Simplified Formulas for Estimating Annual Fuel Saving
For Heating Season of 5088 Hours (N)

Fuel	Assumed Average Calorific Value (*C*)	Method of Firing	Assumed Heating Efficiency (*E*)	Simplified Formulas (F = Values in This Column)	Result Obtained Will Be	Formula Number
1	2	3	4	5	6	7
Coal....	13,000 B.t.u. per pound	Hand (Residences)	0.50	$\frac{(U-U_i)(t-t_o)A}{2550}$	Tons of coal saved	(2)
		Hand (Commercial)	0.60	$\frac{(U-U_i)(t-t_o)A}{3070}$		(3)
		Stoker (Residences)	0.60	$\frac{(U-U_i)(t-t_o)A}{3070}$		(4)
		Stoker (Commercial)	0.70	$\frac{(U-U_i)(t-t_o)A}{3580}$		(5)
Oil......	141,000 B.t.u. per gallon	Conversion	0.60	$0.06(U-U_i)(t-t_o)A$	Gallons of oil saved	(6)
		Oil-designed	0.80	$0.045(U-U_i)(t-t_o)A$		(7)
Manufactured gas....	535 B.t.u. per cubic foot	Conversion	0.65	$14.63(U-U_i)(t-t_o)A$	Cubic feet of gas saved	(8)
		Gas-designed	0.80	$11.89(U-U_i)(t-t_o)A$		(9)
Natural gas....	1000 B.t.u. per cubic foot	Conversion	0.65	$7.83(U-U_i)(t-t_o)A$	Cubicfeet of gas saved	(10)
		Gas-designed	0.80	$6.36(U-U_i)(t-t_o)A$		(11)
Mixed gas sold on therm basis...	100,000 B.t.u. per therm	Conversion	0.65	$\frac{(U-U_i)(t-t_o)A}{12.8}$	Therms saved	(12)
		Gas-designed	0.80	$\frac{(U-U_i)(t-t_o)A}{15.7}$		(13)

accessories necessary with such a combination heating plant. An average efficiency of 65 per cent is recommended for computing a conversion job whereas 80 per cent is recommended for figuring *gas-designed* equipment, whether the fuel is manufactured or natural gas or a combination of these. The efficiencies in Column 4 of Table 2 are based on the recommendations of a large public utility.

SIMPLIFIED FUEL-SAVING FORMULAS

Formula (1) may be simplified by substituting therein average values for the calorific value (C), heating efficiency (E), and the number of hours during the heating season (N). For example, assume a heating season (N) of 5088 hours, an average calorific value (C) for coal of 13,000 B.t.u. per pound, and a heating efficiency (E) of 50 per cent (0.50) for residences where the fuel is fired by hand. Substituting these values in Formula (1), it will reduce to the following:

$$F=\frac{(U-U_i)(t-t_o)A\times 5088}{13{,}000\times 0.50\times 2000}=\frac{(U-U_i)(t-t_o)A}{2550} \qquad (2)$$

The 2000 was introduced into the denominator to change the result to tons instead of pounds of coal.

The simplified formulas in Column 5 of Table 2 were derived in a similar manner by substituting the values in Columns 2 and 4 in Formula (1). Note that these formulas are based on a heating season of 5088 hours (seven months). The average outside temperature (t_o) should therefore correspond with this period of time in using these formulas.

Example 2. The net outside wall area (exclusive of windows) of a residence to be located in the vicinity of New York City is 2100 square feet. The contemplated wall construction is wood shingles, furring, wood sheathing, studding, plasterboard lath and plaster. What would be the average annual fuel saving if the plasterboard lath is faced on one side with aluminum foil having an emissivity of 0.05? The building is to be heated with oil by means of an oil-designed furnace. Inside temperature, 70°.

Solution. For this type of heating plant, Formula (7) of Table 2 $F=0.045(U-U_i)(t-t_o)A$ would be used. According to Table 1, the average outside temperature during the heating season (t_o) for New York City is 40.7 degrees; $t=70$. The coefficient of transmission (U) of the uninsulated wall is 0.25, (Table 4, Transmission Coefficients and Tables) and that of the insulated wall (U_i) is 0.19. Substituting these values in Formula (7):

$$\begin{aligned} F &= 0.045\times(0.25-0.19)\times(70-40.7)\times 2100 \\ &= 166 \text{ gallons of oil per heating season.} \end{aligned}$$

Pitched Roofs. If in Example 2 the roof or top floor ceiling were to be insulated in addition to the walls, the fuel saving resulting therefrom should be added to the wall saving. Flat, horizontal roofs such as those of industrial buildings do not present any unusual problems, but pitched roofs frequently require special consideration. Reference is made in previous chapters to heated and unheated attics having pitched roofs; the following supplementary information on these subjects is important with respect to estimating fuel savings obtained by insulating pitched roofs and top floor ceilings.

Heated Attics. Where the attic is heated and the top floor ceiling applied directly to the underside of the roof rafters, thereby resulting in a sloping ceiling, the method of estimating the fuel saving is identical with that for walls, so long as the ceiling is parallel with the roof. The fuel saving must necessarily be based on some uninsulated construction, and the corresponding coefficient for the insulated construction. The coefficients for the uninsulated and insulated roof and ceiling constructions may be obtained directly from Table 15, Transmission Coefficients and Tables, and these coefficients substituted in the proper fuel-saving formula in this chapter together with the proper values for the roof area (A), the average temperature difference ($t-t_o$), and the other variables entering into the problem.

Example 3. A heated attic similar to that shown in Fig. 7, under Transmission Coefficients and Tables, has a net ceiling area of 1100 square feet. The roof is constructed of asphalt shingles on wood sheathing and the ceiling consists of wood lath and plaster applied to the roof rafters. What would be the fuel saving obtained by insulating this part of the building, if 1-inch insulating board lath is used instead of wood lath, the other conditions being the same as in Example 2?

Solution. According to Table 15 of the chapter Transmission Coefficients and Tables, $U=0.31$ and $U_i=0.17$. $A=1100$. Substituting the proper values in Formula (7):

$$F=0.045\times(0.31-0.17)\times(70-40.7)\times1100$$
$$=203 \text{ gallons.}$$

With the Cape Cod and certain other types of architecture, part of the top floor ceiling (the sloping portion) may be applied directly to the under side of the roof rafters and the remainder may be horizontal, as shown in Fig. 1. For maximum accuracy the latter portion of the roof structure should be estimated for *unheated attics*, because the ceiling of this portion is not parallel with the roof. However, in the majority of cases (especially if 50 per cent or more of the ceiling is applied directly to the rafters), it will be sufficiently accurate to assume that the entire ceiling is applied directly to the underside of the roof rafters, instead of only part of it, and the fuel saving estimated as in Example 3. The roof area (A) to be used in arriving at the fuel saving obtained by insulating the ceiling and/or roof should be the actual area over the heated portions of the house, based on the inside dimensions.

Suppose an attic is neither finished nor heated at the present time, but the owner desires to finish the attic with insulating board

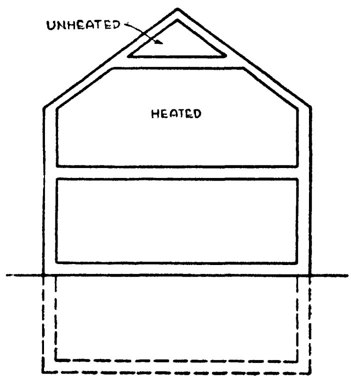


Fig. 1. Section through Cape Cod Type of Building

and to heat this space. The question naturally arises as to whether there would be any fuel saving. To be directly comparable, the temperature conditions must be alike in the two cases, that is, before and after the insulation is applied, but in this problem the attic was originally unheated and uninsulated and a comparison is desired with the attic heated and insulated. The proper solution of this problem is as follows:

1. Estimate the average unheated attic temperature, using Formula (3) from the chapter on Calculating Heat Losses.

2. Estimate the average hourly heat loss through the ceiling into the unheated attic.

3. Estimate average hourly heat loss from the heated and insulated attic, taking into consideration the proper inside temperature (t) and all outside wall, glass and roof surfaces of the attic.

4. If (3) is less than (2) there would be a fuel saving, and the amount of this saving would be determined by calculating the annual B.t.u. difference in the two cases and dividing this difference by the calorific value of the fuel and the heating efficiency.

The foregoing type of problem is somewhat comparable to that involving unheated attics having vertical wall surfaces, because the attic temperature, which must be taken into consideration in such problems, varies according to the amount of insulation applied to the ceiling or roof. This is discussed in the following paragraphs.

Unheated Attics. As vertical attic wall surfaces, particularly those containing windows, may have some bearing on the fuel saving obtained by insulating the top floor ceiling and roof surfaces, it is desirable that a distinction be made between roofs having such wall surfaces and those which do not, or at least have only a small amount. Insulation applied to these vertical wall areas also tends to reduce the fuel consumption. Therefore two types of pitched roof unheated attics will be considered in solving fuel saving problems, namely, (1) hip and double hip pitched roofs sloping in both directions, Figs. 1 and 2, and (2) gable and gambrel roofs having vertical wall surfaces, Figs. 3 and 4, in the chapter Effect of Building Insulation on Heating Plant Size. For the purposes of this discussion, unheated attics of pitched roofs having two or more dormers will be considered as being included in the second classification. The pitch of the roof also has some bearing on the fuel consumption and likewise on the fuel saving with insulation.

There are of course many modifications of the two types of roofs referred to in the preceding paragraph. While reasonable accuracy is desirable in solving problems of this nature, meticulous exactitude even if possible is not necessarily justified. In the majority of cases, a fair estimate of the fuel saving which may be expected is sufficient, but in order to avoid inconsistent or impossible results, all of the known factors having a reasonable bearing on the final answer should be considered.

Hip and Double Hip Roofs. Problems involving roofs of this type are solved by simply calculating the combined coefficients of the roof and ceiling, with and without insulation; U is the combined coefficient for the uninsulated roof and ceiling and U_i is the combined coefficient for the insulated roof and ceiling. These coefficients and the other variables entering into the problem, are then substituted in the proper fuel saving formula in this chapter.

Example 4. A hip roof having an area of 720 square feet consists of asphalt shingles on wood sheathing. The ceiling which has an area of 600 square feet consists of wood lath and plaster. What would be the fuel saving if 2-in. mineral wool were applied between the ceiling joists? The other conditions are the same as in Examples 2 and 3.

Solution. Refer to Formula (7) under Transmission Coefficients and Tables. The two coefficients U and U_i, would be obtained by means of this formula. In this problem $n=\frac{700}{600}=1.2$ and the value of U for the present problem is solved in Example 5, above chapter, this value being 0.28. U_r for the roof, calculated in accordance with Example 5, same chapter, is found to be 0.55; likewise U_c for the insulated ceiling is calculated as follows:

$$U_c=\frac{1}{\frac{1}{1.95}+\frac{1}{2.50}+\frac{2}{0.27}+\frac{1}{1.95}}$$

$$=\frac{1}{0.51+0.40+7.4+0.51}$$

$$=\frac{1}{8.82}$$

$$=0.11$$

Substituting in Formula (7), Transmission Coefficients and Tables, the combined coefficient of the insulated construction is as follows:

$$U_i=\frac{0.55\times 0.11}{1.2\times 0.55+0.11}$$

$$=\frac{0.0605}{0.66+0.11}$$

$$=0.079$$

These coefficients are based on the roof area. Substituting the proper value for U and U_i as well as the other variables in this problem in Formula (7), Table 2 of this chapter:

$$F = 0.045(U - U_i)(t - t_o)A$$
$$= 0.045 \times (0.28 - 0.079) \times (70 - 40.7) \times 720$$
$$= 0.045 \times 0.201 \times 29.3 \times 720$$
$$= 191 \text{ gallons of oil per heating season.}$$

Gable and Gambrel Roofs Having Vertical Wall Surfaces. Problems involving roofs of this type cannot be correctly solved by using the combined coefficients of the roof and ceiling, because the combined coefficient does not take into consideration the vertical wall surfaces, windows, dormers, etc. However, the results obtained by using the combined coefficients, with and without insulation, would not be seriously in error in many cases. For maximum accuracy the proper solution of problems of this type is first to estimate the average attic temperatures (t_a) during the heating season with and without insulation, using Formula (3), Calculating Heat Losses. The next step is to calculate the hourly transmission heat losses through the ceiling by means of Formula (1), same chapter, substituting the attic temperatures (t_a) with and without insulation, for t_o in this equation. The difference between these two quantities should then be multiplied by the number of hours in the heating season and divided by the calorific value of the fuel and the heating efficiency. The result will be the annual fuel saving.

Estimating Fuel Saving with Ventilated Attics. If an unheated attic is vented, or ventilated, or has open or poorly-fitted windows, the problem of estimating the fuel saved by attic insulation becomes somewhat complicated because of the uncertainty of the effect of the ventilation on the attic temperature. Theoretically, the correct procedure would be to estimate the ventilated attic temperature with and without insulation, and then calculate the heat loss through the ceiling, using the proper temperature difference in each case, together with the ceiling coefficients and the ceiling area. The fuel saving due to insulation would be the difference between these two results.

From a practical standpoint it is seldom that this procedure would be justified. Instead, either of two courses would be followed; namely, (1) the effect of the venting or ventilation would be neglected entirely and the attic temperature assumed to be the same as without ventilation, in which case the full value of the roof would be allowed, or (2) the roof would be neglected and the average attic temperature assumed to be the same as the average outside temperature.

Table 3. Annual Fuel Savings per 1000 Square Feet of Insulated Area[a]

This table is based on an average temperature difference during the heating season (t-t_o) of 35 degrees, and 1,000 square feet of insulated area.

Coefficient Difference ($U-U_i$)	Annual Fuel Saving							
	Coal (Tons)		Oil (Gallons)		Manufactured Gas (1000 Cu. Ft.)		Natural Gas[b] (1000 Cu. Ft.)	
	Hand-Fired (Residences)	Stoker (Residences)	Conversion Burner	Oil-Designed	Conversion Burner	Gas-Designed	Conversion Burner	Gas-Designed
	A	B	C	D	E	F	G	H
0.04	0.55	0.46	84	63.0	20.5	16.6	11.0	8.9
0.05	0.69	0.57	105	78.8	25.6	20.8	13.7	11.1
0.06	0.82	0.68	126	94.5	30.7	25.0	16.4	13.4
0.07	0.96	0.80	147	110.3	35.8	29.1	19.2	15.6
0.08	1.10	0.91	168	126.0	41.0	33.3	21.9	17.8
0.09	1.24	1.03	189	141.8	46.1	37.4	24.7	20.0
0.10	1.37	1.14	210	157.5	51.2	41.6	27.4	22.3
0.11	1.51	1.25	221	173.3	56.3	45.8	30.1	24.5
0.12	1.65	1.37	242	189.0	61.4	49.9	32.8	26.7
0.13	1.78	1.48	263	204.8	66.6	54.1	35.6	28.9
0.14	1.92	1.60	284	220.5	71.7	58.2	38.4	31.2
0.15	2.06	1.71	305	236.3	76.8	62.4	41.1	33.4
0.16	2.20	1.82	326	252.0	81.9	66.6	43.8	35.6
0.17	2.34	1.94	347	267.8	87.0	70.7	46.6	37.8
0.18	2.47	2.05	368	283.5	92.2	74.9	49.3	40.1
0.19	2.61	2.17	389	299.3	97.3	79.0	52.1	42.3
0.20	2.75	2.28	420	315.0	102.4	83.2	54.8	44.5
0.21	2.88	2.39	441	330.8	107.5	87.4	57.5	46.7
0.22	3.02	2.51	462	346.5	112.6	91.5	60.3	49.0
0.23	3.16	2.62	483	362.3	117.8	95.7	63.0	51.2
0.24	3.30	2.74	504	378.0	122.9	99.8	65.8	53.4
0.25	3.43	2.85	525	393.8	128.0	104.0	68.5	55.7
0.26	3.57	2.96	546	409.5	133.1	108.2	71.2	57.9
0.27	3.70	3.08	567	425.3	138.2	112.3	74.0	60.1
0.28	3.84	3.19	588	441.0	143.4	116.5	76.7	62.3
0.29	3.97	3.31	609	456.8	148.5	120.6	79.5	64.5
0.30	4.11	3.42	630	472.5	153.6	124.8	82.2	66.8
0.31	4.25	3.53	651	488.3	158.7	129.0	84.9	69.0
0.32	4.38	3.65	672	504.0	163.8	133.1	87.7	71.2
0.33	4.52	3.76	693	519.8	169.0	137.3	90.4	73.5
0.34	4.66	3.88	714	535.5	174.1	141.4	93.2	75.7
0.35	4.80	3.99	735	551.3	179.2	145.6	95.9	77.9

[a]This table is based on the simplified formulas in Table 2.

[b]To obtain saving in *therms*, multiply figures for natural gas by 10.

The first procedure, that of neglecting the ventilation and allowing the full value of the roof, would involve the least error in most cases. According to tests* conducted at the University of Minnesota, at $-10°F$, natural ventilation increased the heat loss about 5 per cent; mechanical ventilation, about 4.3 per cent. Following are the results of the tests (inside temperature, 70°F):

Outside Temperature (Deg. Fahr.)	Attic Temperature (Deg. Fahr.)		
	No Ventilation	Natural Ventilation	Mechanical Ventilation
+15	26.9	24.2	24.3
+10	22.6	19.9	19.7
+ 5	17.3	13.9	14.4
0	11.8	7.8	9.6
−10	3.9	0.2	1.6

If the roof were neglected and the average attic temperature assumed to be the same as the average outside temperature, the proper place to apply the insulation would be in the top floor ceiling or the attic floor. The fuel saving would then be estimated by substituting the average temperature difference $(t-t_o)$, the ceiling coefficients with and without insulation, and the ceiling area (A) in the proper fuel-saving formula.

Fuel Saving Tables. Table 3 may be used for estimating quickly the fuel savings for various types of construction and for various fuels. This table is based on the simplified formulas in Table 2 and an average temperature difference during the heating season of 35 degrees Fahrenheit, which of course would be equivalent to an inside temperature (near the surface involved) of 70° and an average outside temperature of 35°, or an inside temperature of 75° and an average outside temperature of 40°. For temperature differences other than 35 degrees, it is only necessary to divide by 35 and multiply by the actual temperature difference. The fuel savings are for 1000 square feet of net insulated area. Obviously if both the walls

*Note: These data were extracted from Table XII, *Bulletin No. 17* of the Engineering Experiment Station of the University of Minnesota entitled *Methods of Moisture Control and Their Application to Building Construction*, by F. B. Rowley, A. B. Algren and C. E. Lund. Tests were conducted on small-sized test houses provided with attics. The roof consisted of 8-inch pine ship-lap sheathing, covered with roofing paper. The ceilings below the attic were constructed with 2x4 joists, metal lath and plaster, and 3⅝ inches of mineral wool between joists. The natural ventilation openings were 0.125 square inch in each gable per square foot of ceiling area. The mechanical ventilation figures were based on 1.5 cubic feet of outside air supplied to attic space per hour per square foot of ceiling area.

and roof (or top floor ceiling) are insulated, these fuel savings should be added together to get the total fuel saving for the building.

To solve a problem by means of Table 3, ascertain the coefficients of the uninsulated and insulated constructions from the heat transmission tables and then locate this coefficient difference ($U-U_i$) in the left hand column of Table 3. The annual fuel saving per 1000 square feet of insulated area may then be determined by reference to Columns *A* or *B* for coal, *C* or *D* for oil or *E*, *F*, *G* or *H* for gas.

Example 5. A wall of a certain construction has a coefficient without insulation of 0.25 and 0.15 when insulated with a certain material. The net insulated wall area is 1400 square feet and the building is located in Minneapolis, Minnesota. If coal, hand-fired, is the fuel, what will be the fuel saving if the inside temperature is 70°?

Solution. The coefficient difference ($U-U_i$) is 0.25−0.15, or 0.10. Find 0.10 in the left hand column of Table 3 and note under Column *A* that the fuel saving is 1.37 tons of coal per heating season, per 1000 square feet of insulated area. For 1400 square feet the fuel saving will be $\frac{1400}{1000}\times 1.37$ or 1.92. This however is for an average temperature difference of 35 degrees. According to Table 1, the average temperature difference for Minneapolis will be 40.6 for a 70° inside temperature. Therefore, the fuel saving will be $\frac{40.7}{35}\times 1.92$, or 2.23 tons of coal per heating season.

Industrial and Commercial Buildings. The industrial fuel saving problem is essentially the same as that of any other fuel saving problem except that frequently large areas of high ceilings are involved. For ceiling heights above 10 feet, the proper allowance should be made for the fact that the temperature at the ceiling will be higher than at the breathing line. The factors which govern this allowance are (1) the breathing-line temperature, (2) the ceiling height and (3) the type of heating system, and the rules for estimating the air temperature at the ceiling are given in the chapter on Calculating Heat Losses.

The allowance for buildings heated by radiators and convectors is two per cent per foot of height above the breathing line (5 feet from floor) up to ceiling heights of 20 feet. Above 20 feet, the allowance is one per cent per foot of height for this method of heating. The allowance for buildings heated by unit heaters or any type of heating or ventilating system which involves mechanical circulation and distribution of the air by means of fans or blowers is one per cent per foot of height above the breathing line.

Reduced Night Temperatures. If lower temperatures are maintained during the night the fuel consumption will be reduced and the fuel saving will be correspondingly less.

For industrial buildings which may operate at reduced temperatures for long periods, the night temperature may have a greater bearing on the result. The actual allowance to be made may be approximated as follows: Assume that the inside temperature (t) at the ceiling for a certain building is 70° and the average outside temperature (t_o) during the heating season, 30°. The average temperature difference will then be 40 degrees. If the temperature at the ceiling is 60° for 12 hours per night, the average night temperature difference will be 30 degrees instead of 40. But this average temperature difference prevails for 12 hours or ½ of the time; consequently the average temperature difference will be reduced by ½ of 10, or 5 degrees, which is $\frac{5}{40}\times 100$ or 12½ per cent. Hence the fuel saving due to insulation will be 12½ per cent less in this case.

This factor, however, does not amount to as much for residences as is sometimes supposed, usually from about 4 to 10 per cent, depending on the conditions.

Degree-day Method. Another method of estimating fuel savings is by means of the degree-day, which is a unit based on temperature and time. For any day there are as many degree-days as there are degrees Fahrenheit difference in temperature between the average outside air temperature, taken over a 24-hour period, and a temperature of 65°F. Formula (1), modified for degree-days, would be as follows:

$$F_d=\frac{24(U-U_i)AD}{CE} \qquad (14)$$

where

F_d = Fuel saving based on annual degree-days.

D = Degree-days per year.

Degree-days for various cities in the United States are given in the Degree-Day Handbook by Clifford Strock and C. H. B.

Hotchkiss; also in the Heating, Ventilating and Air Conditioning Guide.

Example 6. Solve Example 2 for this chapter by the Degree-Day method, using Formula (14). For New York City, there are 5347 degree-days (D). The area (A) is 2100, $U=0.24$; $U_i=0.19$; $C=141{,}000$ and $E=0.80$. Substituting in Formula (14):

$$F_d=\frac{24(0.24-0.19)\times 2100\times 5347}{141{,}000\times 0.80}$$
$$=120 \text{ gals.}$$

The result obtained by the Degree-Day method will not necessarily coincide with that obtained by the use of the average inside-outside temperature difference and the number of hours during the heating season, as in Formulas (1) to (13) inclusive. This is because the degree-day is based on the difference between 65° and the outside temperature whereas Formulas (1) to (13) are based on the difference between the inside temperature, which usually is other than 65°, and the outside temperature. The 65° base was the result of an investigation which indicated that heat is required when the outside temperature is about 65° or below. It was also found that the temperature at which there was no steam consumption averaged 66°F. for 163 buildings of various types. Theoretically the fuel consumption should be proportional to the difference between the inside temperature and the outside temperature. The discrepancy is apparently due to the combined effects of wind velocity and solar radiation which are not taken into consideration in the degree-day, but which have a tendency to lower the base.

So far as fuel saving with insulation is concerned, it is only necessary to consider the average temperature difference and for this reason, Formulas (1) to (13) inclusive are recommended. Furthermore, these formulas are adapted to take into consideration the inside temperature near the surface involved which may be an important factor in the case of high ceilings where the temperature is comparatively high.

CHAPTER IX

ECONOMICS OF INSULATION

Where fuel economy is the primary consideration, insulating materials are much the same as stocks, bonds and other securities which pay a periodic dividend or return on the investment. In order to arrive at the economic value of an insulation, it is necessary to consider both the dollar value of the annual fuel saving and the cost of the insulation. Where the B.t.u. saving is sufficient to permit a reduction in the size of the heating plant, the dollar value of this saving should be credited against the cost of the insulation, as explained under Effect of Building Insulation on Heating Plant Size.

Cost of Insulating. The cost of insulating a building depends not only on the cost of the insulating materials used, but also on the cost of application including the labor and any required accessory materials such as nails, clips, wire and furring strips. Except where the insulation is to be applied by the home owner, the cost of insulating must necessarily be based on contractors' proposals. These costs will vary with the type and thickness of insulation, labor and material costs, competitive conditions and other factors. With these many variables to be considered, it is obviously impossible to make general statements of cost that will apply to all conditions.

Material Costs. As with other commodities, consumer and contractor prices of insulating materials fluctuate continually and vary with the type of insulation as well as the locality. Contractor prices are, of course, generally somewhat less than consumer prices. Current material prices can always be obtained locally from lumber and building supply dealers and other sources. It should be kept in mind, however, that the price alone is not always a satisfactory index of the value of an insulating material. All of the physical properties, including the insulating value, together with the conditions under which the material is to be used, should be taken into consideration in order properly to judge the merits of an insulation.

Labor Costs. Labor costs depend on the rate at which the materials can be applied as well as the prevailing wage scales. The time required to apply 1000 square feet of insulating material ranges from less than 5 hours per man to about 20 hours. Wage scales vary from about 50 cents to about $1.75, the lower scale in general applying to rural communities and the higher scale to larger cities where the scale usually is fixed by labor unions.

Combined Material and Labor Costs. The applied cost of the majority of insulating materials at current prices, including both labor and materials, ranges from about 4 cents per square foot to 12 cents per square foot for material ½ inch or more thick, based on contractors' prices. Materials of lesser thickness and certain types of reflective materials which are not measured by thickness may in some cases cost less. Certain products may exceed the upper limit. These include corkboard and structural insulating board roof insulation when applied in hot bitumen on flat roofs under built-up roofing in thicknesses up to 2 inches or more, which will vary in cost with the thickness used.

Net Insulating Cost. Insulation costs apply to the addition of an insulating material to a wall or roof structure whereby the entire cost of the insulation and labor is extra. Where other materials are replaced, the net cost of the insulation must be considered. This is the installed cost of the insulation minus the installed cost of the materials replaced. In the case of insulating board sheathing, the installed cost is frequently no more than that of the lumber and building paper it replaces, and hence the net insulation value thus obtained is "free." The fact that the installed cost of insulating board sheathing is about the same (or even less in some cases) than that of conventional lumber is due to the lower labor cost for applying the insulating board sheathing. A survey made by an insulating board manufacturer revealed that the average labor time required for applying 1000 square feet of $\frac{25}{32}$-inch vertical insulating board sheathing was 9 hours, as compared to an average of 15 hours for sheathing 1000 square feet of surface with lumber.

Net Insulating Cost Versus Net Insulating Value. While it is proper to consider the net insulating cost as described in the preceding paragraph, it is also correct to consider the net insulating value for the conditions under which the insulation is to be used. Thus the net insulating value derived by the use of insulating board sheathing in place of wood sheathing would be represented by the difference in the coefficients of transmission of the type of construction involved with and without insulation. For example, the coefficient of transmission of a wood frame wall consisting of wood siding, wood sheathing, studding, wood lath and plaster is 0.25, whereas the coefficient of transmission of a similar wall with structural insulating board sheathing is 0.19. The net insulating value of the insulating board sheathing is represented in this case by the difference between 0.25 and 0.19, or 0.06 B.t.u. per hour per square foot per degree Fahrenheit temperature difference. This coefficient difference can be translated into fuel saving from data in the chapter on Fuel Saving.

There are other conditions of application where the construction is modified from a heat-transmission standpoint in such a manner that the net insulating value should be considered. For example, the application of an insulating material may necessitate the use of furring or nailing strips which would thereby provide an additional air space, so that the net result would include the heat resistance of the air space as well as that of the insulation. An example of this is a flexible insulation installed between the studding so as to divide the air space into two parts. The net value of the insulation should, therefore, be expressed in terms of the coefficient of transmission of the insulated wall.

Still another example is that of the air spaces between studs being completely filled by the insulating material used so as to cancel the value of the air space. Although the relative value of the air space is comparatively small in this case, the difference is sufficient to warrant consideration, and the net insulating value as reflected by the coefficient of transmission with insulation should be used in the calculations.

Ratio of Insulation Cost to Total Cost of Building. The ratio of the insulation cost to the total cost of a building depends on many variables. These include the type and thickness of insulation, how and where it is used, the net cost of the insulation and the total cost of the building. Thus percentage figures of this character are likely to be misleading unless definitely qualified as to the conditions involved.

Fuel Costs. Data on methods of estimating fuel savings due to insulation are given in Fuel Saving. In order to evaluate these savings it is of course only necessary to multiply the saving in each case by the cost of fuel. Thus if the annual fuel saving in a certain instance is 6 tons of coal and the coal costs $10.00 per ton, the annual fuel saving "dividend" will be $60.00.

Return on Investment. The annual *gross* percentage return on the insulation investment is determined by dividing the annual dollar value of the fuel saving (the dividend) by the net cost of the insulation, and multiplying by 100 to change to per cent. To obtain the *net* return on the investment, a deduction should be made for fixed charges such as interest on investment, insurance, building depreciation and repairs.

Example 1. The wall construction of a certain building consists of brick veneer, building paper, wood sheathing, studding, metal lath and plaster. If 1-inch blanket insulation is used (in contact with the sheathing), what will be the annual gross return on the investment, assuming the installed cost to be $60.00 per 1000 square feet of insulated area? Coal, hand fired, is the fuel and costs $10.00 per ton. The average temperature difference during the heating season is 35 degrees.

Solution. According to Table 4, Transmission Coefficients and Tables, the coefficient of transmission of the uninsulated wall is 0.28 and that of the insulated wall is 0.14, and the coefficient difference, therefore, is 0.14. The fuel saving according to Table 3, Fuel Saving, is 1.92 tons of coal per heating season per 1000 square feet of insulated area. Therefore, the annual fuel saving has a value of $19.20 and since the insulation costs $60.00 per 1000 square feet installed, the

$$\text{Return on investment} = \frac{\$19.20}{\$60.00} \times 100 = 32.0 \text{ per cent (gross)}$$

In the case of stocks, bonds and other securities, the investment paying the highest return frequently is the most speculative, while a low return usually is associated with the safest and most secure of investments. Therefore, the return on the investment is not necessarily a reliable index as to the desirability of a security. Similarly the return on the investment is not necessarily a criterion for selecting the type or thickness of insulation to use. If this were so, the material which pays the highest return on the investment would always be the material to use, whereas it may be economical to use more insulation than the type or thickness which will pay the highest return, as will be apparent from a study of the subjects of Diminishing Return and Optimum Thickness, both of which will be found in this chapter.

Diminishing Return. There are many examples in everyday experience of *the law of diminishing return.* This law or principle governs the effectiveness of insulating materials. Diminishing return is the result of an approach toward some limit which is never reached except at infinity. In the case of insulating materials, the limit is a structure or barrier having a zero rate of heat loss ($U = 0.00$) which theoretically is attained by means of an infinite thickness of insulation, regardless of its conductivity. As this limit is approached, the effect of each successive increment of insulation thickness diminishes and finally reaches a point which may be regarded as the practical limit when considered from the standpoint of its effectiveness.

Practically, the law of diminishing return means that the first layer of insulation is always the most effective and that each successive layer of the same thickness is less and less effective. This principle may be illustrated in either of two ways, namely (1) by the diminishing return from each successive layer and (2) by the diminishing efficiencies of each successive layer with respect to the uninsulated construction. Examples of the latter will be found in the next chapter; the following is an example of the former illustration:

Consider a one-inch wood roof deck covered with built-up roofing; for an average temperature difference of 35 degrees, and a heating season of 5088 hours, the first half-inch layer of insulating board will save 2.39 tons of coal per heating season per 1,000 square feet of insulated area, based on coal having a calorific value of 13,000 B.t.u. per pound and a heating efficiency of 60 per cent. The second half-inch layer will save 0.92 ton; the third 0.57 ton, the fourth 0.34 ton, and so on. (See chapter on Fuel Saving.)

If coal costs $10.00 per ton, the value of the fuel saved by each layer will be $23.90, $9.20, $5.70 and $3.40, respectively. Based on the assumption that each half-inch layer of insulation costs the same, or $50.00 per 1,000 square feet installed, the returns per layer will diminish in the same ratio as the fuel saving. The annual return on the investment on the first layer will be

$$\frac{\$23.90}{\$50.00}\times 100 \text{ or } 47.8 \text{ per cent;}$$

that on the second layer, 18.4 per cent; the third, 11.4 per cent; the fourth, 6.8 per cent, and so on.

In practice the insulation cost per layer frequently diminishes as the number of layers (or the total thickness) increases. Consequently this assumption would not be strictly correct in all cases but the figures used are intended simply to illustrate the principle of diminishing return. The law of diminishing return is not applicable to a single material available in only one thickness if the comparisons are made with that material, since there must be successive increments of thickness (or heat resistance) to result in the diminishing return. This principle does apply, however, to aluminum foil or other reflective insulations which may be installed in single or multiple curtains. In this case the diminishing effect applies to successive curtains of foil of the same width of air space, not to thickness.

Optimum Thickness. If fuel had no value, if it were available in unlimited quantities without cost just as air is, there of course would be no object in conserving fuel and consequently no object in using insulation from an economic standpoint. Similarly, if commercial insulations were exorbitant in cost, it is conceivable that the fuel-saving dividend would not be sufficient to warrant the insulation expenditure.

It is apparent, however, from the foregoing data that a reasonable thickness of commercial insulation is well justified in most cases on the basis of the annual return on the investment. But if some insulation is justified, how much? What is the most economical, or the optimum thickness?

The answer to this question is based on two factors, namely (1) the dollar value of the heat lost through the wall (or roof) and (2) the cost of the insulation. If the wall or roof is not insulated, a certain number of B.t.u. will pass through the structure, and these heat units will have a certain value which will depend on the type and cost of the fuel used and the heating efficiency. Now as successive layers of insulation are added to the structure the number of heat units passing through the wall per heating season (and the value thereof) will decrease but the cost of the insulation will increase. At a certain point the annual cost of the heat lost through the wall and the annual cost of the insulation will be a minimum, and the thickness of insulation which will give this result is known as the optimum thickness. In other words, *the optimum thickness of insulation is that thickness which will result in the minimum combined annual costs of the heat lost through the wall and of the insulation added to the wall.* This is also known as the *economic* thickness.

It should be noted that the *annual* costs of both the heat lost through the wall and of the insulation are considered in arriving at the economic thickness of insulation. The annual cost of the heat is obtained by first calculating the amount of heat (expressed in tons of coal, gallons of oil or cubic feet of gas) passing through the wall per heating season. This may be accomplished by means of Formulas (**2**) to (**13**), inclusive, of the chapter on Fuel Saving, except that instead of the term $(U-U_i)$, a single coefficient of transmission (U or U_i) for the wall (or roof) should be used. After the fuel loss has thus been calculated, the annual value thereof may be determined by multiplying by the cost per ton, per gallon or per thousand cubic feet, depending on the fuel involved.

The *annual* cost of the insulation may be determined by multiplying the installed net cost of the insulation per square foot by the annual fixed charges expressed as a percentage of the initial cost of the insulation. These fixed charges include interest on investment, insurance, depreciation, repairs, etc. For example, if the insulation cost is 10 cents per square foot (net) installed and the annual fixed charges amounted to 10 per cent, the annual cost of the insulation would be 1 cent per square foot.

Example 2. Calculate the optimum thickness of insulation for a 4-inch concrete roof (covered with built-up roofing) with a suspended metal lath and plaster ceiling. See Fig. 1. The average temperature difference during the heating season is 35 degrees and the heating season is 5088 hours. The fuel is coal costing $10.00 per ton and the heating efficiency is assumed to be 0.60 (60 per cent). Insulation costs 5 cents per square foot per half-inch layer installed and the fixed charges are assumed to be 10 per cent per annum.

Solution. Formula (**3**) of Table 2 of the chapter on Fuel Saving may be used for calculating the heat lost through the roof expressed in tons of coal per heating season. For convenience, assume an area of 1000 square feet. The value of U of the roof (without insulation) is 0.40. Substituting the proper values in the aforementioned formula, the heat lost through 1000 feet of roof area will be $\frac{0.40 \times 35 \times 1000}{3070} = 4.56$ tons of coal. At a cost of $10.00 per ton this loss would have an annual value of $45.60.

In a similar manner, the annual cost of the heat lost through the roof may be calculated for successive thicknesses of insulation, based

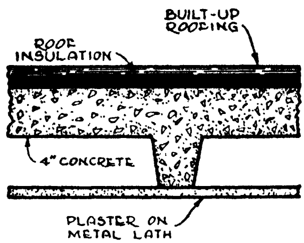


Fig. 1. Section through 4-inch Concrete Roof with Metal Lath and Plaster Ceiling (See Example 2)

on a conductivity of 0.33 B.t.u. per inch. These results are tabulated in Table 1. As previously explained, the annual cost of the insulation

Table 1. Average Annual Costs of Heat and Insulation Per 1000 Square Feet of Area for Typical Problem.*

A	B	C	D	E	F
Thickness of Insulation (Inches)	Coefficient of Transmission of Roof	Annual Heat Loss Through Roof (Tons of Coal)	Annual Cost of Heat Lost Through Roof	Annual Cost of Insulation	Combined Costs of Heat and Insulation
No Ins.	0.40	4.56	$45.60	....	$45.60
½	0.25	2.85	28.50	$ 5.00	33.50
1	0.18	2.05	20.50	10.00	30.50
1½	0.14	1.60	16.00	15.00	31.00
2	0.12	1.37	13.70	20.00	33.70
2½	0.10	1.14	11.40	25.00	36.40
3	0.086	0.98	9.80	30.00	39.80

*See Example 2, also Figs. 1 and 2.

is determined by multiplying the initial installed cost by the annual fixed charges. In this problem, the insulation is assumed to cost

5 cents per square foot or $50.00 per thousand square feet per half-inch layer, installed. If the fixed charges are 10 per cent, the annual insulation cost will be 10 per cent of $50.00 or $5.00 per layer. The annual costs for various thicknesses of insulation are tabulated in Column *E* of Table 1. The combined costs of heat and insulation are given in Column *F* of this table. These costs were determined by adding together the figures in Columns *D* and *E*. The figures in Columns *D, E* and *F* of Table 1 are plotted in Fig. 2. Note that

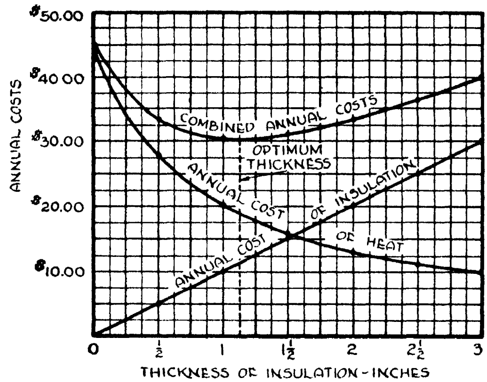


Fig. 2. Graphical Solution of Optimum Thickness Problem (See Example 2)

the curve for the combined costs of heat and insulation is at the lowest point at a thickness of slightly more than one inch of insulation. This would be regarded as the exact *theoretical* economic thickness for this problem. In practice, however, the nearest commercial thickness must be used, which in this case is one inch.

In Example 2 the annual cost of the insulation is assumed to be directly proportional to the thickness, consequently the *Annual Cost of Insulation* curve of Fig. 2 is a straight line. If the cost varies otherwise with the thickness, the values in Column *E* of Table 1 will, of course, be different and the *Annual Cost of Insulation* curve of Fig. 2 will be other than a straight line. This will also change the *Combined Annual Costs* curve of Fig. 2.

Optimum Thickness Formula. The optimum or economic thickness of insulation may also be conveniently determined by means of the following formula.*

*The derivation of this formula is given in a paper entitled "When Does Building Insulation Pay?" by Paul D. Close, Heating, Piping & Air Conditioning, December, 1934.

$$x = \sqrt{\frac{JN(t-t_o)k}{10{,}000Pz}} - \frac{k}{U} \qquad (1)$$

where

x = Optimum or economic thickness of insulation, inches.

J = Cost of useful heat, dollars per million B.t.u.

N = Number of hours during heating season.

$(t-t_o)$ = Average temperature difference during heating season.

k = Conductivity of insulation, B.t.u. per hour per square foot per degree Fahrenheit *per inch thickness.*

P = Annual fixed charges, per cent (expressed as a decimal fraction).

z = Installed cost of insulation, cents per square foot *per inch thickness.*

U = Coefficient of transmission of uninsulated wall or roof.

The quantity J, which represents the cost of producing useful heat in dollars per million B.t.u., depends on the cost of the fuel, its calorific value and the efficiency of utilization. For example, in the preceding problem coal costs \$10.00 per ton and is utilized with an efficiency of 60 per cent, the calorific value being 13,000 B.t.u. per pound. Each ton, therefore, contains $13{,}000 \times 2000 \times 0.60$ or 15,600,000 B.t.u. of useful heat which costs \$10.00. The cost of useful heat per 1,000,000 B.t.u. would, therefore, be $\frac{\$10.00}{1.56}$ or \$0.641. Further information on the cost of useful heat is given later in this chapter.

It should be noted that the installed cost of the insulation (z) is given in Formula (1) on a *per inch thickness basis.* Thus if the installed cost is 5c per square foot per half-inch thickness, the installed cost per 1-inch thickness will be 10c per square foot. In many cases the cost per inch depends on the actual thickness involved. In this event it is necessary to arrive at the economic thickness by a trial and error process. The procedure is to assume a reasonable average cost per inch thickness and to calculate the economic thickness accordingly by means of Formula (1). A certain thickness—say 1½ inches—will be obtained. Using the cost per inch for this thickness, the economic thickness should again be calculated by means of Formula (1). Usually this second trial calculation will be sufficient, but if desired, a third or fourth trial may be made, using in each case the installed cost per inch thickness for the total thickness obtained in the previous calculations. Problems of this character, however, do not usually warrant this degree of refinement; *first,* because the nearest commercial thickness of insulation must necessarily be selected in all cases which may not coincide with the theoretical thickness and, *second,* because the actual exact values of many of the quantities used in the calculations are doubtful.

Special Conditions. Certain questions will naturally arise concerning the application of the economic thickness formula, Formula (1). How is this formula applied where structural materials which may have some heat-resistance value, are replaced? How is the economic thickness determined where only one thickness is possible, such as hand-packed fill materials installed between studding which also alter the conditions of the problem by cancelling an air space and for which there is no provision in the theoretical formula?

Formula (1) is predicated on the assumption that the material in question is available in successive layers or thicknesses. If a product can be installed in one thickness only, obviously that is the only thickness that can be considered. So far as frame walls are concerned, hand-packed, poured or "blown-in" fills are available in one thickness only, the width of the stud space. Bats are usually available in two thicknesses, but the costs are not necessarily proportional to the thickness.

Where materials are replaced and the insulation is "free," as is often the case with insulating board sheathing, there would, of course, be no initial or annual insulation cost. Obviously this insulation is justified from an economic standpoint under any and all circumstances. Whether or not any additional insulation is warranted may be determined by means of Formula (1), using the coefficient of transmission of the insulated wall for the value of U and the proper cost per inch of thickness for the additional insulation.

It should be noted that the economic thickness of insulation is determined independently for each surface of a building. In other words, the proportionate areas of the walls and roof have no bearing on the economic thickness of insulation.

Maximum Wall Coefficient. The following empirical formula is convenient for determining the maximum economical wall coefficient

(U_m) based on the cost of useful heat and the average temperature difference during the heating season:

$$U_m = \frac{1}{\sqrt{J(t-t_o)}} \tag{2}$$

This formula is based on fuel economy only and does not take into consideration the question of summer heat. The wall or roof coefficient should not exceed the value derived from this formula, although a lower wall coefficient may be justified if the cost of the insulation is taken into consideration in accordance with Formula (1).

Example 4. Calculate the maximum economical wall coefficient for coal costing $10.00 per ton, based on a heating efficiency of 60% if the building is located in Chicago and the average temperature difference is 34 degrees for an inside temperature of 70°F.

Solution. For these conditions $J=0.641$ (Table 2) and $t-t_o=34$. Substituting in Formula (2),

$$U_m = \frac{1}{\sqrt{0.641 \times 34}} = \frac{1}{4.72} = 0.21$$

Cost of Useful Heat. Reference has been made to the cost of useful heat represented by the term J. Tabular values for coal in

Table 2. Costs of Useful Heat per 1,000,000 B.t.u.—Coal*

The costs in this table are in dollars per 1,000,000 B.t.u. of useful heat as produced in the building for the various heating efficiencies indicated

Cost of Coal (Dollars per Ton)	Heating Efficiency		
	50%	60%	70%
$4.00	$0.308	$0.256	$0.219
5.00	0.385	0.321	0.275
6.00	0.462	0.385	0.330
7.00	0.538	0.449	0.385
8.00	0.615	0.513	0.440
9.00	0.692	0.577	0.495
10.00	0.769	0.641	0.549
11.00	0.846	0.705	0.640
12.00	0.923	0.769	0.659
13.00	1.00	0.833	0.714
14.00	1.077	0.897	0.769
15.00	1.154	0.962	0.824
16.00	1.231	1.026	0.879
17.00	1.308	1.090	0.934

*This table is based on coal having a calorific value of 13,000 B.t.u. per pound.

dollars per 1,000,000 B.t.u. and based on three efficiencies, are given in Table 2. Values for oil and natural and manufactured gas are given in Fig. 3. The cost of useful heat for oil at 7c per gallon, is,

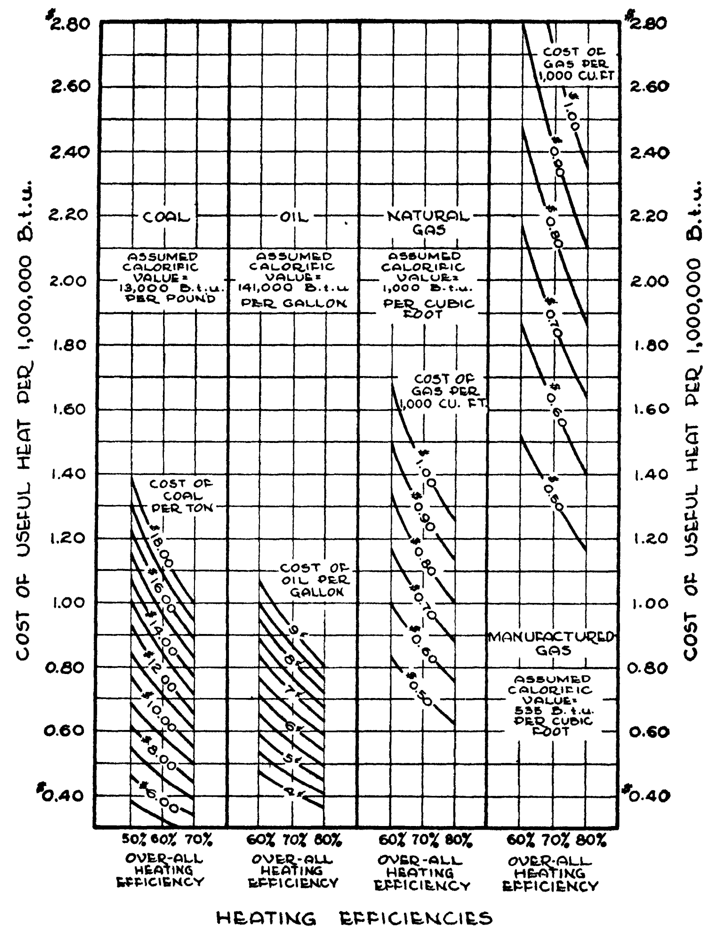


Fig. 3. Chart for Estimating Cost of Useful Heat per 1,000,000 B.t.u. From *A New Chart for Comparing Fuel Costs* by Paul D. Close (Heating and Ventilating, October 1937).

according to this chart, about $0.71 per 1,000,000 B.t.u. based on an over-all heating efficiency of 70%.

This chart is also useful for comparing heating costs based on the various types of fuel. All points on any horizontal line represent the same cost per 1,000,000 B.t.u. Thus, natural gas at $0.60 per

1000 cubic feet and a 60% over-all heating efficiency is equivalent to oil (141,000 B.t.u. per gallon) at about 8½c per gallon and a heating efficiency of 60%. This is also equivalent to 13,000 B.t.u. coal costing $13.00 per ton for a 50% efficiency.

The comparative heating costs of any two fuels can also be obtained from this chart by ascertaining the cost per 1,000,000 B.t.u. for each and then computing the ratio. For example, oil at 7c per gallon and a 70% heating efficiency costs about $0.71 per 1,000,000 B.t.u. of useful heat. Manufactured gas (535 B.t.u.) at $0.60 per 1000 cubic feet and 70% efficiency costs $1.60 per 1,000,000 B.t.u. of useful heat. Therefore, in this case the ratio of the manufactured gas to oil will be $\frac{1.60}{0.71}$ or 2.3. In other words, the manufactured gas will cost 2.3 times as much as the oil for these conditions.

For mixed gas consisting of a mixture of natural and manufactured gases, the calorific value should be ascertained and the cost per 1,000,000 B.t.u. calculated by dividing the cost per 1000 cubic feet by the calorific value and the heating efficiency and multiplying by 1,000,000. Thus 800 B.t.u. gas costing $0.60 per 1000 cubic feet, based on a heating efficiency of 80% (0.80), would cost $\frac{0.60 \times 1{,}000{,}000}{800 \times 1000 \times 0.80}$ or $0.938 per 1,000,000 B.t.u. For gas sold on the basis of the therm (100,000 B.t.u.), use the natural gas scale (Fig. 3) and use ten times the therm price for the price per 1000 cubic feet.

Insulation Pays for Itself. Reference has been made to so-called "free" insulation, or insulation free in the sense that it costs no more than the materials it replaces. However, even though there may be an initial outlay for the insulation, as is more often the case, the insulation may be considered as paying for itself by means of the annual fuel saving dividends. Where an insulation is economically justified, the owner pays for the insulation even if he doesn't get it; that is, he pays for it with wasted heat, whereas if he does use insulation, the insulation ultimately pays for itself.

Thermal Precipitation of Dust: Lath Marks.* It has been known for many years that heat has an effect on dust and that dirt particles will adhere more readily to cold surfaces than to warm surfaces. For

*For more detailed information on this subject see "Dirt Patterns on Walls" by R. A. Nielsen, (American Society of Heating & Ventilating Engineers Journal Section, Heating, Piping & Air Conditioning, June 1940).

example, a cold rod suspended in dusty air becomes dirty, whereas a hot rod remains clean. The extent to which dust or dirt accumulates on a wall surface is a function of the temperature gradient or the difference in temperature between the surface and the air in contact with it, the colder the surface, the greater will be the amount of dirt precipitated. There are other factors which have a bearing on the amount of dust precipitated on a surface, such as the character or finish of the surface, moisture and electrical forces and convection,

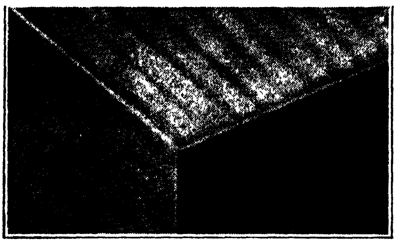


Fig. 4. Closeup View of Corner of Room Showing Dust Deposit on the Cooler Plaster Surfaces between Laths

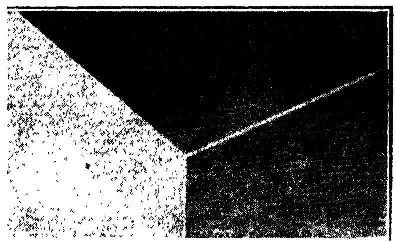


Fig. 5. Corner of Room Plastered on Insulating Plaster Base

but it appears that thermal precipitation is the most prolific cause of dirt patterns on walls and ceilings.

Where there are variations in surface temperatures these surfaces, therefore, do not become uniformly dirty but show a mottled or striated appearance resembling an X-ray of the structure behind the wall and outlining the studding, headers, lath and nails. In the case of uninsulated walls, the surfaces will be substantially colder between the studs than at the studs, thus resulting in greater precipitation of dirt between the studs and leaving lighter colored streaks at the studs. Where wood lath and plaster are used, the lath will have greater heat resistance than the plaster; and the warmer surfaces at the lath will accumulate less dirt by thermal precipitation than the surfaces between the lath. This, of course, is the cause of lath marks. See Fig. 4.

Insulated wall surfaces are warmer in the winter than uninsulated surfaces and hence will acquire less dirt. Furthermore, an insulating plaster base not only decreases the amount of dirt accumulated, but also, due to the uniformity of the surface temperature, eliminates lath marks and streaks caused by surface temperature variations, as is shown by Fig. 5.

INSULATING BOARD ROOF INSULATION BEING APPLIED IN TWO LAYERS TO A ROOF DECK

Courtesy of The Celotex Corp., Chicago, Ill.

CHAPTER X

INSULATING EFFICIENCIES AND EXPANSION OF ROOFS

The addition of an insulating material to a wall, roof or other structure reduces the rate of heat loss through that structure. The percentage reduction in the rate of heat loss due to the insulation is known as the *insulating efficiency* and this quantity or relationship is expressed by the following formula:

$$E = 100 \times \frac{(U - U_i)}{U} \tag{1}$$

where

E = Efficiency of insulation (per cent)
U = Coefficient of transmission of uninsulated construction
U_i = Coefficient of transmission of insulated construction

Example 1. What is the efficiency of 1 in. of corkboard applied to a 4-in. concrete roof deck having a metal lath and plaster ceiling?

Solution. According to Table 14, of the chapter on Transmission Coefficients and Tables the coefficient of transmission (U) of the uninsulated construction is 0.40. The coefficient of transmission (U_i) of the insulated construction is 0.17. Therefore, the efficiency of the insulation in this case is

$$E = 100 \times \left(\frac{0.40 - 0.17}{0.40}\right)$$
$$= 100 \times \left(\frac{0.23}{0.40}\right) = 57.5\%$$

The efficiency of an insulation is the same as or equivalent to the amount of heat, expressed as a percentage, prevented from passing through the wall, roof or other construction in either direction. In Example 1, 57.5% less heat would escape through the roof to the outdoors in the winter due to the application of 1 inch of corkboard. Conversely in the summer, 57.5% less heat would penetrate the roof to the inside, per degree temperature difference.

Efficiency Varies with Construction. The efficiency of an insulation varies with the type of construction and therefore must always be stated in terms of the uninsulated construction. This will be apparent from an inspection of Formula (1), which shows that the value of E varies with the coefficient of the uninsulated construction (U) which also governs the coefficient of transmission of the insulated construction (U_i). For example, if in Example 1 the coefficient (U) had been 0.30 instead of 0.40, the coefficient (U_i) for 1 inch of corkboard would be 0.15 and the efficiency of the 1-inch layer of corkboard in this case would be 50% instead of 57.5%.

Variation of Efficiency with Conductivity. The conductivity of an insulation is sometimes incorrectly referred to as its efficiency. The conductivity does, however, affect the efficiency; the lower the conductivity, the higher the efficiency. Take for example a wall having a coefficient of 0.30, which may be considered to be an average value for an uninsulated wall. One inch of an insulation having a conductivity of 0.40 will have an efficiency in this case of about 43%. If the conductivity were 0.33 instead of 0.40, the efficiency of one inch of insulation would be 47.3%. Thus in this instance, a decrease in the conductivity from 0.40 to 0.33 increases the efficiency from 43% to 47.3%.

Variation of Efficiency with Thickness. The greater the thickness of an insulation, the greater the efficiency. The increase in efficiency, however, is not proportional to the thickness but instead follows the law of diminishing return, referred to in the preceding chapter. In order to illustrate this point, consider a wall having a coefficient of transmission without insulation of 0.30, and assume that successive one-half inch layers of structural insulating board are added. If the conductivity is 0.33, the coefficient of transmission of the wall with a one-half inch layer of this product added will be 0.206 and the efficiency will be

$$E = 100 \times \left(\frac{0.30 - 0.206}{0.30} \right) = 31.3\%$$

If two layers, a total of one inch, are added to the uninsulated wall, the efficiency will be 47.5% and the value of the second layer will be the difference between 47.5% and 31.3%, or 16.2%. In a similar manner, the efficiency of the third layer will be found to be 10.2%, the fourth 6.7%, the fifth 5.0%, the sixth 3.8%, the seventh

2.9%, the eighth 2.3% and so on. While this type of insulation would not ordinarily be used in these thicknesses, the calculations are extended to eight layers to show how the efficiency diminishes with the thickness. The percentage of heat "stopped" by each successive layer will likewise be reduced in the same ratio for those conditions, since, as previously stated, the efficiency of an insulation represents the

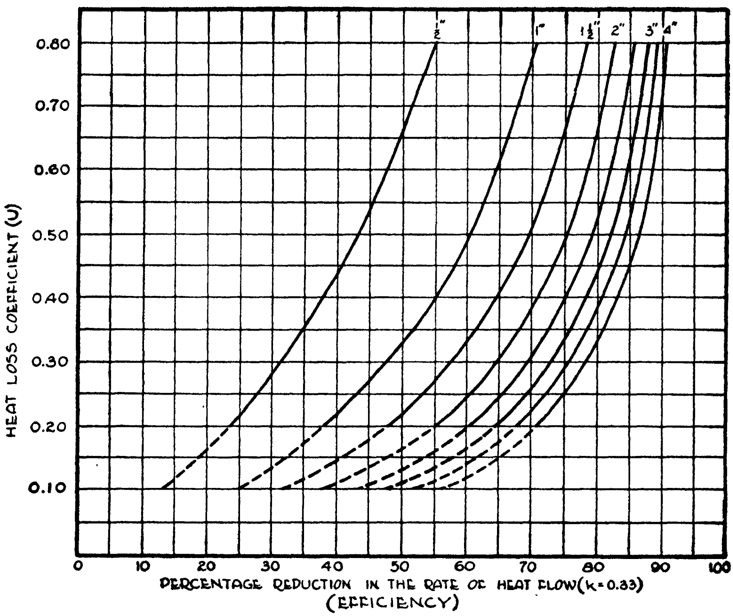


Fig. 1. Curves Showing Efficiencies of Various Thicknesses of Insulation for Various Values of U

amount of heat prevented from passing through the wall in either direction. Curves showing efficiencies of various thicknesses of insulation up to 4 inches for various uninsulated heat-loss coefficients are shown in Fig. 1.

It is obvious that no finite or commercial insulation can have an efficiency of 100%. This fact is illustrated by means of Fig. 2, from which it will be noted that even with 10 inches of insulation, the efficiency or percentage reduction in the rate of heat flow will not be 100%. It will also be noted that the curves begin to flatten out at about 1½ inches of insulation.

Value of Insulation Depends on Initial Coefficient. The value of an insulating material depends upon the initial coefficient of the wall or roof. Consider again a wall with a coefficient of 0.30. A ½-inch layer of insulation ($k = 0.33$) will reduce the coefficient to 0.206, or a reduction of 0.094. Now suppose the wall had an initial value of 0.20. In order to reduce the coefficient by the same amount—0.094—that is, from 0.20 to 0.106, it would be necessary to add a theoretical thickness of 1.465 inches of the same material, or say

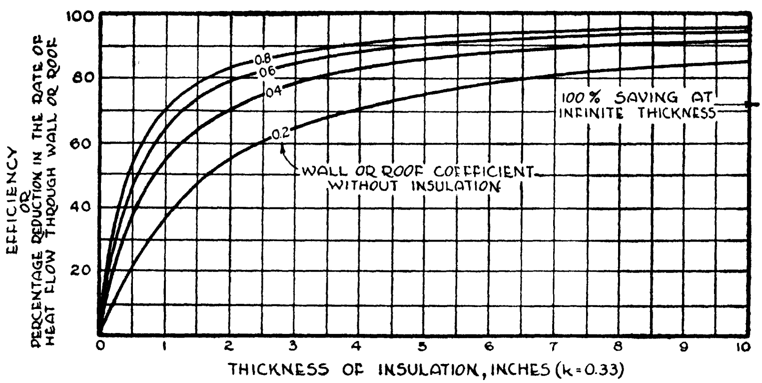


Fig. 2. Curves Showing Efficiencies Plotted against Insulation Thickness for Various Wall and Roof Coefficients

1½ inches. In other words, it would require nearly three times as much insulation to reduce the coefficient from 0.20 to 0.106 as from 0.30 to 0.206, or 0.094 in each case.

The efficiency of the ½-inch thickness which reduces the coefficient from 0.30 to 0.206, is 31.3%. The efficiency of the 1.465 inch thickness of the same material, which reduced the coefficient from 0.20 to 0.106, is 47%, or about 16% per one-half inch layer.

Net Insulation Efficiencies. Reference was made in the preceding chapter to the net insulating value of materials which replace others, such as insulating board sheathing and lath. The net insulating efficiency of the insulating board would be determined in the usual manner, by substituting the coefficients with and without insulation in Formula (1).

Example 2. What is the insulating efficiency of 25/32-in. insulating board sheathing and ½-in. insulating board lath when they are used in place of wood sheathing and plasterboard, respectively, in a wall having wood siding?

Solution. The coefficient (U) of the uninsulated wall is 0.25

and that of the insulated wall is 0.15. Therefore, the insulating efficiency is

$$E = 100 \times \left(\frac{0.25 - 0.15}{0.25}\right)$$
$$= 40\%$$

EXPANSION AND CONTRACTION OF ROOF DECKS

Building materials expand and contract with temperature changes. The amount of expansion varies with different materials and is expressed in terms of the coefficient of expansion, which is the fractional increase in length or volume per degree temperature rise. For example, the coefficient of expansion of concrete is about 0.0000065 per degree Fahrenheit.

When monolithic materials of high coefficient of expansion are used on large areas exposed to wide temperature changes, it is necessary that provision be made to compensate for the resulting expansion and contraction, as otherwise damage to the building is likely to occur. Instances have been reported where the walls of factory buildings have been pushed out of line sufficient to endanger the entire structure as the result of lack of provision for roof expansion. Where comparatively small unit materials such as tile and lumber are employed, the joints between the units generally will provide adequately for the expansion, but where monolithic concrete and gypsum are used over large areas, expansion joints should be installed. However, roof insulation applied to the *top surface* of a roof deck will appreciably reduce the temperature change in the deck, and will therefore reduce the amount of expansion and contraction of the roof. Likewise it will reduce the number of expansion joints necessary, or may completely obviate the necessity for expansion joints in the case of smaller buildings.

In order to illustrate the effect of roof insulation on the expansion and contraction of a roof deck, consider a 6-inch concrete deck covered with built-up roofing (Fig. 3). Such a roof deck, without insulation, will have the following resistances:

Outside surface ($f_o = 6.00$)	0.17
Roofing ($C = 3.53$)	0.28
6-inch concrete ($k = 12.0$)	0.48
Inside surface ($f_i = 1.65$)	0.61
Total resistance	1.54

Now assume that the temperature of the exposed *surface* will vary from −10°F. in the winter to 140°F. in the summer or a range of 150°F. For the purpose of this example, it will be assumed that the inside air temperature is the same in summer as in winter and is 70°F. although actually it will be warmer inside in the summer than in the winter. The problem is to determine the temperature change of the top surface of the concrete (based on the temperature gradient principle discussed in the next chapter) and the amount of expansion and contraction of the roof as the result of this temper-

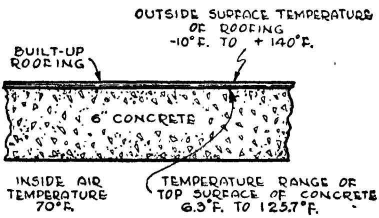


Fig. 3. Section through 6-inch Concrete Roof without Insulation

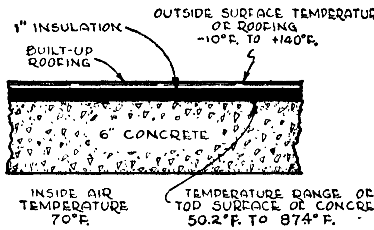
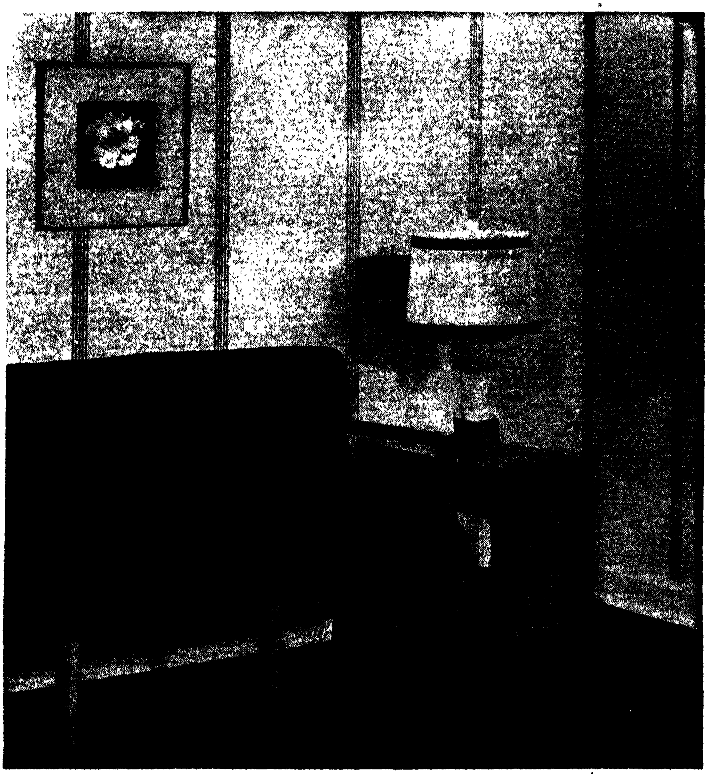


Fig. 4. Section through 6-inch Concrete Roof with One Inch of Insulation Applied

ature change. Since the outside surface temperatures are fixed by the problem, the outside surface resistance is not taken into consideration and the total resistance (exclusive of the outside surface) will then be 1.37. When the outside surface temperature is −10°, the temperature of the top surface of the concrete will be between −10° and 70° (the inside air temperature) or $\left(\frac{0.28}{1.37}\times 80\right)-10 = (0.204\times 80)-10=16.3-10=6.3$°F. When the roof temperature is at the other extreme or +140°F., the surface temperature of the concrete will be $140-\left\{\frac{0.28}{1.37}\times(140-70)\right\}=140-(0.204\times 70)=125.7$°F. Thus if the roof is not insulated the temperature of the top surface of the concrete will range from 6.3°F. to 125.7°F., or 119.4 degrees, as shown in Fig. 3.

If the roof deck is insulated with 1 inch of insulation having a conductivity of 0.33, or a resistance of 3.03, the total resistance will be 1.54+3.03 or 4.57, and the resistance of the roof less that of the top or exposed surface of the roofing will be 1.37+3.03 or 4.40. With this 1 inch of insulation applied to the roof over the concrete, the temperature of the top surface of the concrete will be $\left(\frac{0.28+3.03}{4.40}\times 80\right)-10=\left(\frac{3.31}{4.40}\times 80\right)-10=(0.752\times 80)-10=60.2-10$ $=50.2°F.$ when the outside surface temperature is $-10°F$. When the outside surface temperature is $+140°F.$, the temperature of the top surface of the concrete will be $140-\frac{0.28+3.03}{4.40}\times(140-70)=$ $140-\left(\frac{3.31}{4.40}\right)\times 70=140-(0.752\times 70)=87.4°F.$ The temperature range of the top surface of the concrete when the roof is insulated is, therefore, $87.4-50.2$ (Fig. 4) or 37.2 degrees. Thus the insulation will reduce the temperature range of the top surface of the concrete from 119.4 degrees to 37.2 degrees, or nearly two-thirds. The amount of expansion and contraction will similarly be reduced.



LIVING ROOM FINISHED WITH SCORED INSULATION BOARD

Courtesy of Maizewood Insulation Co., Dubuque, Iowa

APPLICATION OF SHIP-LAP INSULATING BOARD ROOF INSULATION TO A ROOF DECK

Courtesy of Wood Conversion Co., St. Paul, Minn.

CHAPTER XI

CONDENSATION

The problem of moisture condensation as it relates to insulating materials, involves the change from the gaseous state of water, known as water vapor, to the liquid state (water) or the solid state (frost or ice). There are many examples of moisture condensation in everyday experience, such as the formation of globules of water on the outside of a glass of cold water and the sweating and frosting of windows.

Condensation in Buildings. Condensation on the interior surfaces of factory and industrial buildings in which high humidities are maintained or result from manufacturing processes, is especially common. Water dripping from a ceiling may cause damage to manufactured articles and machinery, short circuiting of power and lighting equipment and discomfort to the occupants of the building. This deposition of moisture on the ceiling surfaces may also cause decay of the structural materials and ultimate failure. Sweating of walls is less prevalent and usually less destructive in factory buildings. In residences, wall and ceiling condensation is not as severe a problem as window condensation. The proper thickness of insulation incorporated in the wall or roof structure will prevent condensation on the interior surfaces thereof. This thickness may be determined in accordance with data in this chapter, as explained under *Surface Condensation.*

The water vapor, instead of condensing on the interior surfaces of the building may under certain conditions pass through the building materials and condense within the wall or roof structure unless proper precautions are taken to prevent this occurrence, as explained under the heading *Condensation within Walls,* in this chapter.

Humidity. Water exists in three states or conditions, namely, gaseous, liquid and solid. In the gaseous state, as explained in the introductory paragraph of this chapter, it is known as water vapor or *humidity.*

Air is a mixture of water vapor and a number of gases, including nitrogen and oxygen. The amount of water vapor the air can hold, or that can be mixed with the air, depends *solely* upon the temperature—the higher the temperature, the more water vapor the air can contain. The presence of the air mixed with the water vapor has no relationship to the amount of water vapor or humidity the space can contain, although it is common practice to speak of the humidity of the air.

Relative Humidity. As stated in the preceding paragraph, the capacity of a space to hold water vapor depends upon and increases with the temperature. When a given space contains the maximum amount of water vapor at any temperature without being supersaturated (which is possible under certain conditions), it is said to be saturated or to have a relative humidity of 100%. Usually, however, the air is not saturated with water vapor and therefore the relative humidity is less than 100%. The *relative humidity* is the ratio of the actual partial pressure of the water vapor to the saturation pressure at the dry-bulb temperature.* For practical purposes, this is the ratio of the amount of water vapor present at any given temperature to the amount the space could hold at that temperature if saturated. Thus, if a space at 70° contains 0.70 pound of water vapor per 1000 cubic feet of mixture, the relative humidity will be $\frac{0.70}{1.15} \times 100$ or about 61%, because it can hold a maximum of 1.15 pounds if saturated at this temperature.

Dew-Point Temperature. The capacity of a space to hold water vapor conversely decreases as the temperature decreases. Consequently, if the air at any specified temperature is not saturated and the temperature is reduced, the capacity to hold water vapor will be correspondingly reduced and the relative humidity will be increased until finally the air will be saturated, that is, it will have a relative humidity of 100%. The temperature at which this takes place is called the *dew-point temperature.* If the temperature is reduced below the dew point, some of the water vapor will be condensed to liquid.

*This is an approximate definition and is sufficiently accurate for the purposes of this text. The exact definition is as follows: *Relative Humidity* is the ratio of the partial pressure of the water vapor (calculated from the ratio by weight of water vapor to dry air and the observed pressure of the mixture of water vapor and dry air) to the saturation pressure of pure water corresponding to the actual temperature.

Wet- and Dry-Bulb Temperatures. The relative humidity in a space is usually measured by two ordinary thermometers, secured to a common base. The bulb of one of the thermometers is exposed and the temperature reading taken with this thermometer is the same as that taken with any other ordinary mercury thermometer. This is called the *dry-bulb temperature* to distinguish it from the reading taken with the other thermometer. The bulb of the other thermometer is enclosed in a small cloth bag which is moistened with water and which, due to evaporation* of this water, will give a lower temperature. This is called the *wet-bulb temperature.* Such a combination wet and dry-bulb thermometer is called a *psychrometer* or a *hygrometer.*

In order to obtain a true wet-bulb reading a sufficient period of time must elapse for evaporation of the water to take place and to bring the wet-bulb reading to a stationary point. To expedite this condition, the wet and dry-bulb thermometers may be attached to a handle or chain and whirled through the air until both the wet and dry-bulb readings become stationary. Such an apparatus is known as a *sling psychrometer.*

With the wet and dry-bulb readings known, it is a simple matter to determine the relative humidity and dew-point temperature by reference to a psychrometric table such as Table 1, or a psychrometric chart. If any two of these quantities are known, the other two can be determined from a psychrometric table or chart. For example, if the dry-bulb temperature is 70°F. and the wet-bulb is 65°F., the dew-point will be 62.4°F. and the relative humidity, 77%. See Table 1.

When the wet and dry-bulb readings are widely separated, the relative humidity will be low. As the wet-bulb reading approaches the dry-bulb, the relative humidity approaches 100%. The percentage limits of the relative humidity obviously are zero and 100%.

Surface Condensation. It will be apparent from the foregoing that whenever warm, humid air comes in contact with surfaces which are below the dew-point temperature, condensation of water vapor will take place. Therefore, in order to prevent condensation on any inside wall or ceiling surface, it is necessary to maintain the surface

*Evaporation of liquid lowers the temperature because heat is extracted when the liquid changes to a vapor. The heat required to change a liquid to a vapor is called the *latent heat of vaporization.*

Table 1. Dew-Point Temperatures and Relative Humidities

Reading of Thermometer Deg. F. Dry	Wet	Dew Point Deg. F.	Humidity %
50	50	50	100
	49	48.3	94
	48	46.2	87
	47	44.6	82
	46	42.1	74
	45	39.9	68
	44	37.6	62
	43	34.8	56
	42	32.2	50
	41	29.2	44
52	52	52	100
	51	50.3	94
	50	48.4	88
	49	46.6	82
	48	44.3	75
	47	42.3	69
	46	39.9	63
	45	37.6	58
	44	35	52
	43	32.3	47
	42	29	41
54	54	54	100
	53	52.3	95
	52	50.6	89
	51	48.8	83
	50	46.8	77
	49	44.8	71
	48	42.4	65
	47	40	59
	46	37.6	54
	45	35	48
	44	32.3	43
56	56	56	100
	55	54.3	94
	54	52.6	88
	53	50.8	83
	52	48.8	77
	51	47	72
	50	44.8	66
	49	42.6	61
	48	40.2	55
	47	37.8	50
	46	35	45
	45	32	40
58	58	58	100
	57	56.4	95
	56	54.6	89
	55	52.8	83
	54	51	77
	53	49.2	73
	52	47.3	67
	51	45.1	62
	50	42.9	57
58	49	40.5	52
	48	37.8	47
	47	35.2	42
60	60	60	100
	59	58.4	94
	58	56.7	89
	57	55	84
	56	53.1	78
	55	51.4	73
	54	49.5	68
	53	47.5	63
	52	45.3	58
	51	42.3	52
	50	40.8	49
	49	38.1	44
62	62	62	100
	61	60.5	95
	60	58.8	90
	59	57	84
	58	55.5	80
	57	53.5	74
	56	51.7	69
	55	49.8	65
	54	47.8	60
	53	45.7	55
	52	43.5	51
	51	41	46
	50	38.5	42
64	64	64	100
	63	62.5	95
	62	60.8	90
	61	59.3	85
	60	57.6	80
	59	55.7	75
	58	54	70
	57	52.1	65
	56	50	61
	55	48.3	57
	54	46.1	52
	53	43.8	48
	52	41.4	44
66	66	66	100
	65	64.5	95
	64	62.9	90
	63	61.4	85
	62	59.7	80
	61	57.9	75
	60	56.2	71
	59	54.4	66
	58	52.6	62
	57	50.6	58
	56	48.5	53
	55	46.4	49
66	54	44.2	45
	53	41.7	41
68	68	68	100
	67	66.6	95
	66	64.9	90
	65	63.5	86
	64	61.8	81
	63	60.2	76
	62	58.5	72
	61	56.7	67
	60	55	63
	59	53	59
	58	51.2	55
	57	49	51
	56	46.8	47
	55	44.6	43
70	70	70	100
	69	68.7	96
	68	67	91
	67	65.5	86
	66	63.9	81
	65	62.4	77
	64	60.7	73
	63	59	68
	62	57.2	64
	61	55.3	61
	60	53.6	56
	59	51.6	52
	58	49.6	48
	57	47.5	45
	56	45	41
72	72	72	100
	71	70.6	95
	70	69	91
	69	67.7	87
	68	66	82
	67	64.4	77
	66	62.8	73
	65	61.3	69
	64	59.5	65
	63	57.8	61
	62	55.9	57
	61	54	53
	60	52.2	50
	59	50	46
	58	48	43
74	74	74	100
	73	72.7	96
	72	71.2	91
	71	69.7	86
	70	68.2	82
	69	66.7	78
	68	65	74
74	67	63.4	69
	66	61.7	66
	65	60	62
	64	58.3	58
	63	56.5	55
	62	54.6	51
	61	52.7	48
	60	50.7	44
	59	48.4	40
76	76	76	100
	75	74.6	96
	74	73.2	91
	73	71.8	87
	72	70.3	83
	71	68.8	79
	70	67.2	75
	69	65.6	70
	68	64	67
	67	62.3	63
	66	60.6	59
	65	58.9	56
	64	57	52
	63	55.1	49
	62	53.2	45
	61	51.2	42
78	78	78	100
	77	76.7	96
	76	75.3	92
	75	73.8	87
	74	72.4	83
	73	70.8	79
	72	69.4	75
	71	67.8	71
	70	66.2	67
	69	64.6	64
	68	62.9	60
	67	61.3	57
	66	59.5	53
	65	57.8	50
	64	55.8	47
	63	53.8	43
	62	51.8	40
80	80	80	100
	79	78.7	96
	78	77.3	92
	77	75.9	88
	76	74.5	84
	75	73	79
	74	71.6	76
	73	70	72
	72	68.6	68
	71	66.9	65
	70	65.2	61
	69	63.7	58
80	68	61.9	54
	67	60	51
	66	58.3	48
	65	56.5	45
	64	54.5	42
82	82	82	100
	81	80.7	96
	80	79.3	92
	79	78	88
	78	76.6	84
	77	75.1	80
	76	73.7	76
	75	72.2	73
	74	70.7	69
	73	69	65
	72	67.6	62
	71	65.8	58
	70	64.2	55
	69	62.6	52
	68	60.7	49
	67	59	46
	66	57	43
	65	55.1	40
84	84	84	100
	83	82.7	96
	82	81.3	92
	81	80.1	88
	80	78.6	84
	79	77.3	81
	78	75.8	77
	77	74.3	73
	76	72.9	69
	75	71.3	66
	74	69.8	63
	73	68.2	59
	72	66.7	56
	71	64.8	53
	70	63.1	50
	69	61.5	47
	68	59.7	44
	67	57.7	41
86	86	86	100
	85	84.7	96
	84	83.4	92
	83	82.1	88
	82	80.7	85
	81	79.4	81
	80	77.8	77
	79	76.6	74
	78	75	70
	77	73.6	67
	76	72	63
	75	70.4	60
	74	68.9	57

Table 1. Dew-Point Temperatures and Relative Humidities (Continued)

Reading of Thermometer Deg. F. Dry	Reading of Thermometer Deg. F. Wet	Dew Point Deg. F.	Humidity %
86	73	67.3	54
	72	65.6	51
	71	63.8	48
	70	62	45
	69	60.4	42
88	88	88	100
	87	86.7	96
	86	85.4	92
	85	84.2	89
	84	82.7	84
	83	81.4	81
	82	80.2	78
	81	78.7	74
	80	77.2	71
	79	75.7	67
	78	74.3	64
	77	72.8	61
	76	71.2	58
	75	69.6	55
	74	68	52
	73	66.3	49
	72	64.6	46
	71	62.8	43
	70	61	41
90	90	90	100
	89	88.7	96
	88	87.4	92
	87	86.2	89
	86	84.9	85
	85	83.6	82
	84	82.3	78
	83	80.8	75
	82	79.5	72
	81	78	68
	80	76.4	65
	79	75	62
	78	73.4	58
	77	72	56
	76	70.4	53
	75	68.7	50
	74	67	47
	73	65.3	44
	72	63.6	42
92	92	92	100
	91	90.7	96
	90	89.5	93
	89	88.3	89
	88	87	86
	87	85.7	82
	86	84.3	78
	85	83	75
	84	81.6	72
	83	80.2	69
	82	78.7	66
	81	77.3	63
92	80	75.7	60
	79	74.2	56
	78	72.7	54
	77	71	51
	76	69.4	48
	75	67.8	46
	74	66	43
	73	64.4	40
94	94	94	100
	93	92.8	96
	92	91.5	92
	91	90.3	89
	90	89	86
	89	87.7	82
	88	86.6	79
	87	85.1	76
	86	83.7	72
	85	82.4	69
	84	80.9	66
	83	79.6	63
	82	78	60
	81	76.6	57
	80	74.8	54
	79	73.6	52
	78	71.8	49
	77	70.3	46
	76	68.6	44
	75	66.8	41
96	96	96	100
	95	94.8	96
	94	93.6	93
	93	92.4	89
	92	91	86
	91	89.7	81
	90	88.4	79
	89	87.2	76
	88	85.9	73
	87	84.5	70
	86	83.2	67
	85	81.8	64
	84	80.4	61
	83	78.9	58
	82	77.4	56
	81	75.8	53
	80	74.2	50
	79	72.7	48
	78	71	45
	77	69.4	42
	76	67.7	40
98	98	98	100
	97	96.8	96
	96	95.6	93
	95	94.3	90
	94	93.2	86
	93	91.9	83
98	92	90.5	80
	91	89.3	77
	90	88	74
	89	86.7	71
	88	85.3	67
	87	83.9	65
	86	82.5	62
	85	81.1	59
	84	79.7	56
	83	78.2	54
	82	76.7	51
	81	75	48
	80	73.3	46
	79	71.8	44
	78	70.2	41
100	100	100	100
	99	98.8	96
	98	97.6	93
	97	96.4	90
	96	95.2	86
	95	93.8	83
	94	92.7	80
	93	91.4	77
	92	90	74
	91	88.7	71
	90	87.4	68
	89	86.2	65
	88	84.8	62
	87	83.4	60
	86	82	57
	85	80.5	54
	84	79	52
	83	77.4	49
	82	75.9	47
	81	74.3	44
	80	72.5	41
	79	71	40
102	102	102	100
	101	100.8	97
	100	99.7	93
	99	98.4	90
	98	97.2	86
	97	96	83
	96	94.7	80
	95	93.4	77
	94	92.4	75
	93	90.9	71
	92	89.5	68
	91	88.3	66
	90	86.9	63
	89	85.6	60
	88	84.3	58
	87	82.8	55
	86	81.3	53
	85	80	50
	84	78.3	48
102	83	76.8	45
	82	75.2	43
	81	73.5	40
104	104	104	100
	103	102.8	97
	102	101.6	93
	101	100.4	90
	100	99.3	87
	99	98	84
	98	96.8	81
	97	95.6	78
	96	94.3	75
	95	93	72
	94	91.8	69
	93	90.4	66
	92	89	63
	91	87.8	61
	90	86.4	58
	89	85	56
	88	83.7	54
	87	82.3	51
	86	80.7	48
	85	79.3	46
	84	77.6	44
	83	76	42
106	106	106	100
	105	104.8	97
	104	103.7	94
	103	102.5	90
	102	101.3	87
	101	100.1	84
	100	98.8	81
	99	97.6	78
	98	96.4	75
	97	95.2	72
	96	93.8	69
	95	92.6	67
	94	91.3	64
	93	90	62
	92	88.5	59
	91	87.3	56
	90	86	54
	89	84.5	52
	88	83	49
	87	81.6	47
	86	80.2	45
	85	78.6	43
	84	77	40
108	108	108	100
	107	106.8	97
	106	105.6	94
	105	104.6	91
	104	103.4	88
	103	102.2	84
	102	101	82
108	101	99.7	78
	100	98.5	76
	99	97.3	73
	98	96	70
	97	94.7	67
	96	93.4	65
	95	92.3	62
	94	90.9	60
	93	89.5	57
	92	88	54
	91	86.7	52
	90	85.3	50
	89	84	48
	88	82.5	46
	87	81	44
	86	79.6	41
	85	78	40
110	110	110	100
	109	108.8	97
	108	107.7	94
	107	106.6	91
	106	105.4	88
	105	104.3	85
	104	103	82
	103	101.8	79
	102	100.6	76
	101	99.3	73
	100	98	70
	99	96.8	68
	98	95.6	65
	97	94.3	62
	96	92.9	60
	95	91.7	58
	94	90.4	55
	93	89	53
	92	87.4	50
	91	86.3	49
	90	84.8	46
	89	83.3	44
	88	82	42
	87	80.4	40
112	112	112	100
	111	110.9	97
	110	109.7	94
	109	108.6	91
	108	107.4	88
	107	106.3	85
	106	105.1	82
	105	103.9	79
	104	102.7	77
	103	101.4	73
	102	100.3	71
	101	98.9	68
	100	97.7	66
	99	96.4	63
	98	95.2	61

above the dew-point temperature. As stated above, this dew-point temperature may be determined in the case of existing buildings from the wet and dry-bulb readings taken with a sling psychrometer and then referring to a psychrometric table or chart. For buildings not yet constructed, the probable dew-point temperature can be estimated by comparison with relative humidity and temperature conditions in existing buildings of similar types.

Humidities Required for Industrial Processing. In certain industries the maintenance of a high relative humidity is essential to the manufacturing or conditioning process. In buildings of this type the required relative humidity will usually be known in advance. Desirable relative humidities for certain industrial processes are given in Table 2.

Humidities Resulting from Manufacturing Processes. In many industries the presence of excessive moisture in the air in the building is the result of certain manufacturing processes which produce or require excessive quantities of moisture. Among these are canning factories, laundries, paper mills, creameries, power plants and generating stations, and stone and marble plants. In buildings of this class, the relative humidities are likely to be somewhat more variable than in buildings in which specified humidities are maintained, and frequently vary between 70% and 90%, or higher under extreme conditions.

Humidities in Farm Buildings. High relative humidities are maintained or prevail in certain farm buildings, usually at comparatively low temperatures. For example, dairy barns and hog houses usually have humidities ranging from about 70 to 85%. The optimum humidity for poultry houses is about 65%. The temperatures in insulated dairy barns usually range between 45 and 55°, in hog houses 60 to 65° and in poultry houses 45 to 55°.

Insulation Thickness to Prevent Surface Condensation. After the dew-point temperature has been established, the next step is to determine how much insulation must be added to the wall or roof structure to maintain the interior surface above this dew-point temperature at all times. This involves two steps: *first,* the calculation of the total required resistance of the wall or roof to prevent condensation for the conditions involved, and *second,* the subtraction of the resistance of the wall or roof to determine how much

Table 2. Desirable Temperatures and Relative Humidities for Industrial Processing*

Industry	Process	Temperature (Degrees Fahrenheit)	Relative Humidity (Per cent)
Baking	Cake icing	70	50
	Cake mixing	75	65
	Dough fermentation room	80	76 to 80
	Loaf cooling	70	60 to 70
	Make-up room	75 to 80	55 to 70
	Mixing room	75 to 80	55 to 70
	Paraffin paper wrapping	80	55
	Proof boxes	80 to 90	80 to 95
	Storage of flour	70 to 80	60
	Storage of yeast	28 to 40	60 to 75
Brewing	Fermentation in vat room	44 to 50	50
Ceramic	Drying of refractory shapes	110 to 150	50 to 60
	Molding room	80	60
Chemical	General storage	60 to 80	35 to 50
Confectionery	Chewing gum rolling	75	50
	Chewing gum wrapping	70	45
	Chocolate covering	62 to 65	50 to 55
	Hard candy making	70 to 80	30 to 50
	Packing	65	50
	Starch room	75 to 85	50
	Storage	60 to 68	50 to 65
Electrical	Manufacture of cotton covered wire	60 to 80	60 to 70
	Manufacture of electrical windings	60 to 80	35 to 50
	Storage of electrical goods	60 to 80	35 to 50
Food	Butter making	60	60
	Dairy chill room	40	60
	Ripening of meats	40	80
	Slicing of bacon	60	45
	Storage of apples	31 to 34	75 to 85
	Storage of citrus fruit	32	80
	Storage of eggs in shell	30	80
	Storage of meats	0 to 10	50
	Storage of sugar	80	35
Incubators	Chicken	99 to 102	55 to 75
Laboratory	General analytical and physical	60 to 70	60 to 70
	Storage of materials	60 to 70	35 to 50
Library	Book storage	65 to 70	38 to 50
Matches	Manufacturing	72 to 74	50
Munitions	Fuse loading	70	55
Photographic	Development of film	70 to 75	60
	Drying	75 to 80	50
	Printing	70	70
	Cutting	72	65
Printing	Binding	70	45
	Folding	77	65
	Press room (general)	75	60 to 78
	Press room (lithographic)	60 to 75	20 to 60
	Storage of rollers	60 to 80	35 to 45
Soap	Drying	110	70
Textile	Cotton—carding	75 to 80	50
	combing	75 to 80	60 to 65
	roving	75 to 80	50 to 60
	spinning	60 to 80	60 to 70
	weaving	68 to 75	70 to 80
	Rayon— spinning	70	85
	twisting	70	65
	Silk — dressing	75 to 80	60 to 65
	spinning	75 to 80	65 to 70
	throwing	75 to 80	65 to 70
	weaving	75 to 80	60 to 70
	Wool — carding	75 to 80	65 to 70
	spinning	75 to 80	55 to 60
	weaving	75 to 80	50 to 55
Tobacco	Cigar and cigarette making	70 to 75	55 to 65
	Softening	90	85
	Stemming or stripping	75 to 85	70

*These values extracted from A.S.H.V.E. Guide 1941, Chapter 38.

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insulation resistance must be added, from which the required thickness of insulation may be calculated.

Resistance to Prevent Condensation; Temperature Gradient. The first step—the calculation of the resistance required to prevent surface condensation—is based on the principle that the *temperature gradient* or change is proportional to the resistance. For example, if the over-all temperature difference is 100 degrees and the total

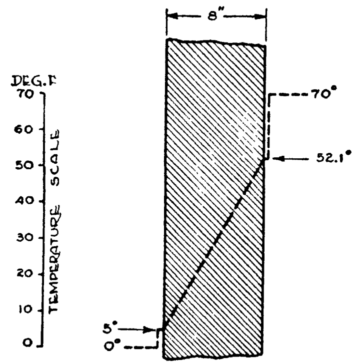

Fig. 1. Section through Brick Wall Showing Temperature Gradient for Inside Temperature of 70°F. and Outside Temperature of 0°F.

resistance (including the inside and outside surfaces) is 10, there will be a change or gradient of 10 degrees for each unit of resistance.

This principle may be more readily illustrated by a specific construction, an 8-inch solid brick wall, Fig. 1, for instance. The component resistances of this wall, based on data in the chapter on Transmission Coefficients and Tables, are as follows:

Inside surface resistance	0.61
8-inch common brick	1.60
Outside surface resistance	0.17
Total resistance	2.38

Now assume that the inside air temperature is 70°F. and the outside air temperature is 0°F. The inside-outside temperature difference is, therefore, 70°F. The over-all or total resistance is 2.38 and since, as stated above, the temperature change is proportional to the resistance, the temperature changes through the wall will be proportional to the ratio of the component resistances to the total resistance. The inside surface resistance is 0.61 and the temperature change from the inside air to this surface will, therefore, be $\frac{0.61}{2.38}\times 70$ or 17.9 degrees. The inside surface temperature will then be $70-17.9$ or 52.1°F. Similarly the temperature drop through the 8-inch brick will be found to be $\frac{1.60}{2.38}\times 70$ or 47.1 degrees and since the inside surface temperature is 52.1°F., the outside surface temperature will be $52.1-47.1$ or 5°F. The temperature changes through each of the component resistances will, of course, be equal to the total temperature difference, or $17.9+47.1+5.0=70$.

The assumed inside and outside *air* temperatures of 70° and 0° respectively, as well as the calculated inside and outside *surface* temperatures of 52.1° and 5°F. respectively are indicated in Fig. 1.

The inside surface temperature could also be calculated by substituting directly in Formula (1) of the chapter on Insulation and Comfort.

Any increase in the total resistance of a wall or roof has a tendency to increase the inside surface temperature, or to make the surface "warmer," which is what takes place when insulation is added to the wall. This fact may be readily verified by increasing the total resistance in the example just cited and noting that the inside surface temperature increases as this total resistance increases, for the same inside and outside temperatures. For example, if the total or over-all resistance were 5.0 instead of 2.38, the inside surface temperature would be about 61.5° instead of 52.1°.

Formula for Resistance to Prevent Condensation. Knowing the inside air temperature (t) and the dew-point temperature (t_d), the problem as previously indicated is to calculate the amount of insulation resistance to be added to the wall or roof structure to increase the inside surface temperature so that this surface will always be at or above the dew-point and moisture will not condense on this surface. The total required resistance to prevent surface condensation based on the foregoing temperature gradient relationship is expressed by the following proportion:

$$\frac{R_t}{R_s}=\frac{(t-t_o)}{(t-t_d)} \qquad (1)$$

where

R_t = Total or over-all resistance required to prevent surface condensation.

R_s = Inside still-air surface resistance

$= \frac{1}{f_i} = \frac{1}{1.65}$ (for average vertical surface)

$= 0.61$

t = Inside temperature near surface involved

t_o = Minimum outside temperature

t_d = Dew-point temperature based on inside temperature (t) and the correct relative humidity (or wet-bulb temperature).

For the average still-air surface resistance of 0.61, the value of R_t may be expressed as follows:

$$R_t = \frac{0.61(t - t_o)}{t - t_d} \quad \textbf{(1a)}$$

The thickness of insulation must be sufficient to prevent surface condensation during the coldest weather. Consequently, the calculations must be based on a reasonable minimum outside temperature (t_o) for the locality of the building. The inside temperature (t) should be the air temperature near the surface involved, but not the surface temperature.

Example 1. Calculate the total required resistance to prevent condensation on the under surface of a 4-inch concrete roof deck (covered with built-up roofing) for a relative humidity of 70%, an inside temperature near the under surface of the roof of 70° and an outside temperature of −10°. Also calculate the required thickness of roof insulation based on a conductivity of 0.33.

Solution. The dew-point temperature (t_d) for a relative humidity of 70% and a dry-bulb temperature (t) of 70° is 59.7°. For this problem $t_o = -10$. Substituting these values in Formula (**1a**),

$$R_t = \frac{0.61 \times [70 - (-10)]}{70 - 59.7} = 4.74$$

This is the required resistance of the roof structure to prevent ceiling condensation. The resistance of the 4-inch concrete roof (including the built-up roofing) is as follows:

Upper surface resistance	0.17
Roofing	0.28
4-inch concrete	0.32
Inside surface resistance	0.61
Total resistance	1.38

Deducting the resistance of the roof structure (1.38) from the required resistance to prevent condensation (4.74) leaves a difference of 3.36, which is the amount of resistance to be added. The resistance of one inch of insulation having a conductivity of 0.33, is 3.03; therefore the required thickness of roof insulation is $\frac{3.36}{3.03}$ or 1.11 inches. The nearest commercial thickness of insulation must, of course, be selected. While a 1-inch thickness would be sufficient for all but the coldest days, a 1½-inch thickness should be used for complete protection.

Condensation Formula. The foregoing discussion and example illustrate the procedure by which the required thickness of insulation to prevent condensation is determined. A more convenient method is to substitute all of the factors in the following formula:

$$x = k\left[\frac{(t-t_o)}{f_i(t-t_d)} - \frac{1}{U}\right] \qquad (2)$$

where

x = Thickness of insulation to prevent surface condensation, inches

k = Conductivity of insulation, B.t.u. per hour per square foot per degree Fahrenheit per inch thickness

f_i = Inside still-air surface conductance

U = Coefficient of transmission of uninsulated wall or roof

t, t_d and t_o are the same as for Formula (1).

Example 2. By means of Formula (2), determine the required thickness of insulation to prevent surface condensation, using the same data as in Example 1.

Solution. The quantity $\frac{1}{U}$ in Formula (2) is the same as the resistance of the uninsulated roof structure which in this case is 1.38; the surface conductance (f_i) is 1.65 and the conductivity (k) is 0.33. Substituting these values in Formula (2),

$$x = 0.33\left[\frac{70-(-10)}{1.65(70-59.7)} - 1.38\right]$$
$$= 1.11 \text{ inches}$$

As in the case of Example 1, the nearest commercial thickness in excess of 1.11 inches would be selected, or 1½ inches.

Graphical Solution. Fig. 2 also may be used for solving problems, although it is not as accurate as Formula (2), the desired result being given in terms of either the maximum coefficient of transmission (Scale *B*) or the corresponding minimum resistance (Scale *C*) to preclude condensation for the conditions of the problem. This chart is based on an inside temperature (near the surface to be considered) of 70°F. and a surface conductance of 1.65. Where the surface conductance of individual materials varies appreciably from this value, the problem should be solved by means of Formula (2), instead of Fig. 2, using the proper surface conductance value. The chart may be used with reasonable accuracy for other inside temperatures from 50° to 90° (near the surface) if the proper inside-outside temperature difference and relative humidity are used. For example, if the temperature near the surface is 80°F. and the outside temperature is zero, the temperature difference will be 80°, and this temperature difference should be used. Actually there will be a slight error due to the fact that the quantity $(t-t_d)$ varies with the value of t, for the same relative humidity.

Example 3. By means of Fig. 2, ascertain the maximum coefficient of transmission to preclude surface condensation for a relative humidity of 64%, an inside temperature of 70°F. and a minimum outside temperature of −10°F. What thickness of corkboard will be required if the roof has a steel deck covered with built-up roofing?

Solution. The dotted line on Fig. 2 indicates the solution of this problem. The temperature difference in this case is 80°F. The relative humidity of 64% is located on Scale *A* and a line drawn horizontally to the "80°F. temperature-difference curve", and a line then drawn downward to Scale *B* indicates that the required coefficient is about 0.26. In other words, the roof coefficient shall not exceed this value to preclude surface condensation for the conditions of the problem. A steel roof deck without a plaster ceiling has a coefficient of transmission of 0.94 (Table 13, Transmission Coefficients and Tables).

A roof of this type with 1 inch of corkboard (the nearest commercial thickness) has a coefficient of 0.23 which is below the maximum required coefficient of 0.26 as determined by the chart. Therefore, 1 inch of corkboard would be required.

Maximum Permissible Relative Humidities. Frequently information is not available concerning the probable relative humidity

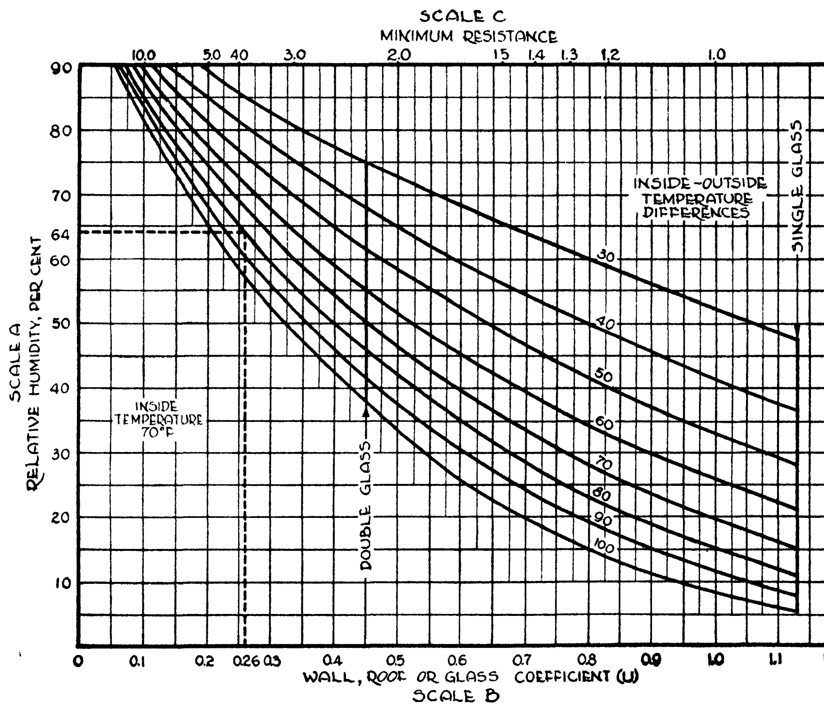

Fig. 2. Condensation Chart

which will prevail in a building to be constructed. Knowing the wall or roof construction and the probable maximum temperature difference, it is possible by means of Fig. 2 to ascertain the maximum permissible relative humidity which can be maintained without surface condensation resulting. It is only necessary to locate the wall or roof coefficient on Scale *B*, draw a line vertically to the proper temperature difference curve and then draw a horizontal line to the relative humidity Scale *A* to obtain the answer.

Example 4. What is the maximum permissible relative humidity for a 12-inch brick wall with an interior finish of metal lath and plaster applied to furring strips, if the probable maximum temperature difference is 80°F.?

Solution. According to Table 6, Transmission Coefficients and Tables, the coefficient of transmission of a wall of this construction is 0.25. Locate this coefficient on Scale *B* of Fig. 2 and draw a line vertically to the 80°F. temperature difference curve, then pass horizontally to Scale *A* and find that the relative humidity is approximately 65% (+) for these conditions. In other words, a relative humidity as high as 65% can exist or be maintained in this building when the temperature difference is 80°F. without condensation taking place on the interior surfaces of the walls.

Condensation on Windows. It will be apparent from the foregoing example that condensation is not likely to take place on the walls of the average residence since the relative humidity seldom is as high as 65% and the wall coefficient frequently is lower than 0.25, especially if insulation is used. It is a well-known fact, however, that window condensation is quite common. This is, of course, due to the high coefficient of transmission (1.13) of single glass windows. This fact limits the relative humidity that can be maintained in humidified buildings in cold weather. The intersection of the vertical "single glass" line of Fig. 2 with the various temperature difference curves, defines the limits of single windows so far as condensation or frost is concerned. For example, condensation (which would become frost), would take place when the temperature difference is 70°F. and the relative humidity is 15%. If double glazing or storm sash were used, there would be no condensation on the windows at this humidity; in fact the relative humidity could be in excess of 50% when the temperature difference is 70 degrees, or approximately 38% when the temperature difference is 100 degrees. This is indicated by the intersection of the "double glass" line with the temperature difference curves of Fig. 2.

Relation of Surface Conductance to Surface Condensation. Any increase in the surface conductance, or decrease in the surface resistance, will increase the permissible relative humidity and/or decrease the over-all resistance required to preclude surface condensation, as will be apparent from a study of Formulas (1) and (2). This, in effect, is what happens when a fan is directed against a window on which condensation or frost has taken place. The motion of the air increases the surface conductance of the glass or decreases the surface resistance and this in turn increases the surface temperature to a degree above the dew-point of the air coming in contact with the surface. The moisture on the glass thus evaporates and is carried away by the air stream and condensation is prevented from precipitating on the surface so long as the motion of the air produced by the fan maintains the surface above the dew-point.

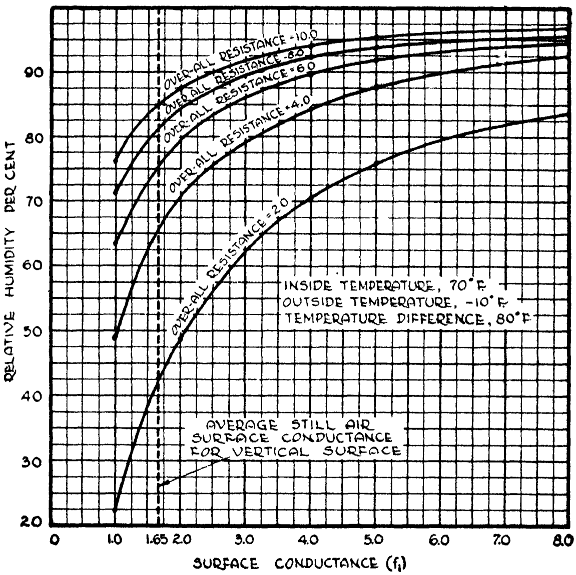

Fig. 3. Relation between Surface Conductance and Relative Humidity for Various Over-all Resistances and the Specified Temperature Conditions

Attention is called to the fact that Fig. 2 is based on a surface conductance of 1.65 or a surface resistance of 0.61. If it is known that the actual conductance of the surface on which condensation is to be prevented varies appreciably from this value, the correct value should be used and the problem solved by means of Formula (2), instead of Fig. 2.

Fig. 3 shows the relationship between surface conductance and relative humidity for various over-all wall or roof resistances from 2.0 to 10.0. This chart is based on an inside temperature of 70°F. and an outside temperature of −10°F., or a temperature difference of 80°F., as indicated. The effect of increase of surface conductance is readily apparent from these curves. A construction having an over-all resistance of 4.0, for example, will permit a relative humidity of about 65% for an inside surface conductance of 1.65, whereas if the inside surface conductance is increased to say 6.0, which is the approximate average value for a 15 m.p.h. air velocity, the permissible relative humidity is increased to about 90% for the same temperature conditions and over-all resistance.

Extreme Humidity Conditions. Other things being equal, the over-all resistance necessary to prevent surface condensation, and likewise the thickness of insulation, increases as the relative humidity increases. As the relative humidity approaches 100%, the required thickness of insulation approaches infinity. To put it another way, the nearer the relative humidity approaches 100%, the nearer will the dew-point temperature (t_d) approach the dry-bulb temperature (t). Thus as the relative humidity approaches 100%, the quantity $(t-t_d)$ in Formulas (**1**), (**1a**) and (**2**) approaches zero and the greater will be the required over-all resistance to prevent condensation.

For example, if the relative humidity is 90% and the temperature difference is 100 degrees, a total or over-all resistance of about 18 will be required to prevent condensation, based on a surface conductance of 1.65. This would necessitate a resistance equivalent to 6 inches of an insulation having a conductivity of 0.33. For a relative humidity of 95%, the required resistance would be about 37.0 and the insulation thickness would exceed 12 inches, or more than double for an increase in this range of 5% in the relative humidity. Above 95%, the theoretical required thickness increases very rapidly because, as stated in the preceding paragraph, the required thickness of insulation approaches infinity as the relative humidity approaches 100%.

Supplementary Measures to Prevent Surface Condensation. Where these extremely severe conditions are encountered and excessive thicknesses of insulation are required, supplementary expedients should be adopted to prevent ceiling condensation. From a practical standpoint, if about 3 or 4 inches of insulation are not sufficient to prevent surface condensation, then these supplementary measures should be considered.

If the moisture is the *result* of some manufacturing process, the humidity may be reduced or "diluted" by an exhaust system or by passing the air through an air washer or dehumidifier. If the moisture is *necessitated* by the manufacturing process—although rarely is a relative humidity above 90% required—the prevention of ceiling condensation may be accomplished by installing a vapor-tight ceiling under the roof deck and passing warm, dry air through the space between the roof deck and the ceiling. The temperature of the air introduced into this space should be sufficiently high to maintain the ceiling temperature above the dew-point. Insulation should be applied to the roof deck mainly to conserve fuel, in this case.

The presence of "free" steam in the air in a building will, of course, tend to increase the percentage of moisture in the air or the relative humidity. Some of the steam will condense in the air forming a mist, and the balance will condense when it comes in contact with cold surfaces. Where there is a considerable amount of "free" steam in a building, it is necessary to supplement the insulation applied to the walls or roof with adequate ventilation.

Where to Apply Roof Insulation for Preventing Ceiling Condensation. Condensation in industrial buildings is more common than in other types of structures, and the roofs of such buildings usually are more vulnerable than the walls. Furthermore, water dripping from the ceiling may cause much more damage than water running down the walls or windows.

In correcting ceiling condensation in industrial buildings, the question frequently arises as to the proper point in the roof or ceiling to apply the insulation. The inclination frequently is to apply the insulation as a part of the existing ceiling structure or, where the under surface of the present roof is exposed, to install the insulation as a ceiling on the under side of the roof, using structural insulating board. This method of application, however, is not recommended where condensation is a severe problem, unless an efficient vapor barrier is installed on the room or warm side of the insulation as explained under the heading *Vapor Barriers.* A barrier that is substantially more efficient than roofing with a bituminous coating is difficult to obtain; therefore it is advisable in most cases to apply the insulation on top of the roof deck over the existing roofing which, if in good condition, serves as a vapor barrier. New roofing should then be applied over the insulation.

If there is a ceiling of lath and plaster or other materials suspended to the under side of the roof deck, this ceiling and the air space should be neglected in arriving at the thickness of insulation necessary to prevent ceiling condensation. In fact, in order to provide a factor of safety, the insulation thickness above the vapor barrier should be sufficient to prevent surface condensation for the conditions of the problem, which in effect, means that practically all of the heat resistance necessary to preclude surface condensation is provided by the insulation on top of the vapor barrier.

Condensation on Basement Walls. Generally speaking, surface condensation in buildings is not a summer problem because the outside temperature is high and the interior surfaces are, therefore, above the dew-point. There is one important exception, namely, that of condensation on basement walls in localities where exceptionally humid atmospheric conditions prevail in the summer, the condensation being caused by contact of the humid air with the cold surfaces.

The more practical solution of this problem is to dehumidify the air by means of a dehydrating agent. These agents are of two types:

1. *Adsorbent.* A material which has the ability to condense water vapor on its internal surfaces without itself being changed physically or chemically. Certain solid materials, such as silica gel, activated alumina and activated carbon have this property.

2. *Absorbent.* A material which has the ability to take up water vapor but which changes physically, chemically, or both, during the cycle. Calcium Chloride is an example of a solid material while liquid materials include solutions of lithium chloride, calcium chloride, lithium bromide and the ethylene glycols.

Most dehydrating agents require special equipment, the use and application of which is outside of the scope of this book. However, for the average residence basement, the use of calcium chloride will reduce the relative humidity sufficiently to prevent surface condensation. This material should be placed in one or more porous or mesh containers, depending on the volume of the space, as specified by the manufacturers. Since summer humidities often approach saturation at high temperatures, comparatively high dew-point temperatures are encountered. For this reason, the prevention of surface condensation by adding insulation is not always practical, since there can be no guarantee that surfaces to be protected will be above the dew-point temperature at all times.

Dampness in Masonry. Concrete usually requires several months to become thoroughly dry and well cured. Brick, tile and other masonry materials used in building construction are frequently damp for several months or even years after the building has been completed, even though they are entirely above ground, due to the inherent capacity of these materials for retaining moisture. Where this situation prevails, the dampness should not be confused with moisture condensation as discussed in this chapter.

Condensation Within Walls. The water vapor mixed with the air has a certain pressure which is dependent upon the temperature and the degree of saturation or relative humidity of the vapor. For example, at 0°F. the pressure of saturated vapor (100% relative humidity) is 0.0185 lb. per square inch and at 70°F. the pressure is 0.363 lb. per square inch, or about 20 times as much. The vapor pressure is also a measure of the amount of water vapor in a given atmosphere. At 0° the weight of saturated vapor is 5.5 grains per pound of dry air and at 70°F. the weight of saturated vapor is 110.2 grains per pound of dry air. At 50% saturation these vapor pressures and weights would, of course, be one-half the amounts stated, and so on for any other degree of saturation.

Most building materials, including concrete, wood, brick, and various building papers, are permeable to water vapor. The rate of movement of vapor through a material is a function of the difference in the vapor pressure on the two sides and inversely proportional to the vapor resistance of the material. The vapor-pressure drop at any point is a function of the vapor resistance at that point, just as the temperature drop is a function of the heat resistance. If the temperature at any point within the wall, as for example, the inner surface of the sheathing, is below the dew-point of the water vapor in the room side of the wall, condensation will under proper circumstances take place at that point, unless a vapor barrier of sufficient vapor resistance is placed at the proper location.

Air at low temperatures, even if saturated, contains a comparatively small amount of water vapor and a correspondingly low vapor pressure, as is evident from the foregoing data for saturated vapor at 0°F. If air at this temperature, for example, is brought into a house and heated to say 70°F., the relative humidity will be only 5%, since at 70°F., the weight of saturated water vapor is 110.2 grains per pound of dry air. Fig. 4 shows the indoor relative humidities for various outside temperatures based on outside saturated air being brought into a building and heated to either 70°F. or 80°F., without the addition of any moisture.

But because of sources of moisture within occupied buildings, the inside vapor pressure and moisture content will generally be substantially higher than that outside or that which would prevail inside if the outside atmosphere were the only source of moisture. Laundries, kitchens and bathrooms contribute large quantities of water

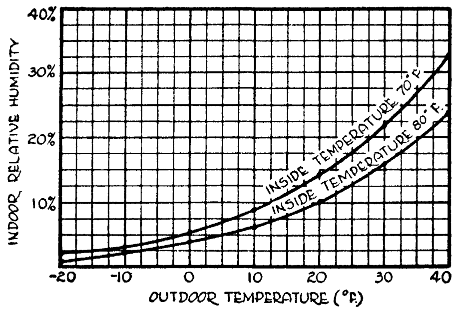

Fig. 4. Indoor Relative Humidities for Various Outside Temperatures, Based on Outside Saturated Air Heated to the Inside Temperature Indicated, without the Addition of Any Moisture

vapor, and these are often supplemented by humidifiers of various types or by automatically controlled humidification devices such as are used in conjunction with air-conditioning systems. Furthermore, with the tendency toward tighter walls resulting from the use of weatherstrips, storm sash, caulking and other improvements in building construction, there is greater probability than formerly was the case for the moisture to be retained and to build up within the enclosure. This problem has been more prevalent during the past few years for these reasons.

Condensation within the walls does not take place in all cases, but is the exception rather than the rule. The probability of condensation increases as the inside relative humidity increases and as the outside temperature decreases. While there is no hard and fast rule governing the temperature limits, it is generally considered that the Ohio River is the dividing line in the United States so far as the probability of condensation is concerned, points to the south being relatively immune and points to the north increasing in susceptibility with increase in latitude. Condensation within walls is a function of the type of construction and the heat and vapor resistances of the component materials. The amount of condensation that can develop within a wall depends upon the resistance of intervening materials to vapor transfusion, difference in vapor pressure and time. In many instances, the process involved is complex. Ordinarily lath and plaster have very low vapor resistance, but if the plaster is finished with certain types of paint the resistance increases.

Vapor Barriers. Condensation within walls can be prevented by installing adequate vapor barriers on the warm side of the construction. In the case of a frame wall, this would be the inside face of the studs. The important requirements are *first* that the vapor barrier be installed at a location such that the temperature on the warm side of the barrier is above the dew point of the air-vapor mixture in the room at all times, and *second* that the vapor resistance of this barrier be substantially greater than that of the materials on the cold side.

Vapor barriers are of two general types; namely, (1) paint or liquid types, applied as finishes on the interior surfaces of the wall, and (2) duplex paper, or sheet types, installed on the inside face of the studs or furring strips before the interior finish is applied. Of the first type, aluminum, asphalt, and varnish vehicle paints are among the most efficient; and in the second classification, duplex or laminated papers, smooth surface roll roofing, and aluminum foil are among the best vapor barriers.

According to J. D. Babbitt,* the following types of papers may be classified as vapor barriers for specified minimum requirements:

1. Asphalt-saturated and coated sheathing felts.
2. Asphalt-saturated and coated kraft papers.
3. Asphalt-coated kraft papers.
4. Duplex papers.
5. Lightweight waxed kraft papers in which the wax is present as a film on the surface.
6. Heavy roofing papers.
7. Infused papers.

*"The Permeability of Building Papers to Water Vapor" (Canadian Journal of Research, May 1940)

Information on the application of the paper type of barriers will be found under Methods of Application.

The comparative permeabilities of various materials to vapor transmission, based on tests conducted at the Forest Products Laboratory, are given in Table 3. The permeability rates of various

Table 3. Comparative Resistances of Various Materials to Vapor Transmission*

The permeability values in this table are expressed in grains per sq. ft. per hr. per inch of mercury.

Material	Permeability Rate
Foil surfaced reflective insulation (double faced)	0.085- 0.129
Roll roofing—smooth surface—40 to 65# per roll 108 sq. ft.	.129- .171
Asphalt impregnated and surface coated sheathing paper glossy surfaced	
50# 500 sq. ft. roll	.213- .77
35# 500 sq. ft. roll	.171- 2.06
Duplex or laminated papers 30-30-30	1.38 - 2.57
Duplex or laminated papers 30-60-30	.52 - .66
Duplex papers reinforced	.69 - 2.06
Duplex paper coated with metal oxides	.52 - 1.29
Insulation backup paper, treated	.66 - 3.42
Gypsum lath with aluminum foil backing	0.085- .385
Plaster—wood lath	11.0
Plaster—3 coats lead and oil	3.68 - 3.85
Plaster—3 coats flat wall paint	4.28
Plaster—2 coats aluminum paint	1.15
Plaster—fiberboard or gypsum lath	19.7 -20.6
Slaters felt	5.15 -26.7
Plywood—¼" Douglas fir, soy bean glue, plain	4.27 - 6.4
2 coats asphalt paint	.43
2 coats aluminum paint	1.29
½" 5-ply Douglas fir	2.67 - 2.74
¼" 3-ply Douglas fir, art. resin glue	4.27 - 4.620
½" 5-ply Douglas fir, art. resin glue	2.74 - 3.36
Insulating lath and sheathing-board type	25.7 -34.2
Insulating sheathing, surface coated	3.03 - 4.36
3/16" compressed fiber board	5.05
1" insulating cork blocks	6.2
½" and 1" blanket insulation between coated papers	1.92 - 2.0
4" mineral wool—unprotected	29.1

*L. V. Teesdale, United States Department of Agriculture, Forest Products Laboratory, Madison, Wis. Data recalculated by author on basis of loss in grains per square foot per hour per inch of mercury pressure difference.

materials based on tests by J. B. Babbitt are given in Table 4. The results of tests at the University of Minnesota of various types of

Table 4. Permeability of Various Materials to Water Vapor*

The permeability values in this table are expressed in grains per square foot per hour per inch of mercury.

Material	Thickness (Inches)	Permeability Rate
Fiberboard, laminated, 2 samples cemented together with asphalt	.985	1.35
Fiberboard, laminated, 6 layers with 5 layers of asphalt	.527	.11
Fiberboard	1.06	18.2
Fiberboard, same reduced in thickness	0.803	21.3
Fiberboard, same reduced in thickness	.599	27.7
Fiberboard, same reduced in thickness	.405	36.6
Fiberboard, same reduced in thickness	.201	65.3
Wood, spruce	.563	1.71
Wood, spruce	.480	1.98
Wood, spruce	.405	1.93
Wood, spruce	.323	2.42
Wood, spruce	.232	3.55
Wood, spruce	.161	5.07
Wood, pine	.80	.92
Wood, pine	.645	1.24
Wood, pine	.496	1.69
Wood, pine	.315	2.72
Wood, pine	.169	4.73
Wood (pine) A	.508	3.17
Wood (pine) A, 1 coat of Al paint	....	1.68
Wood (pine) A, 2 coats of Al paint	....	.45
Wood (pine) A, 3 coats of Al paint	....	.35
Wood (pine) B	.508	3.28
Wood (pine) B, 1 coat of Al paint	....	1.89
Wood (pine) B, 2 coats of Al paint	....	.96
Wood (pine) B, 3 coats of Al paint	....	.75
Kraft paper, 1 sheet	.00394	82.4
Kraft paper, 2 sheets	....	52.5
Kraft paper, 3 sheets	....	39.2
Kraft paper, 4 sheets	....	31.2
Kraft paper, 5 sheets	....	26.3
Kraft paper, 5 sheets	....	32.1
Kraft paper, 5 sheets	....	30.2
Kraft paper, 7 sheets	....	22.3
Kraft paper, 7 sheets	....	18.8
Kraft paper, 8 sheets	....	18.8
Kraft paper, 8 sheets	....	16.25
Black vulcanized rubber, hardness 40	.0791	.091
Plasticized rubber hydrochloride	.00158	.19
30-30-30 paper A	.0071	.90
30-30-30 paper B	.0071	.88
Duplex Scutan 6-6, asphalt between 2 sheets of kraft	.0071	.46
Scutan 0-14 (kraft infused with asphalt on 1 surface) A	.0071	4.22
Scutan 0-14 B	.0071	7.83
Scutan 14 (kraft infused with asphalt on surfaces) A	.0071	6.82
Scutan 14 B	.0071	7.75
Black building paper, black shiny paper infused with asphalt	.0173	.185
Asphalt felt, 15-lb. felt building paper with soft dull appearance	.0319	6.62
Pressed corkboard A	.905	2.33
Pressed corkboard B	.985	2.66
Plaster	1.34	13.3
Plasterboard, plaster between sheets of heavy paper	.37	34.4
Masonite Presdwood, tempered	.13	4.78
Masonite Presdwood	....	10.65
Masonite Presdwood, 5 thicknesses	....	3.07
Masonite Presdwood, 7 thicknesses	....	2.41

*Tests by J. D. Babbitt

membrane barriers are shown in Table 5 which is taken from Bulletin No. 17, issued April 10, 1940, of the Engineering Experiment Station of the University of Minnesota, entitled *Methods of Moisture Control and their Application to Building Construction*, by Frank B. Rowley, Axel B. Algren and Clarence F. Lund.

Table 5. Permeability Values of Membrane Type Vapor Barriers[a]

The permeability values in this table are expressed in grains per sq. ft. per hour per inch of mercury.

Type and Description of Material	Weight (Pounds per 500 Sq. Ft.)	Permeability Rate
Duplex paper, 30-30-30	16.1	0.57
Duplex paper, 30–30–30	16.5	0.98
Duplex paper, 30–60–30	21.9	0.57
Duplex paper	40.7	0.84
Duplex paper	29.6	0.97
Duplex paper	19.5	0.57
Duplex paper	20.7	0.46
Duplex paper (1 side metal coated)	20.3	0.21
Duplex paper (both sides metal coated)	25.8	0.18
Duplex paper reinforced	29.6	0.57
Duplex paper reinforced	32.0	0.44
Duplex paper reinforced (1 side metal coated)	63.0	0.21
Asphalt impregnated and surface coated glossy sheathing paper	51.9	0.36
Asphalt impregnated and surface coated glossy sheathing paper	31.0	0.39
Asphalt impregnated and surface coated glossy sheathing paper	69.0	0.39
Asphalt impregnated and surface coated glossy sheathing paper	47.5	0.64
Insulation back-up paper	15.3	0.75
Insulation back-up paper	15.0	0.50–0.77
Insulation back-up paper (1 side metal coated)	14.3	0.31
Asphalt saturated rag felt building paper	73.0	4.37
Red Resin paper	24.8	24.10

[a] Data from University of Minnesota Engineering Experiment Station Bulletin No. 17.

It will be noted that the permeability rates in Tables 3, 4 and 5 are given in terms of the loss in grains per square foot per hour per inch of mercury vapor pressure difference. This unit has been adopted by many organizations identified with the building field for expressing vapor transmission.

In general, vapor barriers should be used in all residential walls and top-floor ceilings in dwellings north of the 35-degree average January temperature line. Fig. 5 is a map of the United States showing January normal or average temperatures. It should be understood, however, that the 35-degree January normal is only an approximate line of demarkation as it is possible that there are points below this line which would require vapor barriers under certain conditions, whereas other points above this line might not require vapor barriers under certain conditions. The governing factor in all cases is that the vapor barrier should be in a position in the wall where the temperature is above the dew-point of the air-vapor mixture within the room.

The vapor barrier should in general have a permeability rate not to exceed 1.25 grains per square foot per hour per inch of mercury and should be as close to the warm side of the construction as possible. If the vapor barrier is placed on the inside surface, such as the plaster, as a paint finish for example, values up to 20% higher, or 1.5, may be permissible in many cases; in fact, paints even slightly higher in permeability should not be dismissed from consideration.

In general, any vapor barrier which has a continuous coating of water-resistant material such as wax, varnish or bitumen, such continuity being assured by a glossy surface and sufficient thickness, is likely to have sufficient resistance to vapor.

Protecting against Moisture from Basement. Moisture may enter open stud spaces from the basement and thereby by-pass the vapor barrier on the warm side of the studs. It is, therefore, necessary to seal the stud spaces with a vapor barrier in such a manner as to retard the vapor movement into these spaces.

The problem of condensation in walls and the use of vapor barriers is well summarized by H. J. Barre* as follows:

1. The factors which influence the condensation of moisture in walls are:
   a. Temperature and vapor pressure on both sides of the wall.
   b. Water-vapor permeability of the warm and cold sides of the wall.
   c. Thermal properties of the component parts of the wall.
2. The necessary condition for condensation of moisture to take place within a wall subjected to a temperature difference is that the temperature at some point in the wall must be below the dew-point of the air on the warm side of the wall.

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*"The Relation of Wall Construction to Moisture Accumulation in Fill-Type Insulation," by H. J. Barre (Research Bulletin 271, Agricultural Experimental Station, Iowa State College of Agriculture and Mechanical Arts).

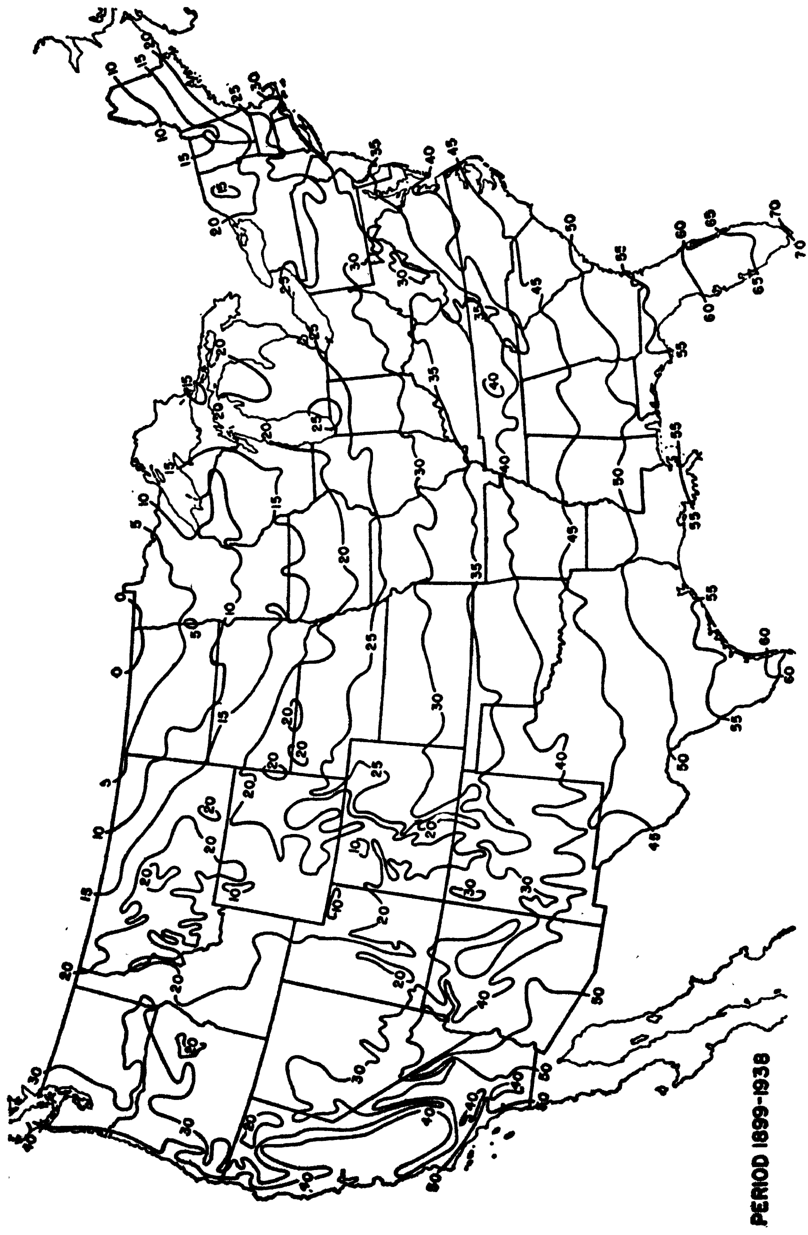

Fig. 5. AVERAGE JANUARY TEMPERATURES

3. The rate of moisture accumulation in a wall increases with the water-vapor permeability of the warm side of the wall and decreases with that of the cold side.

4. For zero accumulation, the permeability of the cold side of the wall must be many times that of the warm side. The ratio depends on the temperature and vapor pressure differences to which the wall is subjected.

5. A vapor barrier used to prevent accumulation of moisture in a wall should be located on the warm side of the isothermal plane in the wall the temperature of which is at or above the dew-point of the air on the warm side of the wall. For extreme conditions it should be placed on the surface of the warm side of the wall.

6. The thermal properties of the wall affect the rate of accumulation of moisture, insofar as the temperature on the inside of the cold side of the wall is influenced.

7. The water-vapor permeability of materials used in building construction varies widely. Rosin sheathing papers and fiber insulation boards which have not been "vapor-proofed" have very high permeabilities. Heavy asphalt-saturated felts and asphalted kraft papers have very low permeabilities. Aluminum paint when applied in two coats is very effective in adding to the vapor resistance of a material. Masonry materials, including concrete, brick, tile and plaster are permeable to water vapor.

8. Venting the cold side of the wall to the cold air by means of small holes does not appear to be effective in preventing moisture accumulation.

9. The condensation of moisture may take place in uninsulated walls as well as in insulated walls. In the former the moisture will condense at the lower part of the wall, which may be more hazardous than moisture accumulation in an insulated wall, where it is fairly well distributed.

10. The rate of moisture accumulation does not appear to be affected by the hygroscopic properties of the insulation.*

11. The moisture in hygroscopic fill insulation will be redistributed when placed in a wall and subjected to a temperature difference. The moisture content is decreased near the warm side and increased near the cold side. The extent to which this takes place depends primarily on the temperature difference and the average moisture content of the insulation, which when too high originally, may result in condensed moisture next to the cold wall.

12. A water-vapor barrier in the form of two coats of aluminum paint on the inside surface of the wall or asphalt-saturated felts and reinforced kraft papers of relatively low permeability placed on the inside of the warm side reduces the rate of moisture accumulation in walls considerably but not completely.

Paint Blistering. According to the National Paint, Varnish and Lacquer Association, "blistering of paint is generally due to the presence of moisture within or upon the surface to which the paint is applied." (Circular No. 428, 8th Revision, August, 1939.) Whether or not wall condensation is the source of the moisture may not be apparent, but if it is, the problem can be solved by providing a vapor

*Authorities differ on this point.—Author.

barrier on the warm side of the wall of substantially greater vapor resistance than that of the materials on the cold side. Since a good outside oil paint job may have a fairly high vapor resistance, the vapor barrier on the warm side should be of proportionately greater vapor resistance than the paint film. Precautions should also be taken to vapor-seal the space between the studs at the bottom to prevent moisture from the basement or the ground from by-passing the vapor barrier in the wall.

For more detailed information on the subject of condensation in walls and the use of vapor barriers, the reader is referred to the papers previously mentioned and the following references on the subject: *Condensation of Moisture and Its Relation to Building Construction and Operation*, by F. B. Rowley, A. B. Algren and C. E. Lund (American Society of Heating & Ventilating Engineers Transactions, Vol. 45, 1939), and various other papers by the same authors based on work at the University of Minnesota and published in the A.S.H.V.E. Transactions; also *Moisture Condensation in Building Walls*, by Harold M. Woolley (B.M.S. 63, U.S. Department of Commerce, Bureau of Standards).

Attics. When insulation is applied to the ceiling of the top floor and the attic space above is unheated, the under side of the roof and attic walls may become very cold and increase the possibilities of condensation of moisture, if water vapor is permitted to pass through the ceiling to the attic space. This condensation will, of course, accumulate as frost if the temperature is sufficiently low. The most effective way of preventing this condensation is to place a vapor barrier on the warm side of the insulation between the attic and the room below.

If it is not practical to install a vapor barrier, another expedient is to ventilate the attic. The amount and type of ventilation, that is, whether natural or mechanical, depends on the conditions involved. Experiments at the University of Minnesota indicate that louvers with a full opening of 12½ sq. in. per 100 sq. ft. of ceiling area, placed at opposite ends of the building, will satisfactorily eliminate condensation.

Even where an adequate vapor barrier is installed in the ceiling, there is the possibility of vapor entering the attic through open scuttle holes, stud spaces or by other means than through the vapor barrier.

If proper precautions are taken effectively to block off or seal these other channels of vapor movement and if adequate ceiling vapor barriers are provided, no trouble from attic condensation is likely to result. But where the vapor can by-pass the ceiling vapor barriers so that an appreciable quantity of moisture enters the attic space, it is possible that it may be necessary to supplement the vapor barrier with attic ventilation. Theoretically, either expedient—vapor barriers or venting—should be sufficient if efficient and adequate for the purpose; where there is any doubt, both should be used.

The objection to attic ventilation is that it may increase the winter heat loss through the ceiling by lowering the attic temperature. However, according to present available data,* small air changes such as are adequate to preclude attic condensation do not appreciably reduce the attic temperature and may therefore be neglected.

Insulation for Air-Conditioned Buildings. Air conditioning involves, among other things, the control of the temperature, humidity, air motion and air distribution within an enclosure. Winter air conditioning, therefore, includes heating and humidifying, and summer air conditioning includes cooling and/or dehumidification. The principal difference then between air-conditioned and non-air-conditioned buildings so far as the insulation is concerned, is the possible effect of humidification in the winter and the cooling or dehumidification in the summer.

Winter Air Conditioning. The effect of humidification in the winter and the relation of insulation thereto is dealt with elsewhere in this chapter. The thickness of insulation required to prevent surface condensation will, of course, depend on the relative humidity maintained which in the case of comfort conditioning, seldom exceeds 40% in the winter. In the case of industrial or process conditioning, the humidity may be higher.

Summer Air Conditioning. Where summer air-conditioning systems for comfort are installed, the conditions are, of course, reversed. Such systems usually involve dehumidification of the air within the enclosure, but (except in the case of basement walls) surface condensation is not ordinarily a problem.

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*For further information on this subject see Attic Temperatures, Ventilation and Heat Loss by Paul D. Close (ASHVE Section, Heating, Piping & Air Conditioning, November, 1942).

Economic Thickness for Air-Conditioned Buildings. This thickness may be determined in accordance with data in the chapter on Economics of Insulation. The relative humidity, either summer or winter, is not taken into consideration in arriving at the economic thickness. Although the cost of cooling an enclosure by refrigeration is considerably greater than the cost of heating for the same temperature difference, this is offset by the shorter period of operation in the summer and the lower average temperature difference. Because of this fact, the economic thickness of insulation for summer air conditioning, disregarding the initial cost of the equipment, is less than for winter air conditioning.

CHAPTER XII

INSULATION AND COMFORT

The atmospheric conditions affecting the sensations of warmth and comfort are the temperature of the air, its moisture content and its movement, plus a fourth environmental factor, namely, the interchange of radiation between the body and the surrounding surfaces and objects. Insulation improves thermal comfort to the extent that it bears a favorable relationship to any of these factors. While insulation has no significant connection with comfort so far as the moisture content is concerned, it has an important bearing on air temperatures, drafts and the interchange of radiation.

Air Temperatures. In the winter when heating is required, the direction of heat flow is from the inside to the outside and indoor air temperatures generally are regulated by the amount of heat supplied, the primary function of the insulation being to conserve fuel. In the summer the direction of the heat flow is reversed, but usually there is no means of regulating the inside temperature, except where mechanical cooling is provided.

Since an insulating material retards the passage of heat through any wall, ceiling or roof structure in which it is installed, less heat will, of course, penetrate the interior in a given period of time, which means that it will be cooler inside. Insulation may therefore have an important relationship to summer indoor air temperatures. The exact effect of the insulation however cannot readily be expressed in terms of degrees of temperature difference, since this problem does not lend itself to a mathematical solution. Any attempted analysis of the summer heat-flow problem on a temperature basis is complicated by the constantly changing inside and outside temperatures and the corresponding change in the inside-outside temperature difference, which temperature difference will also vary at different hours in the case of two similar houses, one of which is insulated and the other not insulated. Assuming that two such similar houses have the same temperature at the beginning of a hot summer day, there will be a gradual rise in the temperatures in the two houses, but other things being equal, the temperature will not rise as rapidly in the insulated house as in the uninsulated house.

The only accurate statement that can be made relative to the effect of the insulation is that the rate of heat flow into the building will be reduced by a certain percentage, which percentage is the same as the *insulating efficiency* discussed in the chapter on that subject. Thus it can be stated that a certain thickness of insulation applied to a wall or roof will prevent a certain percentage of heat from passing through the structure at any given instant, the exact percentage of course depending on the construction, the type and thickness of insulation used and the manner of installation. In Example 1 of the chapter on Insulating Efficiency, the insulating efficiency was 57.5%, which is the same as stating that the rate of heat flow through the roof would be reduced by 57.5% at any given instant, for the type and thickness of insulation considered in the problem.

Home owners have consistently reported that, according to their observations, completely insulated houses have been from 10 to 15 or more degrees cooler in the summer under certain conditions than the same houses without insulation. While such observations cannot be accepted as being scientific, they are nevertheless indicative of the general effect of insulation in providing cooler interiors in warm weather. These observations have also been borne out by temperature readings taken with recording thermometers in similar houses with and without insulation.

Solar Heat. As everyone knows, the transmission of solar heat through windows and skylights is a major source of summer heat in buildings. Likewise everyone is aware that shades and awnings will materially reduce the absorption of solar radiation through windows. Patented screens such as *Koolshade* are also available for keeping out the sun's rays. Light-reflecting paint applied to the walls and roof will reduce the amount of solar radiation absorbed by the exterior surfaces of a building and this in turn reduces the amount of heat transmitted to the inside. See discussion of *Emissivity, Absorptivity and Reflectivity* under Fundamentals of Heat Transfer.

Heat Capacity of Walls and Roofs is another important factor governing the transmission of heat through a structure, because the greater the heat capacity of the materials, the greater will be the time lag. In the case of massive masonry structures the time lag may amount to several hours. The heat flow through a wall or roof actually depends on a combination of the heat capacity and heat resistance. These two quantities taken together are known as the *thermal diffusivity* of the structure which is equal to the conductivity (k) divided by the density (ρ) times the specific heat (c_p) and is expressed in B.t.u. per square foot per hour. A building having walls and roof of low diffusivity will be cooler in the daytime than one with walls and roof of high diffusivity, other things being equal.

Summer Attic Ventilation. The effect of attic ventilation on inside summer temperatures is well known. A roof surface may heat up to say 140 or 150 degrees due to absorption of solar radiation, and the amount of heat transmitted through the roof is correspondingly increased, since the inflow is a function of the outside surface temperature, as well as the inside air temperature. Much of the heat transmitted through the roof can be dissipated by means of attic ventilation, for which purpose mechanical ventilation usually is much more effective than natural ventilation, since the latter may be comparatively ineffective on still days. For these conditions, where summer heat is the problem and the attic is properly ventilated, the most effective place to apply the top floor insulation is in the ceiling, not the roof.

Drafts. There are several causes of drafts, including the cracks around loosely fitted doors and windows through which infiltration takes place, and cold wall, ceiling and window surfaces which cause air circulation or convection currents. Drafts due to air leakage through cracks can be reduced by means of tight construction or weatherstrips and drafts due to cold surfaces can be minimized by insulating the cold surfaces. These cold wall, ceiling and window surfaces result in drafts because the air coming in contact with such surfaces will be cooled and drop to the floor, causing a circulation of air, as shown in Fig. 1. The circulation of air may not take precisely the course shown in Fig. 1 in all cases, but whenever there is an appreciable difference in temperature of the surfaces of an enclosure, convection currents or drafts will be set up. The colder the surfaces, or the greater the difference in temperature between the warm and cold surfaces, the more pronounced will be the air circulation, and the colder the draft. Inasmuch as insulating materials and storm windows increase the surface temperatures in the winter, they will diminish drafts due to this source.

Wall Surface Temperatures, Radiation and Comfort. The average person at rest gives off about 400 B.t.u. per hour. This heat is constantly lost from the body by conduction and convection, evaporation of perspiration and radiation to surrounding surfaces or objects. Bodily comfort depends on the maintenance of the proper balance

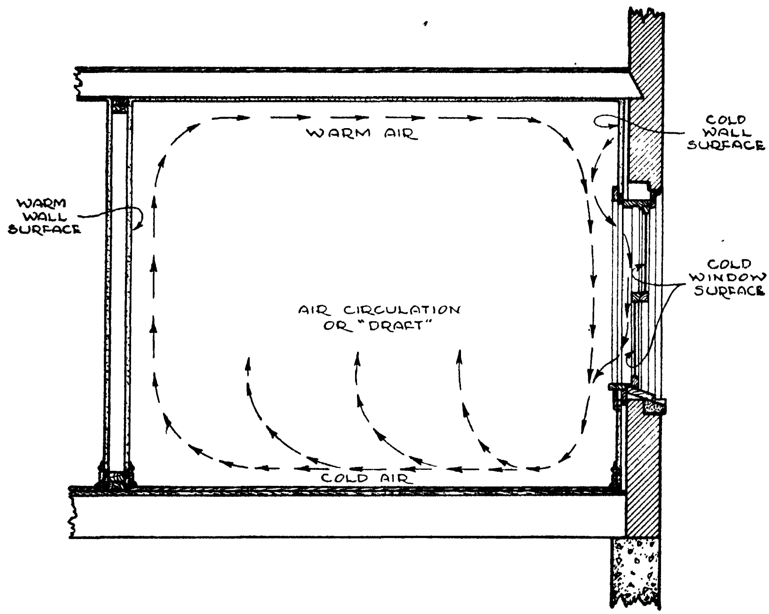


Fig. 1. Diagram Showing How Cold Window and Wall Surfaces Cause Drafts

between internal heat production and the heat given off by the body. While the relationship between temperature and humidity and the sensations of warmth and comfort is generally understood, the effect on comfort of the exchange of radiation between the body and surrounding objects is not so well known.

The loss of heat from the body by radiation diminishes as the temperature of the surrounding surfaces and objects increases, and vice versa. In the summer when the heat flow is from the outside to the inside, the inside surface temperatures of outside walls will generally be higher than the inside air temperature, whereas in the winter the inside surface temperatures will be lower than the air temperature. In the summer, warm walls increase the sensation of warmth because they reduce the body heat loss due to radiation, and conversely in the winter cold walls decrease the sensation of warmth.

According to Thomas Bedford,[a] a depression of the *mean radiant temperature*[b] (M.R.T.) of 1 degree is compensated for by an elevation in the dry-bulb temperature of 0.98 degrees F. A depression of 3 degrees in the M.R.T. necessitated an elevation in the dry-bulb temperature of 2.7 degrees F. and a depression of 6 degrees in the M.R.T. necessitated an elevation of 5.2 degrees. Comparable results were obtained at the American Society of Heating & Ventilating Engineers Research Laboratory[c] in Pittsburgh based on tests involving both the dry-bulb temperature and the relative humidity which together govern what is known as *effective temperature.*

Surface Temperatures. In the chapter on Condensation under the discussion of *Temperature Gradient,* it was shown that insulation increases inside wall surface temperatures of exterior walls in the winter or makes them "warmer". Conversely it can be shown that insulation decreases inside wall surface temperatures in the summer or makes them "cooler". The inside surface temperature for equilibrium or constant conditions may be calculated by means of the following formula:

$$t_s = \frac{tR_t + t_oR_s - tR_s}{R_t} \qquad (1)$$

where

t_s = Inside surface temperature, degrees Fahrenheit
t = Inside air temperature, degrees Fahrenheit
t_o = Outside air temperature, degrees Fahrenheit
R_s = Inside surface resistance
R_t = Total or over-all resistance

Example 1. What will be the inside wall surface temperature based on a 12 in. brick wall with a plaster and metal lath (furred) interior finish, an inside temperature of 70°F. and an outside temperature of −10°F.? Assume surface conductance to be 1.65.

Solution. $t=70$; $t_o=-10$. The coefficient of transmission of the wall is 0.25 (from Transmission Coefficients and Tables) and the

[a]The Warmth Factor in Comfort at Work, by Thomas Bedford (Medical Research Council Industrial Health Report, No. 76, London, 1936)

[b]The *mean radiant temperature* (M.R.T.) is assumed to be the integrated average temperature of all surrounding surfaces from which radiation may come.

[c]Radiation as a Factor in the Sensation of Warmth, by F. C. Houghten, S. B. Gunst and J. Suciu, Jr. (American Society of Heating and Ventilating Engineers Journal Section, Heating Piping and Air Conditioning, February, 1941)

over-all resistance (R_t) is, therefore, 4.0. The surface resistance (R_s) is $\frac{1}{1.65}$ or 0.61. Substituting in Formula (1):

$$t_s = \frac{70\times4.0+(-10)\times0.61-70\times0.61}{4.0}$$

$$= \frac{280+(-6.1)-42.7}{4.0}$$

$$= \frac{231.2}{4.0}$$

$$= 57.8°\text{F}.$$

Formula (1) does not take into consideration the sun effect on the exterior surface, which will increase the exterior surface tem-

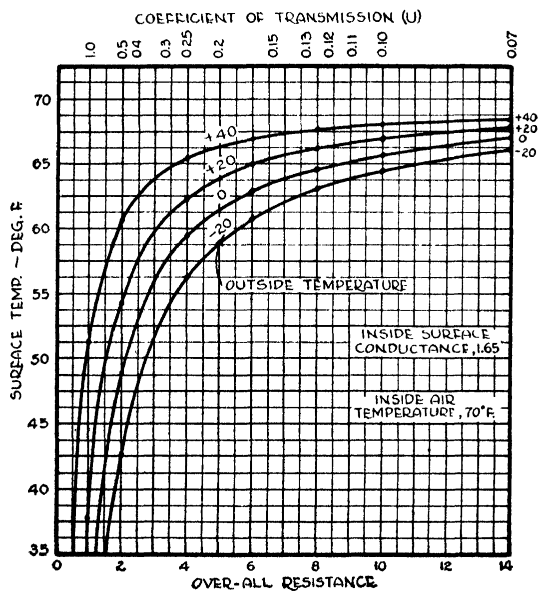


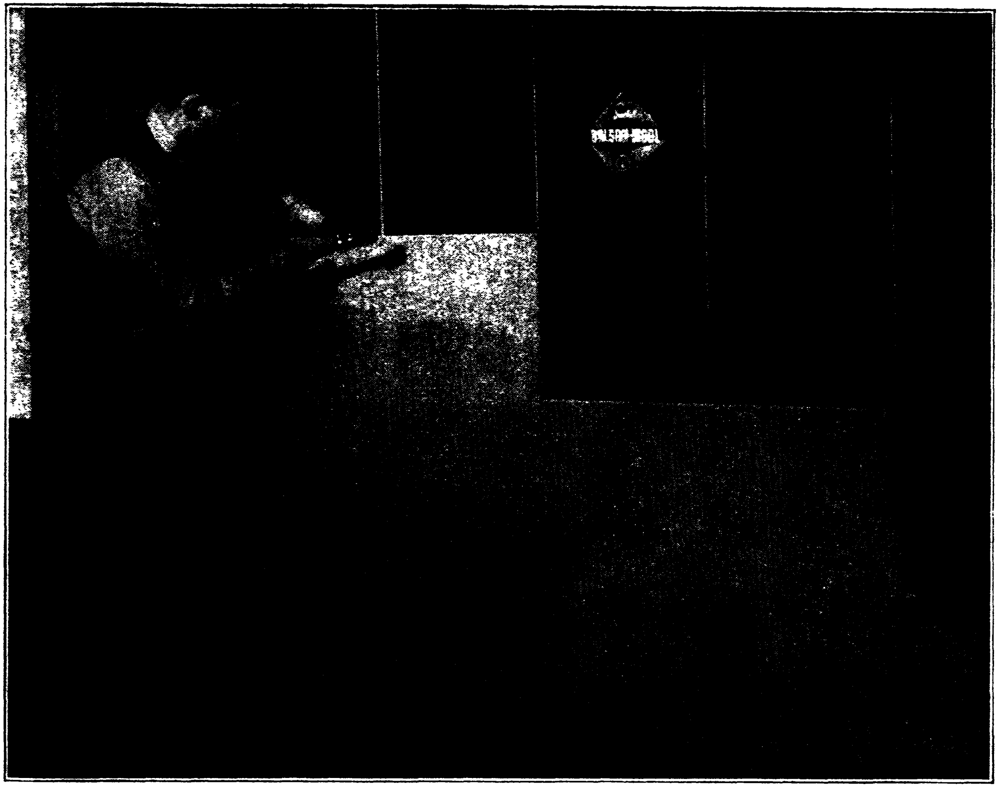
Fig. 2. Chart for Estimating Winter Interior Surface Temperatures of Outside Walls

perature, and this in turn will increase the inside surface temperature. If the exterior surface temperature is known, the interior surface temperature may be estimated from Formula (1) by substituting the outside surface temperature in the formula for the outside temperature (t_o) and neglecting the outside surface resistance in the value of R_t.

Inside winter surface temperatures may also be estimated by means of Fig. 2, which is based on an inside air temperature of 70°F. and an inside surface conductance of 1.65. For example, the intersection of the *+20* temperature line with the vertical *4* resistance line shows that the inside surface temperature will be about 62.5°F. for these conditions.

Now since wall insulation decreases wall surface temperatures in the summer, the insulation decreases the sensation of warmth or makes it "feel cooler". The insulation thus has a twofold effect on summer comfort; it lowers the wall surface temperature and the air temperature, both of which tend to make it "feel cooler." In the winter the reverse is true; wall insulation increases the surface temperatures and therefore increases the sensation of warmth. The latter fact also has a bearing on fuel economy because if the walls are warmer, the air temperature may be lower for the same degree of bodily warmth or comfort and a lower air temperature in the winter means additional fuel economy; that is, fuel economy over and above that resulting from the lower heat loss through the wall due to the insulation.

Note: Inside surface temperatures are influenced by the temperature of nearby surfaces or objects. If the nearby surfaces are substantially colder than the surface under consideration, there will be an increase in the heat loss by radiation to these colder surfaces and this in turn will lower the temperature of the surface under consideration. The relationship shown in Formula (1), therefore, applies to surfaces facing other surfaces or objects of approximately the same temperature as the air temperature (t). The temperature of a surface will increase or decrease with increase or decrease in the temperature of the surfaces it "sees".



APPLICATION OF INSULATING BOARD LATH AND FLEXIBLE INSULATION

Courtesy of Wood Conversion Co., St. Paul, Minn.

CHAPTER XIII

PIPE AND DUCT INSULATION

The internal heat resistance of metallic pipes and ducts, that is, the resistance of the metal, is almost nil, the only appreciable heat resistance being that of the inner and outer surfaces, and as a result such metallic pipes and ducts have an exceptionally high rate of heat transfer. Therefore, steam and hot water pipes and warm air ducts should be insulated whenever they pass through unheated spaces, either (1) for fuel economy or (2) to permit proper temperature regulation in the heated spaces, or both. The same general reasoning, of course, also applies to pipes and ducts used to convey refrigerated liquids or cold air. Pipes should also be insulated to prevent freezing of the liquid conveyed or sweating on the outside surface.

Heat Loss from Bare Pipes. The heat loss from bare pipes depends on the type of pipe and the character of the exposed surface, the pipe diameter, and the temperature difference between the pipe and the surrounding air. For example, the coefficient of transmission of ½-inch bare steel pipe, expressed in B.t.u. per hour *per square foot* of exposed surface per degree temperature difference, varies from about 2.07 for a 50-degree temperature difference to 3.45 for a temperature difference of 267.9 degrees F., based on an air temperature of 70°F. The temperature of 267.9+70 or 337.9°F. corresponds to that of steam at 100-lb. pressure. As the exposed area of one linear foot of ½-inch pipe is 0.22 sq. ft., the heat loss per linear foot will be 0.22×2.07 or about 0.46 for an air temperature of 70°F. and a pipe temperature of 120°F., or a temperature difference of 50°F.

Heat-loss coefficient curves for various diameters of bare steel pipe are given in Fig. 1. To obtain the heat losses per linear foot, multiply the values obtained from Fig. 1 by the surface areas given in Table 1.

Pipe Insulation. Eight types of insulating materials used for medium and high temperature pipe insulation and the conductivities thereof, are given in Table 2. These conductivities are stated in terms of the mean temperature of the inner and outer surfaces of the insulation. The inner surface temperature may be assumed to be the same as that of the fluid in the pipe if the insulation is in contact with the pipe. The conductivities given in Table 2 are average values ob-

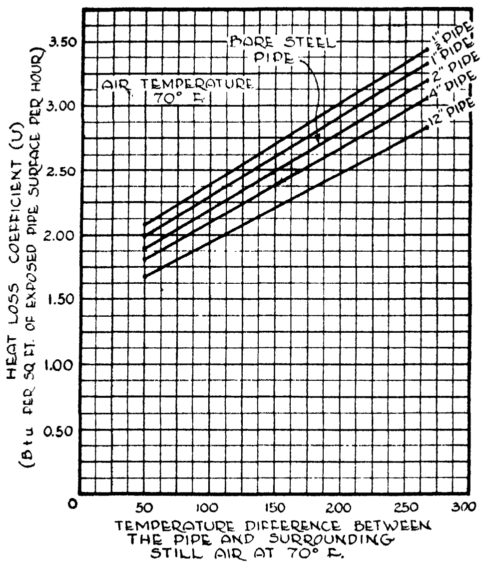


Fig. 1. Heat-loss Coefficients for Bare Steel Pipe (B.t.u. per Hour per *Square* Foot of Pipe Surface per Degree Fahrenheit Temperature Difference between Pipe and Surrounding Air at 70°F.)

tained from a number of tests made on each type of material. Individual manufacturers' products will, of course, vary to some extent from these values.

One of the most popular types of pipe insulation for temperatures up to 600°F. is 85% magnesia. Heat-loss coefficients for pipes insulated with 1, 1½ and 2 inches of 85% magnesia are given in Figs.

Table 1. Surface Area Per Linear Foot of Pipe

Nominal Pipe Size (Inches)	Surface Area (Sq. Ft.)	Nominal Pipe Size (Inches)	Surface Area (Sq. Ft.)	Nominal Pipe Size (Inches)	Surface Area (Sq. Ft.)
½	0.22	2	0.622	5	1.456
¾	0.275	2½	0.753	6	1.734
1	0.344	3	0.917	8	2.257
1¼	0.435	3½	1.047	10	2.817
1½	0.498	4	1.178	12	3.338

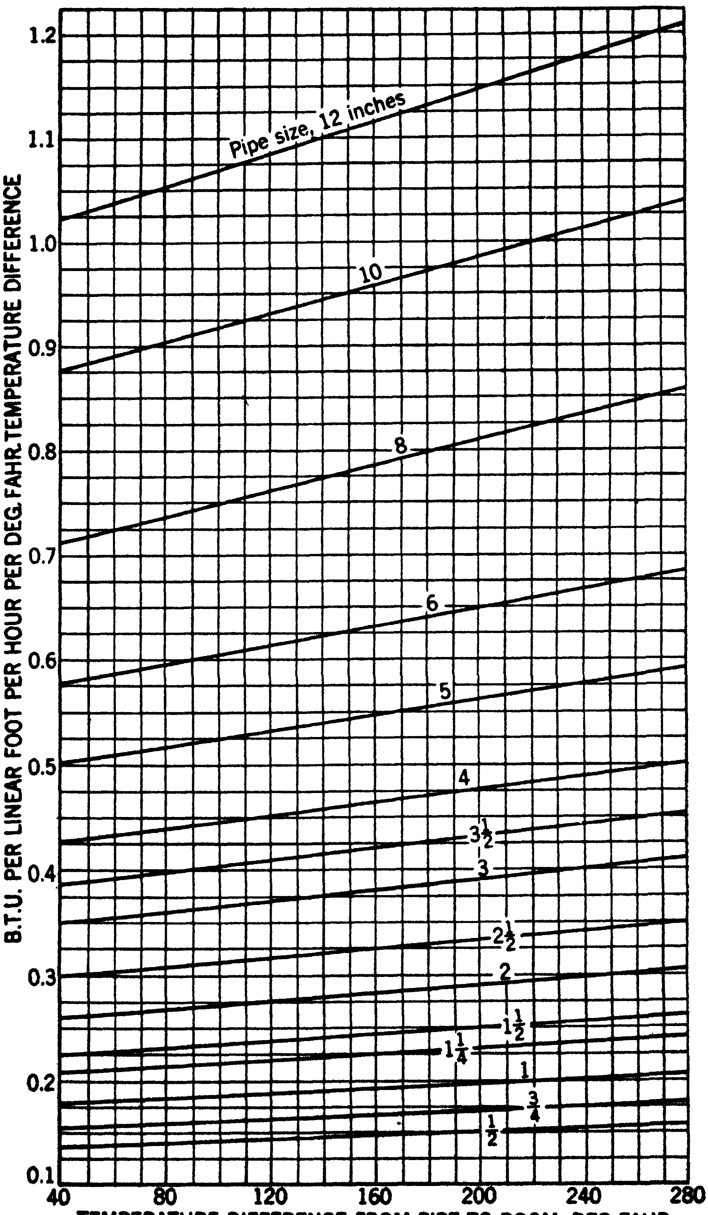


Fig. 2. Heat Loss through 1-Inch Thick 85% Magnesia Type Covering

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Table 2. Conductivity (k) of Various Types of Insulating Materials for Medium and High Temperature Pipes*

Types of Insulating Materials	Mean Temperature, Deg. F.				
	100	200	300	400	500
85 per cent magnesia type	0.359	0.403	0.448	0.493	0.539
Corrugated asbestos type (4 plies per 1 in. thick)	0.495	0.618	0.741	0.864	.....
Corrugated asbestos type (8 plies per 1 in. thick)	0.505	0.598	0.692	0.786	.....
Laminated asbestos type (30–40 laminations per 1 in. thick)	0.326	0.380	0.434	0.488	0.543
Laminated asbestos type (14–20 laminations per 1 in. thick)	0.374	0.445	0.518	0.589	0.662
Mineral wool type	0.350	0.410	0.470	0.530	0.590
High temperature type (Diatomaceous earth and asbestos)	0.576	0.614	0.652	0.689	0.726
Brown asbestos type (Felted fiber)	0.338	0.396	0.453	0.510	0.568

*From tests conducted at Mellon Institute.

2, 3 and 4. It should be noted that these coefficients are expressed in terms of one linear foot of pipe per degree difference in temperature between the pipe and surrounding still air at 70°F. To obtain the heat-loss coefficients for other types of pipe insulation, multiply the values derived from Figs. 2, 3 and 4 by the factors in Table 3.

The heat lost from a pipe in a given period of time is expressed by the following formula:

$$H = U_p(t_p - t)NL \qquad (1)$$

where

H = B.t.u. lost through the pipe and insulation

U_p = Heat-loss coefficient of pipe and insulation, B.t.u. per hour per linear foot of pipe per degree Fahrenheit temperature difference between pipe and surrounding air.

t_p = Temperature of pipe, degrees Fahrenheit

t = Temperature of room air surrounding pipe, degrees Fahrenheit.

N = Number of hours

L = Length of pipe, feet.

Example 1. What will be the heat loss per hour from 100 linear feet of 2-inch pipe insulated with 1 inch of 85% magnesia-type insulation, if the pipe carries hot water at an average temperature of 190°F. and the air temperature is 70°F.?

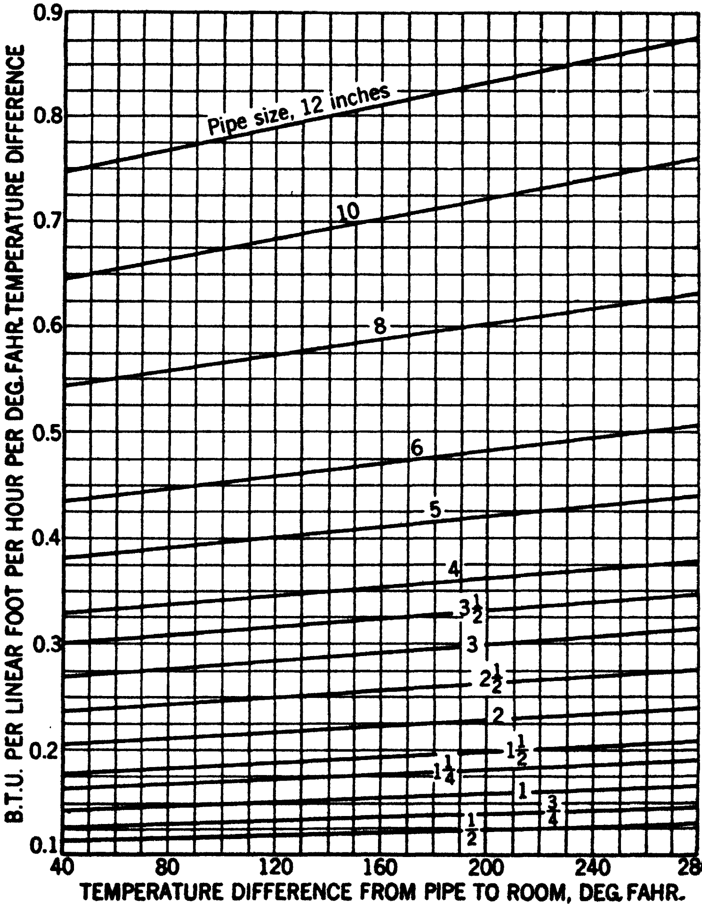

Fig. 3. Heat Loss Through 1½-Inch Thick 85% Magnesia-Type Covering
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Solution. The temperature difference is 190−70 or 120 degrees F. According to Fig. 2, the heat-loss coefficient for a temperature of 120°F. (U_p) is 0.275 B.t.u. per hour per linear foot per degree Fahrenheit temperature difference. $N=1$; $L=100$; $t_p=190$; $t=70$.

Substituting in Formula (1):

$$H = 0.275 \times (190 - 70) \times 1 \times 100$$
$$= 3300 \text{ B.t.u.}$$

Low-Temperature Pipe Insulation. The types of insulation used for covering pipes for conveying ice water, brine and other low-temperature media are somewhat different in character than

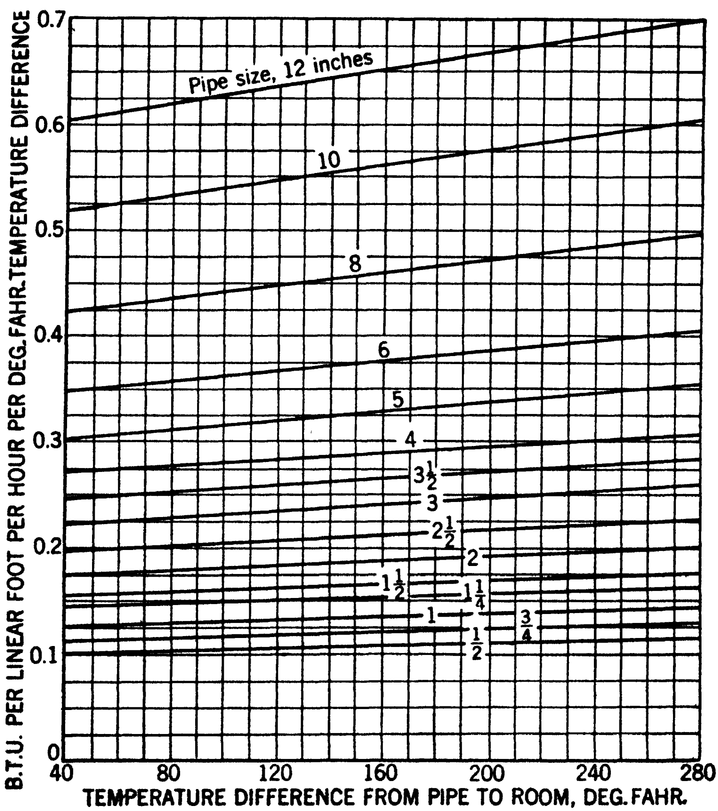

Fig. 4. Heat Loss through 2-Inch Thick 85% Magnesia-Type Covering
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those used for medium- and high-temperature insulation requirements. Low-temperature pipe insulations are commonly made from moulded cork, hair felt and composition materials. Data on this subject will be found in the American Society of Refrigerating Engineers Refrigerating Data book and other similar reference volumes.

Table 3. Pipe-Covering Factors

Types of Insulating Materials	Temperature Difference, Pipe to Air, Deg. F.					
	100	200	300	400	500	600
85 per cent magnesia type...	1.050	1.024	0.997	0.971	0.944	0.918
Corrugated asbestos type.... (4 plies per 1 in. thick)	1.425	1.465	1.505	1.545	.....	.....
Corrugated asbestos type.... (8 plies per 1 in. thick)	1.435	1.437	1.438	1.440	.....	.....
Laminated asbestos type.... (30–40 laminations per 1 in. thick)	0.969	0.960	0.951	0.942	0.933	0.924
Laminated asbestos type.... (14–20 laminations per 1 in. thick)	1.103	1.104	1.105	1.106	1.107	1.108
Mineral wool type..	1.023	1.028	1.033	1.038	1.043	1.048
High temperature type...... (Diatomaceous earth and asbestos)	1.560	1.489	1.418	1.347	1.276	1.205
Brown asbestos type........ (Felted fiber)	1.003	0.997	0.990	0.984	0.977	0.971

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Pipe Insulation to Prevent Freezing. Water or other liquid will freeze if standing in a pipe surrounded by air below the freezing temperature of the liquid. This freezing can be prevented by circulating the liquid at a rate sufficient to prevent the heat content of the liquid from being dissipated through the pipe too rapidly. The colder the air temperature surrounding the pipe and the colder the initial temperature of the liquid, and the longer the pipe run, the more rapidly must the liquid be circulated to prevent freezing. Conversely, for the same temperature conditions, the less rapidly will it be necessary to circulate the liquid to prevent freezing, if the pipe is insulated. Any problem of this type can be solved mathematically, the thickness of pipe insulation necessary to prevent freezing being based on the rate of heat loss through the pipe and insulation for the average temperatures of the liquid and surrounding air, and the rate at which the liquid is to be circulated. The assumed final liquid temperature should not be below the freezing point thereof.

Pipe Insulation to Prevent Sweating. This problem is, of course, similar to that involving the prevention of condensation on interior surfaces as discussed earlier. The thickness of insulation must therefore be sufficient to maintain the surface temperature above the dew-point temperature of the surrounding atmosphere, the lower the temperature of the liquid in the pipe, or the higher the dew point of the atmosphere, the greater will be the required thickness of insulation.

Underground Pipe Insulation. District heating systems involve underground steam distribution lines which are conveyed in tunnels and conduit systems. Pipes conveyed in tunnels are generally covered with sectional insulation and finished with outer jackets of metal or waterproofing membrane. Pipes carried in tunnels may also be insulated with sectional insulation although the more common practice is to fill the entire section of the conduit around the pipes with loose insulating material. A water-proofing membrane is used to enclose the insulation to keep it dry. A drainage system is also provided to divert any water which may enter the conduit. Further information on this subject will be found in the handbook of the National District Heating Association.

Uninsulated Ducts. The rate of heat transfer through uninsulated metallic square or rectangular air ducts is given by the following formula:

$$U=\frac{1}{\frac{1}{f_i}+\frac{1}{f_o}} \tag{2}$$

where

U = Coefficient of transmission, B.t.u. per hour per square foot of flat surface per degree Fahrenheit temperature difference.

f_i and f_o = Inside and outside surface conductances.

The surface conductances will vary with the emissivities, the temperatures, and the air velocities. The inside surface conductance will increase with the velocity of the air passing through the duct. The over-all coefficient (U) likewise increases with the increase in the air velocity. Any movement of air over the outside surface will also increase the outside surface conductance as well as the over-all coefficient, although in most instances, air ducts within buildings are subjected to comparatively still air.

Insulated Ducts. The coefficient of transmission of insulated ducts may be calculated from the following formula:

$$U = \frac{1}{\frac{1}{f_i} + \frac{x}{k} + \frac{1}{f_o}} \tag{3}$$

where x and k are the thickness and conductivity of the insulation respectively. Since the value of f_i will be comparatively high in the case of ducts carrying air at a moderately high velocity, the resistance

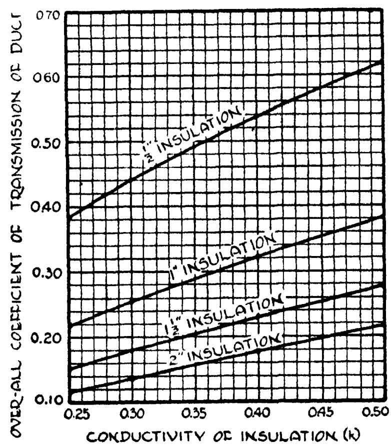
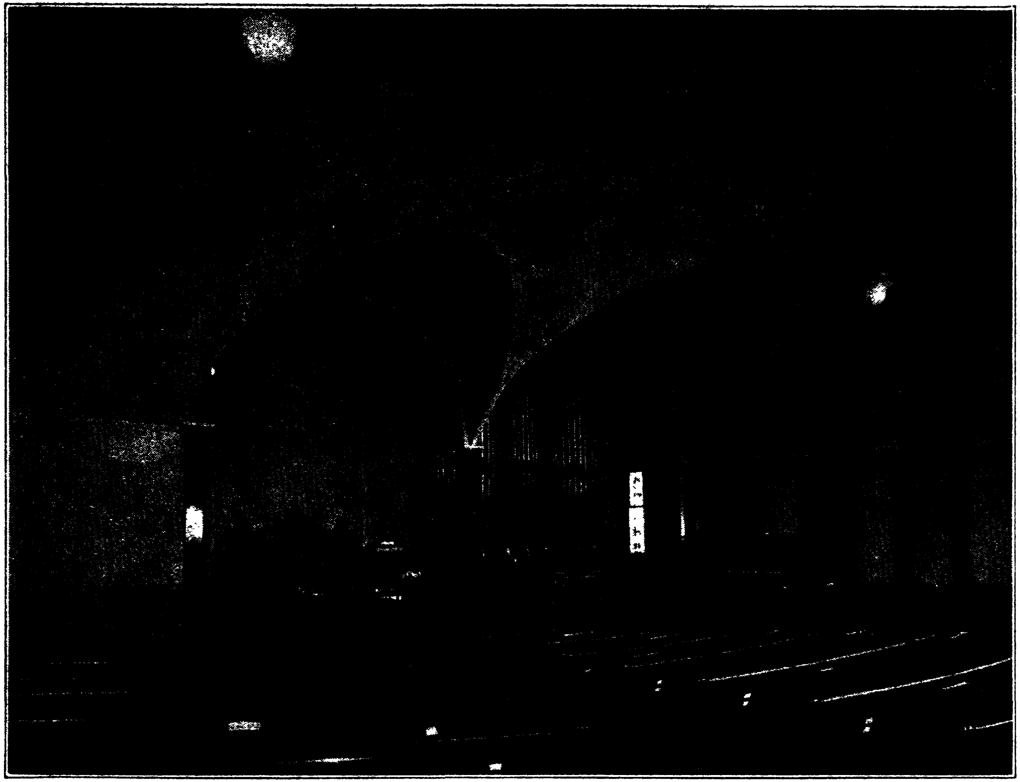


Fig. 5. Over-all Coefficients of Transmission of Insulated Ducts per Square Foot of Flat Surface for Various Conductivities and Thicknesses of Insulation
Note: Inside Surface Resistance Neglected

will be small in comparison with that of the insulation and may be neglected. It will be sufficiently accurate to assume the value of the outer surface conductance (f_o) *for insulated ducts* to be 1.65, the average still air value used for calculating building heat-loss coefficients.

The coefficient of transmission of insulated ducts based on these premises and for the conductivities and thicknesses of insulation indicated may be derived from Fig. 5. The heat loss in B.t.u. per hour through the walls of an insulated duct may be obtained by multiplying the heat-loss coefficient as obtained from Fig. 5 by the average temperature difference and the area. Factory fabricated insulated ducts (*Careyduct*) made of asbestos are now available.



INSULATING TILEBOARD (PANELS) USED TO OBTAIN AN ATTRACTIVE CHURCH CEILING DESIGN

Courtesy of Wood Conversion Co., St. Paul, Minn.

CHAPTER XIV

SOUND INSULATION

Sound-insulation problems in buildings are of two general types, namely, (1) prevention of transmission of sound through partitions and floors and (2) isolation of machinery vibration and noises including the prevention of transmission of air-borne sounds. The first problem is discussed in this chapter and the second in the following chapter. Another related subject, namely, architectural acoustics and noise quieting within rooms and spaces, is discussed in a later chapter.

Nature of Sound. Sound is produced by any body that is in a state of vibration, and travels as compressional waves in the air with a velocity of 1120 feet per second. The sensation of sound is due to stimulation of the auditory nerves of the ear by the sound waves. The *pitch* of sound depends upon the *frequency* of vibration of the sound-producing body. The frequency range of audible sounds varies from 20 to 20,000 vibrations per second. When the frequency of a musical sound is doubled, the pitch is raised one octave. The frequency range of the piano is 27 to 4186 cycles and almost all other musical instruments are within this range. The range of the female voice is 196 to 1046 cycles, and of the male voice, 82 to 466 cycles. Much of the energy of sounds of both musical instruments and voices is in overtones which have much higher frequencies than the foregoing values. The physical *intensity* of a sound is the vibrational energy transmitted per second through a unit cross section of the sound wave. The ear records differences of frequency as differences in pitch.

Transmission of Sound Through Walls and Floors. Sound is transmitted through a wall, floor or partition by means of a diaphragm action. Consider for example a simple partition of a single material such as glass. The sound energy is transmitted in waves to one side of the partition and the impact of the successive sound waves upon the partition causes it to be set in motion like a diaphragm, and because of this motion or vibration, energy is transmitted to the air on the opposite side. The amount of energy transmitted depends on the amplitude of vibration of the partition, which in turn depends on four factors: (1) the initial energy striking the partition, (2) the mass of the partition, (3) the stiffness of the partition, and (4) the method by which the edges are attached, especially as it may affect the damping of the vibrations of the partition.

Definition of Decibel. In most cases, we are interested in the effect of sound upon the human ear. It has been found that the ear does not respond directly to the energy of the sound. As the energy of the sound increases, the response by the ear does not increase in the same proportion, but lags behind. Experiments show that the response by the ear, that is the loudness level of the sound, is approximately proportional to the logarithm of the physical energy of the sound. Thus if there are sound energies of 10, 100, 1000 and 10,000, the loudness levels as heard by the ear would be respectively in the ratio of 1, 2, 3 and 4. The sound-energy loudness-level relationship is shown in Table 1.

Table 1. Relation Between Sound Energy and Loudness Level

Sound Energy Units	Logarithm of Energy Units in Col. A	Loudness Level or 10×Col.B (Decibels)	Examples of Loudness Levels
A	B	C	D
1,000,000,000,000	12	120	Threshold of hearing (varies)
100,000,000,000	11	110	Airplane motor 18 feet away
10,000,000,000	10	100	Loud automobile horn 23 feet away
1,000,000,000	9	90	Subway station
100,000,000	8	80	Loud radio in home
10,000,000	7	70	Stenographic room
1,000,000	6	60	Noisy office or department store
100,000	5	50	Moderate restaurant noise
10,000	4	40	Quiet radio in home
1,000	3	30	....
100	2	20	Whisper 4 feet away
10	1	10	Rustle of leaves
1	0	0	Threshold of audibility

The *decibel* is the unit of loudness level or intensity, referred to an arbitrary reference level. It is defined by the relation $\text{db.} = 10 \log_{10} \frac{P_1}{P_0}$, where P_1 is the unknown intensity and P_0 is the reference level which is commonly taken as 10^{-16} watts per square centimeter. This level or intensity, or zero on the decibel scale, is slightly less than the threshold of audibility for the average ear at a frequency of 1000 cycles per second. The range of the decibel scale is from 0, at which the human ear receives no sensation, although energy may be present, to approximately 130, at which point the sound is so intense as to be painful.

Sound-Insulation Value of Construction. This value is expressed in terms of the transmission loss in decibels. Thus if a wall has a rating of 30 decibels (db.), it reduces the loudness level so that the level will be 30 decibels less on one side than on the other side. This reduction factor or transmission loss for a wall is measured from a point very close to one side of the wall to a point very close to the other side. In an average case in practice, the sound created would be somewhere within a room, a few feet from a wall, and the person hearing the sound on the other side would be a short distance from the wall. The sound may thus be diminished in loudness by the combined effect of distance and sound absorption in the rooms, as well as by the partition.

For example, in the living room of the ordinary home or apartment there is considerable sound absorption due to the rug on the floor, the draperies and curtains at the windows, the upholstered furniture, etc. When a person is talking in such a room, the loudness level of his voice at a point close to his lips may be quite high, say 80 db., but at a point on the opposite side of the room it is very much diminished, to perhaps 60 db. Thus a whisper can be heard if close to the speaker but not very far away because the sound becomes fainter as it travels farther, and it spreads out and is absorbed by the furnishings in the room. How this affects the sound-insulation value of a partition is shown in Fig. 1, which is explained in the following paragraphs.

Masking Effect. Besides absorption in a room and the effect of distance, there is another factor which may increase the effectiveness of a partition. This is the masking effect of the noise level in the receiving room. When our own radio is playing we do not hear our neighbor's radio. When our radio is off, however, and we are reading, or attempting to go to sleep, our neighbor's radio is plainly heard. A high noise level, with its masking effect, therefore may aid in the apparent efficiency of a partition. We live in a constant atmosphere of noise, and even in a quiet city apartment the noise level is usually 15 to 20 decibels.

The masking effect of the general noise level on the sound-insulation value of a partition is illustrated by Fig. 1. Suppose, for example, a 75 db. sound is created in a room. The absorption in the room and the distance from the wall reduces its loudness level by say 10 db. to 65 db. at the wall. The 35 db. wall cuts down the loudness level to 30 db. on the other side of the wall, and the absorption in

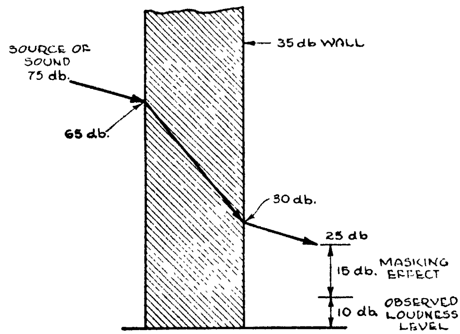


Fig. 1. Section through Wall Showing How Effective Reductions of 35 db. May Appear to Be 65 db.

that room further reduces the loudness level by say 5 db. to 25 db. above the normal threshold of audibility. The noise in the room, however, has a masking or deadening effect of 15 db., so the 25 db. sound is only 10 db. above the threshold of audibility in the room. The effect of absorption, distance and masking therefore has added 30 db. effectiveness to the 35 db. partition, making the total 65 db. Thus a 75 db. sound has an effective loudness level of only 10 db. to an observer in the other room.

In judging whether or not a partition will be satisfactory in use, it is necessary to know not only the sound-reduction value of the partition, but also the absorption in the two rooms, the average distance of the source of the sound from the wall, and the noise level in the rooms. The effect of these last three factors may be greater than any slight change in construction which affects the efficiency of the partition by but a few decibels. Because of the inability correctly to evaluate the effect of these factors, it is difficult to be certain whether a specific type of construction will be satisfactory in practice.

Desirable Sound-Insulation Values. It will be apparent from the foregoing discussion that it is somewhat hazardous to attempt to establish hard and fast rules relative to the proper sound-reduction factors required under various conditions. However, certain general statements can be made. With an average reduction of 25 db., normal speech can be understood quite easily and distinctly through the wall or partition. With a reduction of 30 db., loud speech can be understood fairly well on the opposite side of the partition if conditions are quiet. With a reduction of 35 db., loud speech is audible but not intelligible on the opposite side. With a reduction of 40 db., normal speech is not audible and loud speech can be heard faintly, but cannot easily be understood, and such walls may be considered as relatively "soundproof." Partitions between apartments should have a factor of at least 40 db., whereas for piano and organ rooms, and sound film studios, higher factors than 40 db. are desirable, but the exact requirement will depend on the local conditions. The maximum noise levels which should be tolerated under various conditions are given in Table 2.

Table 2. Maximum Noise Level Which Should Be Tolerated*

Location	Noise Level (Decibels)
Studios for the recording of sound (talking-picture studios)	6 to 8
Radio broadcasting studios	8 to 10
Hospitals	8 to 12
Music studios	10 to 15
Apartments, hotels and homes	10 to 20
Theatres, churches, auditoriums, classrooms and libraries	12 to 24
Talking-picture theatres	15 to 25
Private offices	20 to 30
Public offices, banking rooms, etc.	25 to 40

*V.O. Knudsen, Architectural Acoustics, John Wiley & Sons (1932)

Factors Affecting Sound-Insulating Properties. The most important factor governing the sound-insulating value of a wall, floor or partition is the weight or mass. Next in importance are the nature of the material or materials and the method of attachment or application. Tests on sound-insulating properties of partitions have established the fact that for solid masonry partitions such as brick, concrete or tile, the sound-reduction factor depends only on the

Table 3. Average Sound-Transmission Losses for Various Types of Construction Based on Tests Conducted at the Bureau of Standards.*

Transmission losses in decibels

No.	Description of Panels	Average 256 to 1024 Cycles per Sec.	Average 128 to 4096 Cycles per Sec.	Weight Pounds per Sq. Ft.
1	Constructed of 1½-in. Steeltex channels for studs; Steeltex lath; scratch and brown coats of gypsum plaster; smooth, white finish	30.2	....	17.6
2	Wood studs; ⅜-in. three-ply plywood attached to both sides. Light weight cotton fabric applied to one side with casein glue and a heavy cotton duck on the other side	32.3	31.1	4.57
3	Wood studs; wood lath; scratch and brown coats of gypsum plaster; smooth, white finish	32.5	35.7	15.1
4	Floor panels, 2x8-in. wood joist; plaster on metal lath applied at lower side, subflooring and 13/16-in. oak flooring to upper side	32.7	....	17.1
5	Metal studs of ¾-in. channel iron expanded metal lath; scratch and brown coats of gypsum plaster; smooth, white finish, applied to one side only	33.1	33.3	8.1
6	Wall panels constructed of Thermax sheets 3 in. thick laid in mortar compound of gypsum plaster; plastered both sides with a brown coat of gypsum plaster; smooth, white finish	33.0	34.8	.....
7	Wood studs; Steeltex lath with paper backing nailed to studs with special nail; scratch and brown coats of gypsum plaster; smooth, white finish; thickness of grounds ¾ in.	33.2	35.0	12.6
8	Two-inch plaster partition; ¾-in. channel studs; perforated gypsum lath; gypsum plaster; smooth, white finish	33.9	36.5	19.4
9	Panel constructed of 3-in. one-piece metal studs spaced 16 in. on center; expanded metal lath, scratch and brown coats of gypsum plaster; smooth, white finish	35.7	36.9	19.6
10	Panel constructed of 1½-in. Steeltex channels for studs; Steeltex lath; with rock wool between studs; scratch and brown coats of gypsum plaster; smooth, white finish	35.8	....	.....
11	Panel constructed of 3-in. one-piece metal studs spaced 16 in. on centers with rock wool bats between studs packed to a density of 4.3 lbs. per cu. ft.	36.4	38.0	21.1
12	Two-inch solid plaster partition; ¾-in. channel studs; Ecod metal lath with paper backing applied to one side; gypsum plaster; sand finish	36.0	39.9	.....

*Data published in B.M.S. 17 "Sound Insulation of Wall and Floor Construction" by V. L. Chrisler; and in supplement issued December 20, 1940. For further information, refer to these

Table 3. (Cont'd.) Average Sound-Transmission Losses for Various Types of Construction Based on Tests Conducted at the Bureau of Standards*

Transmission losses in decibels

No.	Description of Panels	Average 256 to 1024 Cycles per Sec.	Average 128 to 4096 Cycles per Sec.	Weight Pounds per Sq. Ft.
13	Hollow clay tile panels constructed of 4-in. by 12-in. partition tile, 3 cells; plastered on both sides with brown coat of gypsum plaster; smooth, white finish	37.8	....	27.5
14	3x12 by 30-in. gypsum tile; brown coat of gypsum plaster; smooth, white finish..................	37.8	38.1	21.0
15	Wood studs; metal lath; scratch and brown coats of gypsum plaster; smooth, white finish...........	38.1	39.2	20.0
16	Cinder-block panels constructed of 4x8 by 18-in. standard Straub hollow cinder blocks; plastered on both sides with ⅝-in. brown coat gypsum plaster; smooth, white finish..................	38.6	....	29.7
17	Wood studs; gypsum lath nailed to studs approx. 6 in. apart; scratch and brown coats of sanded gypsum plaster; smooth, white finish; thickness of plaster ½ in..............................	39.0	41.1	15.2
18	Cinder-block wall panel constructed of 3x8 by 16-inch cinder blocks; plastered on both sides with ⅝-in. brown coat gypsum plaster; smooth, white finish	43.0	45.1	32.2
19	Floor panels, 2x8-in. wood joist; plaster on metal lath applied to lower side; subflooring to upper side; 1-in. Balsam Wool laid over the subfloor and on this were placed small squares (2½x2½ in.) of hard-pressed Nu-Wood spaced 16 in. on centers in each direction; nailing strips 1¾x1¾ in. were placed on top of these Nu-Wood squares and held in place by a metal strap; the finish floor (13/16-in. oak) was nailed on top of these nailing strips.....	46.9	....	.....
20	Wood studs staggered; expanded metal lath; scratch and brown coats of gypsum plaster; smooth, white finish; thickness of grounds ¾ in...............	48.5	49.8	19.8
21	Floor panel constructed by using steel floor section with flat top; top of this section was covered with 2 in. of concrete and a suspended metal lath and plaster ceiling attached to the bottom, leaving approximately 4 in. between the metal section and plaster	52.4	52.9	.....
22	3x12 by 30-in. gypsum tile; United States Gypsum resilient clip; metal lath and gypsum plaster on one side; gypsum plaster applied directly to tile on the other side; smooth, white finish on both sides..	52.7	....	.....

*Data published in B.M.S. 17 "Sound Insulation of Wall and Floor Construction" by V.L. Chrisler; and in supplement issued December 20, 1940. For further information, refer to these reports.

weight of the wall, per unit area; the heavier the wall, the better the sound insulation.

For double walls, the sound-insulating value depends slightly on the width of the air space between the units, but mainly on the degree of structural separation. The fewer the points at which the units are rigidly tied together, the better the sound insulation. For best results, double walls should be connected only at the edges. Even a small connection such as a single nail driven through both sides of a double wall reduces its sound-insulating value by conducting vibration directly across the air space.

Wall fills should not be used for sound insulation in a structurally separated double wall, since they act as a bridge across the air space and thus reduce the sound-insulating value. For hollow walls which are not structurally separated, such as ordinary wood stud partitions, a fill between the studs improves the sound insulation slightly by increasing the weight per unit area.

The sound-reduction factor of any partition is not uniform throughout the pitch range but may vary widely with only a slight change in pitch. In general a partition has a higher reduction factor for high-pitched sounds than for low-pitched sounds, so that an average of the pitch range must be used to obtain a single numerical value for basis of comparison. The variation of efficiency with pitch explains why conversation may be heard only as a low-pitched rumble of sound through a wall. The high-pitched portions of the speech sound, upon which intelligibility depends, are not transmitted.

Sound-insulation tests of partitions and floors have been conducted at the Bureau of Standards, Washington, D. C., Riverbank Laboratories, Geneva, Illinois, and at other laboratories in the United States and abroad. A few typical values selected from the Bureau of Standards results and published in B.M.S. 17 and the supplement thereto of the Department of Commerce are given in Table 3. Values obtained by the Riverbank Laboratories are given in Table 4. Data are not as yet available on many of the recommended sound-insulated constructions.

Sound-Insulated Partitions. Four types of sound-insulating partitions involving the use of structural insulating board are illustrated in Figs. 2, 3, 4 and 5. In the furred sound-insulating partition shown in Fig. 2, the studs are spaced on 16-inch centers and a double

Table 4. Average Sound-Transmission Losses for Various Types of Construction Based on Tests at Riverbank Laboratories, Geneva, Illinois

Type of Construction	Average Reduction Factors (Decibels)	Weight per Square Foot (Pounds)
Solid metal lath and plaster (1½″ thick)	26	13.9
Wood lath and plaster on both sides of 2x4″ studs	29	18.0
Metal lath and plaster on both sides of 2x4″ studs	29	17.4
2″ Gypsum tile, plaster both sides	30	19.6
3″ Gypsum tile, plaster both sides	34	25.4
4″ Hollow clay tile, plaster both sides	35	27.0
Insulating board lath and plaster on both sides of 2x4″ staggered studs (Fig. 3)	37	13.0
Double 2x2″ stud construction with insulating board lath and plaster on both sides and insulating board between studs. (Fig. 4)	46	12.2
8″ Brick wall, 1″ plaster	48	88.0

layer of insulating board applied to each side with furring strips between as indicated. Uniform, straight studding should be selected. The staggered stud sound-insulating partition, consisting of insulating board lath and plaster, on both sides, is shown in Fig. 3.

An efficient sound-insulating partition involves the double stud construction shown in Fig. 4. A double row of 2x2 studding, or 2x4

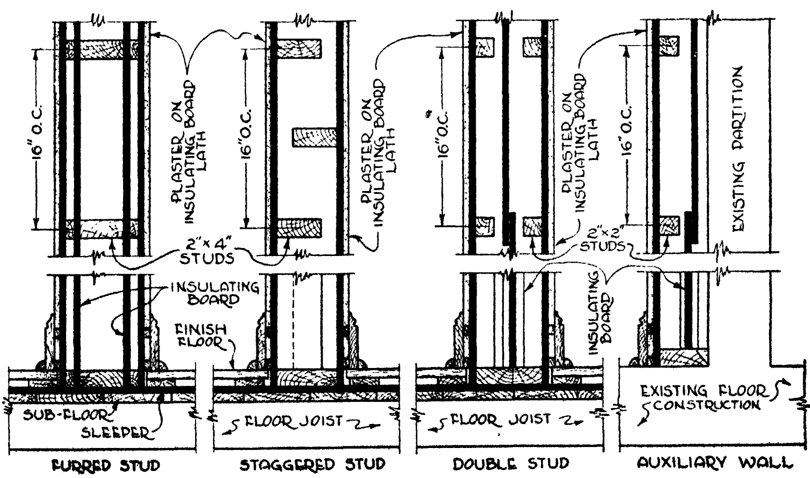


Fig. 2. **Fig. 3** **Fig. 4** **Fig. 5**

Note: See Also Fig. 6 **Note: See Also Fig. 7.**

Various Types of Construction Involving the Use of Structural Insulating Board

studding with the long dimension parallel to the face of the partition, should be spaced on 12 or 16-inch centers and nailed to 2x6 sills. A layer of insulating board is placed loosely between the double row of framing to increase further the sound-insulating efficiency. This type of partition is not recommended for load-bearing purposes. The plates should be placed on structural insulating board in the partitions shown in Figs. 2, 3 and 4.

The auxiliary partition shown in Fig. 5 illustrates a method of sound-insulating existing partitions. A free-standing auxiliary parti-

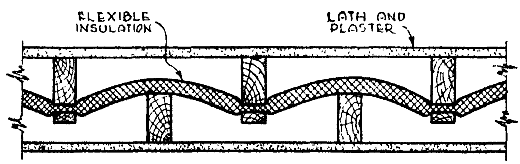


Fig. 6. Staggered Stud Construction Involving the Use of Flexible Insulation

tion is erected on one or both sides of the existing wall, the 2x2 studding being placed on 12 or 16-inch centers. The addition of a layer of insulating board placed loosely between the old and new portions improves results. Partitions consisting of plain 2x4 studding with insulating board nailed directly to both sides, are not recommended where high sound insulating properties are desired.

Fig. 6 shows a sound-insulating partition involving the use of flexible insulation. The partition walls should be constructed with staggered 2x4 studs, spaced 16 inches on centers. Both sets of studs should be placed on a 2x6 plate so that one set centers between the other. The 2x6 plate should be placed on structural insulating board or deadening felt. The flexible insulation should be woven between the two sets of studding as shown in Fig. 6, and secured to the face of one set with lath or tin disks nailed through the insulation and with all joints lapped at least 3 inches. The interior finish applied to both sides of the partition should preferably be lath and plaster.

Fig. 7 shows a method of sound-insulating an existing partition with flexible insulation. A partition wall of 2x4 framing members should be erected on a 2x4 plate. This plate should be padded with structural insulating board or deadening felt and should be placed so that the framing members of the wall will be spaced at least 1 inch from the existing wall. Flexible insulation should be applied to the studding, placing strips of insulation at right angles to the framing members. All joints should be lapped at least 3 inches. Nail 1x2 or 2x2 furring strips to the framing members and at right angles thereto, spaced 16 inches on centers or according to the requirement of the interior finish. The interior finish should be applied to the furring strips.

Sound-Insulated Masonry Floors. The sounds transmitted by floors are either air-borne sounds, such as those of speaking, or

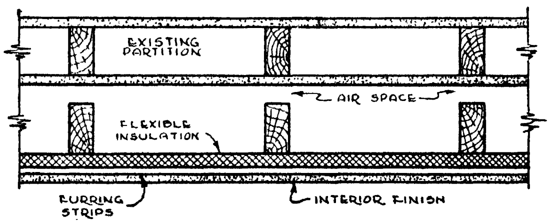


Fig. 7. Sound-Insulating Existing Partitions by Means of Flexible Insulation

sounds having their origin in some physical impact such as walking or the moving of furniture. Air-borne sounds seldom pass through floors to such an extent as to be of annoyance to the occupants of the room below or above the floor, owing to the fact that the floors are usually heavier, for structural reasons, than walls.

Impact Sounds. Sounds due to physical impact are usually the most serious floor problem. When a person walks upon a bare concrete floor, or a hard object strikes the floor, the sound may be transmitted with considerable facility. On the other hand, when a sharp object strikes a padded floor the impact is largely absorbed and much less sound is generated than when the object strikes the solid concrete.

The simplest method of insulating masonry floors against impact sounds is to deaden the sound at the source. Carpeting on carpet lining is particularly effective for this purpose. This may also be accomplished by the use of ½ or 1-inch insulating board placed on top of the concrete or other masonry and covered with a suitable wearing surface such as carpets. The insulating board should be bonded to the concrete by means of hot asphalt, asphalt emulsion or linoleum cement. See Fig. 8. If, however, the floor is to be subjected to pianos or other heavy furniture, the insulating board should be covered with a rigid wearing surface such as wood flooring which should in turn be protected against impact sounds where sounds of this character are likely to be disturbing.

If a wood floor over the concrete is desired, the construction shown in Fig. 9 may be used. Wood sleepers 2x3 inches in size are placed on the concrete on 48-inch centers. These sleepers should be beveled so that when the cinder concrete is subsequently poured they will be held down more effectively. One ½ or 1-inch thickness of insulating board should be placed over the sleepers and cinder concrete and only nailed sufficiently to keep it from shifting its

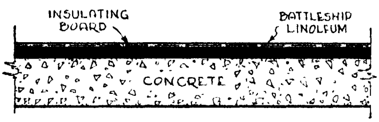


Fig. 8. Insulating Concrete Floor against Impact Sounds
Note: Where Floor Is to Be Subjected to Heavy Furniture, Surface of Insulation Should Be Finished with Rigid Material.

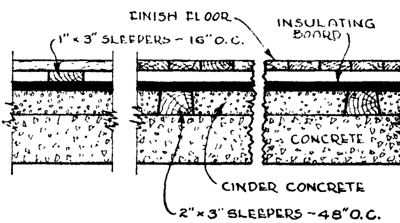


Fig. 9. Floating Floor Construction on Structural Insulating Board over Concrete Slab

position. Wood nailing strips or sleepers 1x3 inches should then be placed on top of the insulating board on 16-inch centers and nailed through the insulating board to the sleepers below. The furred floor, which is usually of hardwood, is then nailed through 1x3-inch nailing strips to the insulating board. Floors of this type are usually referred to as floating floors. As stated above, to reduce impact sounds, wood floors should be carpeted or otherwise covered with a sound-cushioning material. Parquet flooring and ceramic tiles may also be applied over structural insulating board in accordance with manufacturers' specifications.

Sound-Insulating Frame Construction Floors and Ceilings. An adaptation of the floating floor to frame construction involving the use of structural insulating board is shown in Fig. 10. Flexible insulation could be used in place of the insulating board as shown in Fig. 10A with comparable results. The sound-insulating efficiency of this construction may be increased by suspending the ceiling joists independently of and between floor joists as shown in Fig. 11.

Still greater effectiveness will result if the spaces between the floor and ceiling joists are insulated with flexible insulation as shown in Fig. 12. The flexible insulation is woven between the two sets of joists and secured to each floor joist with lath or tin disks nailed through the insulation.

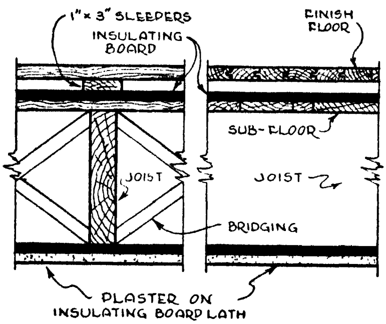


Fig. 10. Floating Floor Construction on Structural Insulating Board over Frame Construction

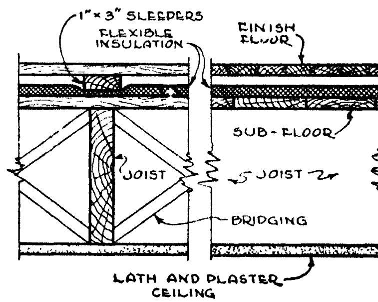


Fig. 10A. Same as Fig. 10, but with Flexible Insulation Instead of Structural Insulating Board

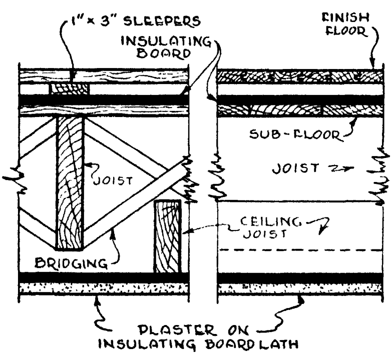


Fig. 11. Suspended Ceiling Construction

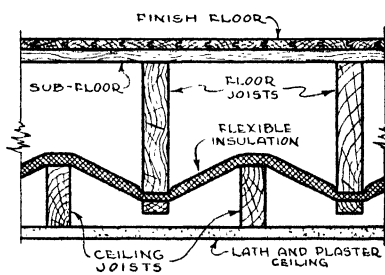


Fig. 12. Flexible Insulation Installed between Ceiling and Floor Joists

There are various adaptations and modifications of these methods of sound-insulating frame construction floors and ceilings with either structural insulating board or flexible insulation. For example, the insulation may be applied directly to the under side of the ceiling joists and furring strips nailed through the insulation to the joists, the interior finish or lath and plaster or other materials being secured to the furring strips, as shown in Fig. 13. This type of ceiling could be used with any of the floor constructions shown in Figs. 10, 10A, 11 or 12. Fig. 14 shows the *Balsam Wool* floor-deadening system which involves the use of certain special accessories including *Nu-Wood* blocks, deadening felt and metal strips.

Clips and Springs. An effective means of reducing sound transmission through floors and walls is by the use of resilient clips and springs. Instead of resting the floor sleepers, for example, on the concrete, they may be supported by means of patented clips which are anchored to the concrete, thus lessening the contact area be-

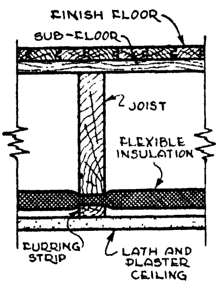


Fig. 13. Sound Insulation Applied to Under Side of Ceiling Joists with Interior Finish Attached to Furring Strips

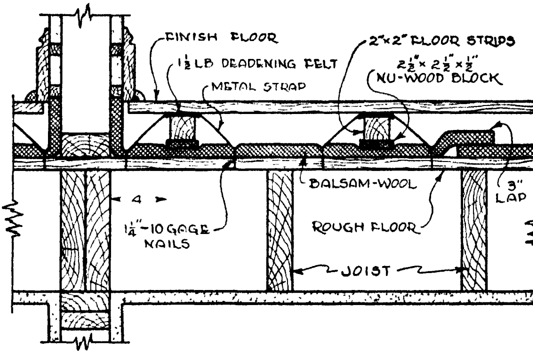


Fig. 14. Balsam Wool Floor-Deadening System

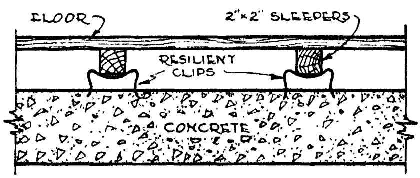


Fig. 15. United States Gypsum Resilient Steel Clip for Supporting Nailing Strips (Baldy Sleeper)

tween the sleepers and the concrete. A typical floor clip is shown in Fig. 15. Springs and wires may also be used with similarly effective results for supporting the ceiling.

Proprietary Sound-Insulating Systems. Various patented sound-insulating systems are available and are especially recommended for rooms or spaces requiring a high degree of soundproofness, such as broadcasting and sound-film studios. These patented systems generally involve special types of construction including combinations of sound-insulating materials and patented springs, clips or other devices for isolating machinery noise and vibration, as discussed in the following chapter, and for reducing sound transmission.

CHAPTER XV

MACHINERY ISOLATION

The problem of insulating against noise and vibration due to machinery involves *first*, the isolation of the machinery to reduce the vibration transmitted to the building structure and *second*, the absorption or cutting down of the air-borne noise. The methods employed for solving these problems are entirely different.

ISOLATING MACHINERY VIBRATION

In general, the transmission of machinery vibration can be reduced by mounting the machine upon a correctly designed resilient base. It is erroneously assumed in many cases, however, that in order to cut down the vibration from a motor or other machine, it is merely necessary to introduce a pad of some resilient material under the entire base. Such a procedure may give satisfactory results, but it is also possible under certain circumstances that the pad may actually make conditions worse, as will be explained later.

Vibration. Vibration is the periodic motion of matter and is of two general types or classes, namely (1) free vibration and (2) forced vibration. *Free vibration* has no driving force but when once started repeats itself without the aid of any external source and would continue indefinitely if it were not for "damping" which tends to counteract or resist it. Damping resistance may be due to external resistance (friction) or to internal resistance (hysteresis). A free vibration has a so-called *natural frequency* of recurrence of the vibration. *Forced vibration* is maintained by an external periodic driving force of any single frequency or combination of frequencies. The problem of machinery isolation deals with the forced vibration of the machinery to be isolated.

Transmissibility is the amount of vibration transmitted to the floor and is a function of the ratio of the frequency or speed of the vibrating force to the natural frequency of the machine upon the elastic pad, as expressed by the following formula:

$$\text{Transmissibility} = \frac{1}{\left(\frac{n}{n_o}\right)^2 - 1} \qquad (1)$$

where

n = frequency of vibration generated by the machine to be isolated such as the commutation frequency of a motor or the blade frequency of a fan.

n_o = natural frequency of the machine unit on the resilient support.

Fig. 1 shows the relationship between transmissibility and various ratios of n to n_o. It will be apparent from Fig. 1 that for values

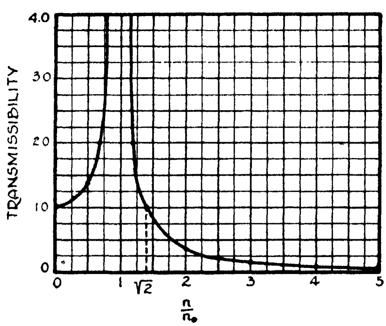


Fig. 1. Curves Showing Transmissibility and Damping for Various Ratios of n to n_o

of $\frac{n}{n_o}$ less than $\sqrt{2}$ the transmissibility is 1.0 or greater, and consequently isolation either is of no value or is a detriment. In other words, if the resilient pad or base is such as to produce a transmissibility factor of 1.0 or more, the pad will actually make conditions worse. Thus, if the fundamental frequency of vibration generated by the machine should coincide with the natural frequency of the mass of the machine resting on the elastic pad ($n_o = n$), a condition of resonance will be established and the machine will actually exert a greater force upon the foundation than it would if the pad were removed.

Effect of Damping. The effect of damping is of considerable importance for ratios of $\frac{n}{n_o}$ less than $\sqrt{2}$. Thus in the range where isolation is of no value or is detrimental, there is a compensating effect due to damping. However, for values of $\frac{n}{n_o}$ greater than $\sqrt{2}$, damping has a negative effect, and it is in the range of values above $\sqrt{2}$ that isolation is effective.

Frequency Ratios. For satisfactory results it is necessary that the elastic pad or support be such that the natural frequency of the machine on the elastic support (n_o) be low in comparison with the frequencies which are generated by the machine (n). Experience has shown that the ratio of $\frac{n}{n_o}$ should be at least 3 to 1 and that it may be economical to go to values of 5 to 1.

Selection of Resilient Mounting.* The types of resilient mountings used include springs as well as pads of corkboard, rubber, insulating board, hair felt or other resilient materials. The selection of the type of material is extremely important.

Springs. For speeds up to about 700 r.p.m., elastic pads are not usually recommended. Instead the machine should be mounted on coil springs. Experience has shown that the spring should be designed with a working height about 1.0 to 1.5 times the outside diameter because a spring with a small diameter compared to the length may not have sufficient transverse rigidity to prevent side drift.

Resilient Pads. According to Aldinger & Neubauer,* for speeds of 700 to 1200 r.p.m., rubber provides a satisfactory mounting material but should be protected from oil, whereas for speeds higher than 1200 r.p.m., isolation corkboard can be used with satisfactory results. It should be understood, however, that these limitations are approximate and that good results may be obtained for a considerable range beyond these values. In mounting equipment operating at high speeds, careful consideration should be given to the critical frequency of the substructure. For effective isolation this frequency should be considerably above the natural frequency of the resilient mounting.

Isolation Corkboard. Of the resilient materials available for

*See also "Isolation of Vibration for Refrigerating Machinery" by J. G. Aldinger and Emil T. P. Neubauer (Journal of the American Society of Refrigerating Engineers, February 1941, Page 115).

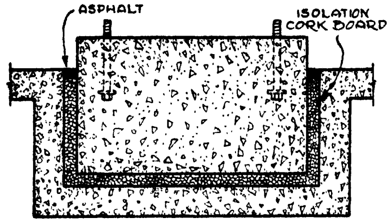


Fig. 2. Typical Depressed Foundation

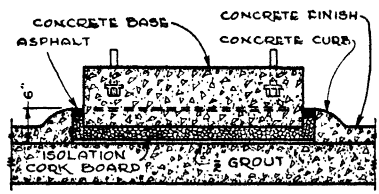


Fig. 3. Floating Foundation for Existing Suspended Slab

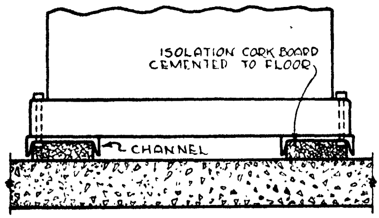


Fig. 4. Typical Light Machine Isolation

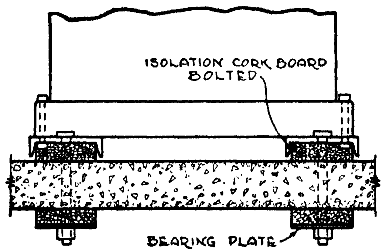


Fig. 5. Typical Light Machine Isolation with Through-Bolting

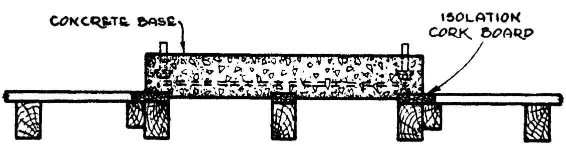


Fig. 6. Foundation—Mill Type Floor Construction

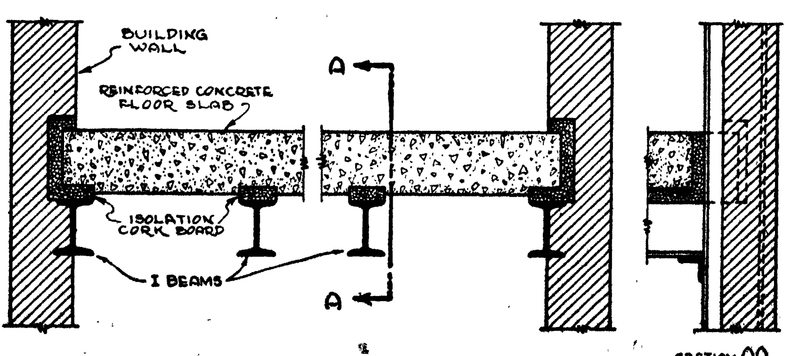


Fig. 7. Suspended Floor Entirely Isolated
Figs. 2 to 7, Courtesy of Armstrong Cork Co., Lancaster, Pa.

isolating the higher frequencies of machinery vibration, corkboard is probably the most extensively used. This is a special product similar to natural corkboard but of somewhat greater density to withstand the heavy loads to which it is subjected. Some manufacturers supply two densities and others three. These densities are based on the number of pounds of cork compressed into one board foot. The most common thicknesses are 1½, 2, 3 and 4-inch.

For loadings ranging from about 2000 to 3000 lb. per sq. ft., it is customary to use either light or medium density, according to the character of the vibration. Light density is used for light vibra-

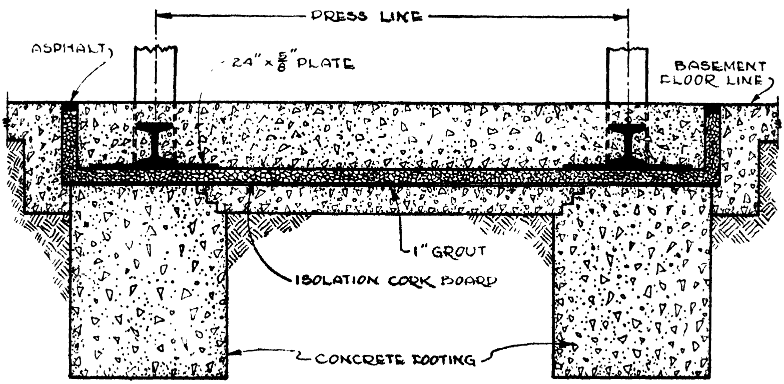


Fig. 8. Typical Printing Press Foundation
Courtesy of the Armstrong Cork Co.

tions and medium density for heavy vibrations. From 3000 to 3500 lb. per sq. ft., either medium density or heavy density is used, according to the character of the vibratory load, and from 3500 to 6000 lb. per sq. ft. it is customary to use heavy density. The thickness of machinery isolation cork used depends upon the frequency and amplitude of the vibration present.

Application of Isolation Corkboard. Figs. 2 to 9 show various typical methods of applying machinery isolation corkboard. The isolation of single or multiple machine units may be accomplished most satisfactorily by the pit type foundation illustrated in Fig. 2. Light or heavy motor-generator sets, pumps and compressors may be placed on existing suspended concrete floors as shown in Fig. 3. Fig. 4 shows a method of isolating machines with strips of machinery corkboard set in channel irons and permanently cemented to the concrete floor.

Fig. 5 shows a method of isolating light machines employing channel-irons but with the machine bolted through the floor and with an extra pad of cork below. A heavy concrete floating foundation (Fig. 6) will serve in some cases if the wood floor is braced and proper distribution of the load is arranged.

Entire building floors may be completely isolated for either light or heavy manufacturing. The manner of installing the isola-

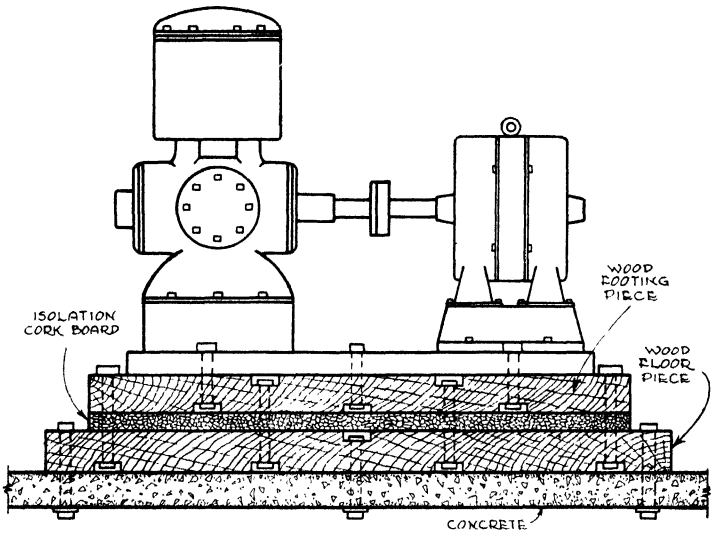


Fig. 9. Pumps and Motors on Same Bedplate
Courtesy of the Armstrong Cork Co.

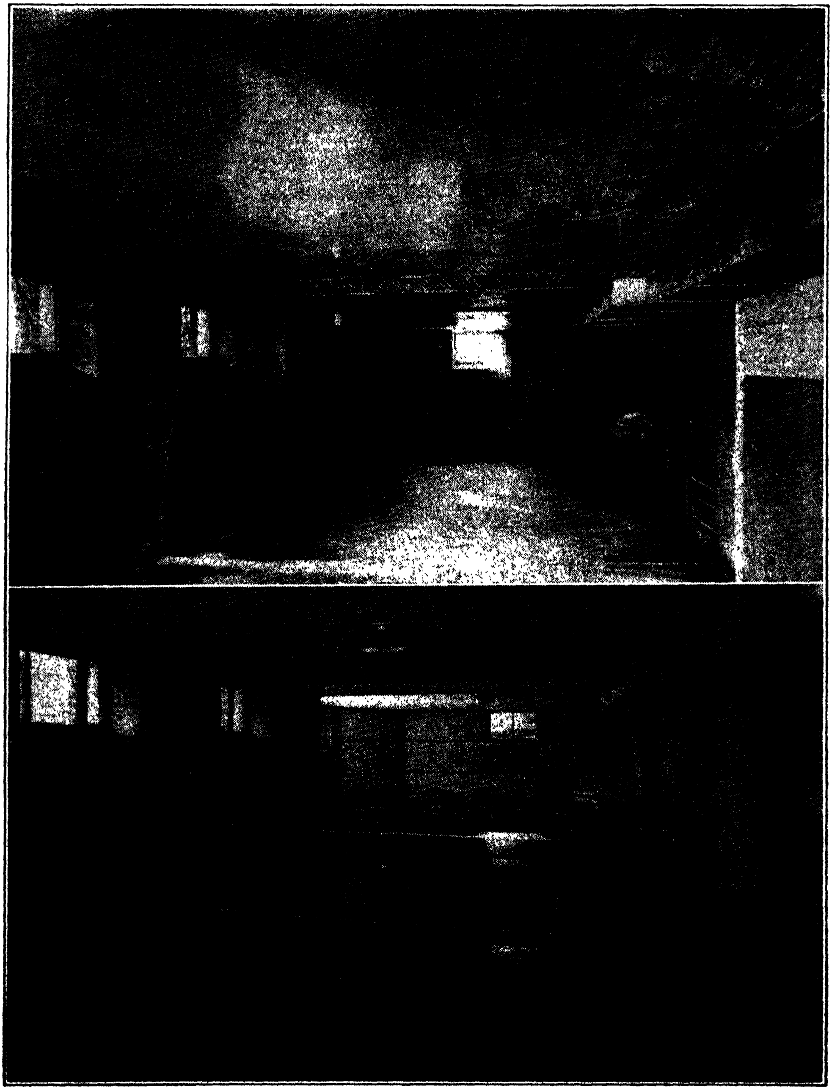
tion will depend on the type of building construction, as indicated in Fig. 7. One of the approved methods of isolating printing presses in large newspaper plants is shown in Fig. 8. This may be varied to suit the building construction. Fig. 9 shows how two units on the same bedplate may be installed on existing wood or concrete floors. This method of isolation is particularly adapted to small motor-generator sets, pumps and other lightweight machinery.

AIR-BORNE NOISES

Another problem encountered is that of air-borne noise of the machinery such as the whining of the rotor and the sparking of the commutator. These noises often can be cut down at the source by building a hood lined with absorbent material over the motor or machine. Insulating board is very satisfactory for this purpose because it is light, provides the necessary sound absorption on the inside of the hood and does not tend to vibrate. The hood must be designed to provide adequate ventilation so that the critical temperature of the motor shall not be exceeded.

With ventilating and air conditioning systems, much of the noise from the motor or fan may be transmitted by the duct if it is rigidly connected to the fan outlet. The noise may be effectively prevented from being transmitted to the duct system by making the connection between the fan and duct with a canvas sleeve.

Such noise as may reach the air stream in the ducts can be controlled by lining the ducts on the inside with a sufficient quantity of sound-absorbing materials. The lining must be properly located, well installed and be applied in a sufficient quantity to reduce the noise level of the air stream to the proper level. The theoretical reduction, in decibels per linear foot, of sound transmitted through a duct lined with sound-absorbing material is related to the size and shape of the duct, to the frequency of the sound, and to the sound-absorbing characteristics of the lining. Lagging material placed on the outside of the ducts serves to prevent noise originating outside the ducts from being carried into the air stream.



BASEMENT BEFORE AND AFTER BEING REFINISHED INTO A SMART RECREATION ROOM WITH INSULATING BOARD INTERIOR FINISH PRODUCTS

Courtesy of Wood Conversion Co., St. Paul, Minn.

CHAPTER XVI

ARCHITECTURAL ACOUSTICS AND NOISE QUIETING

Acoustical correction, including architectural acoustics as well as noise quieting, is a science in itself and many volumes have been written on this subject. The general problems and the solution thereof are summarized in this chapter. For more detailed information the reader is referred to the various textbooks* and reference volumes dealing with this phase of the sound problem.

ARCHITECTURAL ACOUSTICS

Acoustical correction is employed in rooms or spaces in which speech or music must be heard clearly, including auditoriums, theatres, churches, music halls, classrooms, lecture halls, court rooms, meeting rooms and radio studios. In order for an auditorium to be satisfactory acoustically for speech, it is necessary that the separate speech sounds be sufficiently distinguishable for a speaker to be understood. To be satisfactory acoustically for music, the different component frequencies of music must be so preserved as to be heard without distortion.

The main factors influencing the acoustical condition of a room are reverberation, extraneous noises, loudness of the original sound and the size and shape of the auditorium. Of these, reverberation is the most important factor, requiring adjustment in almost all cases where unsatisfactory acoustical conditions exist.

Reverberation. When a sound is produced in a room, sound waves spread from the source in spherical waves at a speed of approximately 1120 feet per second. When they strike the interior surfaces of the room they are partially reflected and transmitted and partially absorbed. That portion of the sound wave which is reflected continues in its path until it strikes another surface, whereupon the performance is repeated. Since most building materials, such as glass, plaster and wood, reflect over 95 per cent of the sound

*_Acoustics of Buildings_ by F. R. Watson (John Wiley & Sons), _Architectural Acoustics_, by V. O. Knudsen and _Acoustics and Architecture_ by W. C. Sabine (McGraw-Hill).

energy that strikes them, sound waves continue to be reflected for many seconds before enough of the energy is absorbed to make the sound inaudible. This continued reflection of sound after the actual source has ceased, is called *reverberation.* In a reverberant room the notes of music and syllables of speech do not die out quickly but continue to be heard along with the new sounds, so that at any instant there is audible in the room a mass of undistinguishable separate sounds, causing poor hearing conditions.

Desirable Reverberation. There are a number of factors which govern the desirable period of reverberation for a given room. Such

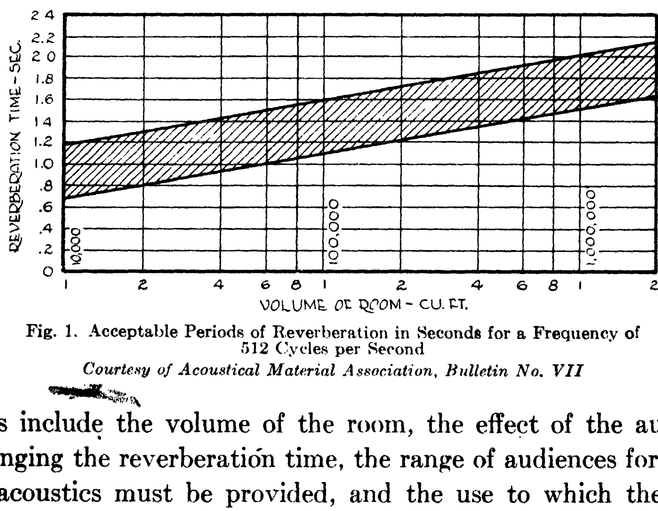


Fig. 1. Acceptable Periods of Reverberation in Seconds for a Frequency of 512 Cycles per Second
Courtesy of Acoustical Material Association, Bulletin No. VII

factors include the volume of the room, the effect of the audience in changing the reverberation time, the range of audiences for which good acoustics must be provided, and the use to which the room will be put, that is, whether for speech or music, or both, and whether for direct or reproduced sound, or both. In general, a somewhat higher reverberation is desirable for music than for speech, for direct sound than for reproduced sound, and for organ, choral and heavy orchestral music than for solo and chamber music. However, in most rooms a variety of uses and audience sizes will be encountered. Moreover, considerable latitude in reverberation time is allowable without any noticeable effect on hearing conditions.

The shaded area of Fig. 1 shows the range of acceptable periods of reverberation for rooms of different sizes. For a given room the reverberation time should be chosen according to the probable use of the room and the correction should be worked out so that this time is obtained with an audience of the most probable size present.

When treating sound film theaters or auditoriums which have a public address system, the reverberation period should fall nearer the lower limit of tolerance. In the case of churches, the times selected should fall nearer the upper limit. Likewise, the reverberation time for the empty room should be held below a certain upper limit in order to insure intelligibility of speech at all times. Experience, as well as tests on speech intelligibility, places this limit at 2.5 to 3.0 seconds.

Acoustical Analysis. The first step in making an acoustical analysis of a room is to determine the period of reverberation, which is defined as the time in seconds required, after the source is stopped, for sound to diminish to one millionth of its initial intensity, or, in other words, for the intensity level to decrease by 60 decibels. The W. C. Sabine formula for calculating the period of reverberation is as follows:

$$t=\frac{0.05V}{a} \qquad (1)$$

where

t = Period of reverberation of room, in seconds
V = Volume of the room in cubic feet
a = Number of units of absorption (sabines) present in the room

When a sound wave strikes an interior surface, the amount absorbed depends upon the porosity and other characteristics of the material forming the surface. The unit of absorption (sabine) has been taken as one square foot of surface which absorbs all of the sound which strikes it, reflecting none. Such a surface is said to have a coefficient of 1.0 or an absorbing efficiency of 100 per cent. A surface which absorbs one tenth of the sound that strikes it has a coefficient of 0.10 and ten square feet of such material will be required to furnish one sound-absorbing unit.

To determine the number of units of absorption in a room, it is necessary to find the area in square feet of each of the component materials, and multiply these areas by the coefficient for each material. The total will be the absorption of the room. Table 1 gives the coefficients at 128, 512 and 2048 cycles of common materials used in building construction. The absorption of the audience, per person, ranges from about 3.0 to 4.3 units at a frequency of 512 cycles. For this reason, the size of the audience is an important factor in determining the hearing conditions in an auditorium. Auditoriums which are acoustically poor when empty, are often satisfactory when filled, because of the large amount of absorption furnished by the audience.

Table 1. Sound-Absorbing Coefficients of General Building Materials[a]
Data for building materials are per square foot; for seats or audience, per person or seat

Material	Coefficients		
	128	512	2048
Brick wall, painted	.012	.017	.023
Same, unpainted	.024	.03	.049
Carpet, unlined	.09	.20	.27
Same, felt lined	.11	.37	.27
Fabrics, hung straight			
Light, 10 ozs. per sq. yd	.04	.11	.30
Medium, 14 ozs. per sq. yd	.06	.13	.40
Heavy, draped, 18 ozs. per sq. yd	.10	.50	.82
Floors			
Concrete or terrazzo	.01	.015	.02
Wood	.05	.03	.03
Linoleum, asphalt, rubber or cork tile on concrete.		.03–.08	
Glass	.035	.027	.02
Insulating Boards and Panels			
*Temlok DeLuxe, ½″ thick, cemented to plasterboard	.10	.28	.24
*Temlok DeLuxe, ½″ thick, on 1″x2″ furring 12″ o. c.	.15	.26	.17
*Temlok DeLuxe, 1″ thick, cemented to plasterboard	.24	.50	.46
*Temlok DeLuxe, 1″ thick, on 1″x2″ furring, 12″ o. c.	.30	.36	.45
*Temlok Panels, ½″ thick, on 1″x2″ furring 12″ o. c.	.18	.33	.32
*Temlok Panels, 1½″ thick, on 1″x2″ furring 12″ o. c.	.41	.65	.69
Marble or Glazed Tile	.01	.01	.015
Openings			
Stage, depending on furnishings	....	.25–.75	....
Deep balcony, upholstered seats	....	.50–1.00	....
Grills, ventilating	....	.15–.50	....
Plaster, gypsum or lime, smooth finish on tile or brick	.013	.025	.04
Same, on lath	.02	.03	.04
Plaster, gypsum or lime, rough finish on lath	.039	.06	.054
Wood Panelling	.08	.06	.06

Table 1—Continued. Absorption of Seats and Audience

Material	Coefficients		
	128	512	2048
Audience, seated, units per person, depending on character of seats, etc.	1.0–2.0	3.0–4.3	3.5–6.0
Chairs, metal or wood	.15	.17	.20
Pew Cushions	.75–1.1	1.45–1.90	1.4–1.7
Theater and Auditorium Chairs			
Wood veneer seat and back	....	.25	....
Upholstered in leatherette	....	1.6	....
Heavily upholstered in plush or mohair	...	2.6–3.0	....
Wood Pews	....	.40	....

•Data from Bulletin No. VIII, published by the Acoustical Materials Association, June 1941. Complete tables of coefficients of the various materials that normally constitute the interior finish of rooms may be found in the various books on architectural acoustics.

*Data preceded by an asterisk, from Bulletin No. VII, Acoustical Materials Association, April, 1940. Material was tested in the Acoustical Materials Association laboratory under test conditions specified by the Association.

Example 1. Calculate the time of reverberation with no audience and full audience for a room 50 by 100 by 20 feet high. The floor is of wood, the walls and ceiling plaster on lath. Assume there are 700 seats with an absorbing power of 0.25 units when empty and of 4.0 units when occupied.

Solution. The volume (V) is $50 \times 100 \times 20 = 100{,}000$ cubic feet. The absorption (a) empty is as follows:

Surface	Material	Dimension	Area or Number	Coeffi-cient	Absorp-tion Units
Floor	Wood	50x100	5000	.03	150
Walls	Plaster	20x300	6000	.03	180
Ceiling	Plaster	50x100	5000	.03	150
Seats	....	....	700	.25	175
Total absorbing power, bare room					655

Time of reverberation (bare room):

$$t = \frac{.05 \times 100{,}000}{655}$$
$$= 7.6 \text{ seconds.}$$

If the 700 seats are occupied, the absorption of the audience will be $700 \times 4.0 = 2800$ units and the total absorption of the room will be $150 + 180 + 150 + 2800 = 3280$ units.

Time of reverberation (with 700 audience):

$$t=\frac{0.5\times 100{,}000}{3280}$$
$$=0.15 \text{ seconds}$$

Amount of Acoustical Material Required. In order to reduce the period of reverberation to a degree sufficient to provide satisfactory hearing conditions, it is necessary to apply the proper amount of sound-absorbing material to the wall, ceiling and other surfaces of the room. The amount to be applied depends on the sound-absorbing efficiency of the material to be used and the desirable period of reverberation. The sound-absorbing coefficients of various acoustical materials are given in Table 2. Thus since the volume (V) of the room is fixed and the desirable period of reverberation is known (t), the required amount of absorption (a) can be calculated from Formula (1). Then in order to arrive at the amount of absorption to be added it is only necessary to subtract the absorption of the room without any acoustical treatment from the absorption required. The number of square feet of acoustical material required is determined by dividing the amount of absorption to be added by the net sound-absorbing efficiency per square foot of the material to be used after deducting the absorption of the surfaces to be covered.

Location of Acoustical Treatment. The reverberation time of a room in general is independent of the location of the acoustical treatment, provided the treatment is placed on areas accessible to sound waves, such as main ceilings and walls. Treatment applied on the rear portion of a deep under-balcony ceiling would not be entirely effective in reducing the reverberation in the main part of the room, since only a part of the sound waves would penetrate to this area. Such treatment is, however, effective in quieting interfering noise, either from the audience itself or from foyers and lobbies.

Heavy treatment of rear walls, particularly in long, narrow rooms, is desirable in order to minimize echoes which would otherwise prove disturbing in the front part of the room. This is particularly important when the rear wall is curved. Surfaces around stages should be reflecting rather than absorbent, so that they may reinforce and project the sound toward the audience.

Shape of Auditorium and Distribution of Sound. It is also necessary to consider the problem of distribution of sound which is mainly affected by the shape of the auditorium. In general, a room of

Table 2. Sound Absorption Coefficients of Acoustical Materials[a]

Material	Manufacturer or Distributor	†Thickness Inches	Type (See Note b)	Mounting (See Note c)	Coefficients 128	256	512	1024	2048	4000	*Noise Red. Coef.
Absorbatone A.	Luse-Stevenson Co.	1	VII	2	.15	.28	.82	.99	.87	.98	.75
Absorbatone A.		1	VII	2	.11	.29	.80	.99	.80	.96	.70
Absorbatone A..		1	VII	5	.25	.55	.99	.99	.85	.96	.85
Absorbex, Type A	Celotex Corp.	1	VII	1	.18	.26	.63	.96	.77		.65
Absorbex, Type A.		1	VII	2 (18″o.c.)	.20	.35	.86	.90	.72		.70
Absorbex, Type A		1	VII	11	.32	.50	.95	.96	.80		.80
Absorbex, Type A.		1	VII	5	.58	.77	.98	.92	.79		.85
Absorbex, Type A		1	VII	7	.91	.99	.87	.84	.88		.90
Absorbex, Type A.		1	VII	12	.54	.96	.90	.95	.85	.93	.90
Absorbex, Type C.		1	VII	1	.15	.23	.40	.66	.62		.50
Absorbex, Type C		1	VII	2 (16″o.c.)	.21	.27	.48	.63	.54		.50
Absorbex, Type F.		1	VII	2 (16″o.c.)	.11	.17	.49	.68	.63		.50
Absorbex, Type F.		1	VII	5	.45	.69	.81	.64	.64		.70
Absorbex, Type F.		2	VII	1	.21	.44	.85	.70	.72		.70
Acousteel, pad	Celotex Corp.	1¼	IV	3	.26	.65	.99	.99	.81	.50	.85
plus metal facing and pad supports..		1⅝									
plus furring.		2½									
Acoustex 30R	National Gypsum Co.	⅝	VII	1	.14	.21	.42	.78	.85		.55
Acoustex 30R.		⅝	VII	2	.22	.23	.57	.87	.72		.60
Acoustex 30R. backed by 1″ rock wool		⅝	VII	2	.17	.38	.98	.96	.85	.75	.80
Acoustex 40R..		¾	VII	1	.16	.27	.50	.88	.80		.60
Acoustex 40R		¾	VII	2	.22	.30	.70	.92	.79		.70
Acoustex 40R		¾	VII	6	.55	.70	.84	.75	.80		.75
Acoustex 40R.		¾	VII	9	.18	.33	.87	.89	.87	.65	.75
Acoustex 50R		⅞	VII	1	.24	.29	.60	.95	.83		.65
Acoustex 50R		⅞	VII	2	.24	.40	.82	.90	.72		.70
Acoustex 60R.		1	VII	1	.23	.28	.63	.95	.81		.65
Acoustex 70R..		1⅛	VII	1	.24	.33	.74	.96	.80		.70
Acoustex 70R......		1⅛	VII	2	.30	.43	.88	.91	.80		.75
Acoustimetal Type P pad		1¼	IV	3	.23	.63	.99	.98	.78	.62	.85
plus metal facing and pad supports...		1⅝									
plus furring......		2½									
Acousti-Celotex, Type C1	Celotex Corp.	½	V	1	.24	.27	.48	.57	.59		.50
Acousti-Celotex, Type C1		½	V	2	.36	.58	.51	.52	.62		.55
Acousti-Celotex, Type C2		⅝	V	1	.19	.20	.69	.85	.65		.60
Acousti-Celotex, Type C2		⅝	V	2	.40	.59	.68	.81	.66		.70
Acousti-Celotex, Type C3		13/16	V	1	.25	.27	.76	.88	.60		.65
Acousti-Celotex, Type C3.		13/16	V	2	.22	.50	.76	.84	.66	.40	.70
Acousti-Celotex, Type C3		13/16	V	9	.22	.56	.76	.87	.60	.25	.70
Acousti-Celotex, Type C4		1¼	V	1	.37	.43	.98	.79	.57		.70
Acousti-Celotex, Type C4		1¼	V	2	.35	.60	.98	.80	.54	.49	.75
Acousti-Celotex, Type C5		13/16	V	1	.14	.35	.63	.83	.90		.70
Acousti-Celotex, Type C6		1¼	V	1	.19	.41	.91	.92	.92		.80
Acousti-Celotex, Type C7..		1	V	9	.37	.50	.69	.84	.77	.83	.70
Acousti-Celotex, Type M1		⅝	V	1	.17	.29	.58	.82	.82		.65
Acousti-Celotex, Type M1		⅝	V	1	.14	.24	.58	.93	.83		.65
Acousti-Celotex, Type M1		⅝	V	2	.17	.43	.53	.79	.88	.63	.65
Acousti-Celotex, Type M2..		1	V	1	.15	.34	.88	.95	.77		.75
Acousti-Celotex, Type M2.		1	V	9	.22	.53	.69	.99	.74	.63	.75
Acoustone D.	United States Gypsum Co.	9/16	VI	1	.06	.16	.61	.90	.82	.82	.60
Acoustone D.		9/16	VI	1	.08	.21	.70	.87	.71	.66	.60
Acoustone D.		11/16	VI	1	.08	.22	.73	.91	.81	.85	.65
Acoustone D.		11/16	VI	1	.13	.26	.79	.88	.76	.74	.65
Acoustone D.		13/16	VI	1	.15	.26	.79	.92	.85	.85	.70
Acoustone D..		13/16	VI	1	.11	.30	.81	.88	.77	.76	.70
Acoustone D.		15/16	VI	1	.20	.40	.84	.88	.85	.88	.75
Acoustone D....		15/16	VI	1	.12	.37	.83	.88	.83	.80	.75
Acoustone F...		9/16	VI	1	.11	.12	.44	.89	.90	.93	.60
Acoustone F..		9/16	VI	1	.04	.12	.53	.95	.85	.85	.60
Acoustone F...		11/16	VI	1	.14	.17	.65	.93	.85	.89	.65
Acoustone F.....		11/16	VI	1	.04	.18	.75	.96	.80	.80	.65
Acoustone F...		13/16	VI	1	.14	.26	.81	.88	.85	.83	.70
Acoustone F.....		13/16	VI	1	.16	.33	.85	.89	.80	.75	.70
Acoustone F.....		15/16	VI	1	.16	.31	.87	.92	.83	.87	.75
Acoustone F.....		15/16	VI	1	.16	.33	.91	.87	.83	.88	.75

[a]From Official Bulletin No. VII of the Acoustical Materials Association, April 1940.

Table 2—Continued. Sound Absorption Coefficients of Acoustical Materials[a]

Material	Manufacturer or Distributor	†Thickness Inches	Type (See Note b)	Mounting (See Note c)	Coefficients						*Noise Red. Coef.
					128	256	512	1024	2048	4000	
Airacoustic	Johns-Manville Sales Corp.	½	VIII	8	.22	.31	.48	.73	.86	.76	.60
Airacoustic		1	VIII	8	.44	.44	.74	.80	.93	.74	.75
Airacoustic		1½	VIII	1	.48	.59	.62	.72	.76		.70
Calicel, Standard	Celotex Corp.	¾	II	1	.16	.19	.57	.95	.71	.68	.60
Calicel, Standard		¾	II	1	.15	.22	.58	.96	.76	.80	.65
Calicel, Standard		1	II	1	.20	.29	.76	.97	.79	.69	.70
Calicel, Standard		1	II	1	.20	.27	.76	.99	.81	.72	.70
Calicel, Standard		1	II	10	.59	.69	.99	.91	.81	.88	.85
Calicel, Tapestry		¾	III	1	.13	.20	.64	.89	.65	.50	.60
Calicel, Tapestry		1	III	1	.18	.32	.83	.82	.67	.62	.65
Calistone		1	I	4	.16	.28	.60	.89	.66	.58	.60
Calistone		2	I	4	.36	.58	.77	.69	.63	.50	.65
Corkoustic B4	Armstrong Cork Co.	1¼	VI	1	.08	.13	.51	.75	.47	.46	.45
Corkoustic B4		1¼	VI	2	.11	.34	.67	.47	.57	.53	.50
Corkoustic B5		1½	VI	1	.13	.20	.68	.59	.54		.50
Corkoustic B5		1½	VI	2	.19	.41	.60	.51	.53		.50
Corkoustic B6		1¾	VI	1	.15	.28	.82	.60	.58	.38	.55
Corkoustic B6		1¾	VI	2	.22	.55	.61	.54	.51	.50	.55
Econacoustic	National Gypsum Co.	½	VIII	1	.05	.31	.54	.84	.76	.90	.60
Econacoustic		½	VIII	2	.09	.39	.73	.71	.78	.82	.65
Econacoustic		1	VIII	1	.25	.40	.78	.76	.79	.68	.70
Fiberglas Acoustical Tile, Type TW-PF 9D	Owens-Corning Fiberglas Corp.	½		2	.08	.24	.67	.93	.71	.46	.65
Fiberglas Acoustical Tile, Type TW-PF 9D		1		2	.22	.46	.97	.90	.68	.52	.75
Fiberglas Decorative Acoustical Blanket		1		2	.26	.40	.70	.93	.88	.82	.75
Fibracoustic	Johns-Manville Sales Corp.	1	VIII	1	.17	.43	.79	.93	.79	.73	.75
Fibracoustic		1	VIII	2	.18	.65	.82	.83	.85	.83	.80
J-M Fibretex, Type 30R		⅝	VII	2	.22	.23	.57	.87	.72		.60
J-M Fibretex, Type 40R		¾	VII	1	.16	.27	.50	.88	.80		.60
J-M Fibretex, Type 40R		¾	VII	2	.22	.30	.70	.92	.79		.70
J-M Fibretex, Type 40R		¾	VII	6	.55	.70	.84	.75	.80		.75
J-M Fibretex, Type 50R		⅞	VII	1	.24	.29	.60	.95	.83		.65
J-M Fibretex, Type 50R		⅞	VII	2	.24	.40	.82	.90	.72		.70
J-M Fibretex, Type 60R		1	VII	1	.23	.28	.63	.95	.81		.65
J-M Fibretex, Type 70R		1⅛	VII	1	.24	.33	.74	.96	.80		.70
J-M Fibretex, Type 70R		1⅛	VII	2	.30	.43	.88	.91	.80		.75
Kencoustic	David E. Kennedy, Inc.	1½	VI	1	.05	.13	.61	.71	.56	.60	.50
Muffletone	Celotex Corp.	1	II	1	.18	.32	.73	.90	.83	.85	.70
Muffletone		¾	II	1	.17	.29	.63	.75	.74	.80	.60
Perfatone, Type B pad	United States Gypsum Co.	1¼	IV	3	.19	.61	.98	.99	.82	.68	.85
plus metal facing and pad supports		1⅝									
plus furring		2½									
Perfatone, Type C pad		1¼	IV	3	.24	.65	.93	.98	.79	.68	.85
plus metal facing and pad supports		1⅝									
plus furring		2½									
Permacoustic	Johns-Manville Sales Corp.	¾	VI	1	.19	.34	.74	.76	.75	.74	.65
Permacoustic		1	VI	1	.21	.47	.74	.72	.75	.73	.65
Q-T Ductliner	Celotex Corp.	½	VIII	8	.35	.25	.54	.75	.76	.66	.60
Q-T Ductliner		1	VIII	8	.43	.37	.69	.78	.78	.70	.65
Quietone	United States Gypsum Co.	1	VIII	1	.30	.52	.73	.82	.75		.70
Quietone		½	VIII	1	.19	.30	.58	.64	.80		.60

[a] From Official Bulletin No. VII of the Acoustical Materials Association, April, 1940.

Table 2—Continued. Sound Absorption Coefficients of Acoustical Materials[a]

Material	Manufacturer or Distributor	†Thickness Inches	Type (See Note b)	Mounting (See Note c)	Coefficients 128	256	512	1024	2048	4000	*Noise Red. Coef.
Sanacoustic, pad		1⅛	IV	3	.25	.56	.99	.99	.91	.82	.85
plus metal facing and pad supports	Johns-Manville Sales Corp.	1⁹⁄₁₆									
plus furring		2½									
Soundex A	Luse-Stevenson	1⅛	VII	2	.22	.28	.72	.97	.76	.75	.70
Sound Isolation Blanket MK	Johns-Manville Sales Corp.	½		4	.16	.34	.67	.77	.61		.60
Sound Isolation Blanket MK		1		4	.29	.72	.83	.78	.72		.75
Sound Isolation Blanket MK		2		4	.66	.74	.84	.88	.83		.80
Spongecoustic		¾	III	1	.10	.22	.80	.89	.76	.66	.65
Spongecoustic		¾	III	2	.11	.37	.88	.81	.74	.68	.70
Temcoustic F1	Armstrong Cork Co.	½	VIII	1	.16	.29	.43	.49	.44	.35	.40
Temcoustic F1		½	VIII	2	.23	.56	.34	.31	.39	.34	.40
Temcoustic F2		⅞	VIII	1	.33	.40	.54	.52	.50	.42	.50
Temcoustic F2		⅞	VIII	2	.47	.50	.39	.44	.49	.35	.45
Tekoustic B5		1½	VI	1	.23	.49	.99	.73	.48	.44	.65
Transite Acoustical Unit, pad	Johns-Manville Sales Corp.	1	IV	2	.28	.55	.83	.91	.76	.67	.75
plus Transite facing		1⅛									
Travacoustic	National Gypsum	1	VI	1	.14	.29	.80	.98	.85	.74	.75

*The noise reduction coefficient is the average of the coefficients at frequencies from 256 to 2048 cycles inclusive, given to the nearest 5%. This average coefficient is recommended for use in comparing materials for noise-quieting purposes as in offices, hospitals, banks, corridors, etc.

†Unless otherwise noted, the thickness given is the thickness of the sound-absorbing element forming the face of the construction. The thickness of other sound-absorbing elements in the construction, if used, is indicated by the type of mounting.

[a]From Official Bulletin No. VII of the Acoustical Materials Association, April, 1940.

Note b—Types:

The following classifications agree with Federal Specification for Acoustical Units; Prefabricated SS-A-118:

I. Cast units composed of small uniform mineral particles held together with Portland cement.

II. Cast units having a surface composed of or resembling small uniform granules. The binder may be gypsum or any other suitable mineral binder.

III. Cast units having a surface composed of or resembling irregular, rough granules. The binder may be gypsum or any other suitable mineral binder.

IV. Units having a mechanically perforated surface, which acts as a covering for the sound-absorbent material.

V. Units which are mechanically perforated, the perforations extending into the sound-absorbent material.

VI. Units having a fissured surface.

VII. Compressed units composed of long wood fibers held together with a mineral binder. This type shall not have a mechanically perforated surface.

VIII. Felted fiber or wood pulp units which have a surface that is not mechanically perforated.

Note c—Mountings:

1. Cemented to plaster board. Considered equivalent to cementing to plaster or concrete ceiling.

2. Nailed to 1-in.x2-in. wood furring 12-in. o.c. unless otherwise indicated.

3. Attached to metal supports applied to 1-in.x2-in. wood furring.
4. Laid directly on laboratory floor.
5. Nailed to 1-in.x3-in. wood furring 18-in. o.c. and filled in between furring with 1-in. mineral wool, .33 lbs. per sq. ft.
6. Nailed to 2-in.x4-in. wood furring 24-in. o.c.
7. Nailed to 2-in.x4-in. studs 18-in. o.c., and filled between studs with 3½-in. thick mineral wool, 1.14 lbs. per sq. ft.
8. Laid on 24 ga. sheet iron, nailed to 1-in.x2-in. wood furring, 24-in. o.c.
9. Attached to special metal supports mounted on 2-in.x2-in. wood furring.
10. Mounted on special metal supports. 2-in. rock wool blanket 2.36 lbs. per sq. ft. behind unit.
11. 1-in. *Absorbex Type A* spot-cemented to 1-in. *Absorbex Type F.*
12. 1-in. *Absorbex Type A* spot-cemented to 3-in. *Absorbex Type F.*

rectangular shape is preferable and large curved surfaces should be avoided as they have a tendency to focus sound in the same manner that a curved mirror focuses light.

An even distribution of sound throughout an auditorium is desirable, so that any surface which concentrates sound in one portion of the room at the expense of another is to be avoided. In certain cases, such as a high curved ceiling or a curved rear wall in a long room, this focusing action may be such as to cause an abnormally loud and distinct echo, which may interfere with hearing. In general, the radius of curvature of a ceiling should be less than half or more than twice the ceiling height, and the same rule applies to a rear wall with respect to the length of the room. The best cure for difficulties due to curved surfaces is to change the radius of curvature in accordance with this rule, but where this is impossible, the intensity of reflections from such surfaces may be reduced by treating them with acoustical material.

✓ *Spaces Under Balconies.* Unsatisfactory hearing conditions are often encountered under balcony spaces. The opening to the under balcony space should naturally be as large as possible to allow sound to enter. A low, deep balcony is undesirable because the low opening does not permit sufficient sound intensity in the rear portion of the space for satisfactory hearing conditions.

Loudness of Original Sound. Another consideration in the acoustical condition of an auditorium is the loudness of the original sound. The intelligibility of speech is directly related to the loudness of the original sound. A person with a loud voice is heard better than one with a weak voice, so that in large auditoriums it is often desirable to use a good public address system to amplify the voices of speakers. Of course, it is necessary that the reverberation in the room be such that even when the sound is amplified and the reverberation is thereby increased, it will not be above acceptable limits. The amplifying equipment must be of good quality, or the distortion introduced will overcome the benefits of amplification.

Effect of Extraneous Noises. The presence of extraneous noises has an important influence on the quality of the hearing conditions of an auditorium. Where such noises are present, the loudness of the original sound must be increased to overcome the effects of the interference and the listeners must concentrate on the original sound to exclude effectively the extraneous noise from their consciousness. While the primary purpose of installing an acoustical material in an auditorium is to decrease reverberation, such treatment may also tend to lessen the annoyance from extraneous noises. Machinery noises may be quieted at their origin, thus reducing the interfering effect thereof. Absorptive linings for ventilation ducts and absorbent housings for machines will often improve conditions.

NOISE QUIETING

Noise quieting is used wherever it is necessary to minimize the disturbance and distraction due to noise and to provide a quiet, comfortable atmosphere. The rooms and spaces requiring noise quieting include offices, banks, restaurants, dining rooms, corridors in schools and hospitals, gymnasiums and swimming pools. The use of acoustical treatment for this purpose involves an extension of the methods used in acoustical correction.

While the primary effect of introducing absorption into a room is to reduce the reverberation, this is accompanied by the secondary effect of reducing the intensity of sound produced in the room. When a continuous sound is made in a room with highly reflecting surfaces, the hundreds of reflections from the surfaces tend to build up the sound intensity to a point much greater than would result from the same source without reflection. If some of these surfaces are made absorbent, the reflections from them will be substantially reduced and consequently the total intensity is reduced to a lower level than before. In acoustical correction the absorption necessary to give the desired reduction in reverberation generally produces only a small quieting effect. In noise quieting, therefore, considerably more absorption is necessary to produce satisfactory results than is needed simply to produce satisfactory hearing conditions.

Calculating Noise Reduction. The quieting effect of treatment in a given room is stated in terms of the reduction of the noise level in decibels.

From the theory of reverberation, it can be shown that the average intensity of sound in a room is inversely proportional to the

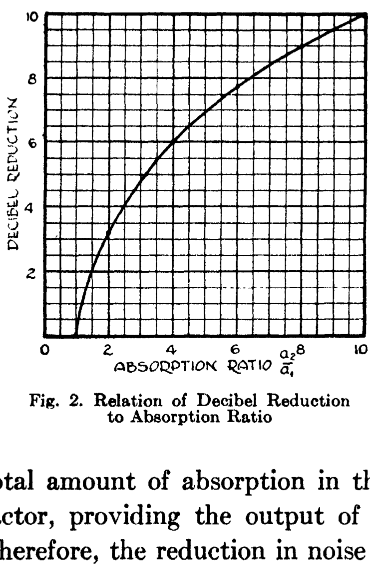


Fig. 2. Relation of Decibel Reduction to Absorption Ratio

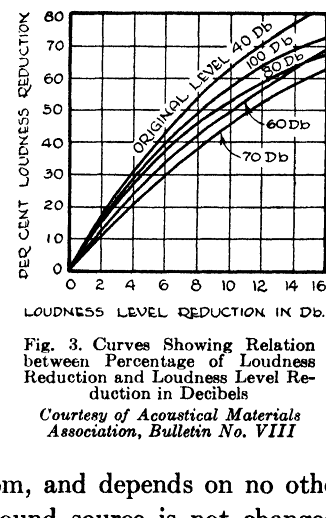


Fig. 3. Curves Showing Relation between Percentage of Loudness Reduction and Loudness Level Reduction in Decibels

Courtesy of Acoustical Materials Association, Bulletin No. VIII

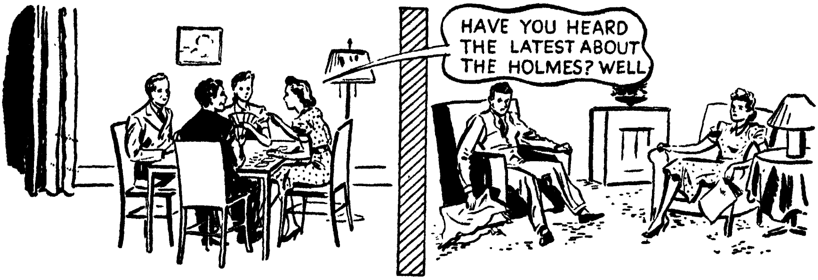
total amount of absorption in the room, and depends on no other factor, providing the output of the sound source is not changed. Therefore, the reduction in noise level due to increasing the absorption in a room from a_1 to a_2 by the addition of treatment is

$$\text{Decibel Reduction} = 10 \log_{10} \frac{a_2}{a_1} \tag{2}$$

This relation is shown graphically in Fig. 2. If the absorption in a room is calculated to be 200 units, the addition of 600 units will make the ratio of $\frac{a_2}{a_1}$ equal to 4 and the loudness reduction will therefore be 6 db. as shown in Fig. 2.

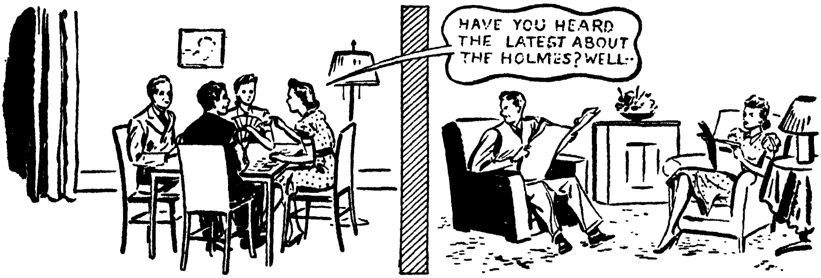
From practical experience, 5 db. is about the minimum reduction which should be attempted for acceptable results and it usually is not practical to attempt a reduction greater than 10 db. as will be apparent from an examination of Fig. 2.

Relative Loudness of Sounds. The psychological sensation of



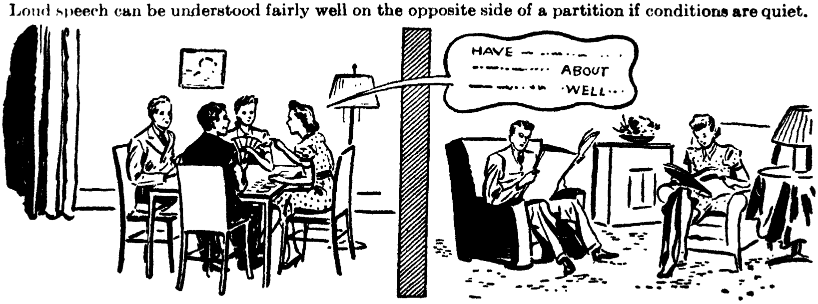
SOUND REDUCTION OF 25 DECIBELS

Normal speech can be understood quite easily and distinctly through a wall or partition.



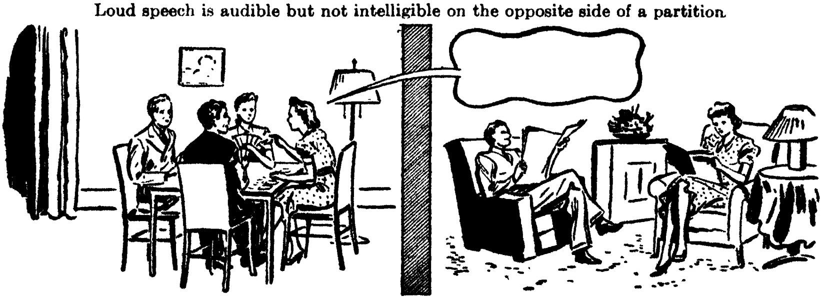
SOUND REDUCTION OF 30 DECIBELS

Loud speech can be understood fairly well on the opposite side of a partition if conditions are quiet.



SOUND REDUCTION OF 35 DECIBELS

Loud speech is audible but not intelligible on the opposite side of a partition.



SOUND REDUCTION OF 40 DECIBELS

Normal speech is not audible and loud speech can be heard faintly, but cannot be understood on opposite side of partition.

Courtesy of Insulation Board Institute, Chicago, Ill.

loudness does not correspond directly to intensity level in decibels, but follows a rather complicated relation. For example, if a sound is reduced by only 5 db., it will be estimated as a reduction in loudness of 25 to 40 per cent, depending on the original level of the sound, whereas if the reduction is 10 db., it will be estimated as a reduction in loudness ranging from about 46 to 64 per cent. This relationship is illustrated by Fig. 3.

Noise Reduction Coefficient. The noise encountered in most cases contains a multitude of frequency components which extend over practically the entire audible frequency range. Acoustical materials vary in absorption at different frequencies, and since a material is expected to be effective in absorbing noise at all frequencies, it is necessary to assign to each material a coefficient which is an average of the coefficients at the various frequencies. The Acoustical Materials Association has recommended that the average to the nearest 5 per cent of the coefficients at 256, 512, 1024 and 2048 cycles be used as a so-called *Noise Reduction Coefficient* for comparing the noise-quieting values of materials.

CHAPTER XVII

INSULATING FARM STRUCTURES

This chapter deals with the use of insulation for farm structures, such as poultry laying houses, brooder houses, dairy barns, milk houses, hog and farrowing houses, and fruit and vegetable storage rooms or houses. Information on the use of insulation for the farm residence is given in other chapters.

Relationship between Insulation, Ventilation, and Vapor Barriers. Proper housing of animals and poultry, as well as the storage of produce, is essential to the efficient operation and profitable management of a farm. Proper housing means, first of all, providing shelter from the elements—rain, snow, and wind. However, of equal or greater importance is the fact that a farm building must also provide, in addition to mere *protection*, optimum atmospheric conditions for animals and poultry, and for the storage of crops.

The building should protect animals from extremes of heat and cold, from sudden temperature changes, and from drafts. The interiors should be reasonably dry and free from disagreeable or unhealthy odors. The interior surfaces should not *sweat* or *frost*. In order to control the atmospheric conditions in an unheated farm structure used for animal housing or storage, the combined use of insulation, ventilation, and vapor barriers is required.

As pointed out in previous chapters, heat will pass through all building materials to some extent when it is warmer or colder outside than inside the building. No material will stop entirely the passage of heat. However, some materials have relatively little heat resistance and consequently heat passes through them rapidly. Other materials have a high degree of heat resistance and heat will not go through them readily. These are known as *insulating materials*, or *insulations*. Such materials have concentrated heat resistance and consequently they slow down the passage of heat through any part of the building, such as a wall or roof, in which they are installed.

Purpose of Farm-Building Insulation. As in other uses, the principal purpose of farm-building insulation is to slow down the passage of heat through the walls and roof so as to keep the building warmer in winter and cooler in summer. In so doing, the insulation also performs other valuable functions. It prevents *sweating* and *frosting* on the building surfaces when installed in the proper thickness depending on the local conditions of indoor temperature and humidity, and outdoor temperature, as explained later in this chapter. See also the chapter on Condensation.

Another purpose of the insulation is to retain enough of the available heat in cold weather to warm the air so that the ventilation system will function properly. Various economic benefits of farm insulation are obtained also and some of these are discussed in the following pages.

Purpose of Farm-Building Ventilation. An efficient farm ventilating system is necessary, first, for regulating inside temperatures and second, for removing excessive quantities of moisture and odors given off by livestock and poultry. Ventilating can be done through open windows and by means of flues, or through the use of thermostatically controlled fans. By carrying off excess moisture, ventilation reduces the amount of vapor in the air and thus helps to prevent *sweating* and *frosting*. Good ventilation is possible only in structures which are kept tight and reasonably warm. Consequently, insulated buildings are easier to ventilate than poorly constructed, uninsulated buildings.

Purpose of Vapor Barriers in Farm Structures. The reasons for using vapor barriers in farm structures are the same as those for other buildings as explained in the chapter on Condensation. However, there is one important difference; in relation to the volume of enclosure the amount of moisture present in animal shelters and storage rooms or buildings, is usually much greater than is the case with structures intended solely for human occupancy. The problem of preventing moisture troubles is thus much more severe in farm structures than in the average dwelling and the need for using vapor barriers is correspondingly greater.

The important interrelationship between insulation, ventilation, and vapor barriers is thus apparent. Insulation keeps buildings warmer in the winter and cooler in summer. Ventilation removes moisture and stale air and brings in fresh air, and helps to regulate temperatures. Insulation and ventilation together prevent surface condensation and make it possible to have buildings that are both warm and dry. Vapor barriers retard the entrance of vapor into walls, and thus prevent condensation within them. Through these three aids, correctly used, it is possible to keep farm buildings at a comfortable temperature, dry and free from both surface and internal condensation, or *sweating*.

ECONOMIC REASONS FOR INSULATION OF FARM BUILDINGS

There are several economic reasons for using insulation in farm structures. Some of the reasons for insulation are: (1) increase in production; (2) lessens mortality; (3) lessens food spoilage; (4) increases life of building; and (5) saves in fuel. In addition to the primary economic advantages involved, insulation of farm buildings also provides greater comfort for the animals, as well as for their caretakers.

Increase in Production. The heat needed for dwellings is obtained artificially by the combustion of wood, coal, oil, or gas. The amount of fuel burned is varied to meet the demand. Thus it is possible to maintain a fairly uniform temperature within the building. The heat for warming animal shelters must come either from the bodies of the animals or from burning fuel. Nearly always, the heat is provided by the animals, hence it is limited to the heat production of their bodies. The inside temperature thus fluctuates to a considerable extent with variations in the outside temperature.

Animals or poultry will consume approximately the same amount of feed regardless of the temperatures of their shelters. However, if a building is extremely cold, more of the feed will be used for keeping up body temperatures and less for production. This will mean, for example, a reduction in the output of milk or eggs. Therefore, warm inside winter temperatures result in greater production.

In a bulletin published by the United States Department of Agriculture, attention is called to the fact that experience has shown it pays to keep cows comfortable.* Experiments made at the Institute of Animal Nutrition of Pennsylvania showed that, under the usual conditions of intensive cattle feeding, the cost of maintenance increases 1.4 per cent for each degree the temperature falls below the point at which the animal begins to feel cold.

*United States Department of Agriculture, Bulletin No. 187.

Maximum production depends upon preventing sudden changes in temperature. Rapid temperature variations are more dangerous than steady cold. Even in mild climates, for example, sudden temperature fluctuations in poultry houses often cause the output of eggs to fall off. The inside temperature of an insulated building is not subject to quick changes because the insulation holds the heat inside and the building cools off gradually.

Lessens Mortality. According to farm experts, the health of young animals, such as chicks, calves, and pigs, is easily undermined by cold and drafty buildings. Insulation helps provide the needed warmth. Insulation also reduces drafts in two ways: first, by providing tighter construction, thus reducing air leakage; and second, by increasing surface temperatures.

Cold wall and ceiling surfaces create drafts because air cooled by these surfaces drops to the floor, thus starting a circulation of air. According to many farm authorities, by reducing to a minimum these serious causes of illness, insulation enables the farmer to keep his stock healthier and to raise more animals to a marketable or productive age.

Lessens Food Spoilage. Temperature and humidity variations have a direct effect on the quality of fruits and vegetables held in storage. Freezing ruins many crops. High humidities are desirable for others in order to prevent shrinkage. Wide variations in temperature generally are harmful. Insulation protects the harvested crops from freezing during cold weather and from excessive heat in summer. Insulation also helps control the humidity and the operation of the ventilating system, both of which are essential in properly maintaining a good storage building.

Increases Life of Building. Insulation, by making possible good ventilation and helping to prevent condensation, keeps buildings dry. Damp farm buildings deteriorate rapidly. Repeated wetting and drying warps, shrinks, and rots framing members and siding. This permits drafts in the buildings which then become colder and less efficient. Therefore, an insulated building will last longer.

Saves Fuel. Where fuel is used to maintain inside temperatures in farm structures, insulation reduces the amount consumed. If a building is heated by the use of wood or coal, insulation not only reduces the cost of fuel but also reduces the amount of wood or coal that must be carried in for heating purposes. If oil, gas, or electricity is used for heating, insulation reduces the size of the fuel bills appreciably. For buildings, such as a farm home, this saving often is a sizable amount. Whether the saving is large or small, it is over and above the other advantages obtained by insulating a building.

Greater Comfort. The foregoing paragraphs give the most important economic reasons for insulating farm buildings, but the matter of comfort for both the livestock and the man who takes care of them is also important, even though it cannot be evaluated exactly in dollars and cents. However, this increased comfort is a bonus. As a prominent farm authority has stated: "Feeding, milking, and other routine operations are more efficiently accomplished in the barn of comfortable temperature than under conditions that arouse an instinctive desire on the part of the workman to slight the work in order to get it done quickly."

TYPES AND APPLICATION OF INSULATION USED ON FARM STRUCTURES

Practically all the types of commercial insulations discussed in the chapter on Types of Thermal Building Insulation are suitable for use in farm structures. However, the most common commercial insulations used in the outbuildings are loose fill, blankets, bats, and insulating board. The most commonly used insulating-board products are the building board in both ½-inch and 1-inch thicknesses and the 25⁄32-inch insulating-board sheathing.

In addition to the commercial insulations, so-called natural or noncommercial insulations are also used to some extent. These are materials produced or available on the farm and include straw, shavings, sawdust, cottonseed hulls, ground corncobs, and buckwheat shucks. However, such materials usually attract vermin, rodents, and insects unless chemically treated beforehand. If wood shavings or sawdust is used, it is common practice to mix about one pound of ordinary hydrated lime with each bushel basket of shavings or sawdust. Even if properly treated with chemicals before installation, most of the so-called natural insulations have a high affinity for moisture and must not only be replaced at frequent intervals, but are likely to induce rotting of the framing members. Thus such materials may prove more expensive in the long run than factory-made commercial insulations which have been properly treated for protection against moisture, rodents, and insects. Therefore, commercial insulations are recommended usually in preference to natural insulations for farm use, even though the initial cost of the commercial products may be greater.

The methods of applying insulating materials to farm structures are in general the same as those for residences and other types of buildings as discussed in the chapter on Methods of Application. However, there are certain precautions and protective measures to be observed in applying insulating materials to farm structures which are not necessary in other types of buildings.

Vapor Barriers for Farm Buildings. Vapor barriers are required in practically all buildings used for animal or poultry housing and for the storage of fruits and vegetables because, as previously stated, of the excessive quantities of moisture present in such structures. The average amounts of moisture given off by various farm animals are indicated in column 6 of Table 1. A 900-pound Jersey cow, for example, gives off about 4,470 grains of moisture per hour, or 0.64 pound per hour.

The vapor barrier should have a permeability rate not to exceed 1.25 grains of moisture per hour per square foot of surface per inch of mercury vapor pressure. The permeability rates of various materials are given in the chapter on Condensation.

Vapor barriers used in farm structures may be either of the paper or membrane type, or of the liquid or paint type. Of the first classification, duplex papers consisting of a layer of asphalt between two layers of kraft paper are economical and efficient vapor barriers for farm use. They should be installed as near the warm side of the wall or ceiling as possible, either directly on the interior wall or ceiling surface or just in back of it. The rule for locating the vapor barrier is that it always should be installed at a point in the wall (or ceiling) where it will be above the dew-point temperature of the room air at all times. However, this can seldom be determined in advance because an exact knowledge of the probable inside winter relative humidity is not known. For this reason, the safest procedure is to locate the barrier as near the inside surface as possible, or on it, as a wallpaper, if the conditions permit.

If applied to the inside surface, as a wallpaper, the barrier may

Table 1. Approximate Heat and Moisture Production of Livestock at Normal Winter Barn Temperatures—Also Approximate Air Flow Required to Maintain a CO_2 Content in the Air of 17 Parts in 10,000*

Animal	Approximate Body Weight	Heat Production (B.t.u. per Hour)			Moisture Production (Grains per Hour)	Air Flow c.f.h. per Animal or Bird to Maintain 17/10,000 CO_2 Content	At Approximate Environmental Temperature of
		Sensible Heat	Latent Heat of Vaporization	Total Heat			
1	2	3	4	5	6	7	8
Jersey cow producing 20 lbs. milk per day	900	2020	670	2690	4470		
Jersey cow producing 30 lbs. milk per day	900	2260	750	3010	5000	3452 (average)	45° to 55°F.
Holstein cow producing 30 lbs. milk per day	1200	2460	820	3280	5450		
Holstein cow producing 40 lbs. milk per day	1200	2770	920	3690	6130		
Light work horse	1000	1340	450	1790	2960	2307 (average)	40°F.
Heavy work horse	1500	1835	610	2445	4060		
Laying hen—average production	4	36	1.6	37.6	20.6	16	35°F.
Hogs—pen holding one 400-lb. sow and 8 pigs 1 week old	450	1130	200	1330	1360	1500	35° to 40°F.

*Data in this table compiled by J. L. Strahan, New York, from the following sources:
Data on cows and horses from *Some Fundamentals of Stable Ventilation*, by Armsby and Kriss.
Data on hens from *Estimated Data on the Energy, Gaseous, and Water Metabolism of Poultry for Use in Planning the Ventilation of Poultry Houses*, by Mitchell and Kelley.
Data on hogs from *Energy Requirements of Swine and Estimates of Heat Production and Gaseous Exchange for Use in Planning Ventilation for Hog Houses*, by Mitchell and Kelley.

be cemented to the surface using a waterproof adhesive, such as a liquid asphalt coating, or it may be attached to the surface by nailing through wood lath or 1x2 furring strips into every stud or framing member, as shown in Fig. 1, using galvanized nails. If the latter method is used, the back of the lath or furring strips should be sealed with asphalt before applying. The method involving the cementing of the vapor barrier to the surface is preferable to nailing, for two reasons: first, because it avoids puncturing the vapor barrier at the nail holes; and second, because the asphalt coating has some vapor resistance. However, the nailing (through lath) method is usually simpler. In either case, it is advisable usually to protect the membrane on wall surface against damage by animals, crates, and machinery to the proper height by means of lumber, hardboard, or asbestos-cement board, applied either solid or spaced.

The membrane or paper type of vapor barrier may also be applied directly to the studs or other framing members *in back of* the interior lining and tacked in place temporarily until the interior wall lining is

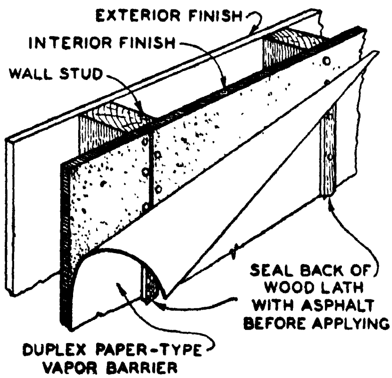


Fig. 1. Duplex Paper-Type Vapor Barrier Applied by Nailing through Lath

applied. This method, likewise, has the disadvantage that the vapor barrier is punctured by the nails which hold the interior lining, obviously decreasing the efficiency of the barrier. Furthermore, if one-inch lumber is used, the vapor barrier may be at a point in the wall below the dew-point temperature which would permit condensation to take place on the barrier or in materials in front of it. This can be determined by a simple calculation if the probable relative humidity is known, as illustrated by the following example:

Example 1. The interior surface of an exterior frame wall is to be lined with one-inch lumber (resistance = 0.98). What will be the total required resistance of the wall to prevent surface condensation on the vapor barrier or within the one-inch lumber interior finish, assuming an inside temperature and relative humidity of 50°F. and 74% respectively and an outside temperature of −10°F?

Solution. The required resistance of the wall to prevent condensation on the vapor barrier may be calculated by means of the following formula:

$$R_v = \frac{R_f(t - t_o)}{t - t_d} \tag{1}$$

where

R_v = required resistance to prevent surface condensation on (or on the warm side of) the vapor barrier.

R_f = resistance of material or materials (including that of exposed surface) on warm side of vapor barrier.

t = inside temperature near surface involved.

t_o = outside temperature.

t_d = dew-point temperature based on inside temperature (t) and relative humidity assumed.

$R_f = 0.98$ (lumber) $+ 0.61$ (surface) $= 1.59$

$t = 50$

$t_o = -10$

$t_d = 42.1$ (see Table 1, of chapter on Condensation)

$t - t_o = 60$

$t - t_d = 7.9$

Therefore:

$$R_v = \frac{1.59 \times 60}{7.9} = 12.1$$

Thus, to prevent surface condensation on the vapor barrier, a total wall resistance of 12.1 would be required. The insulation and other materials on the outside or cold side (in winter) of the vapor barrier should have a combined resistance of not less than $12.1 - 1.59$ or 10.51 to be certain that there will be no condensation on or in front of the vapor barrier if the relative humidity is 74%, the inside temperature 50°F., and the outside temperature −10°F. If the vapor barrier were located on the inside surface (as a wallpaper) it would be warmer in winter than if it were located in back of the interior finish, thus decreasing the likelihood of condensation taking place on the vapor barrier. This illustrates why it is advisable to have the vapor barrier as near the warm side, in winter, as possible where exceptionally high humidities are expected.

The liquid or paint type of vapor barrier is readily applied to interior surfaces in most cases. The types suitable for farm use include: asphalt, aluminum, and oil base paints and liquid asphalt coatings of various types. Usually, from two to three coats are required to provide efficient results and to make certain that the surface is thoroughly covered. Most aluminum paints are particularly well suited to application over asphalted surfaces and are good vapor barriers, but because of the cost are often limited to the final coat, the under coats being asphalt or other vapor-barrier paints.

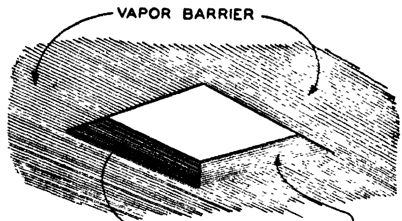


Fig. 2. View of Ceiling Showing Vapor Barrier Carried around Open Hatchway Sealed at Edges with the Vapor Barrier

In using vapor barriers, the following conditions should be observed:

1. The vapor barrier should have a permeability rate not to exceed 1.25 grains per square foot per hour per inch of mercury. (See Tables 3, 4, and 5 of the chapter on Condensation.)

2. The vapor barrier should be placed as near the inside surface as possible, but always at a point in the wall or ceiling that will be above the probable dew-point temperature of the air in the building. This may necessitate the use of a specified amount of insulation where high moisture conditions prevail even if the vapor barrier is located directly on the inside surface.

3. Care must be taken to insure continuous protection over the entire surface to be covered.

4. All openings must be sealed to prevent the vapor from by-passing the surface, Fig. 2.

5. Where the inside and outside conditions are reversed at certain periods of the year and artificial cooling is used as in some types of storages, it is necessary to have vapor barriers on both sides of the framing. For this purpose, duplex papers or other efficient paper types of barriers are recommended.

Application of Loose Fill Insulations to Farm Buildings. The information in the chapter on the Application of Loose Fill Insulations is applicable in practically all cases to farm structures. Vapor barriers should be provided as specified in the preceding paragraphs on this subject and installed on the warm side (winter) of the construction. Loose fill insulations are merely poured in place from bags or hand packed between framing members. The pneumatic method of application is also used in some cases. The application of a fill insulation between wood framing with a vapor barrier on the warm side (winter) and building paper on the cold side is shown in Fig. 3. The applica-

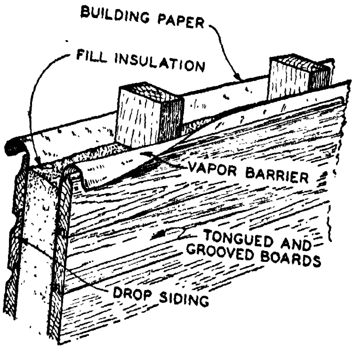


Fig. 3. Frame Wall with Fill Insulation and Vapor Barrier

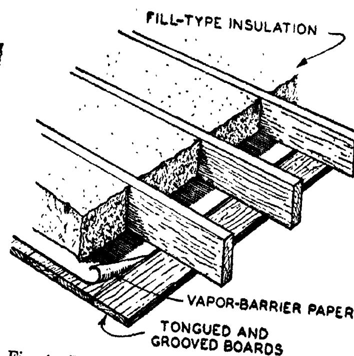


Fig. 4. Fill-Type Insulation Applied between Ceiling Joists over Vapor Barrier

tion of a fill-type insulation between ceiling joists over a vapor barrier is shown in Fig. 4. The application of a fill-type insulation between roof rafters over insulating board with a vapor barrier applied to the under side or exposed surfaces of the insulating board is shown in Fig. 5. The interior finish and vapor barrier should be applied first, after which the roof boards may be applied starting at the eaves and the fill insulation poured or hand packed in place as the roof boards are applied progressively. This work should be done at a time when it can be certain that the entire operation, including the application of the roofing, can be completed before there is any possibility of rain, which would damage the insulation.

Application of Batt and Blanket Insulations to Farm Buildings. The methods of applying batt or flexible blanket insulations given in the chapter on Methods of Application are adaptable also to farm structures. Vapor barriers should be provided as specified in the preceding paragraphs on this subject. However, one important precaution should be observed. If the blanket or batt insulation, as sold, is provided with a vapor barrier (which is also used as a nailing flange), an interior lining of lumber, insulating board, or other material, is usually applied over the insulation. The tendency of the interior lining materials is to decrease the winter surface temperature of the barrier below what it would be if it were exposed to the room without any interior finish or lining. It is possible under certain conditions, when such a lining is installed, for the surface of the insulation

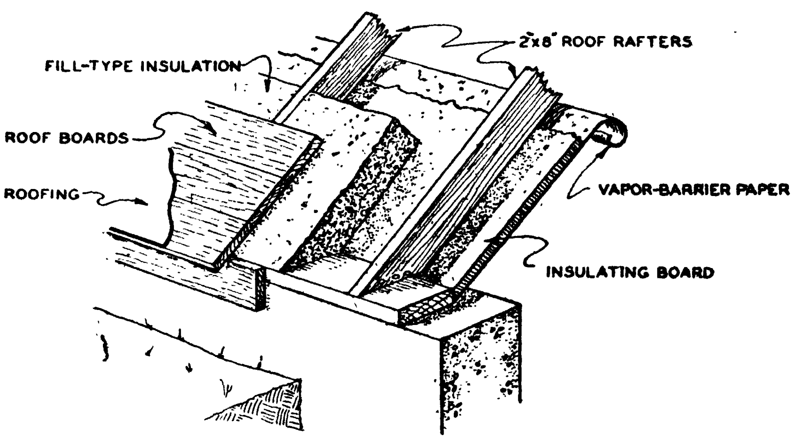


Fig. 5. Fill-Type Insulation Applied over Insulating Board between Rafters of Roof of Below-Grade Vegetable Storage

vapor barrier to be below the room air dew-point temperature, in which case condensation would take place on the vapor barrier or in the materials over it. This can be determined by calculation if the probable relative humidity is known, as well as the inside and average minimum outside temperatures. If there is any doubt about the matter, there are two possible solutions. One solution is to apply another vapor barrier over the surface of the interior finish of an efficiency equal to or greater than that of the insulation barrier. The other solution is to use only thin materials of high heat conductivity, such as asbestos-cement board, over the vapor barrier as a lining or interior finish. However, the insulation in back of the vapor barrier should be of sufficient thickness to preclude condensation on the vapor barrier.

Application of Insulating Board to Farm Buildings. Where insulating board is to be used certain protective measures should be taken. Where insulating board is applied to wall surfaces, or used on the outside of the studs without any additional exterior finish, the board should be protected from damage by abrasion, puncture, and poultry pecking. The use of vapor barriers is recommended in accordance with the foregoing paragraphs on this subject.

In buildings where the interior walls may be bumped or kicked by animals, or rammed by machinery or tools, the surface of the insulating board should be covered to the necessary height with lumber, hardboard, plywood, asbestos-cement board, or other suitable material, nailing through to the underlying studs. Materials ordinarily used for exterior finish will protect insulating board applied to the outside of studs. Exterior corners should be covered on both sides with 1-inch lumber three or four inches wide. Guard rails should be installed to protect exposed exterior surfaces where there is danger of bumping by machinery or animals.

Insulating board installed in poultry-house walls requires a protection against pecking. While many methods have been used with varying success, it has been found that the most complete satisfaction is given when lumber, oil-treated hardboards, asbestos-cement boards, or fine wire screens are used as the protective material. Such covering should be used to a height of 24 inches above the floor and behind roosts and nests. In poultry houses where only one layer of insulating board is used and is applied to the outside of the studs so that the inside of the studs is exposed, put the protective material on first, then nail the insulating board over it.

The directions for applying insulating board, given in the chapter on Methods of Application, should be followed for farm buildings. When the ½-inch-thick board is used for side walls, framing should be installed on not more than 16-inch centers. The framing for the 25/32-inch or 1-inch-thick products should be applied on a maximum of 24-inch centers. Headers should be inserted between framing members at the unsupported ends of insulating boards to serve as a nailing base.

For masonry construction, furring strips should be attached to the masonry on centers, depending on the thickness of the insulating board to be used, as specified in the preceding paragraph. The insulating board should be nailed to these furring strips. Where the masonry is of brick, concrete blocks, or hollow tile, furring strips may be attached to the concrete by means of expansion shields and bolts or nailed into the joints. Masonry walls above grade should be waterproofed on the inside before applying the furring strips. Masonry walls below grade should be waterproofed on the outside before back filling. All furring strips should be painted on four sides with carbolineum before being put in place.

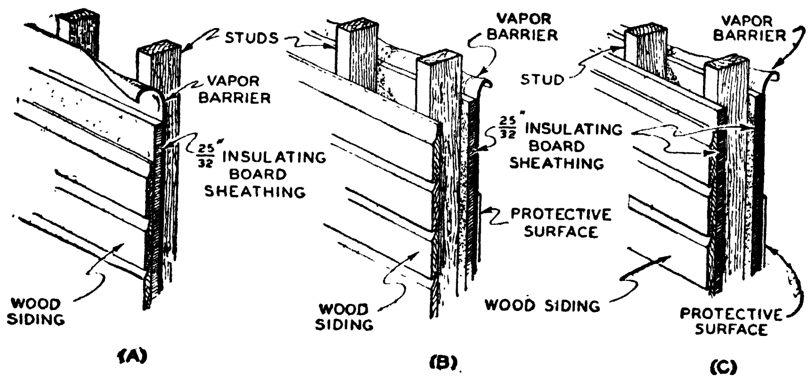


Fig. 6. Three Methods of Insulating Frame Walls with Insulating Board: (*A*) One Layer of Insulating Board on Outside of Studs, with or without Other Exterior Finish; (*B*) One Layer of Insulating Board Sheathing on Inside of Studs, with Wood Siding or Other Exterior Finish; (*C*) Two Layers of Insulating Board Sheathing, One on Each Side of Studs with Wood Siding or Other Exterior Finish over Outside Layer

Insulating boards should not be forced into place. The large 4-foot-wide (up to 12-foot-long) boards should be installed so as to leave a space of ⅛ inch between adjoining boards and at ends. Most insulating boards are cut scant in width and length to allow for space in which to expand. The 2x8-foot sheathing board should be installed so that the interlocking long edges fit snugly, leaving a ⅛-inch space between the ends. Headers are not required at the horizontal (interlocking) joints of the 2x8-foot sheathing.

Applying Insulating Board to Walls of Farm Buildings. Insulating board may be used for insulating either frame or masonry walls. In the case of frame walls it may be applied to either or both sides of studs. Spacing of studs or furring strips should be governed by the thickness of the insulating board to be used, as previously mentioned;

that is, 16 inches for ½-inch insulating board and 24 inches for 25/32-inch or 1-inch insulating board.

When installed on the outside of studs, insulating board should be covered with wood siding, hardboard, asbestos-cement board or other suitable exterior finish materials, using nails of sufficient length to go through both exterior finish and insulating board and into the studs at least one inch. Insulating-board sheathing may be used also without any additional material over the exposed exterior surfaces

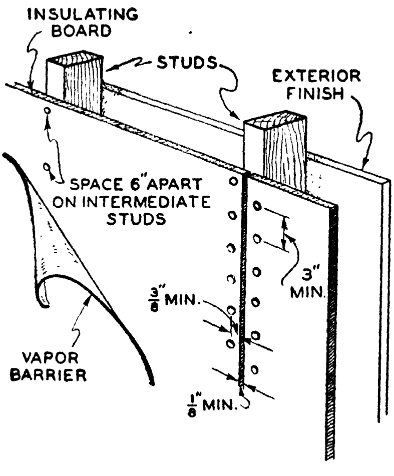


Fig. 7. Interior View of Frame Wall Showing Method of Applying Insulating Board

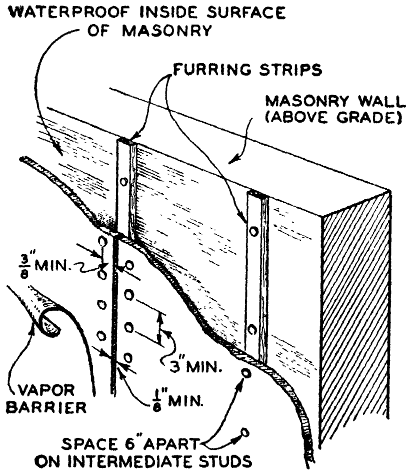


Fig. 8. Interior View of Masonry Wall Showing Application of Furring Strips and Insulating Board

other than two coats of paint. (See paragraph on Painting Insulating Board.) Vertical joints between insulating boards exposed to the weather should be covered with batten strips or sealed with an asphalt emulsion or other sealing compound. Three methods of insulating frame walls of farm buildings with insulation board are shown in Fig. 6. An interior view of a frame wall showing the application of insulating board and a vapor barrier, applied to inside surface where excessively humid conditions exist, is shown in Fig. 7. Large-headed galvanized nails are used. An interior view of a masonry wall, showing the application of the furring strips and insulating board, with strips spaced according to thickness of board used, is shown in Fig. 8.

Applying Insulating Board to Ceilings and Roofs of Farm Buildings. Insulating board may be applied to ceilings as a lining or interior finish in a manner similar to that for walls, spacing the framing on the proper centers, depending on the thickness of the board to be used. The under side of the roof rafters may serve as framing for the ceiling, as shown in Fig. 9; or separate ceiling joists may be used, as shown in Fig. 10.

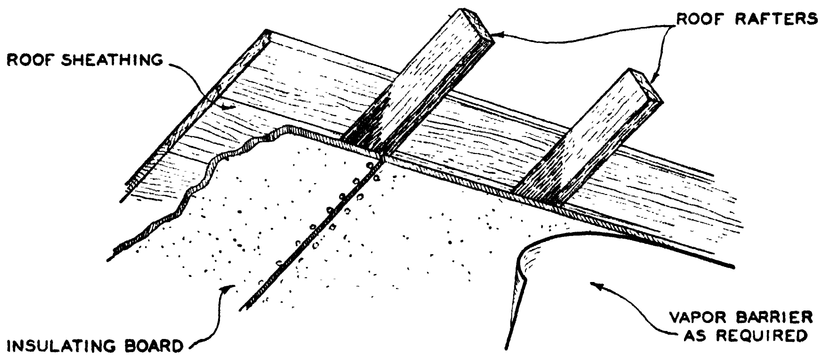


Fig. 9. Insulating Board Applied as a Lining to Under Side of Roof Rafters

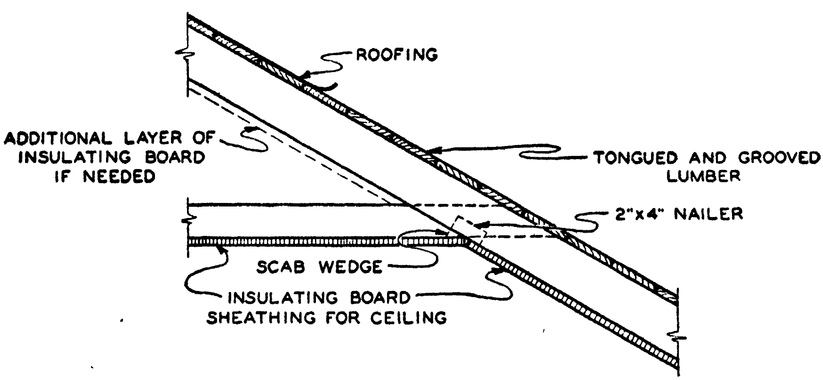


Fig. 10. Pitched Roof with Insulating Board Applied to Both Flat and Pitched Portions of Ceiling; also Showing How Additional Layer of Insulating Board Can Be Applied to Under Side of Rafter

Insulating board may be used also for insulating roofs of farm buildings, where the board may be applied as an insulation between the rafters and the wood sheathing, as shown in Fig. 11, or the board may be applied on the under side of the rafters as a lining, as shown in Fig. 9. If applied on the top of the rafters (Fig. 11), the insulating board should be nailed to the roof rafters and then covered with the wood sheathing, nailing through the wood sheathing and insulating board to the roof rafters, and using nails which are long enough to penetrate the rafters at least one inch. Roofing may then be applied over the wood sheathing in accordance with the specifications given by manufacturers of roofing materials. If the insulating board is applied directly to the under side of the rafters as a lining, the rafters should be spaced on 16-inch or 24-inch centers, depending on the thickness of the insulating board used. If, however, the rafter spacing

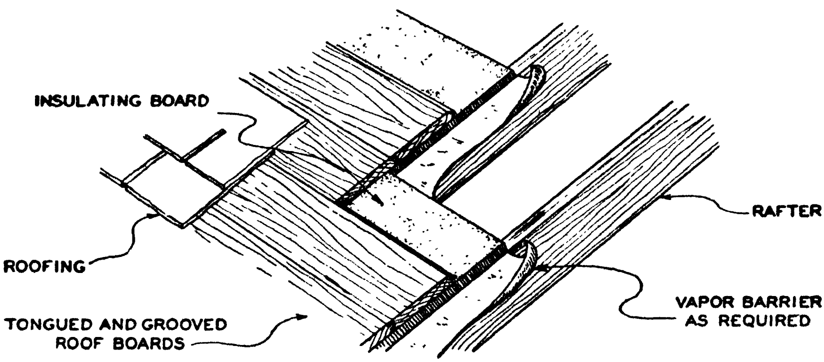


Fig. 11. Insulating Board Applied as Roof Insulation on Pitched Roof and Covered with Wood Sheathing

is too wide, furring strips may be applied to the rafters on the proper centers and the insulating board nailed to these furring strips.

Applying Insulating Board to Floors of Farm Buildings. Insulating board may be used for insulating floors directly above and exposed to the ground. For this purpose $^{25}/_{32}$-inch insulating-board sheathing may be applied to either the top or the bottom of the floor joists, or to both. If applied to the top, the sheathing must be covered with the usual flooring and protected against moisture from damp litter, with a layer of roofing felt on the floor side. A layer of insulating-board sheathing applied to the under side of the floor joists with wood flooring above is shown at (*A*), Fig. 12. The application of two layers of $^{25}/_{32}$-inch insulating-board sheathing, one on the under side of the joists and the other on top of the joists, and covered with wood flooring, is shown at (*B*), Fig. 12.

Framing may be spaced on either 16-inch or 24-inch centers and, as stated previously, the insulating-board sheathing should be covered with a suitable floor-surfacing material, such as lumber or lightweight concrete. The layer of roofing felt should be applied over the insulating board with joints lapped two inches before applying the finish floor.

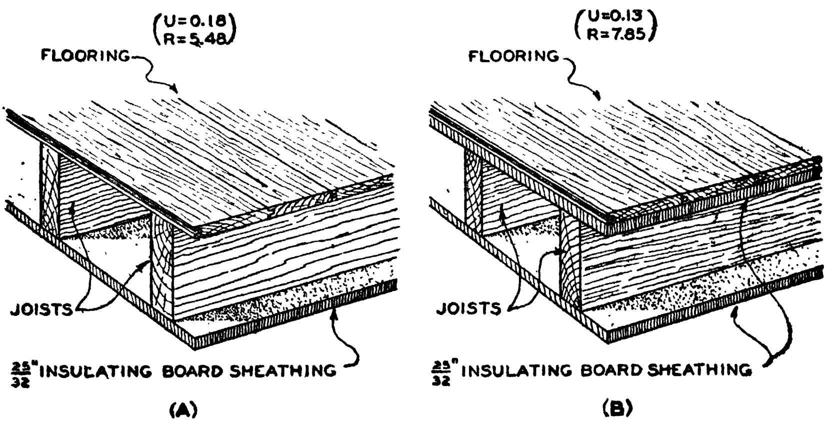


Fig. 12. Insulating Board Applied to Flat Ceilings: (*A*) One Layer on Under Side of Joists; (*B*) Two Layers, One on Under Side of Joists and the Other on Top of Joists, Covered with Flooring

Painting Insulating Board. The instructions for painting insulating board, given in the chapter on Methods of Application, should be observed. The following information is applicable particularly to the use of paint for farm buildings.

Casein and water paints may be applied directly to insulating-board surfaces. Plain insulating-board surfaces must be properly sized before application of oil or varnish paints. The size should be that recommended by the paint manufacturer. Paints applied to asphalt-treated sheathing should be those suitable for application over asphalt as recommended by the paint manufacturer and include certain types of asphalt and aluminum paints, as well as sealers for use over asphalt, to provide a base for oil or other types of paint. Ordinarily, not less than two coats of paint, including the sealer, should be applied to insulating board surfaces for best results.

Venting of Lofts. In addition to the use of vapor barriers in ceilings, loft spaces should be vented by means of louvers or other suitable openings to permit the escape of whatever vapor may pass through the ceiling vapor barrier. There should be at least two such vents, one located at each gable and as high as possible. Their size should be based on the ceiling area, allowing one-fourth square inch of opening for each square foot of ceiling area. This total can be divided between the two or more vents.

CALCULATION OF INSULATION REQUIRED FOR FARM STRUCTURES

Heat Loss Coefficients of Farm Structures. Frame walls and roofs of farm structures are usually of simple design consisting of lumber or other material on one or both sides of the framing and with or without an insulating material between the structural framing. Masonry walls are also of the simplest design. Consequently, few of the heat loss coefficients, or *U* values, given in the tables in the chapter on Transmission Coefficients and Tables are applicable to farm structures. Tables 2, 3, and 4 give *U* values for many of the common constructions used for farm buildings. These tables include the *U* values, as well as the corresponding resistances. The thermal resistances of many building and insulating materials commonly used on the farm are given in Table 5. These resistances may be used for calculating the heat loss coefficients (*U* values) of constructions not given in Tables 2, 3, and 4, using the resistance method given in the chapter on Transmission Coefficients and Tables. Coefficients for frame construction floors are given in Table 10 of the same chapter.

Coefficients of transmission (*U*) and resistances (*R*) of frame construction walls commonly used on farms are given in Table 2. However, this table does not include *U* values for frame construction having blanket, batt, or fill insulation between studs. These values can be found by either of two methods in connection with Table 2; the first uses Fig. 13 of this chapter, the second uses Table 5 of the chapter on Transmission Coefficients and Tables. Illustrations are given in the following:

Example 2. To find the *U* value of a frame wall with 1-inch blanket between studs when the exterior finish is ¾-inch drop siding and the interior finish ⅜-inch gypsum board.

a) As shown in Table 2, the *U* value with no insulation between studs is 0.35 (No. *1*, Col. *B*, Table 2). Next, locate this coefficient on

[*Continued on p. 334*]

Table 2. Coefficients of Transmission (U) and Resistances (R) of Frame Construction Walls
(Commonly Used on Farms; see Notes *a*, *b*, and *c*)

These coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference and are based on a 15 m.p.h. wind velocity

No.	Exterior Finish (on Studs)	Interior Wall Lining (on Studs): None (Studs Exposed)	3/8″ Gypsum Board	5/16″ Plywood	1″ T & G Lumber (25/32″ Thick)	Insulating Board[d] 1/2″ Thick	Insulating Board[d] 25/32″ Thick	Insulating Board[d] 1″ Thick
		A	B	C	D	E	F	G
1	3/4″ Drop Siding	U = 0.58 R = 1.72	U = 0.35 R = 2.90	U = 0.33 R = 3.02	U = 0.28 R = 3.61	U = 0.24 R = 4.15	U = 0.20 R = 5.00	U = 0.18 R = 5.66
2	1/2″ Gypsum Board[e]	U = 0.89 R = 1.13	U = 0.43 R = 2.31	U = 0.41 R = 2.43	U = 0.33 R = 3.02	U = 0.28 R = 3.56	U = 0.23 R = 4.41	U = 0.20 R = 5.07
3	3/8″ Plywood[e]	U = 0.80 R = 1.25	U = 0.42 R = 2.41	U = 0.39 R = 2.55	U = 0.32 R = 3.14	U = 0.27 R = 3.68	U = 0.22 R = 4.53	U = 0.19 R = 5.19
4	1/2″ Insulating Board[e]	U = 0.435 R = 2.30	U = 0.29 R = 3.48	U = 0.28 R = 3.60	U = 0.24 R = 4.19	U = 0.21 R = 4.73	U = 0.18 R = 5.58	U = 0.16 R = 6.24
5	25/32″ Insulating Board[e]	U = 0.32 R = 3.15	U = 0.23 R = 4.33	U = 0.225 R = 4.45	U = 0.20 R = 5.04	U = 0.18 R = 5.58	U = 0.155 R = 6.43	U = 0.14 R = 7.09

Table 3. Coefficients of Transmission (*U*) and Resistances (*R*) of Masonry Walls[a]

(Commonly Used on Farms)

These coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference and are based on a wind velocity of 15 m.p.h.

No.	Type and Thickness of Wall	Interior Wall Lining (On Furring Strips)				
		None (Bare Walls)	1″ T & G Lumber (25/32″ Thick)	Insulating Board[b]		
				1/2″ Thick	25/32″ Thick	1″ Thick
		A	B	C	D	E
6	8″ Concrete Blocks	U = 0.56 R = 1.78	U = 0.27 R = 3.67	U = 0.24 R = 4.21	U = 0.20 R = 5.06	U = 0.17 R = 5.72
7	12″ Concrete Blocks	U = 0.49 R = 2.03	U = 0.26 R = 3.92	U = 0.22 R = 4.46	U = 0.19 R = 5.31	U = 0.17 R = 5.97
8	8″ Cinder Blocks	U = 0.41 R = 2.44	U = 0.23 R = 4.33	U = 0.21 R = 4.87	U = 0.17 R = 5.72	U = 0.16 R = 6.38
9	12″ Cinder Blocks	U = 0.38 R = 2.66	U = 0.22 R = 4.55	U = 0.20 R = 5.09	U = 0.18 R = 5.66	U = 0.15 R = 6.60
10	8″ Solid Concrete	U = 0.70 R = 1.42	U = 0.30 R = 3.31	U = 0.26 R = 3.84	U = 0.21 R = 4.70	U = 0.19 R = 5.36
11	8″ Hollow Tile	U = 0.41 R = 2.45	U = 0.23 R = 4.34	U = 0.20 R = 4.88	U = 0.17 R = 5.73	U = 0.15 R = 6.49
12	8″ Common Brick	U = 0.42 R = 2.38	U = 0.23 R = 4.27	U = 0.21 R = 4.81	U = 0.18 R = 5.66	U = 0.16 R = 6.32
13	8″ Stone	U = 0.63 R = 1.58	U = 0.29 R = 3.47	U = 0.25 R = 4.02	U = 0.21 R = 4.86	U = 0.18 R = 5.53

the left-hand scale of Fig. 13, then draw a dotted line horizontally to the 1-inch blanket insulation curve; from this point draw a dotted line vertically downward to the scale at the bottom of Fig. 13, which indicates the U value for walls with insulation between studs, or framing. The dotted line on Fig. 13 shows the U value in this example to be 0.15.

b) To find this U value by using Table 5 in the chapter on Transmission Coefficients and Tables, after finding the U value 0.35 in Table 2, locate this value in the left-hand column of Table 5; opposite this, in Column A (1-inch blanket insulation) is the U value 0.15. Either of the two foregoing methods will give the U value desired.

The insulation requirements in this chapter are expressed in terms of the required U values or resistances rather than in terms of insulation thicknesses. For practical purposes in calculating heat losses, it is recommended that a minimum U value of 0.10 be used, for the reasons stated in the paragraphs under Minimum Practical Coefficient Value of the chapter on Transmission Coefficients and Tables. This is consistent with findings at the University of Illinois.

NOTES FOR TABLE 2

[a] For other frame-wall coefficients see Table 4, of the chapter on Transmission Coefficients and Tables.

[b] No allowance made for building paper or vapor barriers as these have negligible resistance.

[c] These coefficients do not include any insulation between studding. To obtain coefficients for 1-, 2-, or 3-inch blanket or bat insulation or 3⅝″ mineral wool insulation between studding, first find in columns B to G of Table 2 the U value which applies to your particular problem. Then refer to Table 5 in the chapter on Transmission Coefficients and Tables (using the U values in columns B to G of Table 2).

Example: What is the coefficient (U) of a construction consisting of ¾″ drop siding on the outside of studs and 1″ T & G lumber on inside of studs, with 2″ bats between studs?

Solution. The U value with no insulation between studding (item *1D* of Table 2) is 0.28. Referring to Table 5, in the chapter on Transmission Coefficients and Tables, you will find the U value of this wall with 2″ bats between studding is 0.098. To find the resistance of such a wall, take the reciprocal of this number; that is, $\frac{1}{0.098}$, which equals 10.2. (See also Table D in the chapter on Transmission Coefficients and Tables.)

[d] If the surface of insulating board is protected with lumber, hardboard, or asbestos-cement board in direct contact with the insulating board, add the following resistance to the R values:

1″ lumber (solid)	0.98
⅛″ hardboard	0.09
Asbestos-cement board	neglect

$$U = \frac{1}{R(total)}$$

[e] Use same values if surface is covered with asbestos siding as small resistance of siding may be neglected.

NOTES FOR TABLE 3

[a] These coefficients do not include any insulation between furring strips. If blanket, bat, or fill insulation is applied between furring strips, resistances and coefficients may be calculated in usual manner. If 1″ furring strips are used, the maximum thickness of insulation that can be installed between furring strips is 25/32″. If 2″ furring strips are used, the maximum thickness will be 1⅝″.

[b] If surface of insulating board is protected with lumber, hardboard or asbestos-cement board in direct contact with insulating board, add the following resistances to the R values:

1″ lumber (solid)	0.98
⅛″ hardboard	0.09
Asbestos-cement board	neglect

$$U = \frac{1}{R(total)}$$

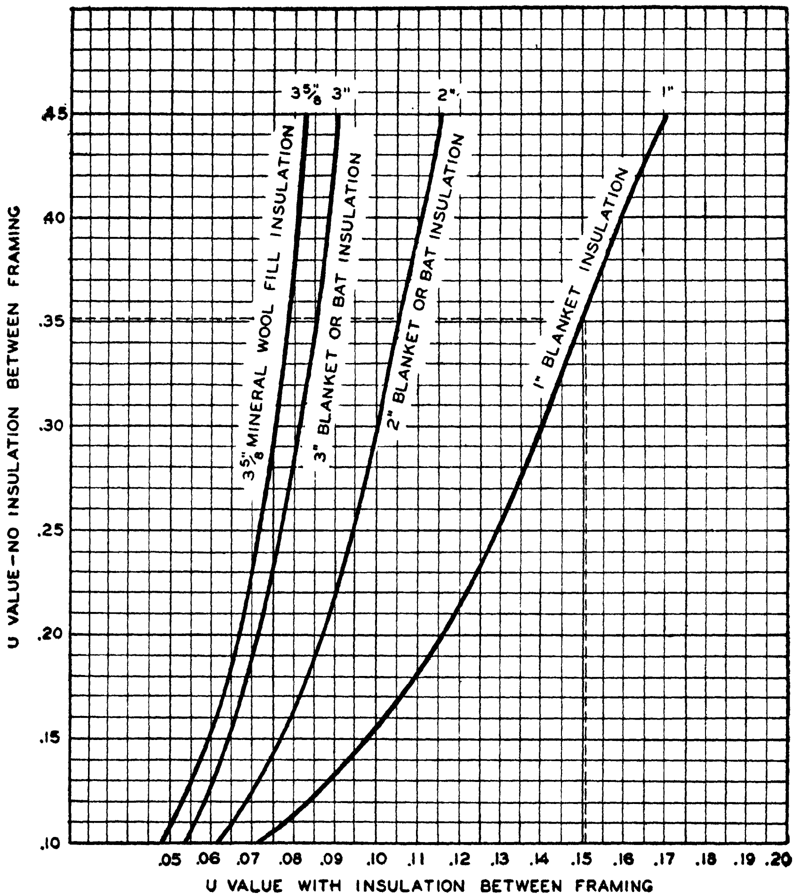
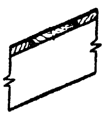
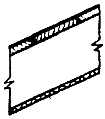
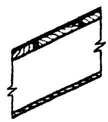
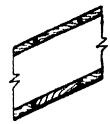
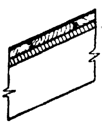
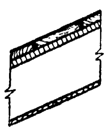
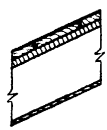
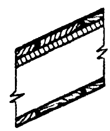
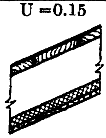
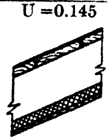
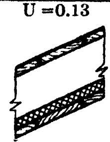
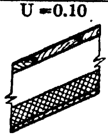
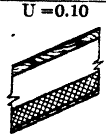
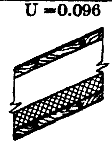
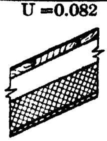
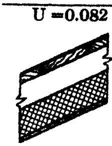
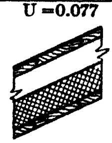
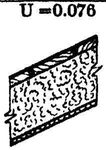
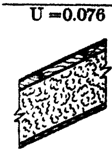
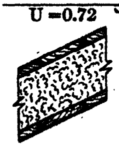


Fig. 13. Diagram Showing Curves for Determining *U* Values of Frame Walls Containing Insulation between Framing

Insulation Requirements for Animal Shelters. In the design of a dwelling or of industrial or commercial buildings, the type of construction and the amount of insulation is decided upon first and a heating plant then selected of the proper size and capacity to maintain the desired inside temperature based on the proper outside design temperature. In the case of most farm structures, if no artificial heat is to be supplied, the reverse procedure must be followed, because the amount of heat available from the animals or stored crops is a more or less fixed and limited quantity and cannot be adjusted or varied to meet the requirements. In other words, the insulation thick-

Table 4. Coefficients of Transmission (*U*) and Resistances (*R*) of Frame Construction Roofs with Roll Roofing with Ceiling Below Indicated[a]

These coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference and are based on a wind velocity of 15 m.p.h.

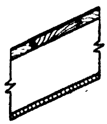
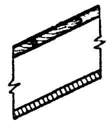
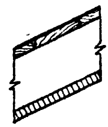
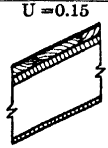
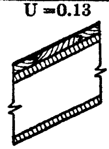
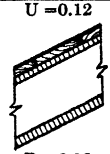
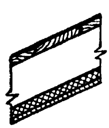
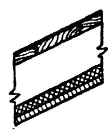
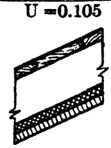
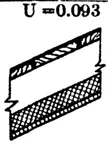
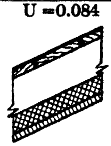
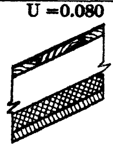
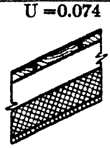
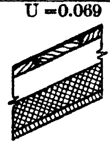
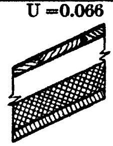
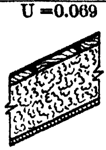
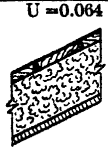
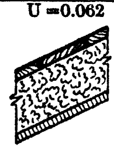
No.	Roof Construction (on Top of Rafters)	Insulation between Rafters	Ceiling Finish (On Under Side of Rafters)			
			No Ceiling (Rafters Exposed)	⅜″ Gypsum Board	5/16″ Plywood	1″ T & G Lumber (25/32″ Thick)
			A	B	C	D
1	Roofing on 1″ Boards (on Rafters)	None	U = 0.53  R = 1.91	U = 0.32  R = 3.09	U = 0.31  R = 3.21	U = 0.26  R = 3.80
2	Roofing on 1″ Boards over 25/32″ Insulation Board Sheathing (on Rafters)	None	U = 0.23  R = 4.28	U = 0.18  R = 5.46	U = 0.18  R = 5.58	U = 0.16  R = 6.17
3	Roofing on 1″ Boards (on Rafters)	1″ Blanket		U = 0.15  R = 6.79	U = 0.145  R = 6.91	U = 0.13  R = 7.50
4	Roofing on 1″ Boards (on Rafters)	2″ Blanket or Bat Insulation[b]		U = 0.10 	U = 0.10 	U = 0.096 
5	Roofing on 1″ Boards (on Rafters)	3″ Blanket or Bat Insulation[b]		U = 0.082 	U = 0.082 	U = 0.077 
6	Roofing on 1″ Boards (on Rafters)	3⅝″ Mineral Wool Fill[b]		U = 0.076 	U = 0.076 	U = 0.72 

[a] For other frame construction roofs, see Table 5, in the chapter on Transmission Coefficients and Tables.

[b] Coefficients in horizontal columns 4, 5, and 6 corrected for 2x4 framing, 16″ on center. These values may be used with sufficient accuracy for 2x6 framing on either 16″ or 24″ centers.

Table 4. Coefficients of Transmission (*U*) and Resistances (*R*) of Frame Construction Roofs with Roll Roofing with Ceiling Below Indicated[a]—*Continued*

These coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit temperature difference and are based on a wind velocity of 15 m.p.h.

No.	Roof Construction (on Top of Rafters)	Insulation between Rafters	Ceiling Finish (On Under Side of Rafters) — Insulating Board ½″ Thick	Ceiling Finish — Insulating Board 25/32″ Thick	Ceiling Finish — Insulating Board 1″ Thick
			E	F	G
1	Roofing on 1″ Boards (on Rafters)	None	U = 0.23  R = 4.34	U = 0.19  R = 5.19	U = 0.17  R = 5.85
2	Roofing on 1″ Boards over 25/32″ Insulation Board Sheathing (on Rafters)	None	U = 0.15  R = 6.71	U = 0.13  R = 7.56	U = 0.12  R = 8.22
3	Roofing on 1″ Boards (on Rafters)	1″ Blanket	U = 0.125  R = 8.04	U = 0.11  R = 8.89	U = 0.105  R = 9.55
4	Roofing on 1″ Boards (on Rafters)	2″ Blanket or Bat Insulation[b]	U = 0.093 	U = 0.084 	U = 0.080 
5	Roofing on 1″ Boards (on Rafters)	3″ Blanket or Bat Insulation[b]	U = 0.074 	U = 0.069 	U = 0.066 
6	Roofing on 1″ Boards (on Rafters)	3⅝″ Mineral Wool Fill[b]	U = 0.069 	U = 0.064 	U = 0.062 

[a] For other frame construction roofs, see Table 5, in the chapter on Transmission Coefficients and Tables.

[b] Coefficients in horizontal columns 4, 5, and 6 corrected for 2x4 framing, 16″ on center. These values may be used with sufficient accuracy for 2x6 framing on either 16″ or 24″ centers.

Table 5. Thermal Resistances for Calculating *U* Values[a] of Building and Insulating Materials Commonly Used on the Farm

Material	Thickness, Inches	Resistance
Asbestos cement board	⅛ to 3/16	Neglect
Batt insulation	1	3.70
Blanket insulation	1	3.70
Brick, common	4	0.80
Concrete (cinder)	1	0.22
Concrete (stone)	1	0.08
Concrete blocks (hollow)	8	1.00
Concrete blocks (hollow)	12	1.25
Cottonseed hulls[b]	1	2.44
Excelsior (dry)[b]	1	0.37
Gypsum board	⅜	0.27
Gypsum board	½	0.35
Hollow tile	8	1.67
Insulating board	½	1.52
Insulating board	¾	2.28
Insulating board	25/32	2.37
Insulating board	1	3.03
Mineral wool fill insulation	1	3.70
Mineral wool fill insulation	3⅝ (wall thick)	13.43
Lumber (yellow pine or fir)	1 (actual 25/32)	0.98
Plywood	5/16	0.39
Plywood	⅜	0.47
Roofing (built-up asphalt or tar and gravel)	As applied	0.28
Roofing, roll (heavy)	As applied	0.15
Sawdust (dry)[b]	1	1.04
Shavings (dry)[b]	1	0.71
Shingles, asphalt	Average, as applied	0.15
Shingles (wood)	Average, as applied	0.78
Siding, wood (drop)	¾	0.94
Stone	1	0.08
Straw (dry)[b]	1	0.39
Vermiculite	1	2.08 to 3.12
Air spaces, tightly sealed	¾ or more	0.91
Inside surfaces		0.61
Outside surfaces		0.17

[a] For other resistances, see the chapter on Transmission Coefficients and Tables.
[b] These materials, when wet or damp, will have considerably less resistance depending upon the percentage of moisture. For average conditions of use, it is recommended that not more than ½ the resistances given for these materials is used.

ness is to a large extent based on the heat available. The selection of the proper amount of insulation for farm structures may be divided into three classifications, namely: (1) insulation for structures used for animal housing; (2) insulation for fruit and vegetable storages; and (3) insulation to prevent surface condensation.

The primary purpose of insulation for animal shelters is to conserve the small amount of heat available from the animals or birds so as to maintain desirable indoor atmospheric conditions and to permit proper and efficient regulation of the ventilating system, where a natural ventilating system is used.

The proper theoretical amount of insulation to use for animal shelters is that thickness which will reduce the heat loss during cold weather sufficiently to balance the heat lost with the heat available

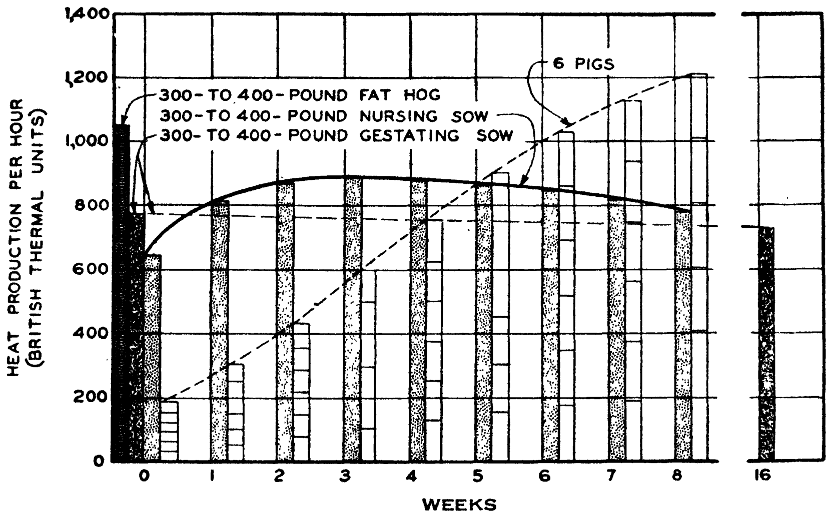


Fig. 14. Diagram Showing Heat Production of Fat Hogs, Brood Sows, and Small Pigs for Each Week of Normal Growth*

from the birds or animals. This heat balance is also necessary to permit the maintenance of the desirable atmospheric conditions with the proper and efficient use of the ventilating system. Suppose, for example, a dairy stable is designed to shelter 50 cows. Assuming a heat production (sensible heat) of 2,800 B.t.u. per hour per cow, the total sensible heat production for the herd will be 50×2,800, or 140,000 B.t.u. per hour. This is the amount of heat available for warming the enclosure and for operating the ventilating system. The total heat loss through the walls and roof and that due to ventilation and air leakage, must not exceed this quantity.

Usually, the sensible heat only is considered *available,* although at least a part of the latent heat of vaporization, that is, the heat con-

*Data from H. H. Michell and M. A. R. Kelley, *Journal Agricultural Research*, 56: 1938.

tained in the moisture given off by the animals, may be considered to be useful. The approximate amounts of available heat are 2,800 to 3,000 B.t.u. per hour for cows at 50°F. and 36 to 38 B.t.u. per hour for hens at 35°F. For the heat production of fat hogs, brood sows, and small pigs, see Fig. 14.

Space Allowance per Animal or Bird. In order to calculate the total amount of heat available in a farm structure consideration must be given to the number of birds or animals to be housed in the enclosure. For poultry, this should not be less than 18 cubic feet of space per bird and not less than 3 square feet of floor area.

For a milk barn, the volume allowance may range from about 500 to 650 cubic feet per cow. For barns with maternity pens, considerably more space must be figured, so that in the latter case the amount of heat available per unit of volume is relatively less. This means that lower U values must be used, as explained later.

A centralized hog farrowing house requires from 650 to 700 cubic feet of space per pen based on a 400-pound sow and an average litter of 8 pigs.

If the required U values are calculated on the basis of these space allowances, the animals must of course be housed accordingly to obtain the calculated results.

Outside Design Temperatures. In order to calculate the heat loss, and to provide a sufficient amount of insulation to balance the heat loss with the heat available, it is necessary to assume the proper inside and outside temperatures. A Zone Map of the United States having four zones based on the average January temperatures is shown in Fig. 15. Zones 1 and 2 are separated by the 20-degree isotherm, Zones 2 and 3 by the 35-degree isotherm and Zones 3 and 4 are separated by the 50-degree isotherm. These zones are useful for heat loss calculations of farm structures. The average January temperatures in the four zones are as follows:

Zone 1	+10°F.
Zone 2	+27½°F.
Zone 3	+42½°F.
Zone 4	over +50°F.

These temperatures as stated are *average* January temperatures and not minimum temperatures. The actual temperatures will of course go below the average January temperatures to various degrees and for periods of various lengths during the winter months. Although there is at present no generally accepted rule for selecting outside design temperatures for farm structures, the temperature used ranges usually between 10 and 25 degrees below the January temperature (Fig. 15) but seldom lower than the average minimum (Fig. 18) plus 10 degrees. Lower temperatures than this range may be encountered which may be compensated for by various means, such as reducing the amount of ventilation during these periods, by supplying

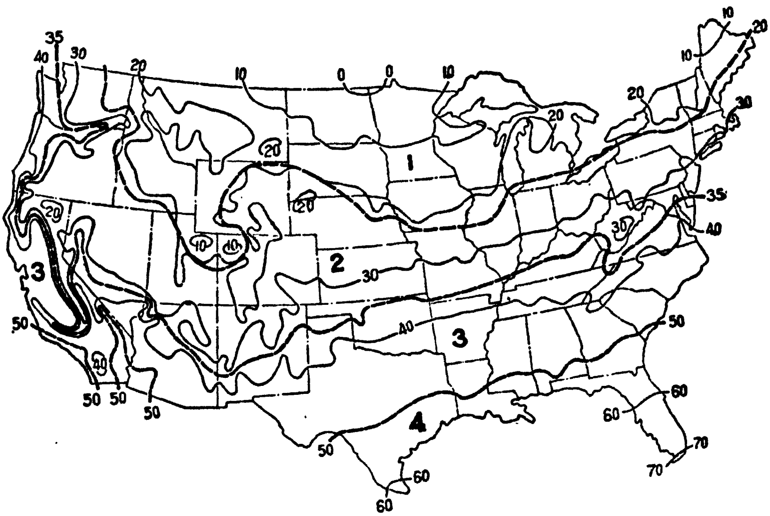


Fig. 15. Zone Map of United States Based on Average January Temperatures.

artificial heat, or by allowing the inside temperature to go below the inside design temperature.

Inside Temperatures in Animal Shelters for Design Purposes. There is some difference of opinion among farm authorities as to what constitutes the most desirable or optimum-indoor atmospheric conditions for animal housing. For this reason it is not within the scope of this book to attempt to specify what these conditions should be in all cases. However, on this subject two publications* have been released by the United States Department of Agriculture, namely: Circular No. 701 and Circular No. 722. According to Circular No. 722 the following dairy-stable temperatures are considered satisfactory for average winter conditions (*see* Fig. 15).

**Hog Housing Requirements*, Circular No. 701, May, 1944.
Functional Requirements in Designing Dairy Barns, Circular No. 722, February, 1945.

Zone 1	35° to 45°F.
Zone 2	40° to 50°F.
Zone 3	45° to 55°F.

According to this circular temperatures in dairy stables should not fall below freezing even on the coldest days, and the relative humidity should not exceed 75 per cent under average weather conditions. In Zone 4 control of stable temperature and relative humidity is not important in winter.

Most authorities agree that an inside temperature of 35°F. is entirely satisfactory for poultry houses in the winter. However, it is recognized also that temperatures as low as +10°F. to +15°F. can be permitted in poultry houses for limited periods without the combs freezing or other serious consequences.

For fattening hogs, according to Circular No. 701, the temperature in the house should not drop below freezing at any time, and a minimum of 40°F. is desirable. The recommended temperature range for farrowing houses is 50° to 60°F. since little pigs chill at lower temperatures. However, it is not practical without supplementary artificial heat to attempt to keep the temperature of the farrowing house above 50°F. during the coldest weather in Zones 1 and 2.

Poultry Houses. The amount of heat available in poultry houses is relatively less in comparison to the volume of space to be heated than with other types of animal shelters. On this account, it is necessary to give more careful consideration to the inside design conditions and the permissible temperature difference. The amount of insulation required in the walls and roof increases rapidly as the inside-outside temperature difference increases. If an attempt is made to design for an inside temperature of 35°F., and the minimum outside temperature likely to be encountered in Zone 1 or 2, a prohibitive thickness of insulation may be required unless supplementary artificial heat is used. An inside design temperature of 35°F. may generally be used in Zone 3 or 4, but lower inside design temperatures are permissible in Zones 1 and 2. For example, if a poultry house were designed for a temperature difference of 30°F. an inside temperature of 35°F. could be maintained when the outside temperature is +5°F. However, a poultry house designed for a 30-degree temperature difference would give satisfactory results for an outside temperature as low as −20°F. if it is assumed that an inside temperature of +10°F. is permissible for limited periods of time.

The following is the general formula for calculating the required wall and roof U values for structures intended for animal housing where the only source of heat is that given off by the animals:

$$U_x = \frac{H_a}{(A_w + A_r)\ (t - t_o)} - \frac{A_g U_g + A_d U_d + 0.018(V)}{A_w + A_r} \qquad (2)$$

where

U_x = required maximum wall and roof U value.

H_a = heat available in B.t.u. per hour equals number of animals or birds times average available heat production per animal or bird.

A_r = net roof area, square feet.

A_g = net glass area, square feet.

A_d = net door area, square feet.

A_w = net wall area in square feet after deducting areas of glass and door openings.

U_g = coefficient of transmission of glass areas.

U_d = coefficient of transmission of door areas.

V = ventilation allowance (including air leakage) in cubic feet per hour.

Note: A tight structure is necessary for the efficient operation of a natural ventilation system. However, the air leakage for a reasonably tight structure may be considered a part of the total ventilation and need not be figured separately.

t = inside design temperature.

t_o = outside design temperature.

$t - t_o$ = temperature difference.

Example 3. Calculate the required U values for both walls and ceiling, assuming the same values for both, for a 20x30 foot shed-roof poultry house having an average ceiling height of 7½ feet and based on a temperature difference of 30 degrees. Assume one bird per 3 square feet of floor area, a heat production of 38 B.t.u. per hour per bird and a ventilation allowance of 16 cubic feet per hour. Also assume 40 square feet (A_g) of glass area with storm windows and 20 square feet (A_d) for the door area (1-inch door).

Solution:

$A_r = 20 \times 30 = 600$ square feet.

$A_g = 40$ square feet.

$A_d = 20$ square feet.

Solution:—Cont.

Gross wall area, 100×7.5	$=750$ square feet.
Less door (20) and glass (40) area	$=\ \ 60$ square feet.
A_w	$=690$ square feet.

Based on 3 square feet of floor area per bird, there would be $\frac{20\times30}{3}=200$ birds. The heat available (H_a) is $200\times38=7600$ B.t.u. per hour. At 16 c.f.h. per bird, $V=200\times16=3200$ cubic feet per hour.

$U_g=0.45$ (Table 17, chapter on Transmission Coefficients and Tables).

$U_d=0.69$ (Table 17, chapter on Transmission Coefficients and Tables).

$t-t_o=30.$

Substituting in Formula (2):

$$U_x=\frac{7600}{(690+600)\times30}-\frac{40\times0.45+20\times0.69+0.018\times3200}{690+600}$$
$$=0.1964-0.069$$
$$=0.1275 \text{ (or 0.13)}$$

Note that U_x in Formula (2) is the required maximum U value for both the walls and roof. However, the U value need not necessarily be the same for both the walls and roof. If, for example, a lower U value is used for the roof than the required value of U_x, a correspondingly higher U value may be used for the walls (or vice versa), taking into consideration the relative wall and roof areas. If the required value of U_x has been calculated according to Formula (2) and a lower roof coefficient (U_r) than U_x is selected, then the required wall coefficient (U_w) may be calculated from the following formula:

$$U_w=\frac{(A_w+A_r)\ U_x}{A_w}-\frac{A_rU_r}{A_w} \qquad \textbf{(2a)}$$

Example 4. If in the preceding example a roof having a coefficient of 0.10 is selected, what would be the maximum permissible wall coefficient for the conditions of the problem?

Solution. In the preceding example $U_x=0.1275$. $U_r=0.10$. Substituting these values in Formula (**2a**):

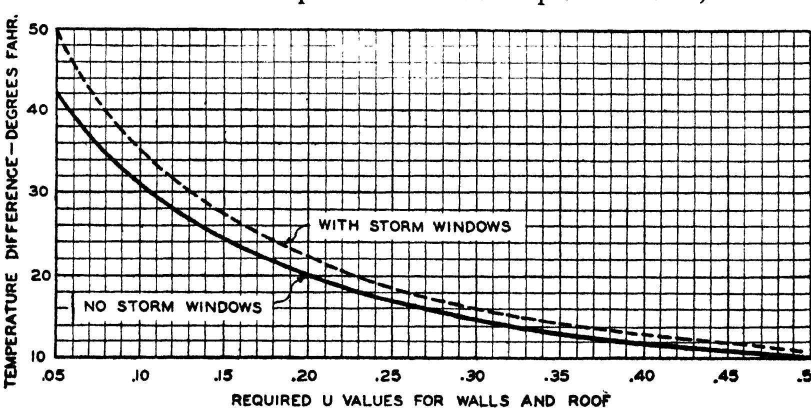
$$U_w=\frac{(690+600)\times0.1275}{690}-\frac{600\times0.10}{690}$$
$$=0.238-0.087=0.151 \text{ (or 0.15)}$$

of 0.10 would give the same result as using a wall and roof coefficient of 0.1275.

The corresponding formula for obtaining the maximum permissible *roof* coefficient (U_r) based on the required U_x for the wall structure is as follows:

$$U_r = \frac{(A_w + A_r)\ U_x}{A_r} - \frac{A_w U_w}{A_r} \qquad \textbf{(2b)}$$

The curves of Fig. 16 are based on conditions similar to those in the foregoing example and may be used for selecting the maximum wall and ceiling U values for other temperature differences for conditions similar to those specified in this example. However, it should



Note: Curves Are Based on the Following Conditions:

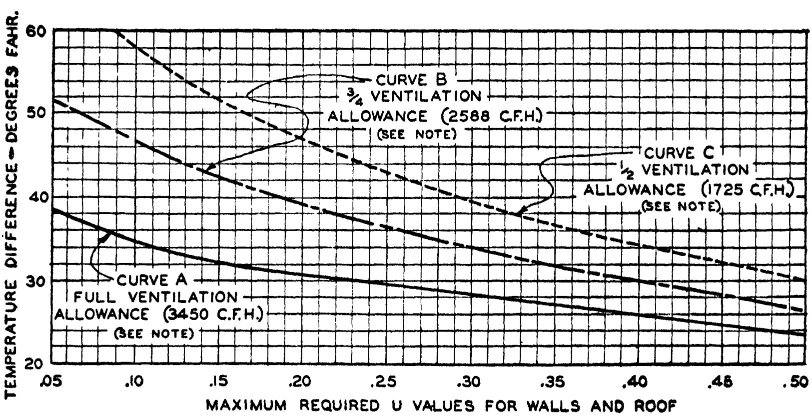
Average Ceiling Height	7½ ft.
Maximum Floor Area per Bird	3 sq. ft.
Ventilation Allowance per Bird	16 cu. ft.
Heat Production per Bird	38 B.t.u. per hour
Window Area—Not Over	5.8 per cent of Net Wall Area

Fig. 16. Diagram Shows Curves for Determining Required U Values for Poultry Houses for Various Temperature Differences

be understood that the required U values will vary with the conditions of the problem. If the density of occupancy were less than one 4-pound bird per 3 square feet of floor area, lower U values would be required for the same temperature differences, other things being equal. On the other hand, if the average ceiling height were less than 7½ feet, higher U values could be used for the same temperature differences, other things being equal. The curves of Fig. 16 may be used as a general guide for selecting the required U values for poultry houses, but if the conditions differ greatly from those on which these curves are based, the U values should be recalculated to make certain that the amount of insulation contemplated is sufficient. Storm win-

Brooder Houses. Because of the small size of the building and the fact that it is artificially heated, a brooder house does not require extensive insulation. A maximum *U* value of 0.35 is recommended for brooder houses except in the northern part of Zone 1 (Fig. 15), where the *U* value should not exceed 0.20.

Dairy Barns. The curves of Fig. 17 are for a one-story milking barn and were derived in a manner similar to those of Fig. 16, using the assumed conditions given in the footnote for Fig. 17. Curve *A* is based on the recommended ventilation allowance of 3,450 cubic feet



Note—Curves Are Based on the Following Conditions:

Heat production per cow	3,000 B.t.u. per hour
Ventilation requirement per cow (Curve *A*)	3,450 cu. ft. hr.
Ventilation requirement per cow (Curve *B*)	2,588 cu. ft. hr.
Ventilation requirement per cow (Curve *C*)	1,725 cu. ft. hr.
Density of occupancy	1 cow per 600 cu. ft.
Size of barn	30x100x8 ft.
Percentage of glass and door area to total wall area	10 per cent

Fig. 17. Curves for Determining Maximum Required *U* Values of Walls and Roof of One-Story Milking Barns

of air per cow per hour given in Table 1. According to this curve, a barn having wall and roof *U* values of 0.15 would permit a temperature difference of about 33 degrees. A *U* value of 0.10 would permit a temperature difference of about 35+ degrees or an increase of about 2+ degrees.

The effect on the temperature difference of reducing the amount of ventilation during cold weather is indicated by Curves *B* and *C*, Fig. 17. If the amount of ventilation were reduced 25 per cent (Curve *B*) a temperature difference of 42+ degrees could be maintained with a *U* value of 0.15, and about 47 degrees with a *U* value of 0.10. Thus by reducing the amount of ventilation by 25 per cent it is possible to increase the temperature differences in this case by about 9 and 12 degrees respectively for *U* values of 0.15 and 0.10. Decreasing the ventilation allowance to 50 per cent of that for Curve *A* as shown by Curve *C*, increases the permissible temperature differences to about 52 and 58+ degrees respectively for *U* values of 0.15 and 0.10, based on the assumed conditions of this problem. While a decrease in the amount of ventilation permits an increase in the permissible temperature difference, it also increases the relative humidity and thus increases the probability of surface condensation.

Table 6. Suggested Maximum *U* Values and Minimum Resistances (*R*) for Dairy Stables*

Zone	Large Stables		Small Stables	
	Walls	Ceiling	Walls	Ceiling
1	U=0.25 R=4.0	U=0.14 R=7.0	U=0.17 R=6.0	U=0.14 R=7.0
2	U=0.33 R=3.0	U=0.20 R=5.0	U=0.25 R=4.0	U=0.20 R=5.0
3	U=0.5 R=2.0	U=0.28 R=3.5	U=0.5 R=2.0	U=0.28 R=3.5

*These suggested maximum *U* values are based on the suggested resistances or *insulating values* which are given in the United States Department of Agriculture, Circular No. 722, *Functional Requirements in Designing Dairy Barns*.

Although the curves of Fig. 17 are for one-story milking barns, they are also applicable to two-story general purpose dairy barns with hay loft, except that somewhat less insulation is needed in the ceilings due principally to the insulation value of the hay which, however, decreases during the winter months as the hay is consumed.

Where the barn includes maternity pens and calf stalls more insulation should be provided than is indicated by the curves of Fig. 17. Maximum *U* values of 0.10, 0.14, 0.18, and 0.22 are recommended for Zones 1, 2, 3, and 4 respectively for barns of this type.

The maximum *U* values for dairy stables suggested in the United States Department of Agriculture Circular No. 722† are given in Table 6. These are calculated from the suggested minimum *insulating values* or resistances given in this circular.

Milkhouses. There is no exact basis for calculating the required *U* values for milkhouses and the matter is therefore largely one of

†*Functional Requirements in Designing Dairy Barns*, Circular No. 722, February, 1945.

judgment. The milkhouse-insulation problem is one of both summer and winter conditions. A good rule to follow is to provide a maximum wall and ceiling U value of not more than 0.15.

Hog Houses. The following information on this subject is quoted from the United States Department of Agriculture Circular No. 701:*

A basis for calculating the amount of insulation needed in hog houses has not as yet been agreed upon, and the subject needs further investigation. The following procedure is suggested until more adequate data can be obtained.

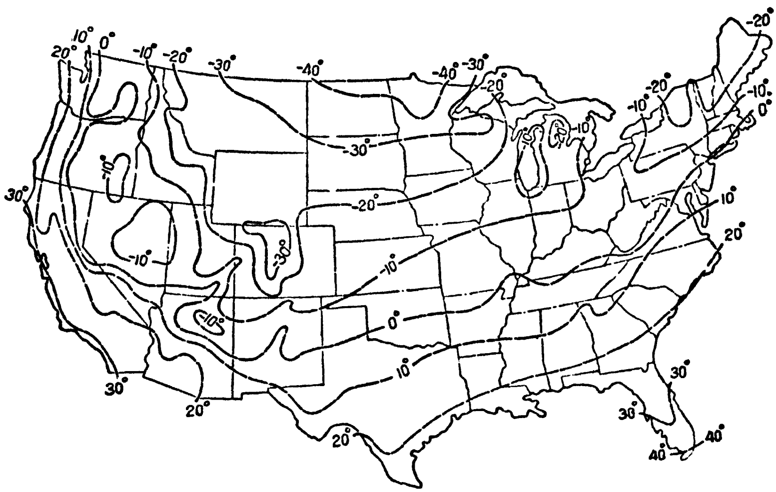


Fig. 18. Average Annual Minimum Temperature—Degrees Fahrenheit

(a) Base the design of winter insulation for a hog house on the number of stock hogs the building will accommodate. In calculating heat losses use of 40°F. inside temperature and an outside temperature of 10° above the average annual minimum Fig. 1 (see Fig. 18) in areas having an average of 3 hours of winter sunshine daily Fig. 2 (see Fig. 19); use 15° above the average annual minimum in areas having 5 hours, or 20° above the average annual minimum in areas having 7 hours in winter daily. Use the heat production data of Fig. 5 (see Fig. 14), and assume that 65 per cent of the heat produced will be lost by ventilation. If the house is to be used for farrowing at a season when the average outside temperature is below 45°F. provide for the use of pig brooders or a jacketed stove. The average temperatures for February are 30° to 45°F. and those for March 40° to 60° above the average annual minimum shown in Fig. 1 (see Fig. 18). Consult weather records for actual temperatures for a particular locality.

(b) Unless very thick insulation is used, provide at least 25 per cent more insulation value for the roof or the roof-ceiling combination than for the walls, so that if condensation occurs it will be on the walls, not above the pens.

Hog Housing Requirements, Circular No. 701, May, 1944.

Note: In the quoted material, Figs. 1, 2, and 5 refer to maps shown in the *Hog Housing Requirements Circular*. As indicated by the numbers shown in parentheses, these illustrations occur in this text as Figs. 18, 19, and 14, respectively.

Until further data are available, Curve A of Fig. 17 may be applied to the design of colony hog houses with reasonable accuracy if the heat available and the ventilation allowance are proportional to those on which Curve A is based.

Individual Farrowing Houses. Because of the small amount of space to be heated, the coefficients for individual farrowing houses need not be more than 0.35 for both walls and roof. However, a U value of not more than 0.20 is recommended for the northern part of Zone 1 (*see* Fig. 15).

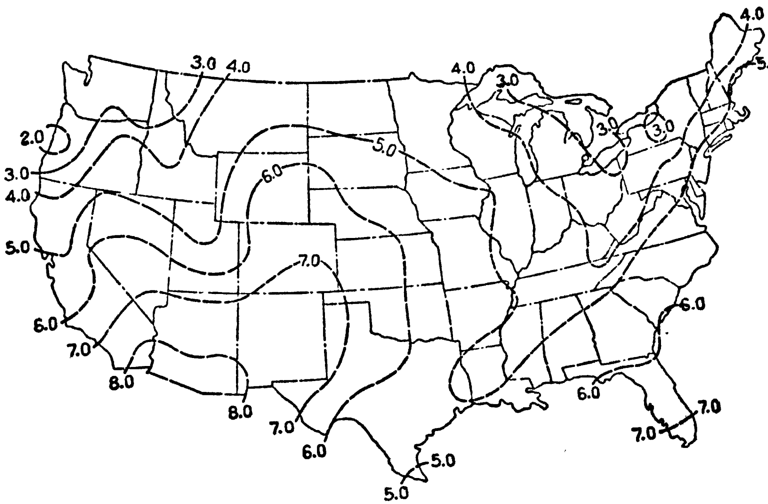


Fig. 19. Average Number of Hours of Sunshine Daily in Winter (December to February)

Insulation Requirements for Fruit and Vegetable Storages. The insulation requirements for fruit and vegetable storages vary over a wide range. For example, above-grade storages usually require considerably more insulation than below-grade storages; that is, storages with the walls below grade and with only the roof and gable ends exposed to the weather. This is due to the fact that the heat loss through above-grade walls is much greater than through below-grade walls. The latter is usually a negligible quantity because of the small temperature difference between the air in the building and the ground in contact with the walls and floor. Consequently, to reduce the heat loss of an above-grade storage to the equivalent for the same size storage below grade would require a considerable thickness of wall and roof insulation. The conditions maintained in storages depend not only on the crop stored but also upon the time of the storage period. Comparatively high humidities are necessary at all times to minimize shrinkage losses but the optimum humidity varies considerably. Temperatures likewise vary, ranging upwards from about freezing (32°F.) to various limits depending on the nature of the stored crops and the time of the storage period.

The insulation of buildings used for storage purposes is sometimes a complex problem and one which does not always lend itself to a precise or exact determination of the insulation requirements. This is because it is necessary to get rid of considerable quantities of the heat generated by the crops stored during a large part of the storage season and the problem is one of cooling and/or ventilation at that time. At other times—and perhaps only for short periods—some artificial heat may be required to keep the produce from freezing. In many cases it is possible by the proper regulation of the ventilating system to maintain satisfactory conditions without the use of artificial heating or cooling. A relatively small percentage of storage buildings is equipped with an artificial cooling system although the number of such installations is increasing.

Because of the necessity of carrying away heat at certain times and retaining the generated heat or providing artificial heat at other times, it is actually possible to have too much as well as too little insulation. The complicated nature of the problem as it applies to only one of many types of storages is illustrated by the following excerpt from a reprint from the 22d annual report of the Nebraska Improvement Association.*

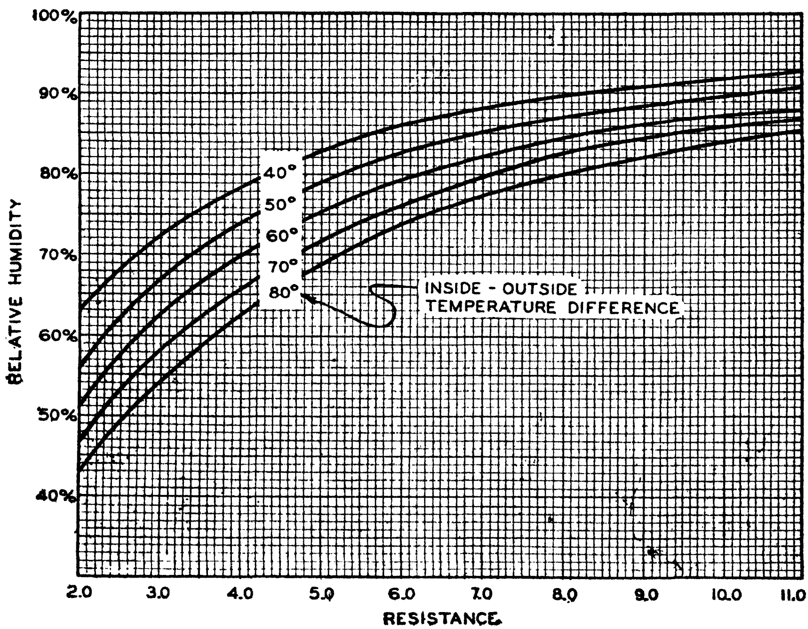
> With the wide difference in lowest winter temperatures between different years and the variation in the quantity of potatoes that may be in storage during the same months of different years, there is no way to calculate the amount of overall insulation that will be just right for a storage under all conditions. We know if there is too much insulation, excessive ventilation will be required to keep the temperature of the storage down; also, that if too little insulation, more attention must be given to storage heating. Excessive ventilation lowers the storage humidity and increases shrinkage; inadequate insulation (which makes heating necessary) results in cold walls and ceilings and excessive condensation.

One of the principal problems of insulating buildings for storage purposes is that of condensation due to the excessive quantities of moisture. The thickness of insulation required to eliminate or minimize condensation on the inside wall and ceiling surfaces is often used

**Storage of Late Crop Potatoes*, by Alfred D. Edgar.

as the basis for determining the maximum U value. This subject is covered in the following paragraphs. As a general rule, the U values for above-ground storages should not exceed 0.15 and for below-grade storages not over 0.20, but the insulation thickness should be sufficient to prevent surface condensation during all but perhaps the most extreme outside low-temperature periods.

Insulation Thickness to Prevent Surface Condensation in Farm Structures. The general principles relating to the prevention of sur-



Note: Curves indicate maximum permissible relative humidities for resistances and temperature differences indicated.

Fig. 20. Curves Showing Resistance Required to Prevent Surface Condensation

face condensation disclosed in the chapter on Condensation are applicable to farm problems. The main difference is that inside temperatures prevailing in farm structures are lower than in most other types of buildings. For this reason a special chart is used for determining the proper thickness of insulation to prevent surface condensation (*sweating* or *frosting*) in farm structures (see Fig. 20).

Suppose, for example, it is desired to plan a new building so that there will be no condensation when the relative humidity is at 80 per cent, the inside temperature at 40°F., and the outside temperature at

−20°F. (a temperature difference of 60 degrees). Referring to Fig. 20, locate the relative humidity of 80 per cent on the left-hand scale and draw a line horizontally to the right to the point where it intersects the 60-degree temperature difference curve. From this point, draw a line downward to the lower scale, which indicates that a resistance of 6.3 would be required to prevent condensation for these conditions. Next refer to Tables 2, 3, or 4 and select a construction of this or a slightly greater resistance.

This chart, Fig. 20, also can be used to ascertain the maximum permissible relative humidity that can be carried for a particular type of construction. For example, suppose a wall having a resistance of 5.70 is to be used. A wall consisting of drop siding, studs and 1-inch insulating board as interior lining, has approximately this resistance. Also assume that the inside temperature is 50°F., and the outside temperature is −20°F., or a temperature difference of 70 degrees. Referring to Fig. 20, locate 5.7 on the lower scale and draw a line vertically to the 70-degree temperature difference curve. From this intersection, draw a line horizontally to the left-hand scale, which indicates that a relative humidity of about 75 per cent can prevail for these conditions without condensation taking place on the inside wall surface.

QUESTIONS PERTAINING TO BUILDING INSULATION

THERMAL BUILDING INSULATIONS

1. Name the six common types of insulation.
2. Name three types of loose fill insulation.
3. What two conditions establish the definition of an insulation?
4. What characteristic of structural insulating board distinguishes this type of insulation from all others?
5. Name and describe six types of structural insulating board.
6. Name and describe four forms of mineral wool insulation.
7. In what respect are reflective insulations distinguished from other types?

METHODS OF APPLICATION

1. Describe three possible methods of applying flexible insulation to outside frame walls.
2. How are the flexible and reflective types of insulation applied to masonry walls?
3. How are the following applied to wood framing: (a) bats, (b) loose fill?
4. Describe a common method of applying mineral wool insulation to old buildings.
5. Describe briefly the methods of applying the following structural insulating board products: (a) sheathing, (b) lath, (c) building board, (d) tileboard, (e) plank.
6. Describe briefly the method of applying structural insulating board roof insulation to (a) wood roof decks, (b) concrete roof decks, (c) unit tile roof decks, (d) steel roof decks.
7. Describe four methods of insulating attics of either new or old buildings.

FUNDAMENTALS OF HEAT TRANSFER

1. What is the molecular theory of heat?
2. Define (a) absolute temperature, (b) British thermal unit, (c) calorific value.
3. Where specific information is not available regarding the heat content of fuels, what values are generally used for (a) coal, (b) No. 2 oil, (c) manufactured gas, (d) natural gas?
4. Name and describe the three methods of heat transfer.
5. What are the principal methods of heat transfer through (a) solid building materials, (b) air spaces?
6. Name the five factors that govern the amount of heat transferred through a material by conduction.
7. Name four properties that govern the conductivity of a material.
8. Calculate the amount of heat transferred per hour by conduction from surface to surface, through 10 sq. ft. of a material 3 inches thick having a conductivity of 0.30, if the temperature difference between surfaces is 50 degrees.
9. What is the relation between absorptivity, emissivity and reflectivity?

10. Calculate the amount of heat transferred by radiation across a 100 sq. ft. air space 3 inches wide if one surface is bounded by a material having an emissivity of 0.10 and a temperature of 100° F., and the other surface is bounded by a material having an emissivity of 0.90 and a temperature of 50° F.

11. Describe the mechanism by which heat is transferred to, through and from a wall.

12. (a) Describe three general methods of insulating a frame wall and (b) explain the *modus operandi* or methods of functioning of mass and reflective insulations.

TRANSMISSION COEFFICIENTS AND TABLES

1. Calculate the over-all coefficient of transmission (U) of a simple wall consisting of 2-inch yellow pine (actual thickness, 1⅝ inches) assuming a conductivity of 0.80, based on the outside surface being exposed to a 15 m. p. h. wind velocity.

2. Calculate the over-all coefficient of transmission (U) of a frame wall consisting of 1 inch of material A on the outside of the studs and ½ inch of material B on the inside of the studs. Material A has a conductivity of 0.50 and material B has a conductivity of 0.33. The wall is exposed to a 15 m. p. h. wind.

3. Calculate the over-all coefficient of transmission (U) for a wall consisting of 6 inches of concrete faced with 4″ hollow clay tile with ½″ of cement mortar between the concrete and clay tile and with the outside finished with ½-inch stucco applied to the clay tile. Use the recommended conductivities and conductances given in Table 3 and assume that the outside surface is exposed to a wind velocity of 15 m. p. h.

4. Using the resistance method, calculate the coefficient of transmission of a 6″ concrete floor slab with a suspended ceiling below consisting of ½″ structural insulating board interior finish. Use conductivities in Table 3.

5. Calculate the weighted or average coefficient of transmission of Problem 2 taking the 3⅝″ studding into consideration, and assuming that they are spaced on 16″ centers, and have a conductivity of 0.80.

6. Calculate the combined coefficient of transmission (U_{rc}) of a roof having a coefficient of 0.50 and a ceiling having a coefficient of 0.20, assuming the roof pitch to be one-half (see Table 18).

7. What are the total resistances of the following materials:
   (a) 4″ of a material having a conductivity of 0.36
   (b) 3″ of a material having a conductivity of 0.25
   (c) 2″ of a material having a conductivity of 0.33
   (d) 1½″ of material having a conductivity of 0.40?

CALCULATING HEAT LOSSES

1. Calculate the transmission heat loss per hour through 750 sq. ft. of wall consisting of 8-inch brick, furring, metal lath and plaster, based on an inside temperature of 75° F. and an outside temperature of —15° F.

2. Calculate the hourly transmission loss in Problem 1 if the plaster base is 1-inch structural insulating board instead of metal lath.

3. What is the air leakage in cubic feet per hour based on the crack method, (a) through a 3x5 average double-hung wood window (unlocked), non-weatherstripped with 1/16-inch crack and 3/64-inch clearance for a wind velocity of 11.5 m. p. h.; (b) for the same window weatherstripped?

4. The air leakage for a certain room is estimated to be 625 cubic feet per hour for a wind velocity of 16 m. p. h. Estimate the amount of heat required per hour to raise the temperature of this air from —10° F. to +70° F.

5. Calculate the attic temperature for the following conditions: room temperature $(t) = 70°$; outside temperature $(t_o) = —10°$; ceiling area $(A_c) = 1000$ sq. ft.; roof area $(A_r) = 1200$ sq. ft.; end wall area $(A_w) = 150$ sq. ft.; glass area $(A_g) = 20$ sq. ft.; roof coefficient $(U_r) = 0.50$; ceiling coefficient $(U_c) = 0.30$; wall coefficient $(U_w) = 0.39$; glass coefficient $(U_g) = 1.13$.

6. Refer to Example 6 of Chapter VI and recalculate the heat loss for the dining room based on the following conditions: inside temperature 75° F.; outside temperature —15° F.; walls 8″ solid brick, air space, ⅜″ plaster board lath and ½″ plaster; doors and windows the same as in this example.

EFFECT OF INSULATION ON HEATING PLANT SIZE

1. How many square feet of equivalent radiation are required for (a) hourly heat loss 4800 B. t. u., steam heat, (b) hourly heat loss 6000 B. t. u., hot water heat?

2. What will be the steam radiation saving for a wall having a net area of 1000 sq. ft., if the inside and outside temperatures are 70° F. and 0° respectively and the coefficients with and without insulation are 0.15 and 0.30 respectively?

3. A small office building to be constructed has a flat roof area of 5000 sq. ft. The contemplated roof construction is 4-inch concrete covered with built-up roofing and the ceiling below is to consist of metal lath and plaster. If the inside and outside design temperatures are 70° F. and —10° F. respectively, what will be the saving in hot water radiation if the roof is insulated with 1 inch of corkboard?

4. Estimate the approximate net cost of the roof insulation in Problem 3 as follows: Obtain from a local heating contractor the approximate value of the saving in cast iron hot water radiation in Problem 3; then also obtain locally the approximate applied cost of 5000 sq. ft. of 1-inch corkboard roof insulation. Deduct the dollar value of the radiation saving from the cost of the roof insulation to get the net cost of the roof insulation.

FUEL SAVING

1. A residence located in New York City has a net wall area of 2000 sq. ft. The wall construction without insulation consists of wood siding, wood sheathing, studding, metal lath and plaster. If 1-inch flexible insulation is applied between studding with two air spaces, what will be the annual fuel saving with coal, hand-fired? Inside temperature 70° F. Use Formula (*2*).

2. With the same uninsulated construction as Problem 1, estimate the annual fuel saving with oil using a conversion burner, if the net wall area is 2200 sq. ft. and the insulated construction consists of 25/32″ insulating board sheathing in place of wood sheathing and ½″ insulating board lath in place of the metal lath. Inside temperature 70° F., building located in the vicinity of Chicago.

3. A residence located in the vicinity of Pittsburgh has a net wall area of 1800 sq. ft. and the construction without insulation consists of brick veneer, wood sheathing, studding, wood lath and plaster. What will be the annual fuel saving if wall-thick mineral wool bats are used in all outside walls based on an inside temperature 70° F. and stoker-fired coal?

4. The ceiling of a residence located in Minneapolis consists of plaster board lath and plaster. The roof is of the mansard type similar to Fig. 2 of Chapter VII and consists of asphalt shingles on wood sheathing. The roof area is 1200 sq. ft. and the ceiling area is 900 sq. ft. The fuel is oil and the heating plant is oil-designed. If the inside temperature is 70° F., what will be the annual fuel saving with 3″ mineral wool applied between the ceiling joists? The attic is not ventilated.

5. Calculate the fuel saving in Problem 4 if ½″ flexible insulation is applied to the top of the ceiling joists, instead of the mineral wool.

6. A residence located in Washington, D. C. has a ceiling area of 800 sq. ft. and has a top floor ceiling of wood lath and plaster. The attic is floored and ventilated. The ceiling is replaced with reflective plaster board and plaster. What will be the annual fuel saving if the fuel is coal, hand-fired, and the inside temperature is 72° F.?

7. A single-story industrial building located in Chicago has a roof area of 100 squares (10,000 sq. ft.). The ceiling height is 12 ft. and the breathing line temperature is 60° F. The fuel is coal, stoker-fired and the roof construction consists of 2″ plank and built-up roofing. What will be the annual fuel saving (based on 50% operation) if the roof is insulated with 1″ structural insulating board applied over the present roofing and covered with new roofing? (Neglect heat resistance of old roofing and determine ceiling temperature from Table 2A.)

8. A natural gas-fired residence with a gas-designed heating plant located in Oklahoma City, Oklahoma, has a flat roof consisting of 1″ boards and built-up roofing. The ceiling underneath is of plaster board lath and plaster. The roof area is 1000 sq. ft. and the inside temperature maintained during the winter is 75° F. What will be the annual fuel saving (a) if 1″ corkboard is applied to the top of the roof and (b) if three inches of vermiculite are installed between ceiling joists ($k=0.38$)? The space between the ceiling and roof is not ventilated in the winter.

ECONOMICS OF INSULATION

(Note: The insulation costs used in these examples are not necessarily typical and should not be considered as being generally applicable in all parts of the United States.)

1. Return on investment. The wall construction of a certain building is 8-inch brick, furring strips and metal lath and plaster. What will be the annual return on the investment if 1-inch insulating board lath is used in place of the metal lath at a net extra cost of $30.00 per 1000 sq. ft. of insulated area. The fuel is coal, hand-fired, at a cost of $10.00 per ton and the average temperature difference is assumed to be 35 degrees.

2. Refer to Problem 1 of the chapter on Fuel Saving. If the installed cost of the insulation is $80.00 per 1,000 sq. ft., what will be the gross annual return on the investment? Assume cost of coal to be $10.00 per ton.

3. Refer to Problem 2 of Chapter VIII. Since the insulating materials replace other structural materials in the wall the net extra cost of the insulation is assumed to be only $10.00 per 1,000 sq. ft. What is the gross annual return on the investment? Assume the cost of oil to be 7 cents per gallon.

4. Refer to Problem 3 of Chapter VIII. What will be the annual return on the investment if the installed cost of the insulation is 6 cents per sq. ft.? Assume cost of oil to be 7 cents per gallon.

5. Refer to Problem 4 of Chapter VIII. What will be the annual return on the investment if the insulation costs $100.00 per 1000 sq. ft. installed?

6. What is the cost of useful heat for the following conditions:

(a) Coal, $11.00 per ton, 60% heating efficiency.

(b) Oil, 7½ cents per gal., 70% heating efficiency.

(c) Natural gas, $0.60 per 1000 cu. ft., 80% heating efficiency.

(d) Manufactured gas, $0.70 per 1000 cu. ft., 70% heating efficiency.

7. Calculate the optimum thickness of insulation for the following conditions: a 2″ wood roof deck covered with built-up roofing (no ceiling, rafters exposed); average temperature difference during heating season of 7 months is 40 degrees; the fuel is coal costing $8.00 per ton; assumed heating efficiency is 60%; annual fixed charges 8% (0.08); installed cost of insulation 10 cents per sq. ft. per inch thickness; conductivity of insulation, 0.30.

8. What is the most common cause of lath marks and dirt patterns?

INSULATING EFFICIENCIES: EXPANSION OF ROOFS

1. A flat roof has a coefficient of transmission without insulation of 0.36. What is the insulating efficiency of 1 inch of insulation having a conductivity of 0.30?

2. What is the insulating efficiency of 3⅝ inch of mineral wool installed in a frame wall consisting of wood siding, wood sheathing, studding, wood lath and plaster?

3. What is the insulating efficiency of ½ inch of flexible insulation installed with two air spaces between the studding of a frame wall consisting of stucco, wood sheathing, studding, plaster board lath and plaster?

4. What is the combined insulating efficiency of 25/32-inch structural insulating board sheathing used in place of wood sheathing and ½-inch structural insulating board lath in place of wood lath in a brick veneer frame wall?

CONDENSATION

1. Define (a) relative humidity; (b) dew-point temperature; (c) wet and dry-bulb temperatures.

2. Calculate the resistance required to prevent surface condensation on a steel roof deck covered with built-up roofing (no suspended ceiling) based on a relative humidity of 68%, an inside air temperature at the ceiling of 80° F. and an outside temperature of 0° F.

3. Using the formula method, estimate the exact thicknesses of insulation ($k = 0.30$) required to prevent surface condensation for a roof deck having a coefficient of transmission (U) of 0.35, if the inside temperature and relative humidity near the roof are 72° F. and 75% respectively and the outside temperature is —20° F. Assume inside surface conductance to be 1.65.

4. By means of the graphical method (Fig. 2) estimate the required coefficient of transmission of a wall to preclude condensation on the inside surface thereof for a relative humidity of 70%, an outside temperature of —15° F. and an inside temperature of +75° F.

5. What is the maximum permissible relative humidity, if surface condensation is to be avoided, for a 6-inch concrete roof deck insulated with 1 inch of cork and covered with built-up roofing, based on inside and outside temperatures of 70° F. and —10° F. respectively? Solve by the graphical method.

6. (a) What is the purpose of vapor barriers, (b) where in the wall should they be installed and (c) what types of vapor barriers are most efficient?

INSULATION AND COMFORT

1. Calculate the inside surface temperature for the following conditions: inside air temperature 70° F., outside air temperature —10° F., 10-inch concrete wall. (Use inside surface conductance of 1.65 and outside surface conductance of 6.0.)

2. What will be the inside roof surface temperature based on a 2-inch wood roof deck covered with built-up roofing, if the outside temperature is 0° F. and the inside air temperature is 70° F. $R_s = 0.61$.

3. In what two ways does insulation increase summer comfort?

PIPE AND DUCT INSULATION

1. What will be the heat loss per hour through 100 linear feet of bare 2″ steel pipe for a 50-degree temperature difference?

2. A 3″ steel pipe, 1000 feet long, is insulated with 2″ of 85% magnesia type insulation. What will be the heat loss per hour if the pipe carries steam at a temperature of 270° F. and the average temperature of the air is 70° F.?

3. (a) What is the coefficient of transmission of an air duct insulated with 1″ of an insulation having a conductivity of 0.30; (b) what will be the heat loss through a duct thus insulated, 50 feet long and having a perimeter of 10 feet, if the average temperature of the air in the duct is 150° F. and the average temperature of the surrounding outside air is 70° F.?

SOUND INSULATION

1. Explain the process by which sound is transmitted through a wall, floor or partition.

2. Define: (a) pitch of sound; (b) physical intensity of sound; (c) decibel.

3. What is meant by masking effect?

4. Give approximate effects of following sound-reduction factors: (a) 25 db.; (b) 30 db.; (c) 35 db.

5. What maximum noise levels should be tolerated for (a) private offices; (b) theatres, churches, auditoriums and class rooms; (c) apartments; (d) hospitals and (e) radio broadcasting studios?

6. What are the two most important factors governing the sound-insulating properties of a wall, floor or partition?

MACHINERY ISOLATION

1. Name and describe the two types of vibration.

2. Define transmissibility.

3. What is the relation between the effect of damping and ratios of $\frac{n}{n_o}$?

4. What are the desirable ratios of $\frac{n}{n_o}$ for satisfactory results?

5. What types of resilient mounting are recommended for (a) speeds less than 700 r. p. m.; (b) 700 to 1200 r. p. m.; (c) over 1200 r. p. m.?

6. What types of isolation corkboard are used for the following loadings per

square foot (a) 2000 to 3000 pounds; (b) 3000 to 3500 pounds; (c) 3500 to 6000 pounds?

ARCHITECTURAL ACOUSTICS AND NOISE QUIETING

1. What are the general requirements of an auditorium to be satisfactory acoustically: (a) for speech; (b) for music?

2. Define reverberation.

3. Calculate the time of reverberation in seconds for a room having a volume of 20,000 cubic feet and a total estimated absorption of 500 sabines.

4. What are the approximate upper and lower limits of desirable reverberation times for rooms or auditoriums having volumes of: (a) 10,000 cu. ft.; (b) 100,000 cu. ft.; (c) 1,000,000 cu. ft?

5. Describe the procedure by which the required absorption of a room is calculated.

6. What factor governs the intensity of sound in a room and what is the general relationship between this factor and the intensity of sound?

7. What is the approximate range of percentage reductions in loudness due to a reduction in loudness level of 8 db.?

INSULATING FARM STRUCTURES

1. (a) What is the principal purpose of farm insulation; (b) what are the two principal purposes of farm ventilation; (c) what is the purpose of vapor barriers in farm structures?

2. Describe five economic reasons for using insulation in farm structures.

3. What will be the total required resistance to prevent surface condensation on the vapor barrier if the inside surface of the vapor barrier is covered with ½″ insulating board, assuming an inside temperature of 50°F., a relative humidity of 68% and an outside temperature of −10°F?

4. Select U values for following constructions from tables in this chapter:
   - (a) Walls: ¾″ drop siding on studs (exposed).
   - (b) Walls: ¾″ drop siding on studs with 25/32″ insulating board as interior wall lining.
   - (c) Wall: same as (b) but with 1″ blanket insulation between studding.
   - (d) Roof: 1″ wood roof boards covered with roll roofing.
   - (e) Roof: same as (d) but with 1″ T & G (tongued and grooved) lumber ceiling finish and 2″ bat insulation between rafters.

5. Calculate the required maximum wall and roof U value (assuming the same for both) for a poultry house assuming the following conditions: dimensions, 20x20x7 ft. (average height); door area, 18 sq. ft.; window area, 32 sq. ft.; assume 1″ wood door and storm sash on windows; heat available per bird = 36 B.t.u. per hour; number of birds = 140; ventilation per bird = 16 c.f.h.; temperature difference = 30°F.

6. By means of the curve (Fig. 17) determine the required maximum U value for the walls and roof of a dairy barn (a) if the temperature difference is 50° and the ventilation allowance is 1,725 c.f.h. per cow and (b) if the temperature difference is 40° and the ventilation allowance is 2,588 c.f.h.

7. What is the required resistance to prevent surface condensation (as determined by the chart, Fig. 20) for a temperature difference of 60° and a relative humidity of 60%?

Courtesy of Insulite Division, M. & O. Paper Co., Minneapolis, Minn.

APPLICATION OF SHIPLAPPED EDGE INSULATING-BOARD ROOF INSULATION TO WOOD ROOF DECK

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