AN
AIR-CONDITIONING
PRIMER

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The A-B-C of Air Conditioning

BY

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WHY THIS BOOK WAS WRITTEN

There is great need for translating scientific facts and data into simple language in order to bring about fuller appreciation of the benefits and advantages of modern equipment that is in daily use.

This is especially true about air conditioning; no other subject has been so thoroughly publicized and yet so completely misunderstood.

Most of the texts on air conditioning that have been published within the past few years deserve favorable comment from a technical standpoint. A few are editorially sound, while none has seemingly attempted to place the simple fundamentals and essentials within the hands of those interested.

The annual business of air conditioning averages hundreds of millions of dollars; that fact alone seems sufficient reason for a text of this kind.

Because of a sincere belief that a subject of such importance needs a common ground for salesman, dealer, manufacturer, planner, banker, and others, this primer has been written. The book is divided into two parts. Part I covers the basic characteristics of heat, air, people, and houses, which comprise the fundamentals and essentials of comfort air conditioning.

Part II covers the application and apparatus which comprise the more practical adaptation of the fundamentals of Part I. Necessary tables and charts are given in the Appendix.

To each and every one who has given something to the air-conditioning industry I extend my sincere thanks for making this book possible.

WILLIAM HULL STANGLE.

FOREST HILLS, N.Y.,
February, 1940.

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PART I
FUNDAMENTALS

CHAPTER I

DEFINITIONS

THE SIMPLE TRUTH ABOUT AIR CONDITIONING

1. Fact. There is no mystery about air conditioning. No mask hides any of its supposed secrets. The truth can be told about it with the utmost sincerity and simplicity

2. Purpose. Fundamentally, air conditioning is intended to provide the right kind of air for a definite use.

3. Uses. Conditioned air may be used to good advantage for the specific purposes of industrial, commercial, or residential air conditioning.

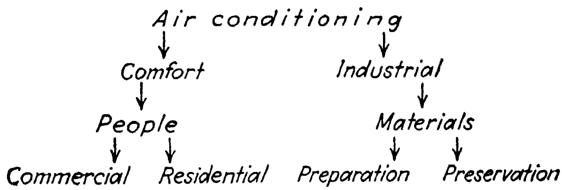


Fig. 1.

4. Industrial. When used for the preparation of a material, such as artificial silk, or for the preservation of a material, such as a foodstuff, it is industrial air conditioning.

5. Commercial. As applied to places of multioccupancy, such as theaters, restaurants, shops, offices, and other mercantile spaces, or in factories or offices to increase the efficiency of employees, for the purpose of maintaining or increasing business profit, it is commercial air conditioning.

6. Residential. If employed to preserve or improve the health, comfort, and convenience of people in their homes, it is residential or home air conditioning.

7. Comfort. Commercial and residential conditioning are classified as comfort air conditioning because they have to do with people, in contrast to industrial air conditioning, which has to do with materials (see Fig. 1).

8. Simple. Comfort air conditioning is simply the refining of air in order that it may be used to the best advantage within an enclosure for the better health, comfort, and convenience of people (see Fig. 2).

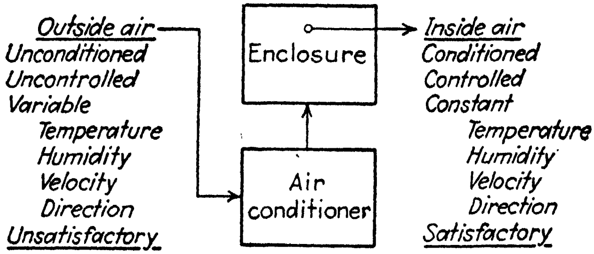


FIG. 2.

9. Scientific. Comfort air conditioning is scientifically defined as the simultaneous control of the temperature, humidity (moisture), circulation, and cleaning of air, without objectionable sound (see Fig. 3).

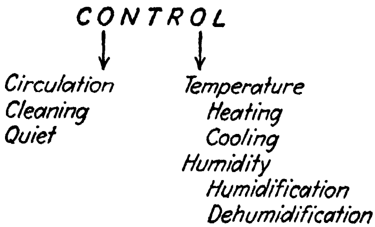


FIG. 3.

10. Winter. Winter-comfort air conditioning is the simultaneous control of the heating, humidification (adding of moisture), circulation, and cleaning of air, without objectionable sound (see Fig. 4).

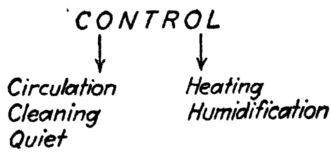


FIG. 4.

11. Summer. Summer-comfort air conditioning is the simultaneous control of the cooling, dehumidification (subtracting of moisture), circulation, and cleaning of air, without objectionable sound (see Fig. 5).

12. Common. The circulation and cleaning of air, and the control of noise below an objectionable level are all common to

CONTROL	
↓	↓
Circulation	*Cooling**
Cleaning	*Dehumidification**
Quiet	

** Cooling may be accomplished in very dry areas by humidification-described later*

Fig. 5.

both winter and summer conditioning (see Fig. 6). In addition, winter air conditioning heats and humidifies (adds moisture to), while summer air conditioning cools and frequently dehumidifies (subtracts moisture from) the air.

CONTROL

↓

Circulation
Cleaning
Quiet

Fig. 6.

13. All-year. All-year or year-round comfort air conditioning is a combination of both winter- and summer-comfort air conditioning (see Fig. 7).

CONTROL	
↓	↓
Circulation	*Heating*
Cleaning	*Humidification*
Quiet	*Cooling**
	*Dehumidification**

** Cooling may be accomplished in very dry areas by humidification-described later*

Fig. 7.

CHAPTER II

PREAMBLE

WHY COMFORT AIR CONDITIONING?

1. Research. Some of the greatest accomplishments of research have been achieved, not with test tubes and retorts, but with people—human beings—and not with their hearts, lungs, livers, and other components of their bodies, but with their needs and desires for better health, greater comfort, and more conveniences.

2. Evolution. It seems that from the beginning man has sought and contrived to protect health, improve comfort, and augment conveniences for himself and those dear to him—his family. What he has evolved and accomplished is amazing and constitutes a record of the "march of civilization."

3. Yesterday. It is but a few years ago that drinking water was "toted" from such unreliable supply sources as the spring or the well. Human wastes were somewhat uncomfortably disposed of in the open privy. Artificial lighting was furnished by flickering candles and smoky coal-oil lamps. Cooking was done on the spit. Laundry was pounded clean on a flat rock at the river. Heating was meagerly accomplished by an inefficient and drafty fireplace.

4. Today. Today, clean and soft water, either hot or cold, is instantly available for every use at the mere turning of a spigot. Wastes are led through sealed and trapped sanitary drainage systems. The flick of a switch gives correctly adjusted illumination from highly efficient electric lamps and fixtures. Food fit for the gods is prepared by the housewife in today's modern superefficient kitchen. Clothes are washed, dried, and ironed in an equally comfortable, convenient, and efficient laundry.

No wonder so many housewives have become expert bridge players.

And that is not all!

5. Warmth. Just for a moment, let us consider what man has done to provide warmth. From the open fireplace, through the various stages of room stoves, to furnaces and boilers, man sought to provide greater warmth and with tremendous success developed heating systems of excellent efficiency and economy. But, what happened?

6. Outside Air. He discovered that outdoor air is most fickle, that it constantly varies in temperature, humidity (moisture), direction, and velocity (speed), carrying with it undesirable dust, dirt, pollen, and obnoxious odors. This is what the fresh-air fiend gets when he opens a window.

7. More Research. He found that to gain true comfort he had to know more about the air in which he lived and moved and breathed, more about himself and his relation to the air, and more about the actual construction of his house, so that he could properly treat or condition the air and control it.

8. Warmth Plus. He was surprised to find that, in addition to proper temperature or warmth, the humidity or water vapor in the air had much to do with health and comfort and that properly regulated air circulation within the house provided zephyrlike air movement instead of unfriendly drafts.

9. Cleaning. Man's ingenuity also developed filters to remove the dust, dirt, and pollen from the air, to reduce the drudgery of house cleaning, and to alleviate the suffering of members of the family afflicted with hay fever or other olfactory or pulmonary ailments.

10. Electric Cleaning. Just recently there has been developed an electric precipitator that removes dust, dirt, and pollen from the air, and it is claimed, also reduces obnoxious odors to an imperceptible concentration and purifies the air by delicate ozonation and ionization. The device is too new and too lacking in sufficient proof of experience to warrant present acceptance of the claims made for it.

Let us now see what man found out about himself, and the air and the house in which he lives.

11. Relation. He found that there is a relation between the movement, temperature, and humidity (moisture) of air which, if properly balanced and controlled, results in the greatest comfort. Air moving at a high velocity will cause a cooling effect. Comfort air conditioning is today designed on a low-velocity basis and air with a velocity of about thirty feet per minute (through the room) is considered "still" air.

12. Real Comfort. Actual tests were run, to determine the best conditions for the greatest comfort of people. These tests were run in "still" saturated air and the temperature recorded was given the name "effective temperature." Then different percentages of humidity (moisture) were used in subsequent tests. With "still" air the temperatures and humidities for the greatest relative or effective comfort were established.

13. Winter Comfort. For the winter, the best apparent condition was found to be about 70 degrees Fahrenheit, temperature, and 50 per cent relative humidity (per cent of moisture in the air). The relative humidity in the house may have to be reduced below 50 per cent during the extreme cold days, if the walls are not properly insulated and the windows not furnished with double glazing or storm sash. Condensation on the walls and glass may result with the higher humidities inside and the colder temperatures outside. When these lower interior humidities are required the interior temperatures must be slightly increased to obtain equivalent comfort.

14. Refrigeration. With equal ingenuity man had developed methods of cooling, called refrigeration, which have since been used in the generally practiced methods for the production of summer conditioned air.

15. Summer Comfort. For the summer, the best apparent condition was found to be about 76 degrees Fahrenheit and 50 per cent relative humidity. But in the summer another condition arises which is even more important because it concerns the health, as well as the comfort and convenience, of people. Details of this condition are covered in the chapter of this book on People and under the specific section on Temperature Shock.

16. All-year Comfort. By adding refrigeration to his winter air-conditioning system, man has been able to provide the additional summer requirements of cooling and dehumidification to obtain all-year comfort.

17. Conscious Need. Finding out all these things about the air, himself, and his house, has made man conscious of his real need and desire for comfort air conditioning.

18. Trend. The inevitable trend is toward all-year air conditioning. Complete air-conditioning systems, found until recently only in the more pretentious houses, are now available to houses in the lower price brackets and will soon be found in every house or home that lays claim to being modern.

19. Tomorrow. There is no escaping this trend. It is important that we recognize it and its effect on house values of the future. The day is near when a house without complete all-year comfort air conditioning will be considered practically, if not actually, obsolete. Another thing to remember is that an all-year conditioned house will have an infinitely greater resale value.

20. Plan. Anyone planning a new house or remodeling an old one, whether it be for residential or commercial purposes, should at least plan the house for all-year comfort air conditioning. If all-year air conditioning cannot be afforded immediately, the all-year distribution system should be planned and installed with the winter air-conditioning equipment so that the summer equipment may be added as soon as it is economically possible.

Essentials

AIR CONDITIONING IN A NUTSHELL

To understand comfort air conditioning, it is necessary to know only certain things about

Heat

Air

People

Enclosures

CHAPTER III

HEAT

NATURE TAKES A HAND

1. Science. The natural laws that have to do with air conditioning are found in those sciences called physics and chemistry. They are well established and simple to understand. Of these the principal law is that of heat.

2. Temperature. The intensity of heat is determined by the temperature indicated on a thermometer (see Fig. 8). We say that ice is cold at 32 degrees Fahrenheit, water is warm at 120 degrees Fahrenheit, and steam is hot at 212 degrees Fahrenheit.

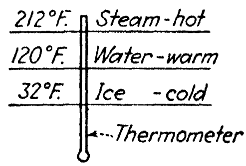


FIG. 8.

3. Absolute Zero. Some years ago a European scientist discovered that a gas, like air, when cooled, contracts $\frac{1}{492}$ per degree Fahrenheit. If a gas were cooled 492 degrees Fahrenheit, below the melting point of ice, or 460 degrees Fahrenheit below 0 degrees Fahrenheit, it would theoretically occupy no volume. Since heat is regarded as molecular vibration, and there is no

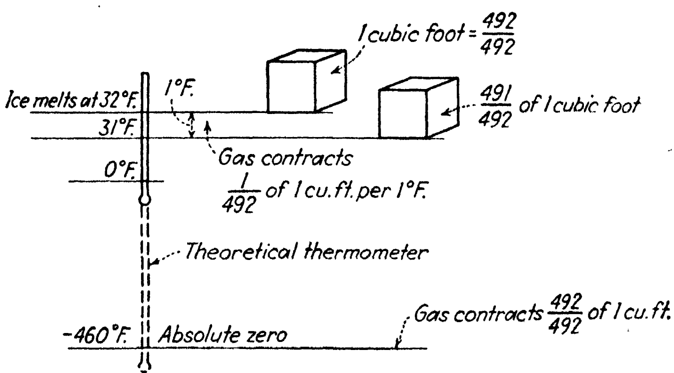


FIG. 9.

room for the molecules to vibrate at this lowest temperature, this point of −460 degrees Fahrenheit was established as absolute zero (see Fig. 9).

4. Absolute Temperature. The absolute temperature is the sum of the temperature indicated on the Fahrenheit thermometer,

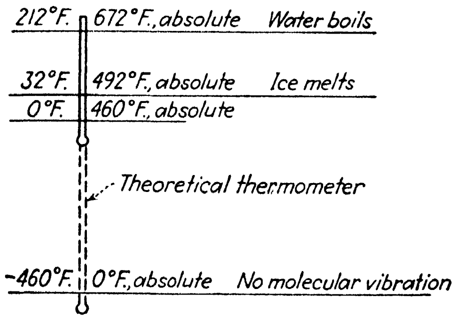


Fig. 10.

plus 460. For example, the melting point of ice is 32 degrees Fahrenheit, and the sum of 32 plus 460 is 492 degrees Fahrenheit, absolute. Also, the boiling point of water at atmospheric pressure is 212 degrees Fahrenheit, and the sum of 212 plus 460 is 672 degrees Fahrenheit, absolute (see Fig. 10).

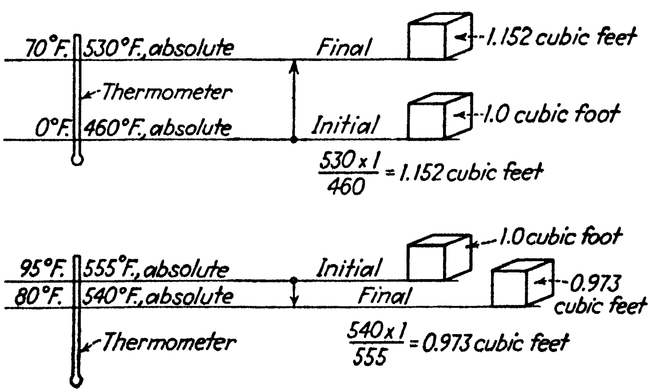


Fig. 11.

5. Expansion or Contraction. From the facts obtained about absolute zero and absolute temperature there resulted the so-called Charles' law, that "a volume of a gas, like air, under constant pressure, will vary in *direct* proportion to the variation in the *absolute* temperature of the gas." For example, a cubic foot of air at 0 degrees Fahrenheit will expand when heated to 70 degrees Fahrenheit as the ratio of 460 or (460 plus 0) to 530 or (460 plus 70), *i.e.*, it will expand to the volume of 1.152 cubic feet. Also, a cubic foot of air at 95 degrees Fahrenheit will contract when cooled to 80 degrees Fahrenheit, as the ratio of 555 or (460 plus 95) to 540 or (460 plus 80), *i.e.*, it will contract to the volume of 0.973 cubic foot (see Fig. 11).

6. Heat. All materials or substances, like air, are considered as made up of molecules. Heat is considered a vibration of these

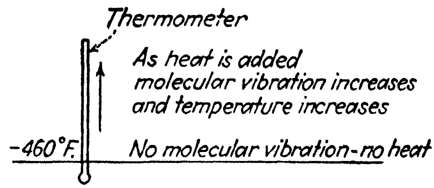


FIG. 12.

tiny particles and is recognized as a form of energy. The relative vibration of these molecules may be indicated on the thermometer scale as the intensity of heat or the temperature of the material (see Fig. 12).

7. Heat Unit. In addition to the intensity, heat may also be measured as a quantity, like a pound of butter or a quart of

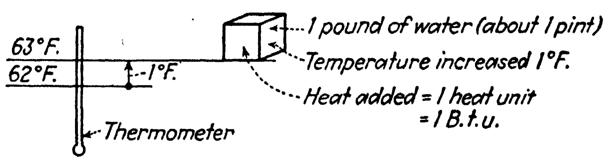


FIG. 13.

milk. The standard heat unit is defined as the quantity or amount of heat required to raise one pound of water one degree Fahrenheit. One pound of water is about one pint (see Fig. 13). The technical name for this heat unit is the British Thermal Unit. It is abbreviated B.t.u., and is commonly called a "Bee-tee-you."

8. Specific Heat. The amount of heat required to raise one pound of any substance one degree Fahrenheit, represented as a ratio, is the specific heat of that substance and is often referred to as the quantity factor. Because one B.t.u. is required to raise one pound of water one degree Fahrenheit, the specific heat of water is one and is used as unity, or the standard from which the relative specific heats of other substances are established. For example, the specific heat of ice is 0.5, of water is 1.0, of steam is 0.45, and of air is 0.24. It is interesting to note

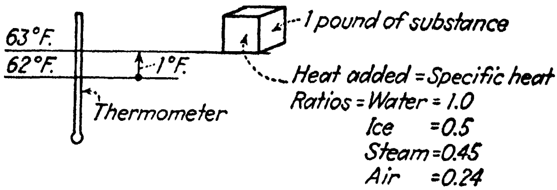


FIG. 14.

that practically all specific heats of substances are less than 1.0 (see Fig. 14).

9. Temperature Differential. When the temperature of a substance, such as air, is changed, the difference between the initial temperature and the final temperature is called the temperature differential, and it is often referred to as the intensity factor. For example, if air is heated from an initial temperature

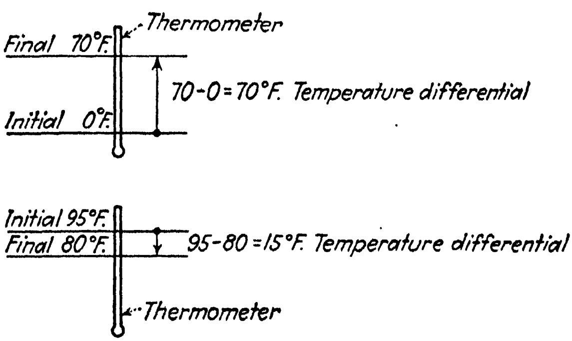


FIG. 15.

of 0 degrees Fahrenheit to a final temperature of 70 degrees Fahrenheit, the intensity factor or temperature differential is 70 − 0 or 70 degrees Fahrenheit; conversely, if air is cooled from an initial temperature of 95 degrees Fahrenheit to a final temperature of 80 degrees Fahrenheit, the intensity factor or temperature differential is 95 − 80 or 15 degrees Fahrenheit (see Fig. 15).

10. States of Materials. Substance may exist in one of three states: (*a*) solid, (*b*) liquid, or (*c*) gas. Liquids and gases are commonly called fluids (see Fig. 16). When a substance changes from a solid (see Fig. 16) to a liquid it is said to melt or fuse; if it changes from a liquid to a solid it is said to freeze or solidify. When a substance changes from a liquid to a gas it is said to

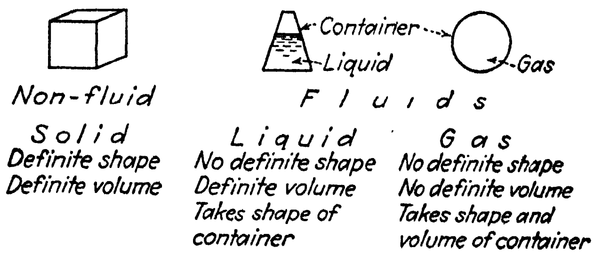


FIG. 16.

evaporate or boil; if it changes from a gas to a liquid it is said to condense or liquefy.

11. Sensible Heat. The quantity of heat required to change the temperature, without changing the state, of a substance is sensible heat (see Fig. 17). For a pound of a substance, the sensible heat is the specific heat multiplied by the temperature differential, *i.e.*, the quantity factor times the intensity factor.

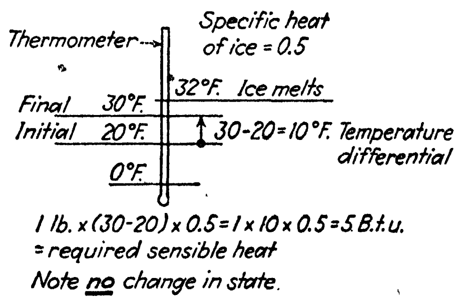


FIG. 17.

12. Latent Heat. The quantity of heat required to change the state, without changing the temperature, of a substance is latent heat (see Fig. 18).

13. Latent Heat of Fusion. The quantity of heat required to be added to change a pound of a solid into a liquid at the fusion or melting point (without a change in temperature) is the latent heat of fusion of the substance (see Fig. 19). For example, a pound of ice at 32 degrees Fahrenheit (melting or fusion point) will change to a pound of water at 32 degrees Fahrenheit (no temperature change) if 144 B.t.u. (latent heat of fusion of ice) are added.

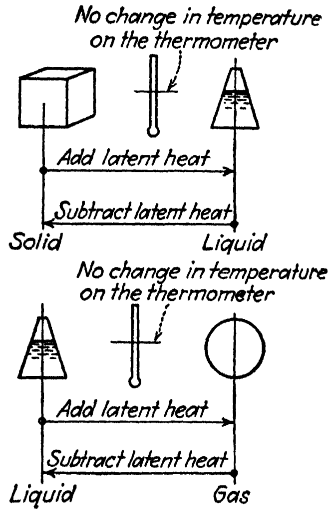


FIG. 18.

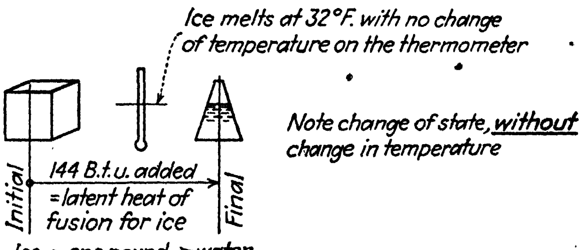


FIG. 19.

14. Latent Heat of Solidification. The quantity of heat required to be extracted to change a pound of a liquid into a solid at the solidification or freezing point (without a change in temperature) is the latent heat of solidification of the substance (see Fig. 20). For example, a pound of water at 32 degrees Fahrenheit (freezing or solidification point of water) will change to a pound of ice at 32 degrees Fahrenheit (no temperature change) if 144 B.t.u. (latent heat of solidification of water) are extracted.

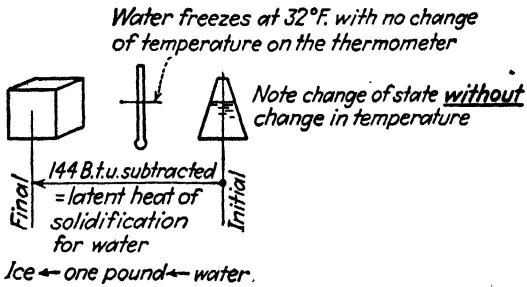


FIG. 20.

15. Latent Heat of Evaporation. The quantity of heat required to be added to change a pound of liquid into a gas at the evaporation or boiling point (without a change in temperature) is the latent heat of evaporation of the substance (see Fig. 21). For example, a pound of water at 212 degrees Fahrenheit (evaporation or boiling point at atmospheric pressure) will change to a pound of steam at 212 degrees Fahrenheit (no change in temperature) if 970 B.t.u. (latent heat of evaporation of water at atmospheric pressure) are added.

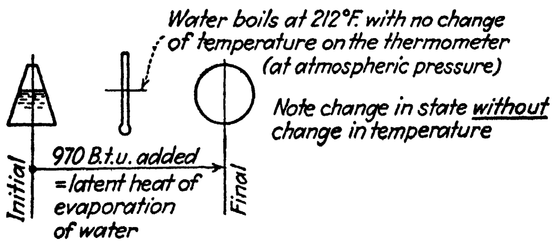


FIG. 21.

16. Latent Heat of Liquefaction. The quantity of heat required to be extracted to change a pound of gas into a liquid at the condensation or liquefaction point (without a change in temperature) is the latent heat of liquefaction (see Fig. 22). For example, a pound of steam at 212 degrees Fahrenheit (condensation or liquefaction point at atmospheric pressure) will change to a pound of water at 212 degrees Fahrenheit (no change in temperature) if 970 B.t.u. (latent heat of liquefaction of steam at atmospheric pressure) are extracted.

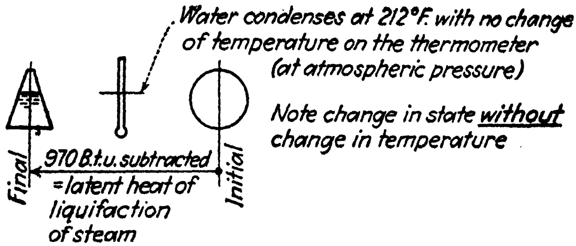


FIG. 22.

17. Total Heat. The quantity of heat required to change the condition of a substance, either temperature or state, or both, is the total heat. If there is no change in state, but a change in temperature, the total heat is the sensible heat. If there is no change in temperature, but a change in state, the total heat is the latent heat. If there is a change in temperature and a change in state, the total heat is the sum of the sensible and latent heats.

18. Example of Total Heat.

a. When sensible heat equals total heat, and there is no change in state (see Fig. 23).

Two pounds of water are heated from 60 degrees Fahrenheit to 180 degrees Fahrenheit. The sensible or total heat is $2 \times 1 \times (180 - 60)$ or $2 \times 1 \times 120$ or 240 B.t.u. Note that

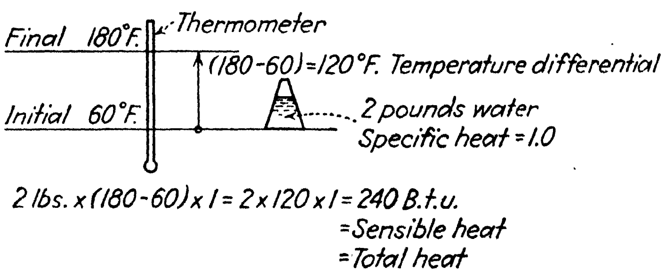


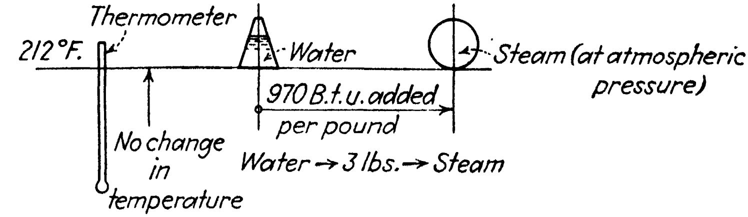
FIG. 23.

the quantity is two pounds, the specific heat of water is 1, and the temperature differential is 120.

b. When latent heat equals total heat, and there is no change in temperature (see Fig. 24).

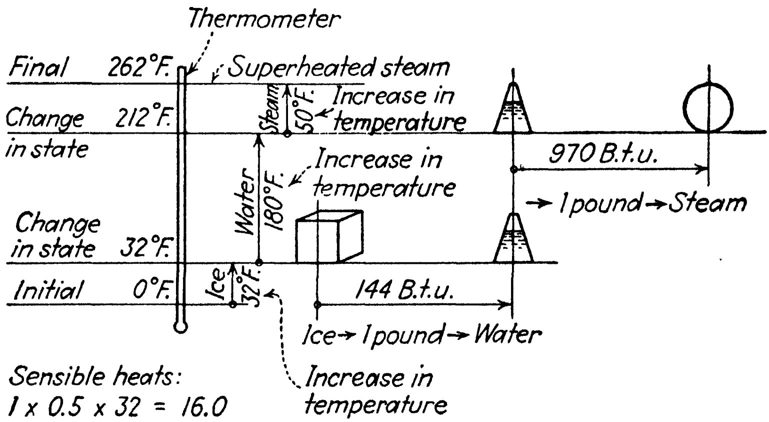
Three pounds of water at the boiling point at (212 degrees Fahrenheit at atmospheric pressure) are boiled to steam at

212 degrees Fahrenheit. The latent heat is 3 × 970 or 2910 B.t.u. Note that the quantity is 3 pounds and the latent heat per pound is 970 (from standard steam tables).



3 lbs. x (970) = 2910 B.t.u.
= Latent heat
= Total heat

FIG. 24.



Sensible heats:
1 x 0.5 x 32 = 16.0
1 x 1.0 x 180 = 180.0
1 x 0.45 x 50 = 22.5
Summation of sensible heats: 218.5

Latent heats
1 x 144 = 144
1 x 970 = 970
Summation of latent heats 1114.0
Total heat 1332.5 B.t.u.

FIG. 25.

c. When the sum of sensible and latent heats equals the total heat, and there is a change in temperature and state (see Fig. 25).

One pound of ice at 0 degrees Fahrenheit is changed to steam at atmospheric pressure and 262 degrees Fahrenheit temperature. The total heat is given in Table *A* and shown in Fig. 26.

TABLE *A*

	Specific heat, B.t.u.	Latent heat, B.t.u.
Ice S.H. $- 1 \times 0.5 \times (32 - 0)$	16	
Ice L.H. $- 1 \times 144$		144
Water S.H. $- 1 \times 1 \times (212 - 32)$	180	
Water L.H. $- 1 \times 970$		970
Steam S.H. $- 1 \times 0.45 \times (262 - 212)$	22.5	
Total S.H.	218.5	
Total L.H.		1114
Total heat		**1332.5**

Note that the quantity is one pound; the specific heat of ice is 0.5, of water is 1, and of steam is 0.45; the latent heat of fusion of ice is 144 and the latent heat of vaporization of water is 970.

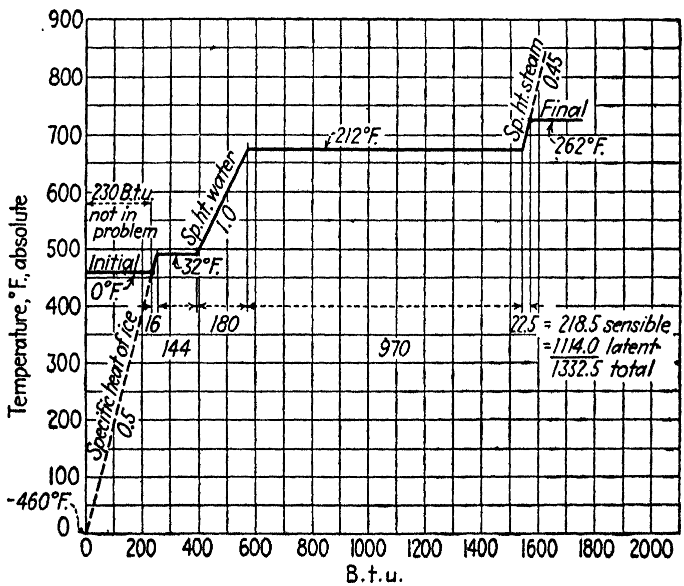


FIG. 26.

19. Heat Propagation. For practical purposes heat is considered as flowing from a warm to a cool substance or body.

Actually, and technically, heat flows from a warm to a cool substance faster than it does from a cool to a warm body. This continues until both bodies are at the same temperature, *i.e.*, until there is no temperature differential; then the flow of heat is the same in each direction and a balance, or state of equilibrium, exists (see Fig. 27).

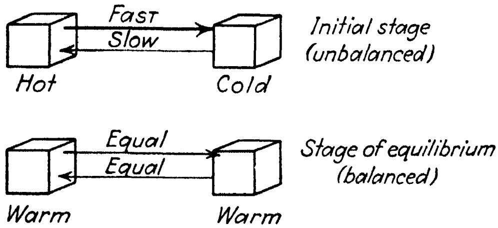


FIG. 27.

20. Kinds of Propagation. The ways in which heat is propagated or transmitted are (*a*) by radiation, (*b*) by conduction, (*c*) by convection, and (*d*) by change of state.

21. Radiation. At a point several hundred miles above the earth's surface, and beyond, there is no substance in the vast spaces. It is this empty space in which heat or light rays travel. Since there are no molecules of any substance in this space, the temperature must be absolute zero, or 460 degrees below zero degrees Fahrenheit, and the pressure is a perfect vacuum, *i.e.*, there is no pressure at all. As the earth is approached from this outer space, stray molecules of air are encountered. The nearer

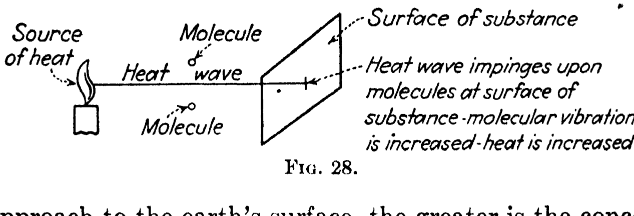


FIG. 28.

the approach to the earth's surface, the greater is the concentration of these air molecules. Radiant heat never manifests itself until it has passed through this space, between the air molecules, and impinges upon some of the air molecules or upon some other substance—the earth's surface, buildings, people, or the like—when the radiant heat is converted into molecular vibration and the substance itself is heated. Within an enclosure, heat passes in a similar manner, as radiant heat from a radiator or heat-giving body, through the space between the molecules of air within the enclosure, and impinges upon some of the air molecules or upon objects in the room (see Fig. 28). Radiant heat is generally absorbed least by white or light-colored surfaces, and most by black or dark surfaces; that is why white clothes are so popular in the tropics.

22. Conduction. When the vibration of a molecule is increased and it contacts another molecule it will cause the second molecule to increase its vibration. This is conduction (see Fig. 29).

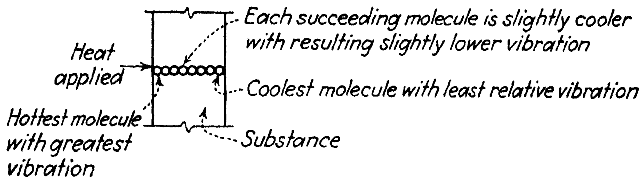


FIG. 29.

23. Convection. When the vibration of a molecule of a fluid is increased, moves to another location, and contacts another molecule of a similar or different substance at a lower temperature, it gives up some of its heat energy to the other molecule. This is convection (see Fig. 30).

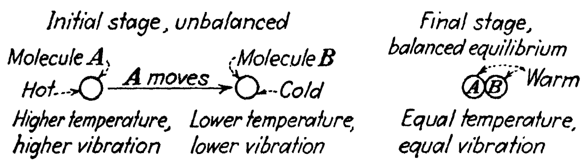


FIG. 30.

24. Change of State. When a substance changes from a solid to a liquid or from a liquid to a gas (or vice versa), heat is transmitted into (or from) the substance. The substance can be carried, in its new state, to a distant point, where, if conditions permit, the substance can be changed back into its original state with a release (or absorption) of the same amount of heat that was transmitted into or from it at the beginning.

For example: *a.* Put a small piece of ice in your mouth and close the lips. The ice slowly melts (changes from solid to a liquid) and removes or transmits the required amount of heat for this change from the mouth (as evidenced by the cooling of the mouth). Now spit out the water. The heat from your mouth has been transmitted to the cuspidor because you changed the ice to water—a change in state.

b. Dip your fingers into water. Now wave the same fingers in the air. Your fingers get cooler and the water slowly vanishes. The water has been changed into gaseous water vapor (a change in state). Heat has been transmitted from your fingers and the air to the evaporated water vapor in the air.

25. Heating. The process of increasing the temperature of a substance, such as air, is heating (see Fig. 31). Heating is

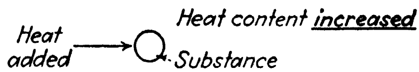


FIG. 31.

simply the moving of heat from where it is not needed to a place where it is desired.

REFRIGERATION

26. Cooling. The process of decreasing the temperature of a substance, such as air, is cooling (see Fig. 32).

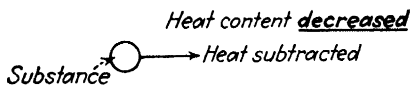


FIG. 32.

27. Relation. Heat has been defined as a form of energy. When heat is added to a substance, it is called heating. When heat is subtracted from a substance, it is called cooling.

28. Heat Again. The temperature of a substance indicates the *intensity* (and kinetic quantity) of heat. The heat required to increase (heating) or decrease (cooling) the temperature of a substance is *sensible* heat. The state of a substance indicates the latent (or potential quantity) of heat. The temperature and state of a substance indicates the total heat as a sum of the sensible (kinetic) and latent (potential) heats.

29. Refrigeration. Refrigeration is simply the moving of heat from where it is not wanted to a place where it is disposed.

30. Unit. The unit of refrigeration is the ton. It is derived from the latent heat required to freeze one ton of water at 32 degrees Fahrenheit to one ton of ice, also at 32 degrees Fahrenheit.

31. Ton of Refrigeration. It requires 144 B.t.u. of latent heat to change a pound of water at 32 degrees Fahrenheit to ice at 32 degrees Fahrenheit. 288,000 B.t.u. will convert 2000 pounds of water to ice and thus equal one ton of refrigeration. The original ice-making rate covered a period of twenty-four hours. The real ton of refrigeration is, therefore, a rate and is

288,000 B.t.u. per 24 hours
12,000 B.t.u. per hour
200 B.t.u. per minute

32. Methods. Refrigeration is accomplished by the use of

a. Water
b. Ice
c. Volatile liquid

Liquid air, carbon dioxide, or dry ice is capable of producing refrigerating effect in air conditioning, but these are used only in rare cases.

33. Water. Water may be used for refrigeration with any of the following:

a. Cooling coils
b. Washer
c. Evaporator
d. Compressor

34. Ice. Ice may be used for refrigeration with systems that are either

a. Direct or
b. Indirect

35. Volatile Liquids. Volatile liquids, generally called refrigerants, may be used for refrigeration with systems that are either

a. Direct or
b. Indirect

36. Apparatus. For sections 32, 33, 34, and 35 see Chap. VIII, on Apparatus.

CHAPTER IV

AIR

AN OCEAN—WE LIVE IN IT

1. Air. Air is a mixture of several components. These components may be classified as

a. Substances that are constant in proportion.
b. Substances that are not constant in proportion.
c. Substances that are not common to, but frequently enter, air as foreign particles.

2. Constant Components. Those substances (see Fig. 33) found in practically constant proportions in air are, by volume,

a. Oxygen gas, 21 per cent
b. Nitrogen gas, 78 per cent
c. Rare gases, 1 per cent

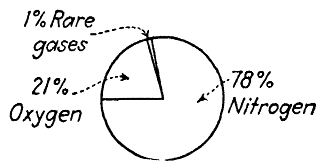


Fig. 33.

3. Inconstant Components. The substances usually found in air that are not constant in proportion, are

a. Water vapor
b. Carbon dioxide gas
c. Dust
d. Dirt
e. Pollen

4. Foreign Components. Substances such as undesirable by-products from industrial processes, vapors, and gaseous odors from cooking, laundry, bath, and toilet centers inadvertently or accidentally may contaminate or vitiate air.

5. General Properties. Air is considered to be a typical gas, composed of minute particles called molecules, which are separated by relatively large spaces. These particles are in constant motion in proportion to their temperature. The molecules have mass and therefore have weight. They occupy space by moving about in it, and do not settle out. They are in a true gaseous state of perfect elasticity; such a gas has neither definite volume nor definite shape. Any gas at the same pressure and temperature will occupy the same volume, and in that volume will be the same number of molecules, the difference in weight between two different gases being the difference in weight of their respective molecules. Some idea of the minuteness of a molecule may be gained by the fact that there are, according to Milliken, about 1,056,801,000,000,000,000, molecules in one cubic foot of standard air!

6. Specific Properties. Air may be

a. Heated
b. Cooled
c. Humidified
d. Dehumidified
e. Compressed
f. Expanded
g. Changed in shape
h. Changed in volume
i. Cleaned
j. Circulated
k. Distributed
l. Diffused

7. Psychrometer. A simple instrument comprising two thermometers, one with a dry bulb and one with a wet bulb, is known

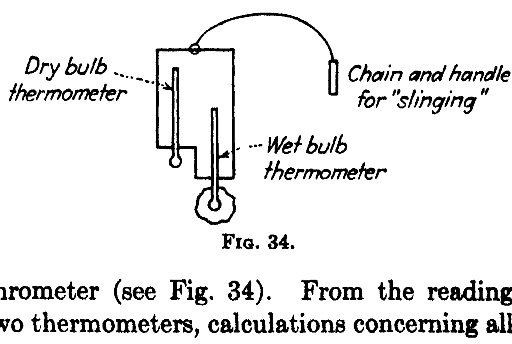
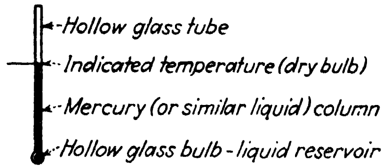


FIG. 34.

as a psychrometer (see Fig. 34). From the readings obtained on these two thermometers, calculations concerning all properties of air can be made.

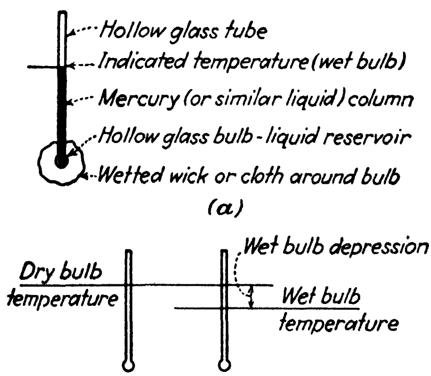
8. Dry-bulb Thermometer. The common type of Fahrenheit thermometer, most popularly used in the home, is a dry-bulb thermometer (see Fig. 35). On it is indicated the actual temperature of the air being tested. This type of thermometer is not affected by the water vapor in the air.



This is the ordinary or common thermometer usually found in the average household

FIG. 35.

9. Wet-bulb Thermometer. To measure the humidity or water vapor and the total heat content of air, the wet-bulb thermometer (see Fig. 36) is used in conjunction with the dry-



Note: At saturation, 100% relative humidity or dew point, the dry and wet bulb temperatures are the same, that is, there is no wet bulb depression

(b)

FIG. 36.

bulb thermometer. As its name implies, this is a standard thermometer (as is the dry-bulb thermometer) with the bulb encased in a cloth saturated with water. The two thermometers are rapidly revolved, as a psychrometer, in the air, or air is rapidly passed over the wet bulb, and it is found that, unless the air within the enclosure is saturated, the wet-bulb thermometer reading is lower than the dry-bulb thermometer reading in the same atmosphere. The difference in the two readings is called the wet-bulb depression. The reason is simple. In the air being tested there is some water vapor. The wet bulb is saturated. Air passing over the wet bulb picks up water vapor from the wetted cloth. When the pressure of water vapor in the air and in the cloth are the same, an equilibrium exists. In the period prior to equilibrium, heat was required to evaporate the water from the cloth; this heat was taken from the saturated cloth, cooling the bulb and lowering the temperature of the wet bulb and resulting in the wet-bulb depression.

10. Diffusion. The air in air conditioning may be considered to be a mixture of dry-air molecules and water-vapor molecules.

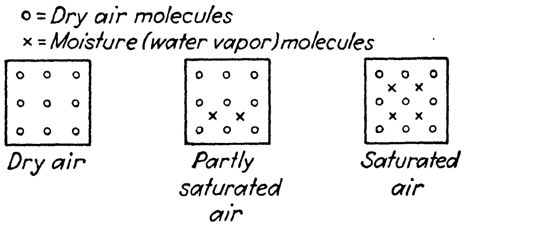


FIG. 37.

When dry air or partly saturated air is exposed to water, the water-vapor molecules diffuse into the spaces between the dry-air molecules and the two kinds of molecules form an intimate mixture (see Fig. 37).

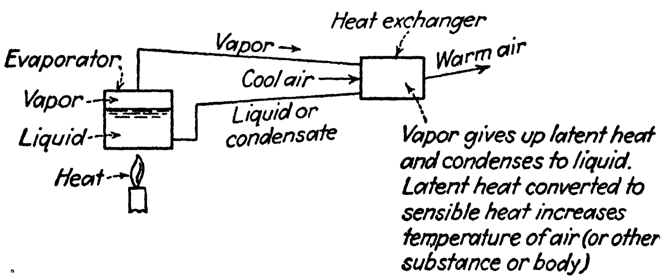


FIG. 38.

11. Evaporation. When a liquid evaporates, it is necessary to add the latent heat of evaporation, as potential energy. This latent heat can be released upon contacting a surface or body requiring heat. It then becomes kinetic energy and heats the body. The vapor or gas is condensed back into a liquid with a release of the latent heat of condensation, which becomes the sensible heat of the warmed body (see Fig. 38).

12. Water Vapor. If some water is placed in a sealed container in which there is nothing but bone-dry air, water molecules will leave the surface of the water and enter into the spaces

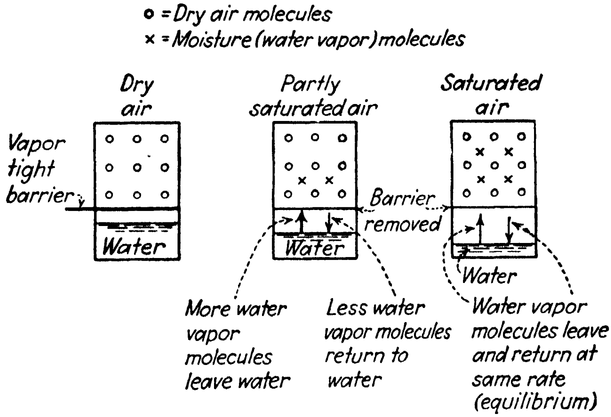


FIG. 39.

between the dry-air molecules, forming a mixture of dry-air and water-vapor molecules. Since all gas molecules are in constant motion (except at absolute zero), the vapor molecules will go back into the liquid, to be replaced by others coming from the liquid. It is a sort of perpetual motion. In dry air the vapor molecules leave the water at a rate faster than they return to it, until the same number leave and return to the water in the same period of time; then equilibrium is established, the space between the dry-air molecules holds all the water-vapor molecules it can accommodate, and the dry air is saturated with water vapor (see Fig. 39). This will happen only when there is a sufficient or excess amount of water.

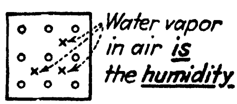


FIG. 40.

13. Humidity. Water vapor in the air is the humidity (see Fig. 40).

14. Saturation. Air is saturated when it has in it all the water vapor it can accommodate at that temperature (see Fig. 41).

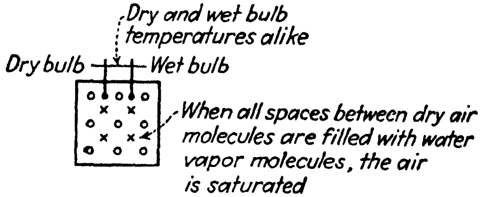


FIG. 41.

15. Dew Point. When an unsaturated mixture of dry-air molecules and water-vapor molecules is cooled at constant pressure, the temperature at which condensation of the water-vapor molecules begins, or at which there is no room for any more water-vapor molecules, is the dew-point or saturation temperature (see Fig. 42). In other words, the temperature at which air is saturated is the dew point.

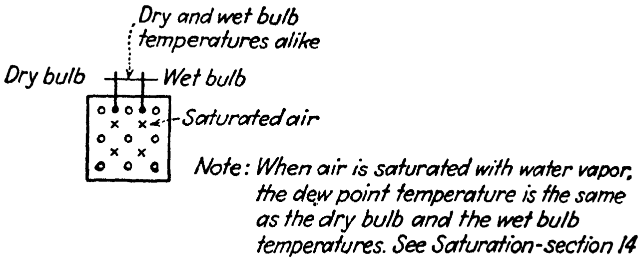


FIG. 42.

16. Humidification. The process of adding water vapor to air is humidification.

17. Dehumidification. The process of extracting water from air is dehumidification.

18a. Absolute Humidity. The actual weight of the water vapor in a cubic foot of dry air is the absolute humidity (see

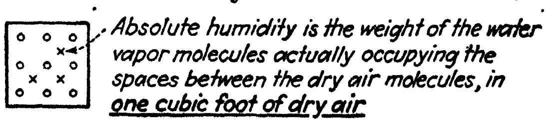


FIG. 43.

Fig. 43). Because the amount is so small, it is expressed in grains. There are 7000 grains per pound. Absolute humidity is expressed in grains per cubic foot of dry air.

18*b*. Specific Humidity. The actual weight of the water vapor in a pound of dry air is the specific humidity (see Fig. 44), expressed in grains per pound of dry air. Note that specific humidity is the weight of the moisture in a *pound* of dry air in

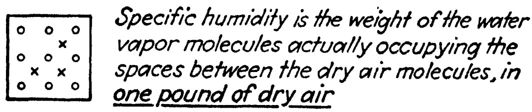


FIG. 44.

contrast to absolute humidity, which is the weight of the moisture in a *cubic foot* of dry air.

19. Relative Humidity. The relative humidity is the ratio, expressed in percentage, of the specific humidity of the air sample, compared to the specific humidity at saturation, for the same temperature (see Fig. 45).

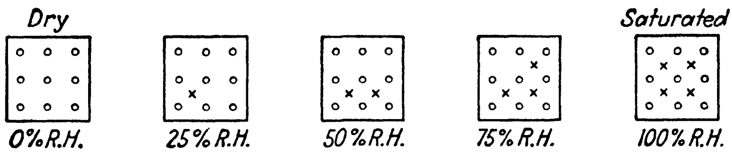


FIG. 45.

20. Dew Point vs Relative Humidity. The pressure of the water vapor almost doubles for every 20 degrees Fahrenheit from 65 degrees to 90 degrees Fahrenheit, dry bulb. This results in an unusual relationship between the dew point and the relative humidity, which is used in air conditioning to simplify calculations. These relations for 50 per cent relative humidity are given in Table *B*.

TABLE *B*

Dry-bulb temperature, deg. Fahr.	Dew-point temperature, deg. Fahr.	Difference, deg. Fahr.
65	45.8	19.2
70	50.5	19.5
75	55.25	19.75
80	59.75	20.25
85	64.25	20.75
90	68.75	21.25

21. Pressure. The force exerted upon a unit area is called pressure. It is usually measured in pounds per square inch.

22. Partial Pressures. According to Dalton's law, the dry-air molecules within a container or an enclosure exert a pressure upon it on the inside. When water-vapor molecules are introduced into the enclosure, they exert an additional pressure on it. Each type of molecule exerts its own partial pressure as if it were alone, and the sum of these partial pressures is the total pressure on the enclosure. The pressure exerted by the dry air is the dry-air pressure and that exerted by the water vapor is the vapor pressure.

23. Inches of Mercury. A cubic inch of mercury weighs 0.491 pound (nearly one-half pound). Vapor pressures are indicated as inches (or fractions of inches) of mercury. For example, one inch of mercury is equal to 0.492 pound of vapor pressure.

24. Atmospheric Pressure. The air envelope which surrounds the earth exerts a pressure at sea level of about 14.7 pounds per square inch. This is referred to as atmospheric pressure (see

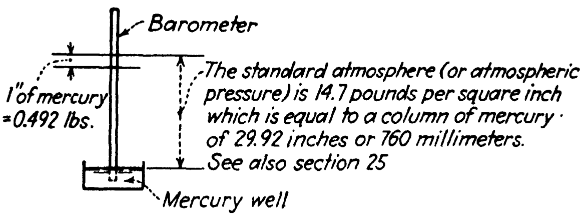


FIG. 46.

Fig. 46), or a pressure of one atmosphere, and is indicated as 29.92 inches, or 760 millimeters, of mercury.

25. Barometer. Atmospheric pressures are measured by the barometer (see Fig. 46), which is a long, thin glass tube, sealed at one end, and filled with mercury. The open end is inverted into a bath or well of mercury. The column of mercury in the tube rises or falls with an increase or decrease in the atmospheric pressure. Since a cubic inch of mercury weighs 0.492 pound and one atmosphere is 14.7 pounds per square inch, a column of mercury 29.92 inches in height equals one atmosphere. It is on this basis that the barometer is calibrated, at sea-level standard.

26. Vacuum. Any system operating at a pressure of less than one atmosphere is said to work under a vacuum (see Fig. 47). Vacuum gauges are usually calibrated to read in inches of mercury with zero inches at one atmosphere pressure and 29.92 inches at total vacuum. For example, 14.96 inches vacuum is equal to 7.35 pounds per square inch absolute.

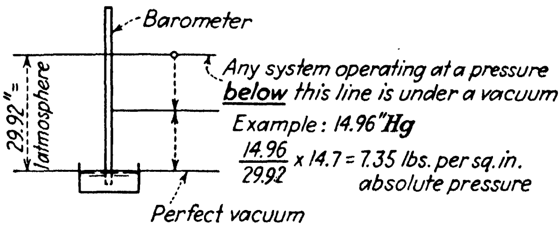


FIG. 47.

27. Gauge Pressure. The pressure exerted by a fluid such as air, steam, or water, above atmospheric pressure, is the gauge pressure (see Fig. 48).

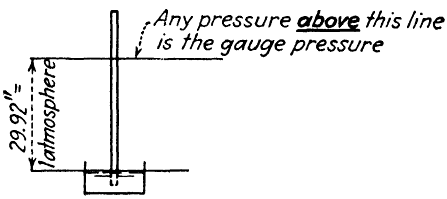


FIG. 48.

28. Absolute Pressure. Starting at absolute vacuum, absolute pressure is the pressure upon the system, above that point. One atmosphere is 29.92 inches of mercury, or 14.7 pounds per square inch absolute. The sum of atmospheric pressure plus gauge pressure is the absolute or total pressure (see Fig. 49).

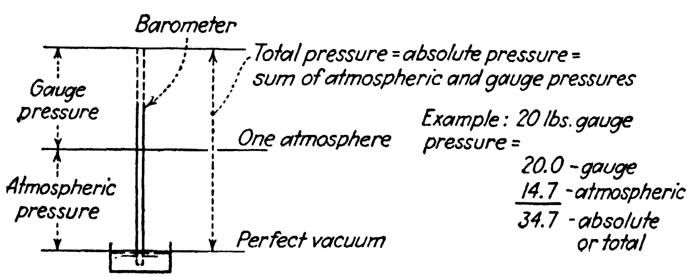


FIG. 49.

29. Inches of Water. When air is circulated or distributed in air conditioning, the pressures used are very small (see Fig. 50). To measure these pressures, a column of water is used instead of a column of mercury. A cubic inch of water weighs 0.037384 pound, therefore, an inch of water equals a pressure of about 0.0374 pound per square inch.

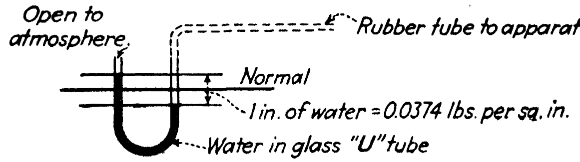


FIG. 50.

30. Pressure Changes. When the pressure on air is increased, the volume decreases and the temperature increases; and when it is decreased, the volume increases and the temperature decreases. According to Boyle's law, "The volume of a gas, like air, at constant temperature, will vary in *indirect* proportion to the variation between the initial and final pressures exerted upon the gas."

31. Combined Changes. Air may be subjected to combined changes of pressure (according to Boyle's law) and to temperature (according to Charles' law). In all cases it follows these laws, principally because of the fundamental (Graham's) law of diffusion.

32. Density. The weight in pounds per cubic foot is the density of air. It is sometimes called the specific density. Under constant pressure, the density of air decreases with an increase in temperature, due to the expansion of the air, the relative increase in spaces between the molecules, and the resultant lesser number of molecules per unit volume. At standard atmospheric pressure of one atmosphere (29.92 inches of mercury), dry air at 70 degrees Fahrenheit weighs about 0.075 pound per cubic foot. Saturated air at the same pressure and temperature is only 0.07425 pound per cubic foot, of which the dry-air molecules weigh 0.0731 and the water-vapor molecules 0.00115 pound in the cubic foot of the saturated air. Dry air weighs more than moist or saturated air because, of the principal components of air, oxygen weighs 32 and nitrogen 28, while water vapor weighs 18, per relative volume. The standard pressure at which densities are measured is one atmosphere, or 29.92 inches of mercury (mercury is sometimes referred to as Hg—its chemical symbol). No basic temperature is commonly used, although 70 degrees Fahrenheit is understood to be standard, unless otherwise specified.

33. Volume. The volume in cubic feet per pound of air is the specific volume. Under constant pressure, the specific volume varies inversely as the density or weight, because a volume increase is accompanied by a decrease in the number of molecules per unit volume, with a resultant decrease in density or weight. The specific volume varies directly as the absolute temperature because the space between the molecules increases with an increase in temperature, and vice versa.

34. Atmospheric Air. The earth is enveloped by a gaseous atmosphere of air that is estimated to be from fifty to several hundred miles in depth. This air is constantly changing in temperature, humidity, velocity, and direction. It is necessary to refine this air under proper control in order that it can be used, as conditioned air, within an enclosure.

35. Atmospheric Pressure Again. The air envelope surrounding the earth exerts a normal pressure of 14.7 pounds per square inch at sea level. This pressure varies and reduces with altitude above sea level (see Fig. 51). It also varies constantly with

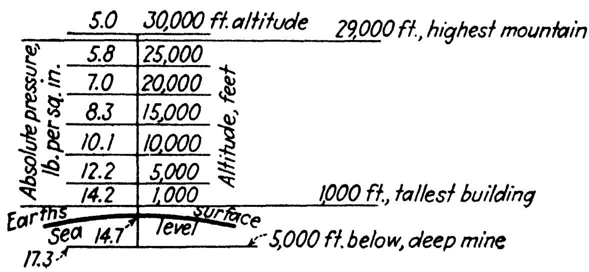


Fig. 51.

atmospheric conditions, above and below the standard barometric pressure. Atmospheric pressures do not materially affect the mechanical operation of air-conditioning equipment.

36. Vitiated Air. Air that is not up to standard air, or conditioned air that has been contaminated, is vitiated air. As unconditioned air, it is air that does not have the correct temperature, humidity, or air motion, or that is unclean.

37. Conditioned Air. Conditioned air is either atmospheric air or vitiated air or both, as unconditioned air, that has been refined so that its temperature, humidity, circulation, and cleanliness are satisfactory for use in an enclosure.

CHAPTER V

PEOPLE

YOU AND I—WHAT MAKES US TICK

1. People. It is essential that certain characteristics of people be understood in order that their health and comfort can be conveniently protected by air conditioning.

2. Environment. People live and move about in the gaseous fluid atmosphere of air, just as fish move about in their natural habitat, the liquid fluid, water. Because people have evoluted, and have always lived, in this atmosphere of air, they are scarcely conscious of its existence, except for the air currents, or winds, and an occasional full realization that they are breathing; yet air is the most necessary thing given to people by nature. A person can live several weeks without food, several days without water, but only several minutes without air. People literally live at the bottom of a vast sea of air.

3. Body. The human body is a self-contained, self-sufficient entity, but it is very delicate in certain respects. From birth until death there is a constant cycle of functions that require an atmosphere to protect the health and comfort of the individual. The permissible variations in the condition of this atmosphere are narrower and more exacting than is generally realized or appreciated.

4. Metabolism. Life is sustained by the assimilation of foods, which, with the resulting chemical reactions within the human body, is known as metabolism. The process of building up the body is called anabolism and the breaking down of the body structure is known as katabolism. Both of these actions are continuously and simultaneously in process, anabolism being more pronounced in youth and katabolism more active in old age. This process of metabolism is due to the fact that living organisms, like the human body, are composed of living cells, called protoplasm.

5. Protoplasm. The outstanding characteristic of these living protoplasmic cells, making them distinctly different from any other known substance, is their ability to maintain themselves by borrowing material or energy from their surroundings.

The specific protoplasm of any organism is able to take up foodstuffs from its suitable environment and to break them down into simpler compounds, and then to rebuild these substances into more of its own particular kinds of protoplasmic ingredients. Living protoplasm is also able to use up its own substance, chiefly by the process of oxidation, and in so doing liberates energy in the form of heat, together with chemical by-products, the most important of which, from an air-conditioning standpoint, are carbon dioxide and water vapor. The body also produces oils, salts, and excretions that result in body odor.

6. Foodstuffs. People eat from six to seven pounds of food daily in order that the body may assimilate the necessary chemical compounds. In these compounds are two elements that are of major importance to air conditioning. One is carbon and the other hydrogen, and each is a combustible that will, under suitable environment, unite with the oxygen in the air.

7. Water. People drink from three to four pounds of water daily to aid in digestion, organic functions, and the metabolic processes. The foodstuffs are assimilated in it and the oxygen dissolved in it to permit the chemical reactions to take place.

8. Air. People breathe about thirty pounds of air daily so that the oxygen in the air can be supplied to the body for the oxidation of the foodstuff chemicals.

9. Oxidation. The chemical elements carbon and hydrogen unite with oxygen within the body. This chemical reaction is known as oxidation.

10. By-products. Air contains about 21 per cent oxygen by volume. About 5 per cent of the air is used in the body as oxygen for the oxidation. The excess oxygen and original other components are exhaled with the breath. In exhaled air are carbon dioxide and water vapor that are produced in the body as a result of the oxidation of the carbon and hydrogen from foodstuffs. As a result of this reaction, heat is produced and dissipated by the body. Therefore, from an air-conditioning standpoint the two by-products from the body are heat and water vapor. Heat and water vapor are exhaled with every breath and are also dissipated from the body in the form of perspiration. Sensible heat is dissipated by radiation, conduction, and convection, while latent heat is dissipated by evaporation of the perspiration (see Fig. 52).

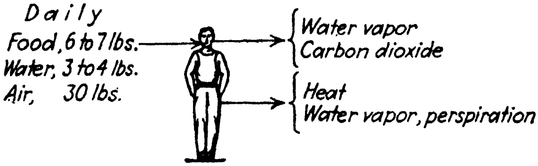


FIG. 52.

11. Plant-animal Cycle. Nature has provided a remarkable balance to use up carbon dioxide and reproduce oxygen. The undesirable carbon dioxide exhaled by the human being, together with carbon dioxide from other sources, is the main diet of plant life. The carbon dioxide and water vapor are breathed in by the green foliage. Owing to the presence of a catalyst called chlorophyll and the action of sunlight, the carbon dioxide forms cellulose or wood fiber, with a resulting liberation of free oxygen

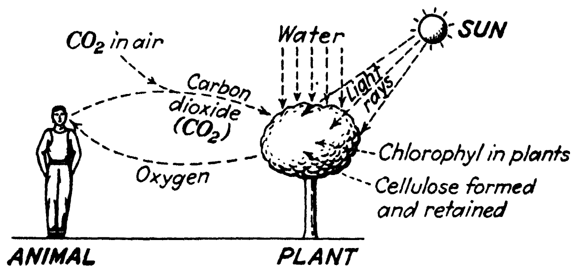


FIG. 53.

back into the air (see Fig. 53). This process is known as photosynthesis.

12. Diet. Human beings require a mixed diet comprising proteins, carbohydrates, and fats and oils. In addition, there are required certain mineral salts, enzymes, and vitamins. The requirement of foodstuffs, depending upon activity and expressed in B.t.u. are

TABLE *C*.—DAILY DIET

Man at rest	8,800 to 11,200 B.t.u. per day
Woman at rest	7,200 to 10,000 B.t.u. per day
Youth, 14 to 16	6,000 to 12,000 B.t.u. per day
Active woman	11,200 to 12,000 B.t.u. per day
Active man	14,000 to 16,000 B.t.u. per day
Active soldier	16,000

13. Limits of Environment. The temperature of the blood in a normal person is constantly at 98.6 degrees Fahrenheit. The external body temperature varies but may be considered as 80 degrees Fahrenheit. Since heat is dissipated by radiation, con-

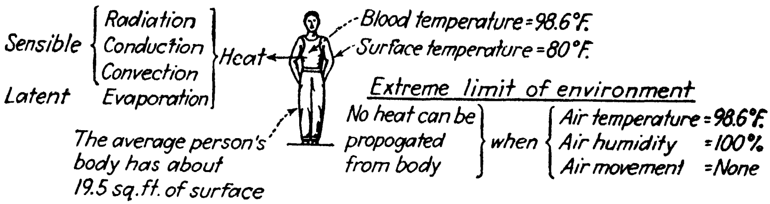


FIG. 54.

duction, convection, or evaporation, the environment must permit heat to leave the body by one or more of these means. It is obvious that should the dry bulb of the air be 98.6 degrees Fahrenheit, or higher, the air be saturated with water vapor, and

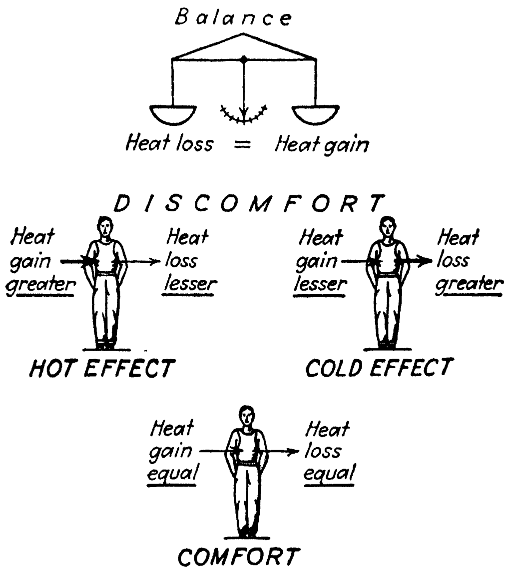


FIG. 55.

there be no air movement, there could be no heat propagated from the body. This may be considered as the extreme limit of the environment (see Fig. 54), and this or an equivalent condition would result in prostration.

14. Balance. In all transfers of heat, equilibrium or balance can be maintained only when the heat loss is equal to the heat gain. If the heat lost from the body is less than the heat gained from the oxidation of foodstuffs or from activity, discomfort or hot effect will result. Conversely, if the heat loss is greater than the heat gain, discomfort will result as cold effect (see Fig. 55).

15. Senses. The human being has five major senses: feeling, hearing, seeing, smelling, and tasting. Of these senses, that of feeling is the one most directly affected by atmospheric changes or variations in air conditions. Because of the mechanical nature of air-conditioning systems, certain noises may develop to such a degree as to create sound above a pleasant level to the sense of hearing. Concentration of certain odors may become sufficiently obnoxious as to create an unpleasant reaction to the sense of smell. So far, there is no direct evidence that the senses of seeing and tasting are affected by changes of atmospheric or conditioned air.

16. Comfort Essentials. It has been noted that if one or more means be provided for permitting heat to be dissipated from the

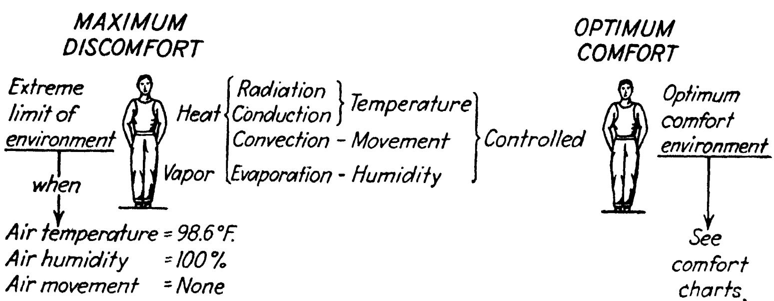


FIG. 56.

body, some degree of comfort below the upper environment limit may be enjoyed. It is the aim of air conditioning to provide the greatest comfort, and this can be accomplished by controlling the temperature, humidity, and motion of the air (see Fig. 56).

17. Effective Temperature. Since there are the three essentials—humidity, air movement, and temperature—a method of standardizing was developed wherein the humidity was fixed at 100 per cent (or saturation) and the air movement made negligible (not over thirty feet per minute), and then the temperature recorded for relative comfort was established as the effective temperature (see Fig. 57). By further tests and mathematical interpolations the relation of dry-bulb and wet-bulb temperatures (or relative humidities) were correlated to the effective temperatures. Effective temperature may therefore be defined as the saturation temperature of still air in which a person experiences a certain degree of comfort.

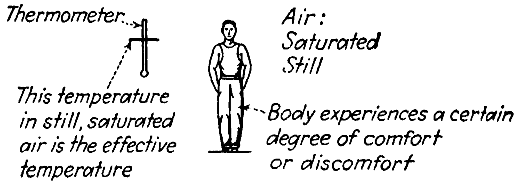


FIG. 57.

18. Comfort Line. The comfort line indicates the combination of dry- and wet-bulb temperatures that correspond to an equal degree of comfort. The optimum comfort line for summer is 71 degrees Fahrenheit, and for winter, 66 degrees Fahrenheit, effective temperatures.

19. Comfort Zone. The comfort zone indicates the limits of comfort with dry- and wet-bulb temperatures, effective temperatures, and relative humidities.

20. Summer Differentials. To reduce the possibility of shock, it is necessary to control the indoor dry-bulb, wet-bulb, and effective temperatures with definite relation to the outdoor dry-bulb temperature as indicated.

21. Excessive Heat. A temperature above 75 degrees Fahrenheit reduces the heat production from foodstuffs. The reason is not definitely established, but it is thought by some to be due to the action of heat-producing organs at the liver and spleen. More blood flows to the skin, giving off sensible heat. When the heat is not sensibly propagated fast enough, the nervous system calls the sweat glands into action. Sweating is the more effective in propagating heat since the latent heat of evaporation is relatively high. If sweating fails to balance the system, distress or collapse occurs.

Prolonged excessive heat will actually produce a chill, which is probably a safety measure, for excessive sweating causes a lowering of the acid-base equilibrium within the system to the point of breakdown. When this point is reached, so-called goose-pimples appear. This is apparently a closing of the pores of the sweat glands to slow up or stop the flow of perspiration, to give the body an opportunity to balance the system. At the same time, the nervous system conveys this fact to the conscious mind, suggesting external relief.

The acid-base equilibrium may be partly balanced under excessive sweating conditions by drinking a solution of water in which are dissolved seven grams of sodium chloride ($NaCl$) and ten grams of potassium chloride (KCl) to the gallon, provided the humidity is low enough to allow for evaporation or the air movement is sufficient to allow for the propagation of heat. Prolonged sweating may result in cramps or more serious conditions. When the body temperature goes above 105 degrees Fahrenheit, death may result.

Summing up, excessive heat affects the human being by

Increasing total heat due to activity
Decreasing total heat due to temperature
Decreasing sensible heat
Increasing latent heat
Increasing respiration
Increasing heartbeat
Increasing pulse
Increasing blood flow
Decreasing oxidation
Increasing energy of system
Increasing sweating
Increasing evaporation
Decreasing reserve
Decreasing activity
Producing lassitude
Producing dizziness
Producing illness
Producing shock
Producing death

22. Excessive Cold. Temperatures below 55 degrees Fahrenheit increase the heat production from foodstuffs. Less blood flows to the skin, giving off less heat, causing the sweat glands to slow up and ultimately to close the pores to reduce heat propagation by evaporation. When this action is too rapid or the external temperature is too low, a chill results, calling for external correction, artificial stimulation, or greater activity.

Lower temperatures cause a cold sensation. Low humidity causes a cold sensation because of the rapid evaporation. High-velocity air movement causes a cold sensation because of the rapid conduction, convection, and evaporation.

Excessive cold or reduced activity causes the body to respond in a direction opposite to that of the responses to excessive heat. In addition, there is a coagulation of blood and a sinking of the surface capillaries deeper in the skin to provide better insulation. When the body temperature, (normal at 98.6 degrees Fahrenheit) falls to about 80 degrees Fahrenheit or less, death may result.

Summing up further, excessive cold affects the human being by

Increasing total heat due to activity
Increasing total heat due to temperature
Increasing sensible heat
Decreasing latent heat
Decreasing respiration
Decreasing heartbeat
Decreasing pulse
Decreasing blood flow
Increasing oxidation
Decreasing energy of system
Decreasing sweating
Decreasing evaporation
Increasing reserve
Increasing activity
Reducing lassitude
Producing illness
Producing shock
Producing death

23. Temperature Shock. On a zero day in winter a person will be clothed in heavy wearing apparel. If he enters a room with temperature of about 70 degrees Fahrenheit, the outer apparel is removed, and if the room is at a temperature above 70 degrees Fahrenheit the jacket or vest even may be removed.

The procedure is reversed upon leaving the warm room and going out into the cold air. This is done to avoid discomfort and prevent temperature shock. During the summer months, when a person leaves the hot, highly humid outside atmosphere and steps into the cooler, partly dehumidified air-conditioned atmosphere of a room, he does not think of putting on a vest, jacket, and top coat. To have to do so would be most inconvenient. Because this is true, the temperature of a conditioned enclosure in the summer should not be much lower than the outside temperature. The average difference is only from 10 to 15 degrees. This is also for the sake of avoiding discomfort and temperature shock.

There have been established relative effective dry- and wet-bulb temperatures for summer conditioning as indicated. Over-ambitious operators of commercial establishments have frequently advertised (and maintained) a guaranteed temperature of 70 degrees Fahrenheit in their establishments. When the air is over 80 degrees Fahrenheit outside, this is wrong and a menace to the health and comfort of patrons or customers. By painstaking effort on the part of manufacturers and engineers, this abuse is being eliminated. When a condition does exist that the inside temperature is too low on a summer day, it is not the fault of the system but is to be directly attributed to the operator, and his attention should be called to the fact.

24. Psychology. Many people imagine things. This is very true regarding heating, cooling, or air conditioning. Time and again, excessive heat or cold complaints are proved to be imaginative to a certain degree, or to be the result of a peculiar momentary condition of the person. People who make such complaints are not to be criticized. The complaint should be investigated and a remedy found if possible. Recently, a complaint that there was insufficient air was met by putting colored streamers on supply grilles. The conditioned air made the streamers wave vigorously, and the person who originally complained was the first to announce her comfort and speak of the wonderful "breeze." Except for putting the visual streamers in place, no adjustment to the system had been made!

25. Body Heat. The relation between the total heat loss from the human body and the effective temperature for still air is indicated by Table *D*.

TABLE D.—TOTAL B.t.u. HOUR FOR AVERAGE MAN*

Effective temperature, deg. Fahr.	A	B	C	D
30	1200	940	810	
40	1300	860	710	
50	1300	850	670	480
60	1300	850	670	420
70	1270	850	670	400
80	1120	820	630	400
90	790	650	470	360

* A = 66,150 ft.-lb. B = 33,075. C = 16,538. D = seated at rest.

Since total heat is the sum of sensible and latent heats, the following table will aid in understanding those relations as affected by temperature change.

TABLE E.—SENSIBLE AND LATENT BODY HEAT*
(Per Cent)

Effective temperature, deg. Fahr.	A		B		C		D	
	S	L	S	L	S	L	S	L
30	86	14	87	13	88	12		
40	82	18	84	16	85	15		
50	70	30	78	22	82	18	86	14
60	56	44	65	35	70	30	84	16
70	43	57	50	50	53	47	74	26
80	30	70	30	70	33	67	55	45
90	18	82	12	88	8	92	26	74

* A, B, C, D, same as previous table.
S and L = sensible and latent heat (percentage).

26. Carbon Dioxide. Until the advent of air conditioning and the more intelligent understanding of the balanced needs of temperature, humidity, and air movement, the concentration of carbon dioxide within an enclosure was used as the basis of ventilation requirements. This theory has been generally abandoned in principle, although the need of some filtered outside air, admixed with inside recirculated air, is recognized and applied. For air requirements see Chap. VII, on Application.

CHAPTER VI

ENCLOSURES

ALL WRAPPED UP IN CELLOPHANE

1. Development. The same ingenuity that enabled man to learn more about heat, air, and people has developed newer, more effective, and more economic house construction, resulting in economies of operation, together with better health, greater comfort, and more convenience.

2. House. Fundamentally, a house is an enclosure the purpose of which is to protect the space inside from one or more of

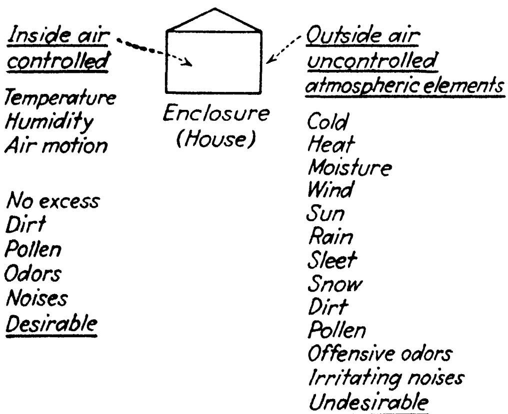


FIG. 58.

the elements of the atmosphere on the outside (see Fig. 58). These atmospheric elements are cold, heat, moisture, wind, sun, rain, sleet, snow, and the like, together with dirt, pollen, offensive odors, and irritating noises.

3. Industrial. A building used for the preparation of a material, such as artificial silk, or for the preservation of a foodstuff is an industrial house.

4. Commercial. A building of multioccupancy, such as a theater, a restaurant, a shop, an office, or any other mercantile space, used for the purpose of maintaining or increasing business profit, is a commercial house.

5. Residential. A building used as a home for one or more families is a residential house.

6. Home. A house intended as an enclosure in which people live or reside, and in which they and their furnishings are protected from the outside elements, is a home or residence. It is usually divided into functional centers for living, sleeping, and servicing (see Fig. 59).

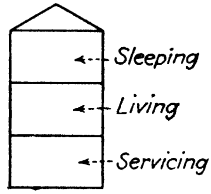


FIG. 59.

7. Barriers. To keep the undesirable outside atmospheric elements from getting inside, the house is constructed of barriers. The most common barriers are the walls, windows, exterior doors,

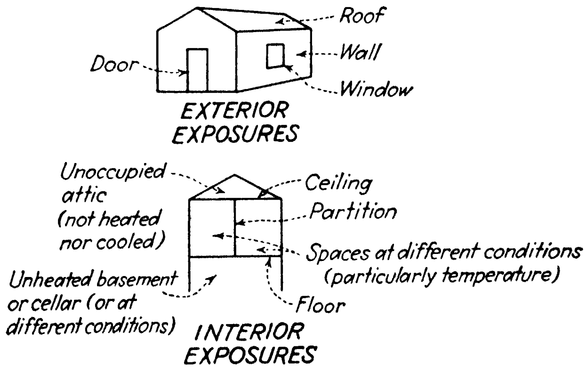


FIG. 60.

and roofs. Partitions, ceilings, and floors may also be barriers (see Fig. 60).

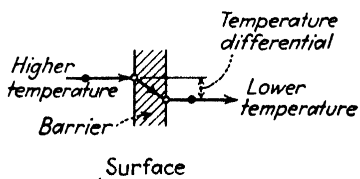


FIG. 61.

8. Function. Barriers offer resistance to the elements of the atmosphere and retard their transmission from outside to inside, or vice versa (see Figs. 61 to 63). Every material or combination of materials used in building construction as a barrier has its own specific resistance to the passage of these elements. Exhaus-

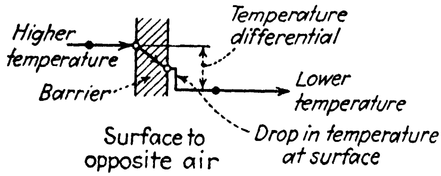


FIG. 62.

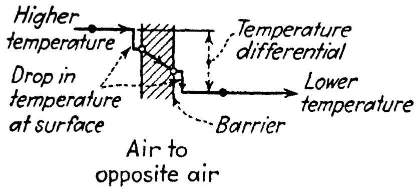


FIG. 63.

tive tests have established most of the mathematical values of these resistances or their reciprocal conductivities.

9. Exposure. An exposed barrier is one having the outside air on one side, or air of different characteristics on each side. An unexposed barrier is one having no outside air on either side, or air of similar characteristics on each side (see Fig. 64).

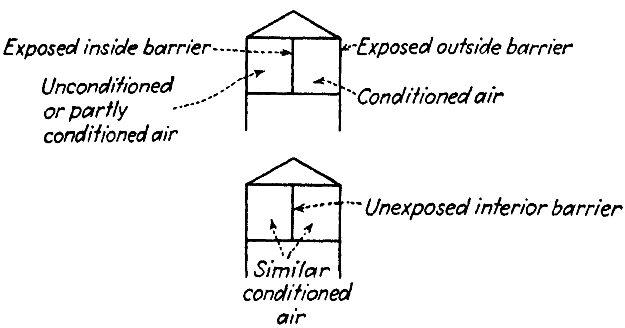


FIG. 64.

10. Nature. Most barriers, such as walls, windows, and roofs (see Barriers, section 7) are, to a certain degree, capable of resisting the four fundamental elements:

a. Heat
b. Moisture
c. Air
d. Sunlight

The nature of the barrier can be changed by use of certain materials and the relation of these materials, one to the other. In air conditioning it should be the objective to select the barriers that will give the greatest desired resistivity with the least relative cost. By cost is meant, not only the initial cost of the construction of the barriers, but the cost of installation and operation of the air-conditioning system, in order to enjoy operating and maintenance savings.

11. Desires.

a. Heat. It is undesirable to have heat pass from the inside to the outside during the winter air-conditioning season.

It is undesirable to have heat pass from the outside to the inside during the summer air-conditioning season.

Heat is always endeavoring to pass from the warmer to the cooler atmospheres.

b. Moisture. It is usually undesirable to have moisture, or water vapor, pass from the inside into the barrier, or the outside, during the winter air-conditioning season.

It is usually undesirable to have moisture, or water vapor, pass from the outside to the inside during the summer air-conditioning season.

Moisture is always endeavoring to pass from an atmosphere of higher humidity to one of lower humidity.

c. Air. It is undesirable to have uncontrolled air pass (as leakage) from the outside to the inside during the winter air-conditioning season; and, from an economic standpoint, to have air pass from the inside to the outside during the same season.

It is undesirable to have uncontrolled air pass (as leakage) from the outside to the inside during the summer air-conditioning season; and, from an economic standpoint, to have air pass from the inside to the outside during the same season.

Air is always endeavoring to pass from an atmosphere of higher pressure to one of lower pressure.

d. Sunlight. It is undesirable to have sunlight pass into an enclosure or be absorbed by a barrier, during the summer air-conditioning season, because the impinging sun rays are converted into undesirable additional heat.

Sunlight always adds heat to an enclosure, depending upon its admission to the enclosure (as through a glass window) or by being absorbed by darker, rougher, exterior surfaces.

Although absorbed heat, from sunlight, may be desirable during the winter air-conditioning season, it is not attempted or recognized, because it cannot be depended upon during cloudy days or night periods.

12. Simple Barrier. A simple barrier may be considered as one intended to resist one of the fundamental elements, and may be arbitrarily classified as

a. Heat barrier
b. Moisture barrier (vapor)
c. Air barrier
d. Sunlight barrier

13. Heat Barrier. Because nothing is perfect and no barrier has 100 per cent resistance to heat, some heat will pass or be transmitted from the warm to the cool side. In the winter, the heat passes from the warm interior to the cool exterior. In the summer, the heat passes from the warm exterior to the cool interior. The objective in selecting a heat barrier is to obtain one with the highest possible resistance or the lowest conductivity, with the greatest relative economy of installation. Several such barriers are now obtainable through the use of highly resistant heat-insulation materials. Doors and windows are made more highly heat resistive through the use of double glazing or storm sash.

14. Vapor Barrier. Water vapor, always in the air in some proportion, is in the minutest or tiniest form, and is said to be in the gaseous molecular state. These molecules are so small that they cannot be seen even with the most powerful microscope. Because they are so small they permeate, or pass through, most materials. In the winter months—the heating season—air conditioning introduces higher humidities within the house than have been usually encountered heretofore.

This greater water-vapor content of the air would cause a higher permeation of water vapor into the barriers exposed to the colder outside air, the barriers would absorb or adsorb sufficient water vapor to cause condensation into water particles. Subsequent freezing of the water particles would result in damage to the structural barrier of the house. Authorities differ as to the type and location of the barrier best suited for vapor retarding. There seems to be a logical tendency to place the vapor barrier on the inside rather than the outside of the structural barrier, such as wall, roof, ceiling, or floor.

15. Air Barrier. Air, like water vapor, is in very tiny molecular form and will pass through barriers in the same manner. Usually, the greatest passage of air through a barrier is around doors, windows, and similar apertures. Proper weather stripping and calking will reduce this leakage appreciably and result in fuel or power saving. Building papers, tight construction, and nearly impervious or impermeable materials also aid in reducing the air leakages.

16. Sunlight Barrier. Sunlight, passing through the vacant spaces in the air, between the molecules, impinges upon the

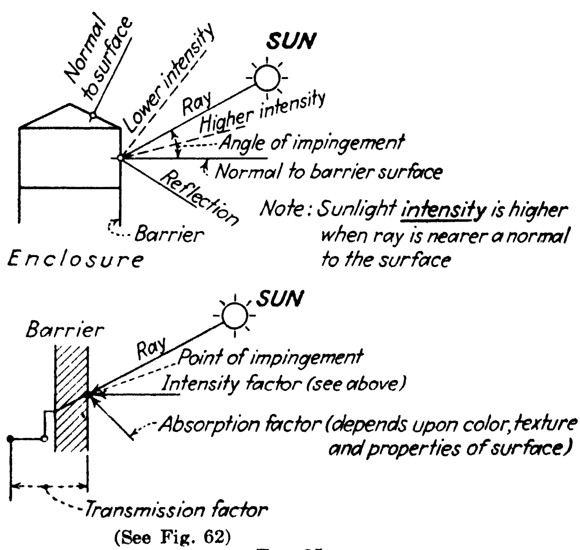


FIG. 65.

exterior surfaces of barriers (see Fig. 65). The light waves are converted into heat as they impinge upon these surfaces. The heat that is absorbed depends upon the angle of impingement, the color, texture, and properties of the surface material. The heat (from the sunlight) that is admitted by the exterior surface, passes through the remainder of the structural barrier, according to accepted rate, into the interior air. It is obvious that the proper treatment of exterior surfaces, and the erection of barriers at glazed openings (such as awnings, blinds, shades, Venetian blinds, or the like) are important in summer air conditioning.

17. Status. At the present time, quite ample information regarding heat resistance (or conductivity) from outside to inside air, or vice versa, together with air leakage, is available. Some data are now accepted for sunlight effect. Valuable research work is being done on moisture and air barriers. Of these, at this time, those most used in calculations are air leakage and heat transmission.

18. Combined Barriers. Since barriers are built for structural purposes and their natures can be modified for air-conditioning purposes, practically any barrier can be made to give desired combined resistance to heat, moisture, air, and sunlight. The selection of such barriers is dependent upon their economic feasibility.

PART II
APPLICATION AND APPARATUS

CHAPTER VII

APPLICATION

THE SHOE MUST FIT

1. Objective. The objective of comfort air conditioning is to provide the best, or optimum, atmosphere, within an enclosure, for preserving or improving the health, comfort, and convenience of people.

2. Essentials. Certain necessary things about heat, air, people and enclosures have been explained, and a fundamental knowledge of comfort air conditioning has been presented.

3. Application. To attain the objective, it is necessary only to apply the essentials; to do so with proper routine is to gain efficiency of application.

4. Routine. For better continuity and clarity, the essentials given in the earlier sections of this book were then arranged as heat, air, people, and enclosures. Now, they are rearranged for greater adaptability, application, and efficiency, as

I. People
II. Air
III. Enclosures
IV. Heat
V. Sound

DIVISION I. PEOPLE

1. People. Since comfort air conditioning has to do with people, the correct atmosphere for their best, or optimum, health, comfort, and convenience must first be established. It is obvious that a review of Chap. V, on People, would be of value.

2. Health. Much pathological research is being conducted in an effort to determine the health value of air conditioning. There seem to be two distinct applications: one is to maintain existing good health, and the other is to treat patients in prescribed atmospheres to improve impaired health. The maintenance of existing good health is a simple matter with a properly designed and operated air-conditioning system.

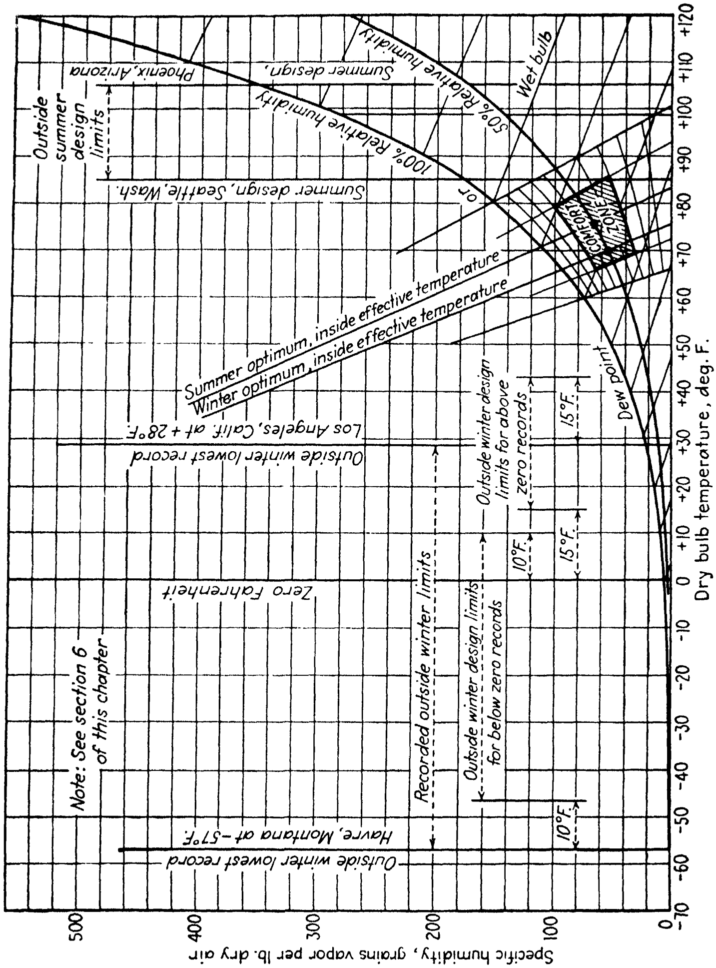

Outside summer design limits
Phoenix, Arizona
Summer design,
100% Relative humidity
50% Relative humidity
Wet bulb
Summer design, Seattle, Wash.
COMFORT ZONE
Summer optimum, inside effective temperature
Winter optimum, inside effective temperature
Dew point
Los Angeles, Calif. at +28°F.
Outside winter lowest record
Outside winter design limits for above zero records
15°F.
10°F.
Zero Fahrenheit
Note: See section 6 of this chapter
Recorded outside winter limits
Outside winter design limits for below zero records
Havre, Montana at -57°F.
Outside winter lowest record
500
400
300
200
100
0
Specific humidity, grains vapor per lb. dry air
-70
-60
-50
-40
-30
-20
-10
0
+10
+20
+30
+40
+50
+60
+70
+80
+90
+100
+110
+120
Dry bulb temperature, deg. F.

FIG. 66.

3. Prescription. Not enough is yet known to warrant a treatise on the prescribed atmospheres for specific ailments; therefore, it is not within the province of this text to do more than mention the subject. It is a vast field in its own application and the future use of synthetic atmospheres is worthy of serious consideration.

4. Convenience. The relief from the anxiety, exertion, and strain of attending to heating, cooling, and ventilating equipment, through the use of automatic controls, is of the utmost convenience and undoubtedly aids in the preservation and improvement of the health and comfort of occupants within an air-conditioned atmosphere.

5. Comfort. It was early apparent that comfort was the logical measure by which people could indicate their relative contentment within conditioned atmospheres.

6. Range. It is astonishing to observe the narrow range of body comfort, which requires exacting control of inside air, compared to the broad range of outside air, occasioned by its fickle and constantly changing conditions. This is vividly portrayed in Fig. 66.

7. Comfort Charts. What are apparently the best, or optimum, conditions within an enclosure for people are graphically indicated on the following winter, summer and all-year comfort charts (Figs. 67–69).

8. Winter Comfort Chart. Referring to the winter comfort chart Fig. 67, observe that the chart is constructed around the effective temperature line (same as saturation or dew point) and the per cent of comfort graph. From these, the comfort lines, or effective temperatures, for various percentages of comfort are established. Related dry-bulb, wet-bulb, and relative humidity lines are developed.

9. Inside Winter Design. Referring to the winter comfort chart, Fig. 67, observe that the per cent comfort varies from 0 per cent at 60 degrees Fahrenheit, effective temperature, to 97 per cent (the highest) at 66 degrees Fahrenheit, and back to 0 per cent at 74 degrees Fahrenheit. The optimum inside winter design effective temperature is obviously at 66 degrees Fahrenheit. Note that at effective temperatures of 63 degrees Fahren-

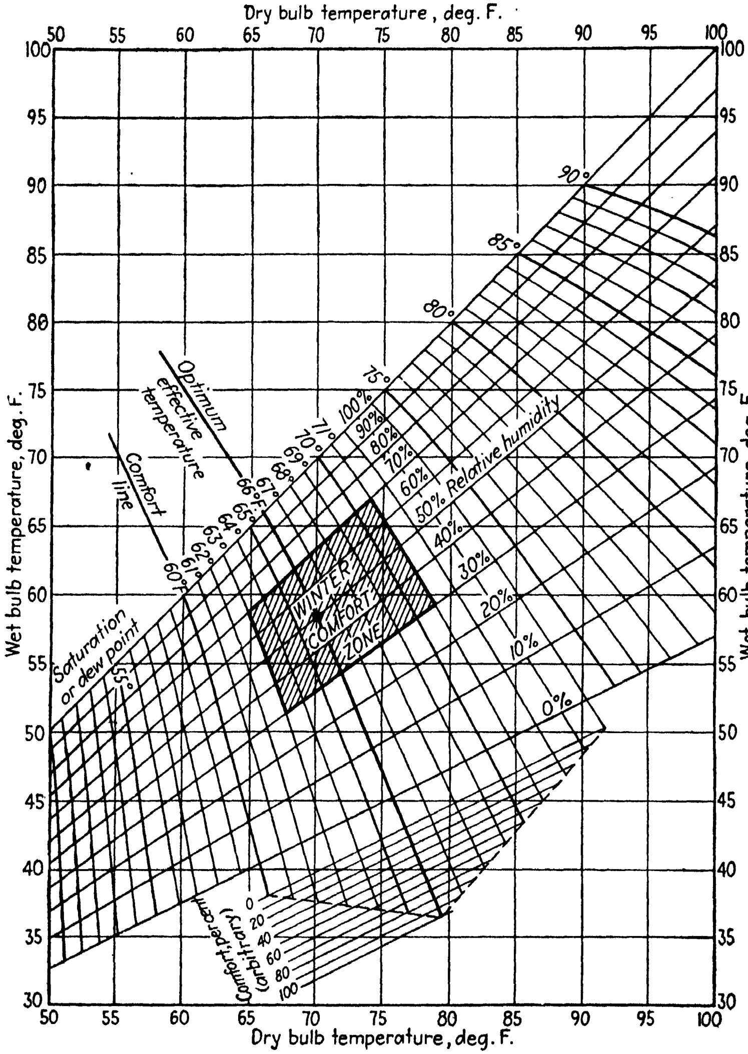


FIG. 67.—Winter comfort chart. *(Prepared by the author from data provided through the courtesy of ASHVE.)*

heit, and 71 degrees Fahrenheit there are the theoretical low and high limits of the winter comfort zone.

Also, note that the winter comfort zone is limited to above 30 per cent and below 70 per cent relative humidity; humidities below 30 per cent are considered too dry and those above 70 per cent, too humid for comfort—as demonstrated by actual tests. The ideal design is apparently on the 66 degrees Fahrenheit effective temperature (comfort) line. Converting this to dry- and wet-bulb temperatures and relative humidities, the ideal point is at 70 degrees Fahrenheit dry bulb, 58 degrees Fahrenheit wet bulb, and 50 per cent relative humidity.

It is to be especially noted that other points on the same 66 degrees Fahrenheit effective temperature line, for instance, a dry bulb of approximately 67.5 degrees Fahrenheit, a wet bulb of 62.5 degrees Fahrenheit, and 70 per cent relative humidity on the one hand and a dry bulb of approximately 71 degrees Fahrenheit, a wet bulb of 55 degrees Fahrenheit, and a relative humidity of 30 per cent on the other, are theoretically equal to the same degree of comfort as the apparent ideal point of 70 degrees Fahrenheit dry bulb, 58 degrees Fahrenheit wet bulb, and 50 per cent relative humidity. In plain words, the same percentage comfort exists at any point on the same comfort or effective temperature line.

10. Inside Temperatures. Suggested winter inside dry-bulb design temperatures, for various enclosures are given in Table 1, page 193.

11. Inside Winter Operation. The ideal comfort conditions within an enclosure in the winter are not always practical, from an operating standpoint, because of the possibility that water vapor may condense or freeze, owing to low outside air temperatures.

Because there is considerable variation in outside temperatures and in the construction of the barriers forming the enclosure, no fixed rules can fairly be given. Obviously, the more efficient the barriers as to heat and vapor resistance, as well as wind resistance, the more nearly the operating conditions may approach the ideal design conditions. To repeat, on days which are cold outside and with inadequate barriers, the principal difficulties are condensation or frosting on the glass and inner wall surfaces and the freezing of moisture within the exposed barriers.

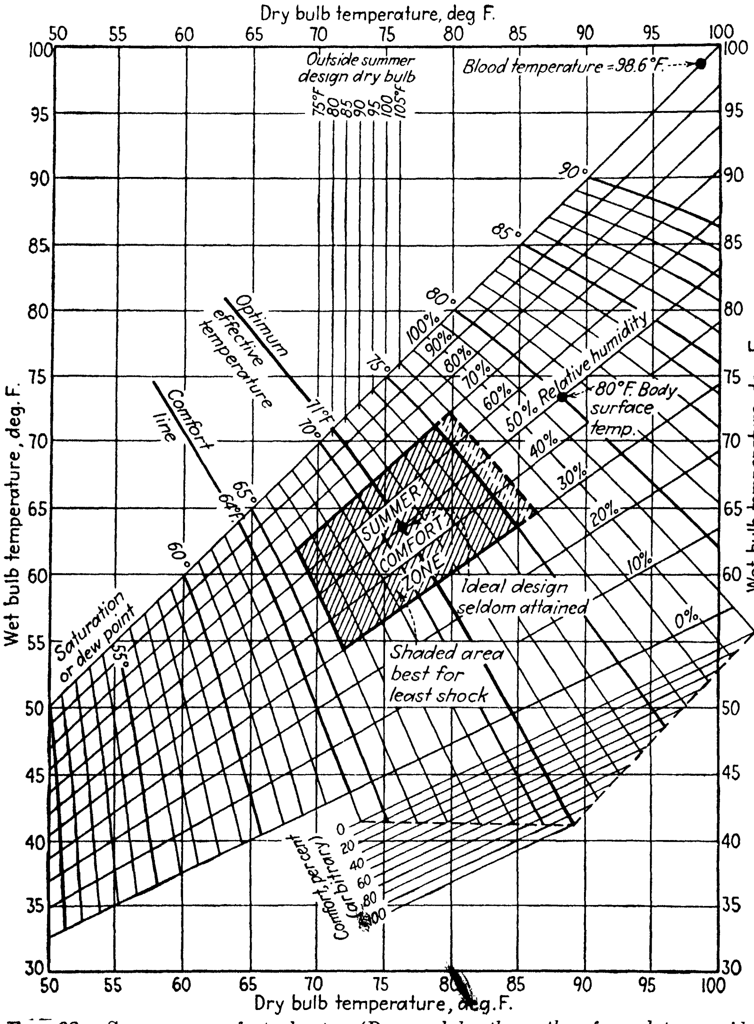


Fig. 68.—Summer comfort chart. (*Prepared by the author from data provided through the courtesy of ASHVE.*)

12. Summer Comfort Chart. Referring to the summer comfort chart, Fig. 68, observe that, like the winter comfort chart, Fig. 67, it is constructed around the effective temperature line (same as saturation or dew point) and the per cent of comfort graph. Also, that from these the comfort lines, or effective temperatures, for various percentages of comfort, are established. Related dry-bulb, wet-bulb, and relative humidity lines are developed. Note that the extreme limit of environment, and the average body-surface temperature are indicated on this chart.

13. Summer Comfort vs. Outside Temperature. The ideal conditions within an enclosure in the summer are not always practical, because of the possibility of temperature shock if too great a differential between outside and inside air is used. The outside design temperatures from Table 2, page 194, are superimposed upon the summer comfort chart (Fig. 68), affording a simple method of determining what are apparently the best inside effective temperatures.

The relations between the outside design dry-bulb and inside effective temperatures are derived from the simple formula,

$$E = 70 + \frac{T - 75}{5}$$

where E equals inside effective temperature and T equals outside design dry-bulb temperature. (Refer to Chap. V, on People, section 23, regarding Temperature Shocks.)

14. Inside Summer Design. Referring to the summer comfort chart, Fig. 68, observe that the per cent comfort varies from 0 degrees at 64 degrees Fahrenheit effective temperature to 98 per cent (the highest) at 71 degrees Fahrenheit and back to 0 per cent at 70 degrees Fahrenheit but, owing to the possibility of temperature shock, and in many instances because of economic necessity, the inside design effective temperature is not established as 71 degrees Fahrenheit. Instead, the inside summer effective temperature is selected through a relation to the outside summer design dry-bulb temperature.

For example: The outside summer design dry-bulb temperature for New York City is 95 degrees Fahrenheit (see Table 15). At the top of the summer comfort chart, Fig. 68, locate 95 degrees; follow down this line to the saturation line and observe that the effective temperature should be 74 degrees Fahrenheit. At 50 per cent relative humidity, the 74 degrees effective temperature line gives a related dry bulb of 80 degrees Fahrenheit and a wet bulb of 67 degrees Fahrenheit and a dew point of 60 degrees Fahrenheit. (Actually, the relative humidity is 51 per cent for these temperatures.) It is observed that a maximum of 105 degrees Fahrenheit outside summer design dry bulb is shown and that the related effective temperature of 76 degrees Fahrenheit is just beyond the arbitrarily established upper limit of the inside summer comfort zone. There are several schools of thought on subjects of this sort. In a study relatively so new, conflicts of this kind may arise. The wise person is tolerant and understanding and uses his own good judgment.

Note that at effective temperatures of 66 degrees Fahrenhelt and 75 degrees Fahrenheit there are theoretical low and high limits of the summer comfort zone. Also, note that the summer comfort zone is limited to above 30 per cent and below 70 per cent relative humidity.

Any combination of dry bulb and wet bulb (or relative humidity) on the same effective temperature (comfort) line will give a theoretically equal per cent of comfort.

15. Inside Summer Operation. The ever-changing outside air conditions require control of the inside air and the differential between outside and inside air. Automatic controls are available, but they are frequently too expensive for the average installation. However, the thermostat can be set for the desired inside condition against the outside condition, the setting of the thermostat being determined from the summer comfort chart, Fig. 68.

16. All-year Comfort Chart. Refer to the all-year comfort chart, Fig. 69, and note that it is a combination of the winter comfort chart, Fig. 67, and the summer comfort chart, Fig. 68. The chart is simple to use. For example: The optimum winter effective temperature for inside air is 66 degrees Fahrenheit. The related conditions are 70 degrees Fahrenheit, dry bulb, 58 degrees Fahrenheit, wet bulb, or about 50 per cent relative humidity. The optimum summer effective temperature for inside air would be 71 degrees Fahrenheit, but the outside summer design dry bulb must be considered—for New York City it is 95 degrees Fahrenheit. (See Table 15.) Now, for 95 degrees Fahrenheit outside summer design dry bulb, read down this line to the saturation line and find the required inside effective temperature of 74 degrees Fahrenheit, the related conditions

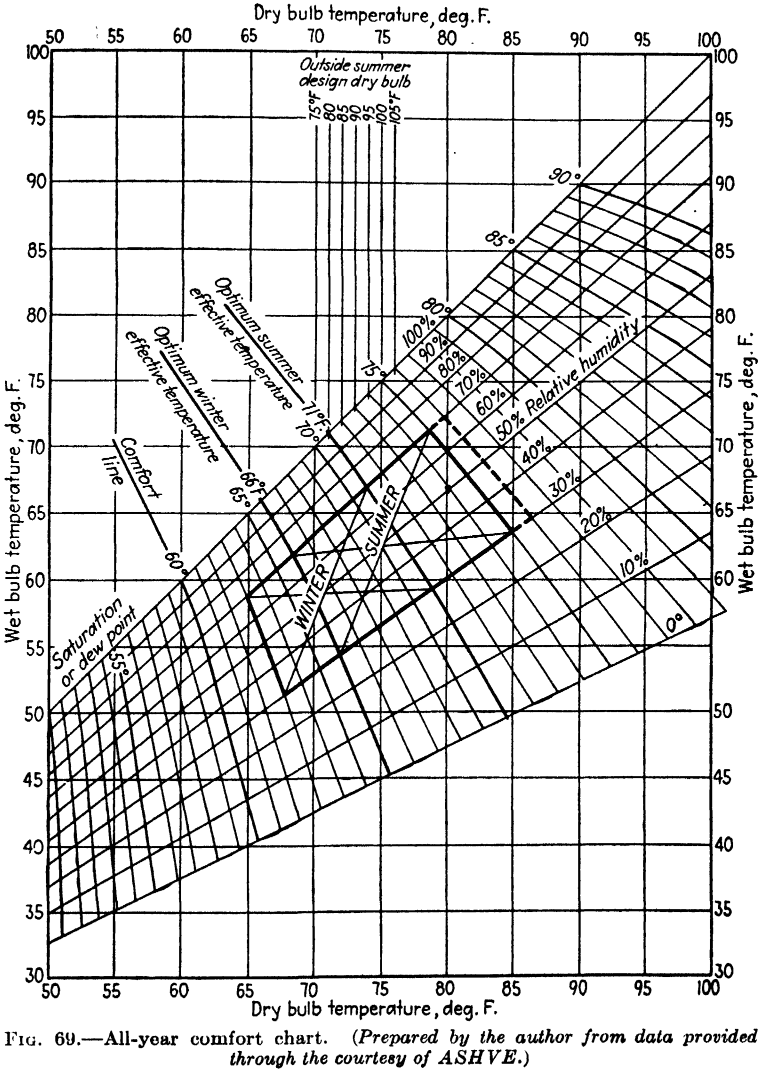


FIG. 69.—All-year comfort chart. *(Prepared by the author from data provided through the courtesy of ASHVE.)*

being 80 degrees Fahrenheit, dry bulb, 67.5 degrees Fahrenheit, wet bulb, or about 51 per cent relative humidity. Now read up the effective temperature (comfort) line and observe the per cent of comfort is about 67 per cent. Also, observe that the maximum per cent of summer comfort can be approximated on the 71 degrees Fahrenheit effective temperature line, corresponding to an outside summer dry bulb of 80 degrees Fahrenheit (which has been discussed in a previous section of this chapter).

17. Ventilation. In air conditioning, ventilation means the circulation of, and the addition of, outside air. There are several simple rules to observe, all of which are open to discussion:

Rule 1. Provide a minimum of thirty cubic feet per minute per person.

Rule 2. Of the thirty cubic feet per minute per person, at least ten cubic feet per minute should be outside air admixed with twenty cubic feet of recirculated inside air.

Rule 3. In the winter, provide a minimum of four air changes per hour for each conditioned room. The National Warm Air and Air Conditioning Association specifies five changes per hour, but many manufacturers have arbitrarily adopted four.

Rule 4. In the summer, provide a minimum of one and one-half air changes per hour for each conditioned room. This is the average of several prominent manufacturers and is subject to individual recommendation.

Rule 5. When ozone, ionization, or electric precipitation equipment is used, the manufacturer's recommendations should be considered and generally adopted.

DIVISION II. AIR

1. Air. It is suggested that Chap. IV, on Air, be reviewed.

2. Inside Air. The requirements of inside air have just been established in this chapter, under the division on People. To obtain such required inside atmospheres it is necessary to condition or refine outside and vitiated inside air.

3. Unconditioned Air. Outside and vitiated air, as unconditioned air, need to be refined and placed under control before they may be properly used as inside or conditioned air.

4. Differentials. When air is refined or conditioned, it is usually necessary to change the temperature, humidity, and motion of unconditioned air, to meet the more exacting requirements of conditioned air. The difference between the unconditioned and the conditioned air introduces the differentials in temperature (heat), humidity (moisture), and motion (ventilation), as well as cleanliness. These differentials must be provided and controlled.

5. Composition. Air has already been described as composed of substances

a. Constant in proportion
b. Inconstant in proportion
c. Usually foreign to air

6. Inconstant Substances. Those substances constant in proportion—such as oxygen, nitrogen, and rare gases—can be disregarded, except for ventilation needs. However, those substances inconstant in proportion, such as

a. Moisture
b. Heat
c. Volume

are of principle importance to air conditioning.

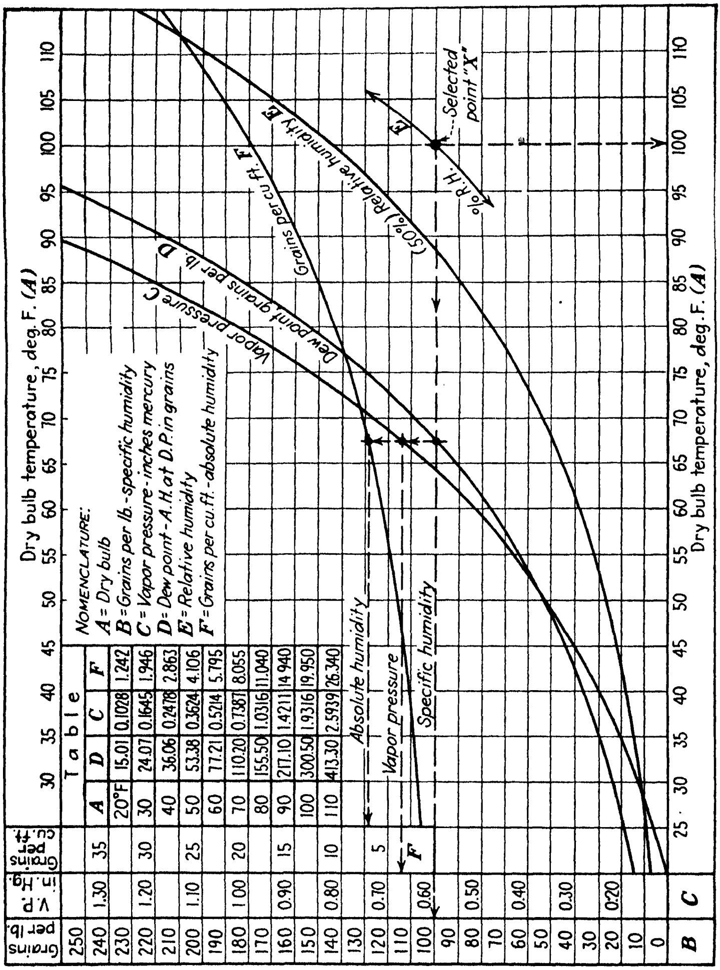
7. Psychrometry. Psychrometry is defined as "that branch of the science (of physics) that treats of the measurement of degree of moisture, especially the moisture mixed with the air."

8. Psychrometric Chart. As its name implies, a psychrometric chart, of which there are several forms, graphically indicates the conditions of dry air with various quantities of moisture admixed. In addition, practically all such charts include heat and volume related to the moistened air. To simplify the construction and understanding of the use of the psychrometric chart, it is here reduced to the three simple parts, *i.e.*,

a. Moisture chart
b. Heat chart
c. Volume chart

and then, the three are combined as a complete psychrometric chart. The form of the charts used herein is based on the formulas and chart developed by the Carrier Corporation, because of its simpler construction.

9. Moisture Chart. The moisture chart, Fig. 70, is basically constructed upon the moisture (water vapor) content of dry air saturated. From this the other facts about air are readily established (see Table 2 in the Appendix).



Table

A	D	C	F
20°F	15.01	0.1028	1.242
30	24.07	0.1645	1.946
40	36.06	0.2478	2.863
50	53.38	0.3624	4.106
60	77.21	0.5214	5.795
70	110.20	0.7387	8.055
80	155.50	1.0316	11.040
90	217.10	1.4211	14.940
100	300.50	1.9316	19.950
110	413.30	2.5939	26.340

FIG. 70.—Moisture chart.

10. Standard Pressure. The pressure of one atmosphere, at sea level, is considered standard and is the pressure used in preparing this, or any other similar, psychrometric chart. One atmosphere pressure is equal to 29.92 inches (760 millimeters) of mercury or 14.7 pounds per square inch.

11. Dew Point. To find the dew point (D.P.) on the accompanying chart, from any selected point *X*, read directly left to the dew-point line marked *D*. Note that this is the dew point, saturation, or 100 per cent relative-humidity (R.H.) line.

12. Specific Humidity (per pound). To find the specific humidity (S.H.) from any selected point *X*, read from the selected point directly left to the dew-point line *D* and continue directly left to the *B* column of figures and read the specific humidity expressed in grains of moisture per pound of dry air. This figure in grains (the specific humidity) is the moisture in one pound of dry air under the conditions prevailing at the selected point *X*.

13. Absolute Humidity (per cubic foot). To find the absolute humidity (A.H.) per cubic foot of dry air saturated with moisture, from a selected point *X*, read directly left from the point *X* to the dew point line *D*, then directly up to the absolute humidity or grains of moisture per cubic foot line *F*, then directly left to the column of figures *B* and read the absolute humidity per cubic foot for conditions prevailing at the selected point *X*.

14. Relative Humidity. To find the relative humidity (R.H.) from any selected point *X*, find the relative-humidity line at the point *X* and read the relative humidity on this line. If the point is between two relative-humidity lines, interpolate for the more exact figure.

15. Vapor Pressure. To find the vapor pressure (V.P.) from any selected point *X*, read directly left from the point to the dew-point line *D*. Then read directly up (or down) from the point on the dew-point line to the vapor-pressure line *C*. Then read left to the *C* column of figures and read the vapor pressure, expressed in inches of mercury (Hg).

16. Moisture Table. The table on this chart, Fig. 70, gives the dry-bulb temperatures in ten-degree increments from 20 to 110 degrees Fahrenheit, in column *A*. In column *D* are the weights of moisture in grains per pound of dry air (the specific humidities). In column *C* are the vapor pressures in inches of mercury, and in column F are the weights of moisture in grains per cubic foot of dry air (the absolute humidities).

17. Heat Chart. The total heat content of air is distinctly a function of the wet-bulb temperature; therefore the total heat line (called a matrix) is always shown with the wet-bulb lines.

18. Wet-bulb Lines. The wet-bulb lines are plotted, and the total heat for each specific wet bulb is from the simple formula:

$$H = C(t - 0) + Wh$$

where H equals total heat, C equals mean specific heat of dry air (0.24), t equals wet-bulb temperature, 0 equals zero Fahrenheit since the total heat is given as above 0 degrees Fahrenheit, W equals weight of water vapor (in pounds) in one pound of the dry air saturated, *i.e.*, it is the saturation specific humidity expressed in pounds, and h equals latent heat of evaporation at wet-bulb temperature t in B.t.u. (heat units) per pound of air. It is to be especially observed that at any point on a specific wet-bulb line, from 0 per cent to 100 per cent, R.H., the total heat is the same. Note that at 0 per cent, relative humidity, there is no water vapor and the dry bulb is highest. As the moisture or humidity increases, the dry bulb, for the same wet bulb, decreases until the wet-bulb and dry-bulb temperatures are the same, which occurs at dew point. Some of the sensible heat indicated by the dry bulb, is used up as latent heat to evaporate the added moisture. This is known as adiabatic saturation.

19. Total Heat. The total heat or heat content of a mixture of dry air and water vapor is the same for any two states of the mixture at the same wet bulb. To find the total heat from any selected point X, read up the wet-bulb (W.B.) line to the dew-point (*D.P.*) line, then directly up to the total-heat (T.H.) line or (matrix), then directly left to the column K, indicating the total heat in B.t.u. per pound.

20. Heat Table. The table on this chart, Fig. 71, gives the wet-bulb temperature (the wet- and dry-bulb temperatures are the same at dew point) in column A and the total heat in B.t.u. per pound of dry air saturated (which is the same at any point on the same wet-bulb line) in column K.

21. Volume Chart. Volume of air is a function of absolute temperature, which has been defined as the sum of the dry-bulb temperature plus 460 degrees Fahrenheit. The dry-air line (or

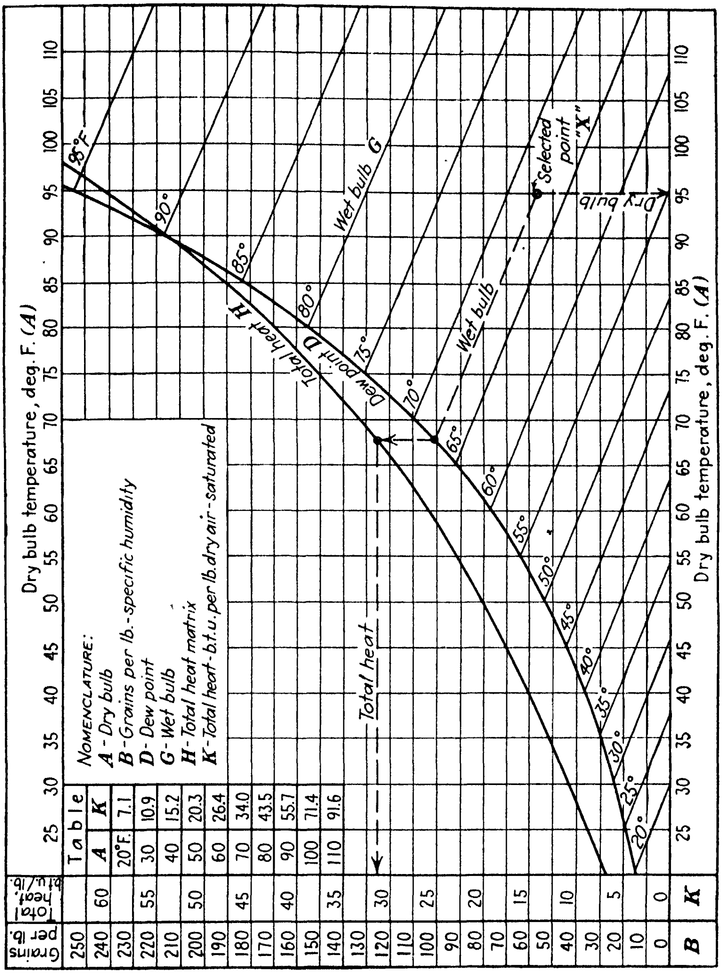
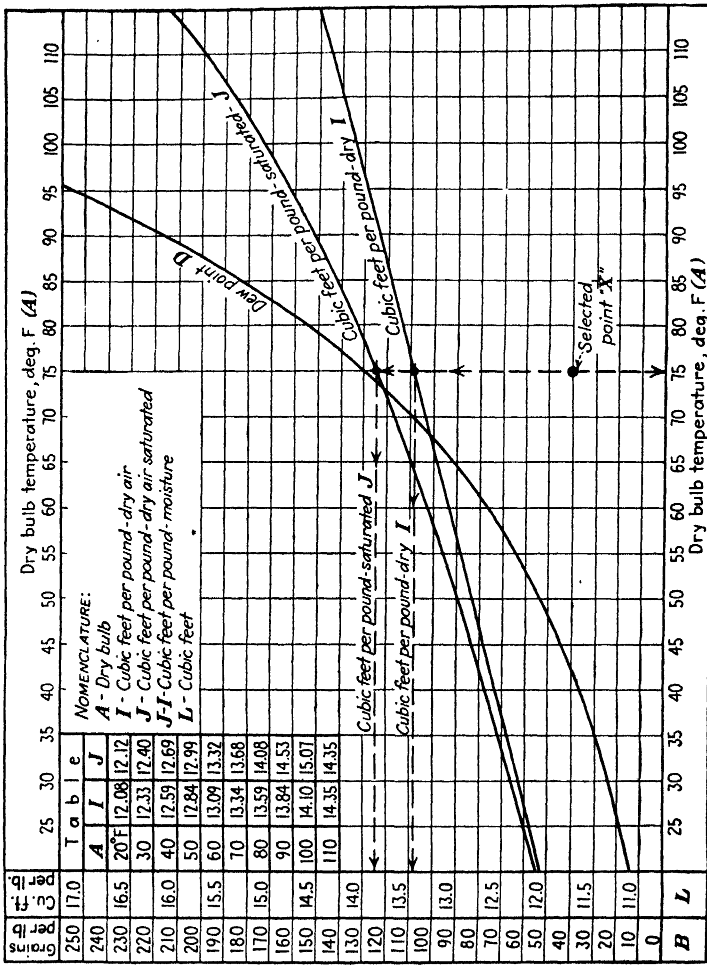


FIG. 71.—Heat chart.



A	I	J
20°F	12.08	12.12
30	12.33	12.40
40	12.59	12.69
50	12.84	12.99
60	13.09	13.32
70	13.34	13.68
80	13.59	14.08
90	13.84	14.53
100	14.10	15.07
110	14.35	14.35

B (Grains per lb.)	L (Cu. ft. per lb.)
250	17.0
240	
230	16.5
220	
210	16.0
200	
190	15.5
180	
170	15.0
160	
150	14.5
140	
130	14.0
120	
110	13.5
100	
90	13.0
80	
70	12.5
60	
50	12.0
40	
30	11.5
20	
10	11.0
0	

FIG. 72.—Volume chart.

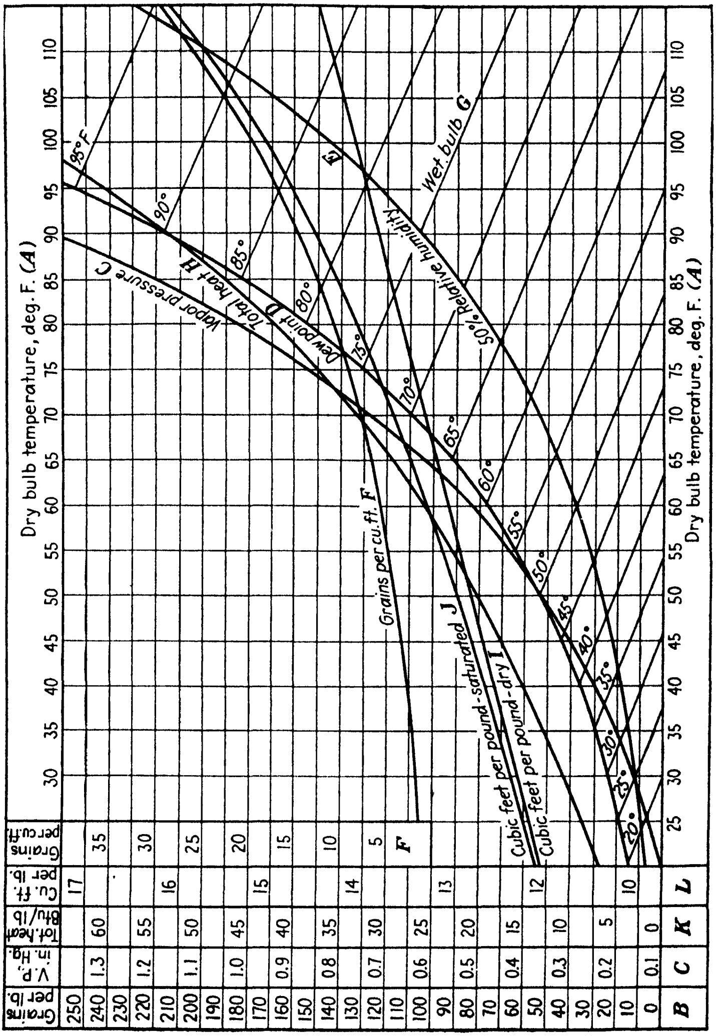


FIG. 73.—Psychrometric chart, moisture-heat-volume.

matrix) I indicates the volume of dry air per pound, while the saturated-air line J indicates the volume of dry air per pound saturated with water vapor.

22. Dry Air Volume. To find the volume of one pound of dry air from any selected point X read directly up (or down) to the dry air line I, then directly left to the column L, indicating cubic feet per pound of dry air.

23. Saturated Air Volume. To find the volume of one pound of dry air saturated with water vapor from any selected point X read directly up (or down) to the saturated air line J, then directly left to the column L, indicating volume per pound of dry air saturated.

24. Partially Saturated Air Volume. To find the volume of partially saturated air from any selected point X, follow the rules below.

Rule 1. Find the volume of one pound of saturated air from line J.

Rule 2. Find the volume of one pound of dry air from line I.

Rule 3. Subtract the volume of dry air (I) from the volume of saturated air (J) and obtain the volume of the saturated water vapor.

Rule 4. Find the relative humidity of point X on line E.

Rule 5. Divide the relative humidity E from Rule 4 by 100, as $E/100$, and obtain the decimal equivalent of the relative humidity.

Rule 6. Multiply the saturated water vapor from Rule 3, by the decimal equivalent of the relative humidity from Rule 5, and obtain the volume of the actual water vapor present.

Rule 7. Add the dry air from Rule 2, to the actual water vapor from Rule 6, and obtain the actual total volume of the partially saturated air (V_a).

Rule 8. For examples, see sections 30 and 31.

25. Volume Table. The table on this chart, Fig. 72, gives the dry-bulb temperatures in column A, the volume of dry air in cubic feet per pound in column I, and the volume of saturated air in cubic feet per pound of dry air saturated with moisture.

26. Combined Charts. The combined moisture, heat, and volume charts comprise this combined chart, Fig. 73.

27. Complete Psychrometric Chart. The complete psychrometric chart in the back of this book is more detailed and on a larger scale than the combined chart and should be used for the more accurate work.

28. Work Tables. For exacting calculations and the following examples, use Table 2 in the Appendix.

29. Examples. Examples of the use of the comfort and psychrometric charts follow—section 30 covering a winter problem, and section 31, a summer problem.

30. Winter Example:

a. Inside Air.

The desired effective temperature for a winter air-conditioning design is 66 degrees Fahrenheit for the inside air (see Fig. 67). The dry-bulb temperature for a residence is selected as 70 degrees Fahrenheit (see Table 1), and the relative humidity is 50 per cent (see Fig. 67). Determine the properties of the air.

Answer:

Effective temperature	66°F.	
Dry-bulb temperature	70°F.	
Wet-bulb temperature	58.5°F.	
Dew-point temperature	50°F.	
Relative humidity	50 per cent	
Specific humidity (110.2 × 0.5)	55.1	grains
Absolute humidity (8.055 × 0.5)	4.0275	grains
Total heat	25 0	B.t.u.
Vapor pressure (0.73866 × 0.5)	0.37	in.
Volume, air saturated	13.68	cu. ft.
Volume, dry air	13.34	cu. ft.
Volume, saturated vapor	0.34	cu. ft.
Relative humidity ÷ 100	0.5	
Volume, actual vapor	0.17	cu. ft.
Volume, dry air	13.34	cu. ft.
Volume, actual total	13.51	cu. ft.

b. Outside Air.

The lowest recorded winter outside air temperature for New York City is −14 degrees Fahrenheit. Allowing 10 degrees Fahrenheit higher for design (explained later in this chapter in the division on Heat) the approximate design temperature is −4 degrees Fahrenheit, say, −5 degrees Fahrenheit. Relative humidities are not fully established, but may be considered as 50 per cent. Determine the properties of this air.

Answer:

Effective temperature..................		
Dry-bulb temperature.................	−5°F.	
Wet-bulb temperature.................		
Dew-point temperature................		
Relative humidity..................	50 per cent	
Specific humidity (4.2210 × 0.5)........	2.1105	grains
Absolute humidity (0.36917 × 0.5).	0.1846	grains
Total heat...........................	−0.8823	B.t.u.
Vapor pressure (0.02898 × 0.5).........	0.01449	in.
Volume, air saturated.................	11.46	cu. ft.
Volume, dry air.......................	11.45	cu. ft.
Volume, saturated vapor...............	0.01	cu. ft.
Relative humidity ÷ 100..............	0.5	
Volume, actual vapor..................	0.005	cu. ft.
Volume, dry air.......................	11.45	cu. ft.
Volume, actual total..................	11.455	cu. ft.

c. *Differentials.*

The differentials, from examples *a* and *b*, for winter, are

Properties	Inside	Outside	Differential
Effective temperature....	66°F.		
Dry-bulb temperature...	70°F.	−5°F.	75°F.*
Wet-bulb temperature...	58.5°F.		
Dew-point temperature..	50°F.		
Relative humidity.......	50%	50%	
Specific humidity........	55.1 grains	2.1105 grains	52.9895 grains*
Absolute humidity.......	4.0275 grains	0.1846 grains	3.8329 grains
Total heat..............	25.0 B.t.u.	−0.8823 B.t.u.	25.8823 B.t.u.*
Vapor pressure..........	0.37 in.	0.0145 in.	0.3555 in.
Volume, air saturated....	13.68 cu. ft.	11.46 cu. ft.	
Volume, dry air.........	13.34 cu. ft.	11.45 cu. ft.	
Volume, saturated vapor.	0.34 cu. ft.	0.01 cu. ft.	
Relative humidity ÷ 100	0.5	0.5	
Volume, actual vapor....	0.17 cu. ft.	0.005 cu. ft.	
Volume, dry air.........	13.34 cu. ft.	11.45 cu. ft.	
Volume, actual total.....	13.51 cu. ft.	11.455 cu. ft.	+2.055 cu. ft.*

* Usually important differentials used in air-conditioning calculations.

31. Summer Example:

a. Inside Air.

The summer outside design dry bulb for New York City is 95 degrees Fahrenheit. Referring to summer comfort chart,

Fig. 68, find that for this condition the desired effective temperature for a summer air-conditioning design is 74 degree Fahrenheit for the inside air. The apparent optimum dry bulb is 80 degrees Fahrenheit and the relative humidity, 50 per cent. Determine the properties of this air.

Answer:

Effective temperature	74°F.	
Dry-bulb temperature	80°F.	
Wet-bulb temperature	66.5°F.	
Dew-point temperature	59.5°F.	
Relative humidity	50 per cent	
Specific humidity (155.5 × 0.5)	77.75	grains
Absolute humidity (11.04 × 0.5)	5.52	grains
Total heat	31.35	B.t.u.
Vapor pressure (1.0316 × 0.5)	0.5158	in.
Volume, air saturated	14.08	cu. ft.
Volume, dry air	13.59	cu. ft.
Volume, saturated vapor	0.49	cu. ft.
Relative humidity ÷ 100	0.5	
Volume, actual vapor	0.245	cu. ft.
Volume, dry air	13.59	cu. ft.
Volume, actual total	13.835	cu. ft.

b. Outside Air:

The summer outside design dry bulb for New York City is 95 degrees Fahrenheit, and the wet bulb is 75 degrees Fahrenheit (explained later in this chapter in the division Heat). Determine the properties of this air.

Answer:

Effective temperature	85°F.	
Dry-bulb temperature	95°F.	
Wet-bulb temperature	75°F.	
Dew-point temperature	65.5°F.	
Relative humidity	38 per cent	
Specific humidity (255.6 × 0.38)	97.13	grains
Absolute humidity (17.28 × 0.38)	6.57	grains
Total heat	37.19	B.t.u.
Vapor pressure (1.6591 × 0.38)	0.6305	in.
Volume, air saturated	14.79	cu. ft.
Volume, dry air	13.97	cu. ft.
Volume, saturated vapor	0.82	cu. ft.
Relative humidity ÷ 100	0.38	
Volume, actual vapor	0.3116	cu. ft.
Volume, dry air	13.97	cu. ft.
Volume, actual total	14.2816	cu. ft.

c. Differentials.

The differentials from examples *a* and *b*, for summer, are

Properties	Outside	Inside	Differential
Effective temperature	85°F.	74°F.	11°F.
Dry-bulb temperature	95°F.	80°F.	15°F.*
Wet-bulb temperature	75°F.	66.5°F.	8.5°F.
Dew-point temperature	65.5°F.	59.5°F.	6.0°F.
Relative humidity	38%	50%	
Specific humidity	97.13 grains	77.75 grains	19.38 grains*
Absolute humidity	6.57 grains	5.52 grains	1.05 grains
Total heat	37.19 B.t.u.	31 35 B.t.u.	5.84 B.t.u.*
Vapor pressure	0.6305 in.	0.5158 in.	0.1147 in.
Volume, air saturated	14.79 cu. ft.	14 08 cu. ft.	
Volume, dry air	13.97 cu. ft.	13.59 cu. ft.	
Volume, saturated vapor	0.82 cu. ft.	0.49 cu. ft.	
Relative humidity ÷ 100	0.38	0.5	
Volume, actual vapor	0.3116 cu. ft.	0.245 cu. ft.	
Volume, dry air	13 97 cu. ft.	13.59 cu. ft.	
Volume, actual total	14.2816 cu. ft.	13.835 cu. ft.	0.4466 cu. ft.*

* Usually important differentials used in air-conditioning calculations.

DIVISION III. ENCLOSURES

1. Enclosures. It is suggested that Chap. VI, on Enclosures, be reviewed.

2. Purpose. In Chap. VI, it has been demonstrated that from an air-conditioning standpoint, an enclosure is intended for the purpose of providing a barrier between atmospheres of different characteristics—usually between outside and inside air.

3. Limits. It has also been demonstrated that barriers are intended to resist the passage of

a. Heat
b. Moisture (vapor)
c. Air
d. Sunlight

Of these, heat is the best known at this time. (It includes some data on sunlight.) Next to heat, air is known, particularly for leakage. Moisture is still in the laboratory or research stage, as to passage through barriers. Note that in Division II under Moisture, and in sections 30 and 31, examples *a*, *b*, and *c*, the moisture differentials are explained.

4. Heat. No matter how well the structure is built, or what materials or combination of materials are used, some heat will pass, or be transmitted, from the inside to the outside air in winter, and from the outside to the inside air in summer. This is the basic need for air-conditioning engineering, which will be elaborated upon in Division IV.

5. Transmission. In either winter or summer, heat is transmitted from the warmer to the cooler air through a barrier at a rate depending upon the nature of the barrier. This rate is called the transmission coefficient.

6. Transmission Coefficient. For the transmission of heat from air on one side of a barrier to air on the other side of the same barrier, the coefficient is universally known as the *U* coefficient or factor. *U* values for most barriers used are given in Table 3 in the Appendix. Each coefficient of transmission which is the reciprocal of resistivity, represents the heat transmitted through *one square foot* of the barrier, *in one hour*, for *one degree differential* (Fahrenheit), *expressed in B.t.u.*

7. Common Barriers. One or more of five kinds of transmission barriers may be involved in determining the heat transmission out of or into an enclosure; they are

a. Outside walls
b. Outside glass
c. Inside walls or partitions
d. Ceilings or roofs
e. Floors

8. Walls and Partitions. These have been arbitrarily classified structurally as

a. Masonry walls
b. Masonry walls, with various types of veneers
c. Frame construction
d. Frame interior walls and partitions
e. Masonry partitions

9. Floors and Ceilings. These have been classified structurally as

a. Concrete floors on ground
b. Concrete floors and ceilings
c. Frame construction floors and ceilings

10. Roofs. These have been classified structurally as

a. Flat roofs
b. Pitched roofs

11. Glass. This has been arbitrarily classified structurally as

a. Windows
b. Skylights
c. Doors

12. Examples—Transmission Coefficients. The transmission coefficients or U factors (expressed in B.t.u. per square foot per degree Fahrenheit) are underlined in each of the following examples, the characteristics of which are found in tables in the Appendix.

a. Outside and inside walls and partitions

1. Table 3, wall 2, column *C*
   U is 0.24 B.t.u.
2. Table 3, wall 2, column *K*
   U is 0.11 B.t.u.
3. Table 4, wall 21, column *B*
   U is 0.33 B.t.u.
4. Table 4, wall 21, column *K*
   U is 0.11 B.t.u.
5. Table 5, wall 41, column *A*
   U is 0.25 B.t.u.
6. Table 5, wall 41, column *I*
   U is 0.061 B.t.u.
7. Table 6, wall 53, column *B*
   U is 0.34 B.t.u.
8. Table 6, wall 53, column *C*
   U is 0.11 B.t.u.
9. Table 7, wall 60, column *C*
   U is 0.40 B.t.u.

b. Floors and ceilings

1. Table 8, No. 1, column *B*
   U is 0.46 B.t.u.
2. Table 8, No. 9, column *D* or *E*
   U is 0.060 B.t.u.
3. Table 9, No. 1, column *A*
   U is 0.65 B.t.u.

4. Table 9, No. 21, column *C*
   U is 0.12 B.t.u.
5. Table 10, No. 1, column *A*
   U is 1.07 B.t.u.
6. Table 10, No. 7, column *D*
   U is 0.22 B.t.u.

c. Roofs, pitched

1. Table 12, No. 1, column *A*
   U is 0.46 B.t.u.
2. Table 12, No. 5, column *D*
   U is 0.062 B.t.u.
3. Table 12, No. 6, column *A*
   U is 0.56 B.t.u.
4. Table 12, No. 10, column *I*
   U is 0.045 B.t.u.

d. Roofs, flat

1. Table 11, No. 1, column *A*
   U is 0.84 B.t.u.
2. Table 11, No. 3, column *H*
   U is 0.12 B.t.u.
3. Table 11, No. 5, column *I*
   U is 0.32 B.t.u.
4. Table 11, No. 9, column *J*
   U is 0.19 B.t.u.
5. Table 11, No. 11, column *P*
   U is 0.11 B.t.u.

e. Outside glass and doors

1. Table 13*a*, single glazing
   U is 1.13 B.t.u.
2. Table 13*a*, double glazing
   U is 0.45 B.t.u.
3. Table 13*b*, 1¾ inches thick
   U is 0.51 B.t.u.
4. *Note:* Doors with thin wooden panels are usually assumed as single glazed windows.

13. Moisture—Water Vapor. At the present time there are insufficient available data upon which to establish exact rules and calculations regarding the passage of moisture or water vapor into or through a barrier. Considerable research is now being conducted, but much time is necessary to arrive at definite or recommendable conclusions.

14. Air. Air leakage is the displacement of inside air (within an enclosure) by outside air (outside the enclosure). When the inside air is at a pressure higher than the outside air, the air leakage is outward; when the outside air is at a pressure higher than the inside air, the air leakage is inward.

15. Infiltration. Usage has given the title of infiltration to air leakage. Actually, infiltration is the inward passage of air and exfiltration is the outward passage.

16. Location. Air leakage usually takes place

a. Through exposed walls
b. Around exposed windows
c. Around exposed doors

17. Velocity. The air leakage depends upon the velocity of the outside wind, as well as its direction, and the difference in density of the outside and inside airs, due to their temperature differential. For velocities, see Tables 14 and 15.

18. Direction. Air will leak inwardly (infiltrate) on the windward (prevailing wind) side and outwardly (exfiltrate) on the leeward side of an enclosure. Of course, the direction of the wind, as well as its velocity, is constantly changing, but prevailing conditions must not be overlooked. For directions of winds, see Tables 14 and 15.

19. Walls. The amount of air leakage through walls of reasonably good and certainly of well-constructed barriers is insufficient to warrant mathematical consideration and is therefore ignored in general.

20. Windows. For infiltration or air leakage around windows, see Table 16. The average wind velocities will be found in Tables 14 and 15.

Example: Find the infiltration around the average double-hung wood-sash weatherstripped window in New York City in winter.

Answer: From Table 14, the average winter velocity is 17.1 miles per hour. From Table 16, the cubic feet of air per minute per foot of crack is 23.6 and for 20 miles per hour is 35.5. Interpolating, 35.5 − 23.6 is 11.9—say, 12—and 17.1 is about halfway between 15 and 20 miles per hour. So, one-half of 12 is 6, and 6 + 23.6 = 29.6—say, 30 cubic feet per minute per linear foot of crack.

21. Doors. For infiltration or air leakage around doors, see Table 17. Note that for residences, doors are usually considered the same as windows, the door being considered as a single sash of a double-hung window.

22. Crack. For area and crack length of windows see Table 19. In computing total crack for air infiltration or leakage for a room, the following rules are usually observed.

a. When windows or doors are in only one exposed wall of a room, use all the linear feet of crack of all the windows and doors in that exposed wall.
b. When windows or doors are in two exposed walls of a room, use the linear feet of crack of all windows and doors in the wall having the greater linear feet of crack.
c. When windows or doors are in three or four exposed walls of a room, use one-half of all the linear feet of crack in all the windows and doors of all the exposed walls.

23. Air Changes. For homes or residences, the number of air changes usually taking place under average conditions due to infiltration, and exclusive of air provided for ventilation, is given in Table 18.

24. Sunlight. Sunlight or solar heat transmission through walls and roofs is dependent upon several factors:

a. Solar intensity, a function of
  1. Orientation
  2. Latitude
b. Absorption
c. Transmission

25. Solar Intensity. Figure 211 is an idealized chart showing the solar intensity for August 1 on a perfectly clear day at north latitude 40 degrees (about that of Philadelphia or Pittsburgh). It is interesting to note that the intensity on the surface, normal to the sun rays, the horizontal surface, and the south wall are in the same phase with the maximum at high noon, while those on the east and west walls are opposite; with the east-wall maximum at 8:00 A.M. and the west-wall maximum at 4:00 P.M.

This solar intensity should not be confused with the heat transmitted through a barrier, due to sunlight.

26. Solar Heat Gain. The method of estimating the amount of solar heat transmitted through a barrier, from the exterior surface into the inside air will be found in Division IV.

27. Solar-intensity Factors. The solar-intensity factors are found in Tables 20*a*, 20*b*, 20*c* and 20*d*, which closely follow the curves on the solar-intensity chart (Fig. 211). Observe that these tables coincide with the chart in the intensity factors for the south wall and horizontal surfaces, being maximum at 12:00 noon, and that for the east wall the maximum is at 8:00 A.M. and for the west wall at 4:00 P.M. Note that further orientation is provided, in the tables, through the inclusion of northeast, southeast, northwest, and southwest exposures.

The factor I is for walls or roofs, while factor I_g is for windows or skylights, *i.e.*, transparent glazed surfaces.

Also observe that the several tables are each for a separate latitude. See the map of the United States (Fig. 212) and Table 21 of prominent cities in their respective latitudes.

28. Absorption Factors. Not all the solar radiation which strikes a wall or a roof is absorbed by the exposed surface. Some of this energy is reflected back into space and the remainder is absorbed by this exposed surface. Absorption factors are given in Table 22. The factors a are expressed as decimals of the percentage of heat absorbed per square foot per hour.

29. Transmission Factor. The solar heat absorbed by an exterior surface is transmitted from this heat exterior surface to the inside air. The rate of this propagation of heat is the transmission factor. The factors F are expressed as decimals of the percentage of heat transmitted per square foot per hour and are given in the chart (Fig. 213).

30. Window-shading Factors. The factors I_G in Tables 20*a*, 20*b*, 20*c*, and 20*d* are for unshaded transparent glazed areas, such as windows and skylights. The actual solar heat transmitted through these glazed areas is a function of the shading. Shading factors are given in Table 23, expressed in decimals.

DIVISION IV. HEAT

1. Heat. It is suggested that Chap. III, on Heat, be reviewed.

2. Loads. Since heat can be added to or subtracted from substance, the heating load (for winter air conditioning) and the cooling load (for summer) may both be properly classified as functions of heat.

3. Conditions. The three fundamental factors which govern the heating and cooling loads are

a. Inside conditions
b. Outside conditions
c. Building construction

4. Inside Conditions. Conditions of the inside air may be determined from Divisions I and II. Note examples in sections 30*a* and 31*a* in Division II.

5. Outside Conditions. Conditions of the outside air may be determined from Division II. Note examples in sections 30*b* and 31*b*.

6. Construction. Building construction determines the rate of heat transmission through the barrier (see Division III).

7. Differentials. The difference between outside and inside conditions establishes the differentials. Note examples in sections 30*c* and 31*c* of Division II.

8. Symbols and Formulas. In order to expedite the calculations, certain symbols and formulas are used, as a shorthand method of explanation and determination. The formulas follow in their respective places; the symbols are

a = coefficient of solar absorption.
A = area of barrier, square feet.
B_e = body latent heat per person.
B_s = body sensible heat per person.
B_t = body total heat per person.
cfm = cubic feet per minute.
CFH = cubic feet per hour.
d = density of air = 0.075 lb. per cubic foot (at 70 degrees Fahrenheit).
f_g = shading factor for glass, as a decimal.
f_l = percentage of latent body heat, as a decimal.
f_s = percentage sensible body heat, as a decimal.
F = coefficient of solar transmission.
H = heat, B.t.u. per hour.
H_a = heat, B.t.u. per hour, air equivalent.

H_g = heat, B.t.u. per hour, solar, through glass.
H_l = heat, B.t.u. per hour, latent, from occupants.
H_m = heat, B.t.u. per hour, moisture equivalent.
H_p = heat, B.t.u. per hour, total from occupants (people).
H_r = heat, B.t.u. per hour, from solar radiation.
H_s = heat, B.t.u. per hour, sensible from occupants.
H_t = heat, B.t.u. per hour, transmitted through barrier.
I = solar intensity, B.t.u. per hour, per square foot.
I_g = solar intensity, B.t.u. per hour, through glass.
l = linear feet of crack, around window or door.
L = latent heat of evaporation (1060 B.t.u. per hour per pound).
M_a = moisture added or subtracted, pounds.
M_i = moisture, inside air.
M_o = moisture, outside air.
P = number of occupants (people).
q_v = quantity of air per minute for ventilation.
Q = quantity of air, cubic feet per hour.
Q_i = quantity of air, cubic feet per hour, infiltration.
Q_v = quantity of air, cubic feet per hour, ventilation.
t_i = temperature, dry bulb, inside.
t_o = temperature, dry bulb, outside.
U = coefficient of heat transmission, B.t.u. per square foot per hour.
V = volume of air, cubic feet per linear foot of crack per hour.
0.24 = specific heat of air.
7000 = grains per pound.

9. Heating Load. The heating load for the winter air conditioning of an enclosure is estimated by determining

a. Heat-barrier transmission
b. Air, ventilation
c. Air, infiltration } Heat equivalent
d. Air, make-up
e. Moisture, heat equivalent

10. Winter-heat Barrier Transmission. The transmission of heat through the barriers from the warmer inside air to the cooler outside air, during the winter, is estimated by determining

a. Area of barrier
b. Coefficient of transmission through barrier
c. Inside temperature
d. Outside temperature

The area of barrier is determined by measuring the plans or the actual building.

The coefficient of transmission is determined from Tables 3 to 13, inclusive.

The inside temperature is determined from the winter comfort chart, Fig. 67.

The outside temperature is determined from Table 14.

From the above, the actual amount of heat transmitted (H_t) through the barrier in one hour and expressed in B.t.u. is found from the formula:

$$H_t = AU(t_i - t_o) \tag{1}$$

Example:

$$A = 200 \text{ square feet}$$
$$U = 0.25$$
$$t_i = 70$$
$$t_o = 0$$

then

$$H_t = 200 \times 0.25 \times 70 = 3500 \text{ B.t.u. per hour}$$

This procedure is carried out for each kind of exposed barrier for each room.

11. Winter Air Transmission. The transmission of air by leakage, into or out of an enclosure, is estimated by determining

a. Crack length, feet
b. Type of crack
c. Wind velocity, miles per hour
d. Air through foot of crack per hour
e. Density of air, pounds
f. Quantity of air, cubic feet
g. Inside temperature, degrees Fahrenheit
h. Outside temperature, degrees Fahrenheit

Crack length is determined from the plans or actual building measurement, and selected from Table 19.

Type of crack is determined from plans and Tables 16 or 17.

Wind velocity is determined from Table 14.

Air through foot of crack is determined from Tables 16 and 17.

Density of air is arbitrarily fixed, for average of 70 degrees Fahrenheit at 0.075 pound per cubic foot.

Quantity of air is calculated from the very simple formula:

$$Q = LV \tag{2a}$$

where Q = cubic feet per hour (CFH).
L = crack length in feet.
V = air through foot of crack per hour, at prescribed wind velocity.

The inside temperature is determined from the winter comfort chart (Fig. 67).

The outside temperature is determined from Table 14.

From the above, the actual amount of heat (H_a) (due to infiltration or leakage) transmitted from the inside to the outside in one hour, and expressed in B.t.u., is found from the formula:

$$H_a = 0.24Q_i d(t_i - t_o) \tag{2b}$$

Since $d = 0.075$, then $0.24 \times 0.075 = 0.018$ and the formula is simplified to

$$H_a = 0.018Q_i(t_i - t_o) \tag{2c}$$

Example:

$L = 20$ linear feet
$V = 23.6$ cubic feet per hour
$Q_i = LV = 20 \times 23.6 = 572$ cubic feet per hour
$t_i = 70$ deg. Fahr.
$t_o = 0$ deg. Fahr.

then

$$H_a = 0.018 \times 572 \times 70 = 721 \text{ B.t.u. per hour}$$

12. Winter Ventilation Transmission. The recommended average of thirty cubic feet per minute of air per person should be made up of approximately ten cubic feet of outside (new) and twenty cubic feet of inside (recirculated) air. The outside air must be heated from outside to inside air temperature. The quantity of outside air required per minute for ventilation becomes

$$q_v = 10P \tag{3a}$$

since there are 60 minutes in the hour. Then

$$Q_v = 60q_v = 60 \times 10P \tag{3b}$$

Example:

$$P = 40 \text{ occupants}$$

then

$$q_v = 10 \times 40 = 400 \text{ cubic feet per minute}$$

and

$$Q_v = 60 \times 10 \times 40 = 2400 \text{ cubic feet per hour}$$

13. Winter Ventilation Recirculation. The recommended average of twenty cubic feet of recirculated air per person should be recirculated with the ten cubic feet of new outside air. There is, theoretically, no heat differential, because the heat for transmission or infiltration has already been included.

14. Winter Ventilation vs. Infiltration. The amount of air infiltrated should be compared with the amount required for ventilation. If the infiltrated amount is less than the ventilation required, the difference should be made up by admitting this difference into the enclosure. The heat required is included in the ventilation transmission.

15. Make-up Air. The difference between the ventilation requirement and infiltrated air is the make-up air. In older buildings it is usually found that the infiltrated air will be in excess of the ventilation requirement, and no make-up air is required.

In the newer modern building or enclosure, where air barriers, weather stripping, storm sash, and the like are used, the infiltration is much lower, and make-up air may be necessary.

16. Winter Air vs. Heat. Observance of the following rules will be of assistance:

Rule 1. If infiltrated air is more than ventilation required, use the infiltrated quantity Q_i.

Rule 2. If the ventilation requirement is more than the infiltrated air, use the ventilation requirement quantity Q_v.

Rule 3. Then, calculate the heating requirement by using formula (2*a*) or (2*b*).

17. Winter Moisture Transmission. The winter infiltrated or required ventilation air (whichever is the larger amount) must be humidified. The amount of water vapor required is

$$M_a = (M_i - M_o) \tag{4}$$

where M_a = moisture to be added.

It is necessary to provide the latent heat of evaporation to the water. This may be determined by the formula:

$$H_m = Qd\frac{(M_i - M_o)}{7000}L \tag{5a}$$

Since $d = 0.075$ and $L = 1060$, then

$$0.075 \times \frac{1060}{7000} = 0.0114$$

so

$$H_m = 0.0114Q(M_i - M_o) \tag{5b}$$

18. Winter Summation of Heating Load. The heat gain expressed in B.t.u. per hour required to offset the heat loss from a room (or single enclosure) during the winter is the sum of

a. Winter—heat barrier transmission
b. Winter—air transmission
c. Winter—moisture transmission

19. Cooling Load. The cooling load for the summer air conditioning of an enclosure is estimated by determining

a. Heat barrier transmission
b. Air, ventilation
c. Air, infiltration
d. Air, make-up

(*b*–*d*: Heat equivalent)

e. Moisture, heat equivalent
f. Solar radiation, heat equivalent
g. Heat from occupants (people)
h. Heat from appliances

20. Summer Heat Barrier Transmission. The transmission of heat through the barriers from the warmer outside air to the cooler inside air is estimated by determining

a. Area of barrier
b. Coefficient of transmission through barrier
c. Outside temperature
d. Inside temperature

The area of barrier is determined by measuring the plans or the actual building.

The coefficient of transmission is determined from Tables 3 to 13, inclusive.

The outside temperature is determined from Table 15.

The inside temperature is determined from the summer comfort chart, Fig. 68.

From the above, the actual amount of heat transmitted (H_t) through the barrier in one hour and expressed in B.t.u. is found from the formula:

$$H_t = AU(t_o - t_i) \tag{6}$$

Example:

$$\begin{aligned} A &= 200 \text{ square feet} \\ U &= 0.25 \\ t_o &= 95 \\ t_i &= 80 \end{aligned}$$

then

$$H_t = 200 \times 0.25 \times 15 = 750 \text{ B.t.u. per hour}$$

21. Summer Air Transmission. The transmission of air by leakage into or out of an enclosure is estimated by determining

a. Crack length, feet
b. Type of crack
c. Wind velocity, miles per hour
d. Air through foot of crack, per hour
e. Density of air, pounds
f. Quantity of air, cubic feet
g. Outside temperature, degrees Fahrenheit
h. Inside temperature, degrees Fahrenheit

Crack length is determined from the plans or actual building measurement, and selected from Table 19.

Type of crack is determined from plans and Table 16 or 17.

Wind velocity is determined from Table 15.

Air through foot of crack is determined from Table 16 or 17.

Density of air = 0.075 pound per cubic foot.

Quantity of air is calculated as in the foregoing formula (2*a*) in section 11.

The outside temperature is determined from Table 15.

The inside temperature is determined from the summer comfort chart, Fig. 68.

From the above, the actual amount of heat (H_a), due to infiltration or leakage, transmitted from the outside to the inside in one hour and expressed in B.t.u., is found from the formula

$$H_a = 0.24Q_id(t_o - t_i) \tag{7a}$$

which reduces to

$$H_a = 0.018Q_i(t_o - t_i) \tag{7b}$$

Example:

$$\begin{aligned} L &= 20 \text{ linear feet} \\ F &= 23.6 \text{ cubic feet per hour} \\ Q_i &= 572 \text{ cubic feet per hour} \\ t_o &= 95 \\ t_i &= 80 \end{aligned}$$

then

$$H_a = 0.018 \times 572 \times 15 = 154 \text{ B.t.u. per hour}$$

22. Summer Ventilation Transmission. The winter ventilation transmission, section 12, should be reviewed, and formulas (3*a*) and (3*b*) should be used.

23. Summer Ventilation vs. Infiltration. The winter ventilation vs. infiltration, section 14, should be reviewed, as should section 12.

24. Make-up Air. Section 15 should be reviewed.

25. Summer Air, Heat. Observance of the following rules will be of assistance.

Rule 1. Same as Rule 1, section 16.
Rule 2. Same as Rule 2, section 16.
Rule 3. Then, calculate the cooling requirement by using formula (7*a*) or (7*b*).

26. Summer Moisture Transmission. The summer infiltrated or required ventilation air, whichever is the larger amount, must usually be dehumidified. The amount of water vapor required to be removed is

$$M_a = (M_o - M_i) \tag{8}$$

The latent heat required is

$$H_m = Qd\frac{(M_o - M_i)}{7000}L \tag{9}$$

which reduces to

$$H_m = 0.0114Q(M_o - M_i) \tag{10}$$

27. Sunlight Heat Transmission. Review Division III, sections 24 to 30.

28. Summer Solar Barrier Transmission. The transmission of solar heat through the barriers from the outside surface of the barrier to the inside air is estimated by determining

a. Area of barrier
b. Coefficient of solar absorption
c. Coefficient of solar transmission
d. Intensity of solar radiation

The area of barrier is determined by measuring the plans or the actual building.

The coefficient of solar absorption is determined from Table 22.

The coefficient of solar transmission is determined from Figure 213.

The intensity of solar radiation is determined from Tables 20*a*, 20*b*, 20*c*, and 20*d*.

From the above, the amount of solar heat (H_r) transmitted is found from the formula:

$$H_r = AFaI \tag{11}$$

Example:
A = 200 square feet
F = 0.06 (for 0.26 U value, assumed)
a = 0.7 (for stucco, assumed)
I = 211 B.t.u. (latitude 40 degrees, east, 8:00 A.M., assumed)
then

$$200 \times 0.06 \times 0.7 \times 211 = 1772 \text{ B.t.u. per hour}$$

29. Summer Solar Glass Transmission. The transmission of solar heat through glass is estimated by determining

a. Area of glass
b. Solar radiation transmitted through glass
c. Shading factor

The area of glass is determined by measuring the plans or the actual building and from Table 19.

The solar heat (or radiation) transmitted through glass is determined from Tables 20*a*, 20*b*, 20*c*, and 20*d*

The shading coefficient (or factor), as a decimal, is determined from Table 23.

From the above, the amount of solar heat transmitted through a glazed window, skylight, or door is found from the formula:

$$H_g = AI_Gf_g \tag{12}$$

Example:
A = 20 square feet
I_G = 182 B.t.u. (latitude 40 degrees, east, 8:00 A.M., assumed)
f_g = 0.58 (inside Venetian blind, aluminum external surface)
then

$$H_g = 20 \times 182 \times 0.58 = 2111 \text{ B.t.u. per hour}$$

30. Summer Occupancy Heat. The heat gain within an enclosure, due to occupants, is estimated by determining

a. Occupants
b. Effective temperature
c. Body activity
d. Body heat

The occupants are determined by several arbitrary methods. For commercial establishments this should be determined from the owner and verified by him. For a residence an accepted rule is two persons per bedroom for any one room in the house at one time.

Effective temperature is determined from the summer comfort chart, Fig. 68.

Body activity is determined from Table *D*.

Body heat is determined from Table *D*.

From the foregoing, the amount of heat gained due to occupants is found from the formula:

$$H_p = PB \tag{13}$$

Example:

$P = 8$ (assumed 4 bedrooms)
$B = 400$ (body at rest — 80 degrees E.T.)

Then

$$H_p = 8 \times 400 = 3200 \text{ B.t.u. per hour.}$$

The summer occupancy heat is readily separated into sensible and latent heat by determining

a. Body heat
b. Effective temperature

From these, the amounts of sensible (H_s) and latent (H_l) heats are determined by the formulas:

$$H_s = PB_sf_s \tag{14}$$
$$H_l = PB_lf_l \tag{15}$$

Examples:

$P = 8$
$B = 400$
$f_s = 0.55 =$ from Table *E*
$f_l = 0.45 =$ from Table *E*

Then

$H_s = 8 \times 400 \times 0.55 = 1760 =$ sensible
$H_l = 8 \times 400 \times 0.45 = 1440 =$ latent
$H_p = 8 \times 400 \times 1.00 = 3200 =$ total

31. Summer Appliance Heat. The heat gain within an enclosure, due to appliances, is estimated by determining

a. Number of appliances
b. Heat gain from appliance

The number of appliances is determined by actual count. The heat gain from appliances is determined from Table 24.

32. Summer Summation of Cooling Load. The heat loss, expressed in B.t.u. per hour, required to offset the gain into a room (or enclosure) is the sum of

a. Summer heat barrier transmission
b. Summer air transmission
c. Summer moisture transmission
d. Summer solar barrier transmission
e. Summer solar glass transmission
f. Summer occupancy heat
g. Summer appliance heat

33. Theoretical Refrigeration Rate. It is suggested that sections 26 to 31 in Chap. III be reviewed.

The cooling load can be converted into the theoretical refrigeration rate, since both are actually on a B.t.u. basis. The cooling load is usually calculated or estimated in B.t.u. per hour; therefore, the cooling load, as such, divided by 12,000 equals the theoretical refrigeration rate.

DIVISION V. SOUND (QUIET)

1. Quiet. From an air-conditioning standpoint, and consequently from the vantage points of health, comfort, and convenience, *quiet* is a freedom from *apparent irritating* noise or disturbance.

2. Sound. Technically, sound is a wave—an air wave. It is caused by a vibration that sets the surrounding air in motion above normal. The wave carries, as a ripple does on a still pond into which a pebble or a stone has been thrown. Even our own vocal chords vibrate to produce sound. Vibrations may be caused by one or more of innumerable things (see Fig. 74).

The human ear is capable of picking up and indicating to the conscious mind sound waves of a certain band of frequencies that are audible to the ear. Frequencies above and below this band are not audible.

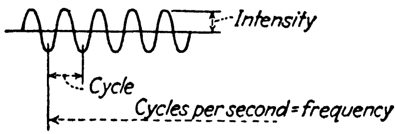


Fig. 74.

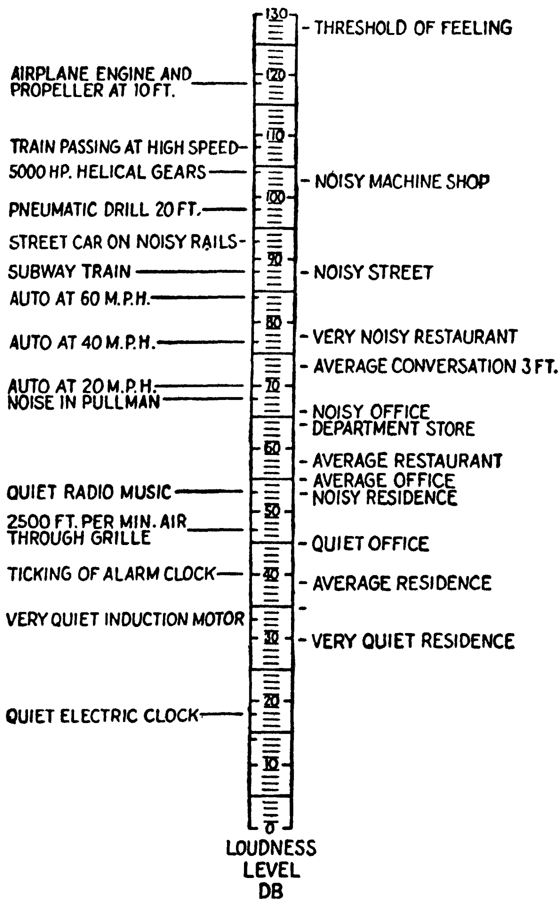


Fig. 75.—Loudness levels. *(From Allen and Walker, Heating and Air Conditioning.)*

In addition, the audible frequencies vary in intensity, being soft, medium, loud, etc.

3. Noise. The words "sound" and "noise" have become almost synonymous, but noise usually indicates something disagreeable, *i.e.*, it is sound at an unfriendly frequency or intensity. It is the objective in air conditioning to keep these frequencies and intensities equal to or below the normal tendencies of the enclosure.

4. Vibration. In addition to audible sound or noise, certain vibrations may be produced by the apparatus and moving air which are not precisely audible but which do cause an uncomfortable sense of feeling; they may be in a borderland between feeling and hearing.

5. Kinds of Noise. Fundamentally, from an air-conditioning point of view, there are two kinds of noise:

a. Vibrations that can be partially eliminated at the source, or in progress, by isolation.

b. Vibrations that can be partially reduced within the enclosure by insulation.

These noises may reach a room or enclosure from

a. Apparatus
b. Moving air
c. Outside
d. Inside

Apparatus noises may be transmitted by vibration through

a. Building construction
b. Ducts

6. Noise Unit. The standard unit of measurement is the decibel. Noise is generally referred to as so many decibels above

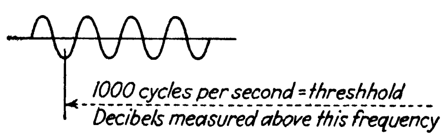


FIG. 76.

a standard level (see Fig. 76). This level is based on a so-called threshold of audibility for the average human ear of 1000 cycles per second frequency. From this threshold, the decibel becomes a ratio of frequency and intensity.

7. Measuring. The popular method of measuring noise is through the aid of a sound level meter, which is a combination of a microphone, an audio-amplifier, and milliammeter (which indicates the decibels directly upon the dial).

The meter is usually calibrated to read in decibels above the standard threshold of audibility.

8. Typical Levels. The present anticipated noise levels (in decibels) for usual rooms and vehicles are given in Table 25.

9. Procedure. The objective of sound control is to prevent the addition of an acoustical nuisance to the conditions within, or intended for, an enclosure. To accomplish this it is necessary to

a. Establish a noise level within the enclosure *without* air-conditioning equipment.

b. Establish a noise level within the same enclosure *with* equipment but *without* sound control.

c. Provide sound control with the equipment that will maintain a noise level equal to condition *a* or to a condition above *a*, agreeable to the owner and within the limits of good practice.

10. Control. To obtain proper sound control, it is the usual practice first to exercise care in the equipment and duct design and installation. Vibrations are kept at a minimum by isolation and sound is entrained by insulation, depending upon the building construction, the equipment, and the duct work.

11. Application. Sound control or acoustical engineering is a broad subject demanding much training and experience. For those interested, reference is made to the ASHVE 1938 Guide.

CHAPTER VIII

APPARATUS

IT'S IN THE SYSTEM

1. Apparatus. Equipment is necessary to meet the functional requirements of an air-conditioning system.

2. Requirements. The functional requirements of air-conditioning equipment or apparatus are shown in Table *F*.

TABLE *F*

Function	Winter	Summer	All-year
Control	Yes	Yes	Yes
Common:			
Circulation	Yes	Yes	Yes
Cleaning	Yes	Yes	Yes
Quiet	Yes	Yes	Yes
Seasonal:			
Heating	Yes	No	Yes
Cooling	No	Yes	Yes
Humidification	Yes	No*	Yes*
Dehumidification	No	Yes*	Yes*

* In hot, humid atmospheres dehumidification may be accomplished by cooling or refrigeration equipment. In hot, very dry atmospheres the cooling may be accomplished by humidifying the very dry air, the latent heat required for evaporating the humidity being extracted from the air itself, thereby cooling it. In some highly humid atmospheres dehumidification is accomplished by absorption or adsorption, which, in reverse of humidification, releases the latent heat of condensation and adds heat to the air. See later discussions.

3. Common Requirements. The requirements common to winter, summer, or all-year conditioning are

a. Control
b. Circulation
c. Cleaning
d. Quiet

4. Seasonal Requirements. The winter seasonal requirements are

a. Heating
b. Humidification

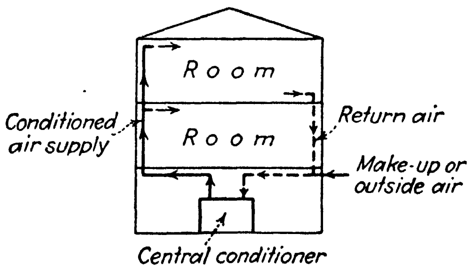
The summer seasonal requirements are

a. Cooling
b. Dehumidification or humidification[1]

5. Systems. There are four fundamental air-conditioning systems:

a. Central
b. Self-contained
c. Semicontained
d. Combined

6. Central System. A central system conditions air for all the common requirements and either one or both of the seasonal



All conditioning accomplished in central conditioner. Conditioned air distributed to rooms and return air brought back to central conditioner, through ducts. Make-up or outside air added as desired. Applicable to winter, summer or all-year conditioning

Fig. 77.

requirements at a central or focal point. The conditioned air is then distributed to the various rooms or enclosures that are to be conditioned.

7. Self-contained System. A self-contained system (frequently referred to as a room unit) conditions air for all of the common and either one of the seasonal requirements within the unit itself (see Figs. 79 and 80).

[1] See footnote to table in section 2.

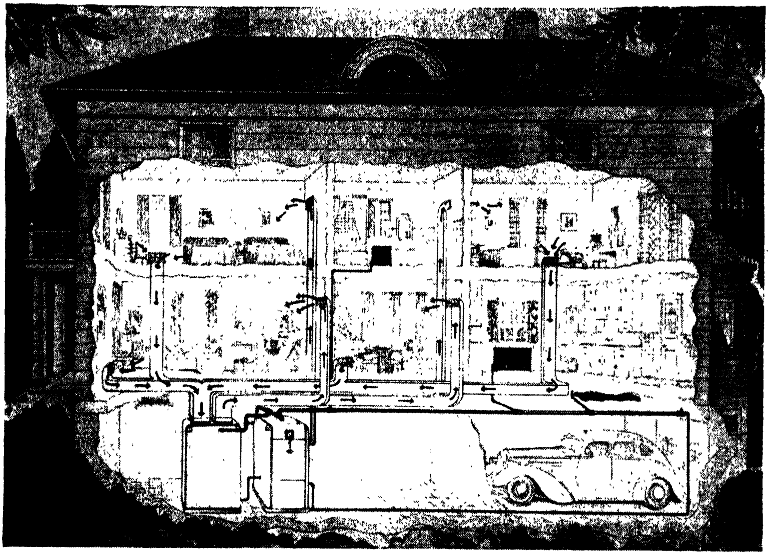


FIG. 78.—Central (split) system. (*Fitzgibbons Boiler Company, Inc.*)

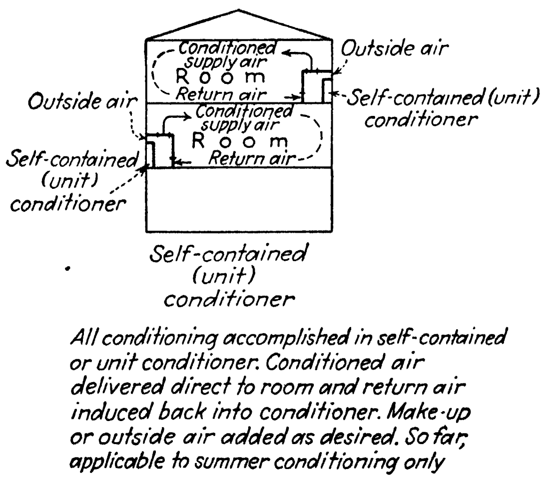


FIG. 79.

8. Semicontained System. A semicontained system usually conditions the air for all of the common and one or both of the

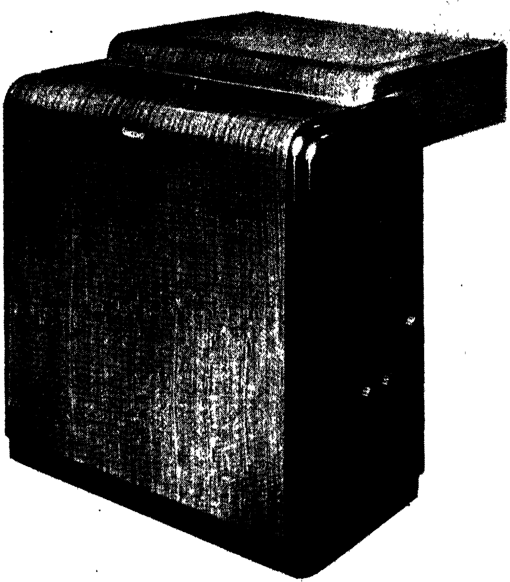


FIG. 80.—Self-contained (unit) conditioner. (*Carrier Corporation.*)

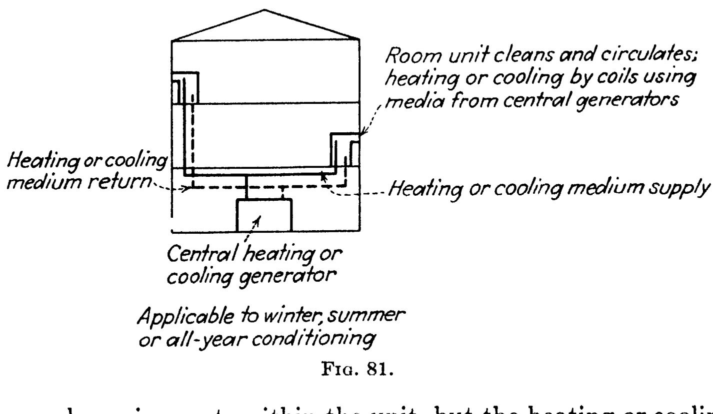


FIG. 81.

seasonal requirements within the unit, but the heating or cooling mediums—steam, refrigerated water, and the like—are generated at some other point and delivered to the individual units (Fig. 81).

9. Combined Systems. A combined system may be one of the combinations of

a. Central and self-contained
b. Central and semicontained
c. Self- and semicontained

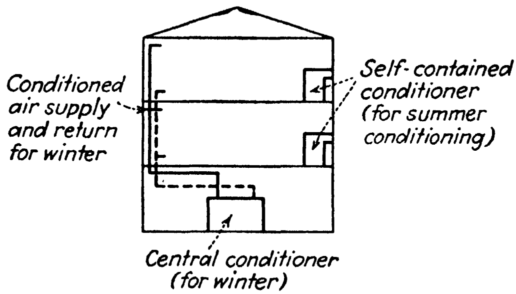


FIG. 82.

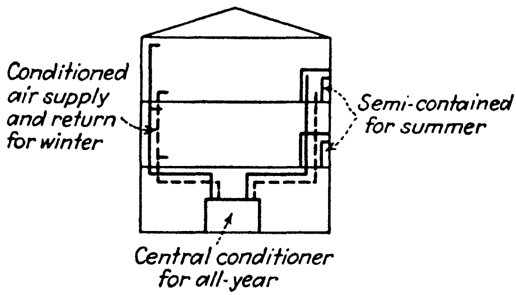


FIG. 83.

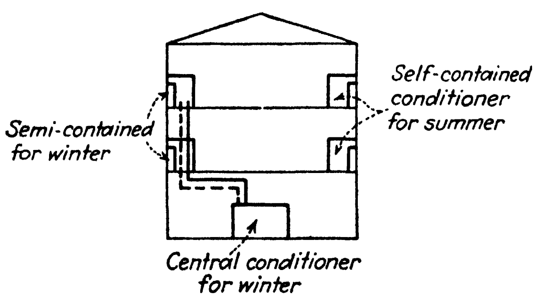


FIG. 84.

DIVISION I. AIR CIRCULATION

1. Air Circulation. The circulation of air is essential to any air-conditioning system. It corresponds to the work of the heart and circulatory system of the human body, and its apparatus comprises

a. Air pump (fan or blower)
b. Air-delivery system (supply and return ducts)
c. Air-distribution system (outlets and inlets)

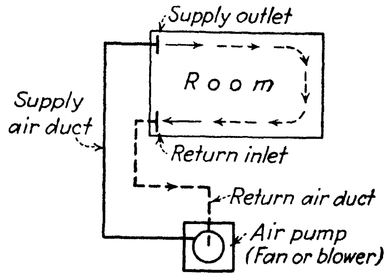


FIG. 85.

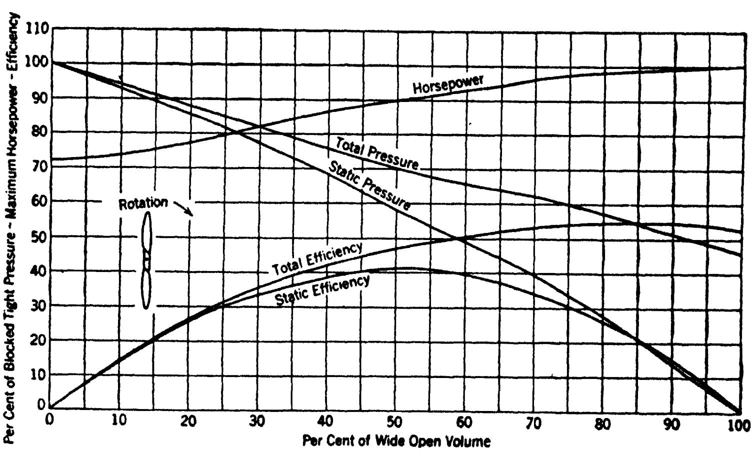


FIG. 86.—Operating characteristics of an airplane propeller fan. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 27.)

2. Fans or Blowers. Air pumps used in air conditioning are classified as

a. Axial flow, propeller or fan type
b. Radial flow, centrifugal or blower type

The propeller (airplane type) is used to produce air flow in volume but at relatively low pressures. A modified form, called a disk fan, will produce slightly higher pressures.

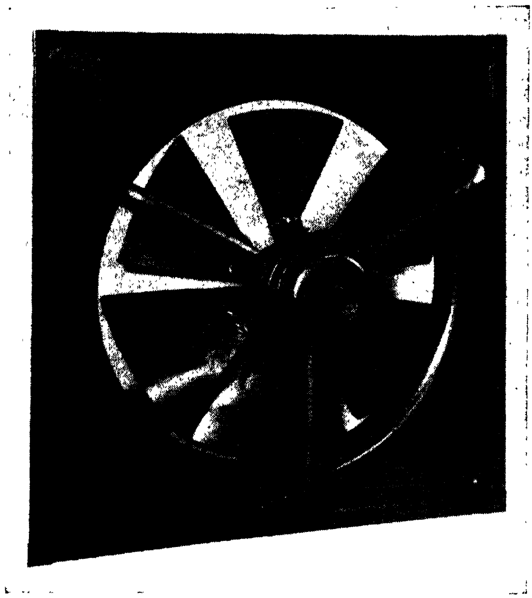


FIG. 87.—Propeller fan. (*B. F. Sturtevant Company.*)

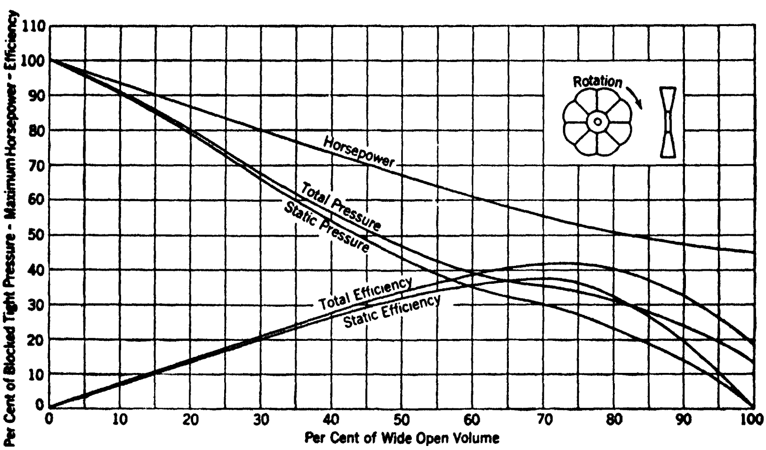


FIG. 88.—Operating characteristics of an axial-flow fan. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 27.)

The centrifugal or blower types that are generally used in air conditioning are of forward- or backward-curved blade design.

FIG. 89.—Axial-flow (disk) fan. (*B. F. Sturtevant Company.*)

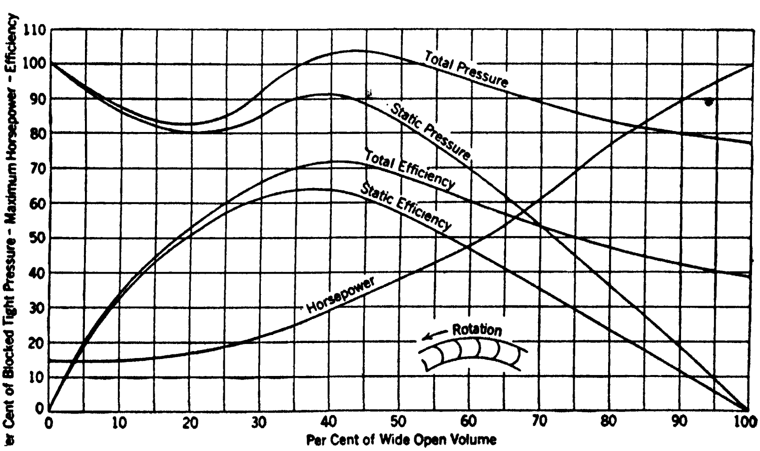


FIG. 90.—Operating characteristics of a fan with blades curved forward. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 27.)

3. Fan Performance. All fans follow laws of operation that are well known and established, as

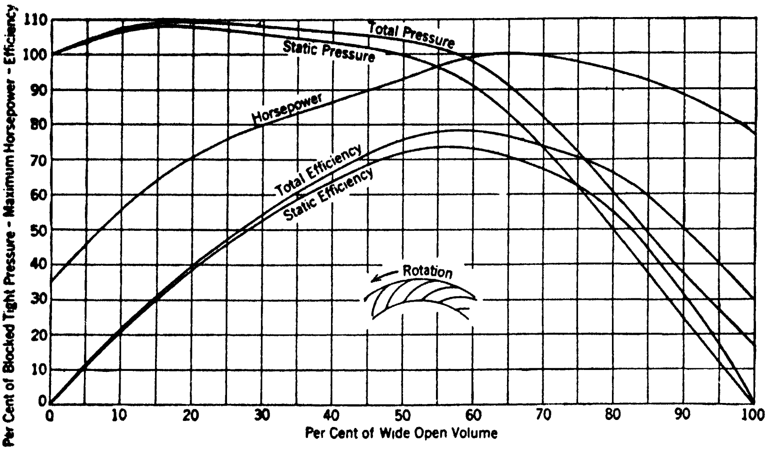


FIG. 91.—Operating characteristics of a fan with blades curved backward. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 27.)

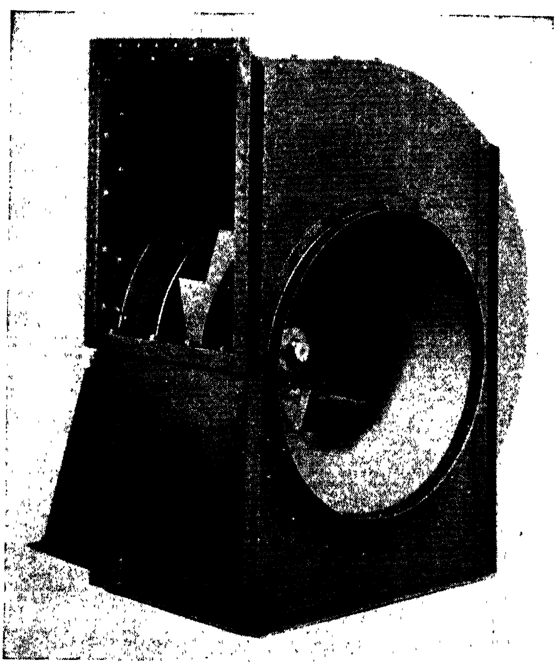


FIG. 92.—Centrifugal blower. (*B. F. Sturtevant Company.*)

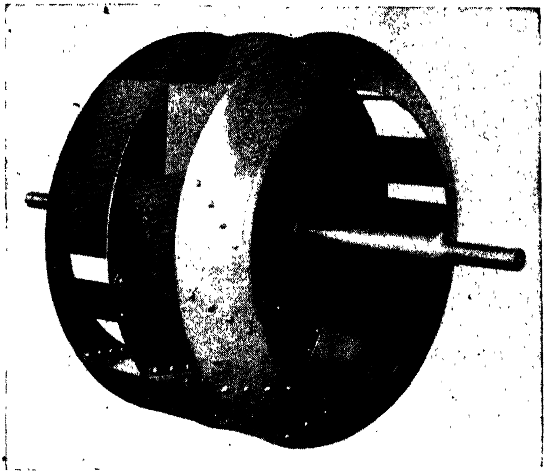


FIG. 93.—Centrifugal blower multiblade (backward) wheel. (*B. F. Sturtevant Company.*)

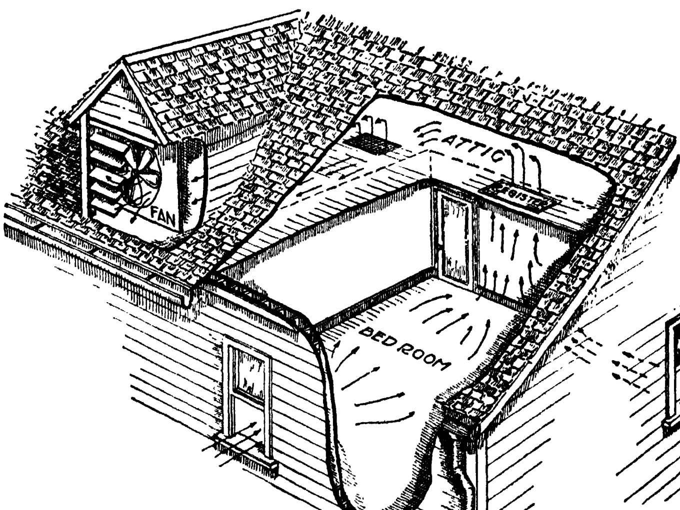


FIG. 94.—Attic-fan installation. (*From Allen and Walker, Heating and Air Conditioning.*)

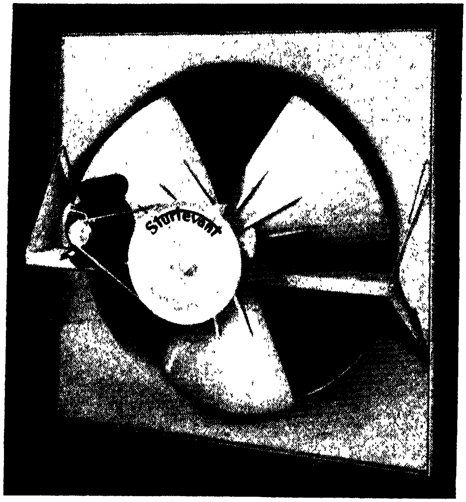


FIG. 95.—Attic fan. (*B. F. Sturtevant Company.*)

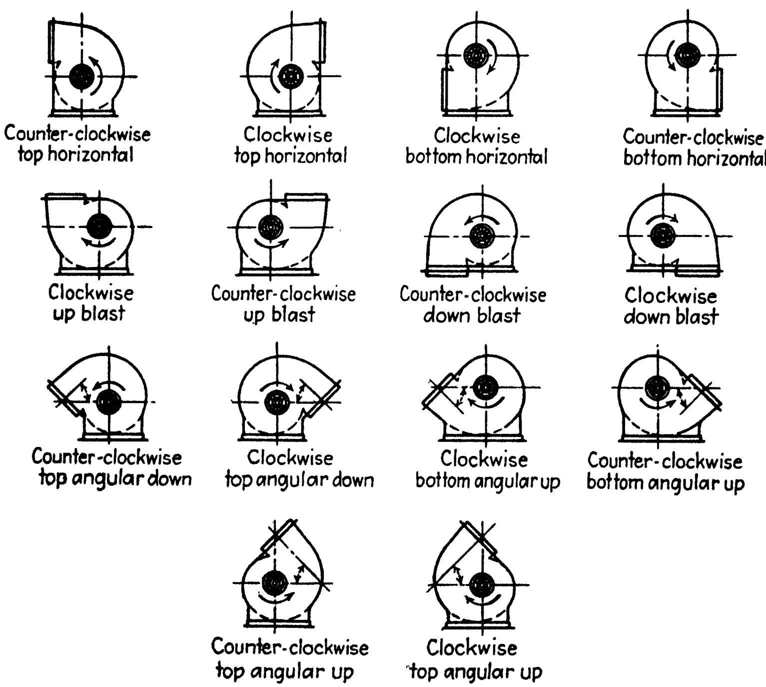


FIG. 96.—Standard designation of fans. (*B. F. Sturtevant Company.*)

a. The air capacity varies directly as the fan speed.
b. The air pressure varies as the square of the fan speed.
c. The power demand varies as the cube of the fan speed.

Examples: A fan driven by a 2-horsepower motor and operating at a speed of 200 revolutions per minute delivers 6000 cubic feet per minute at 12-inch pressure. If the fan is speeded up to 300 revolutions per minute what will be the

a. Capacity
b. Pressure
c. Power

Answers:

(*a*) $\frac{300}{200} \times 6000 = 9000$ cubic feet per minute capacity

(*b*) $\frac{(300)^2}{(200)} \times 0.5 = 1.125$ inches pressure

(*c*) $\frac{(300)^3}{(200)} \times 2 = 6.75$ horsepower power

4. Fan Selection. Fans are selected upon the following requirements:

a. Efficiency
b. Cubic feet of air to be pumped
c. Static pressure required by system
d. Type of available motive power
e. Single or parallel operation
f. Permissible noise level
g. Load variables—volumes, pressures, etc.

5. Fan Classification. Fans are classified by manufacturers according to the following characteristics:

a. Volume of air in cubic feet per minute
b. Outlet velocity
c. Revolutions per minute (r.p.m.)
d. Brake power
e. Tip or peripheral speed
f. Static pressure

6. Air-delivery System. The air-delivery system conveys the conditioned air from the blower or fan through the supply ducts to the supply outlets in each room or enclosure and back through the return inlets and return ducts to the blower.

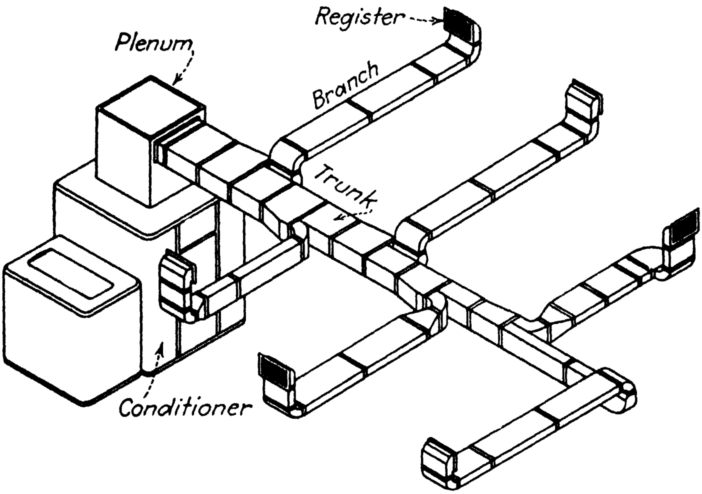


FIG. 97.—Supply air-duct system. (*Lamneck Products, Inc.*)

It comprises

a. Supply ducts
b. Return ducts
c. Dampers
d. Duct insulation

7. Ducts. Ducts are usually made of metal sheets formed to size and shape as required.

8. Supply Ducts. The supply ducts are carefully calculated and designed for proper air volume, velocity, and pressure in order that proper distribution, through the aid of the supply outlets, may be obtained for each room or enclosure.

9. Return Ducts. The return ducts should be as carefully calculated and designed as are the supply ducts. In the better applications this is done, but in the poorer or cheaper ones, less care is given to the returns. In some instances part of the return air is conveyed between studs, joists, or rafters, resulting in lowered efficiency and a building up of undesirable supply-air pressure.

10. Dampers. Dampers, manual or automatic, are placed in the ducts, as required to control the direction, velocity, and volume of circulating air.

11. Duct Insulation. Supply ducts, from the conditioner to the supply outlets should be properly insulated. This is not done in the cheaper installations but is essential for all jobs. It saves and controls the heat of conditioned air and prevents condensation within the ducts, or on the surfaces, during summer conditioning.

12. Distribution. The proper distribution of supply air is probably the most important single factor in the successful operation of an air-conditioning system. The correct amount of properly conditioned air may be delivered to the supply outlets, but if these outlets are improperly designed, selected, or located, the desired effect may not be obtained. It is to be noted that, for the sake of simplicity, the distribution of air from apparatus to the outlets, or into the return inlets, has been arbitrarily classified as air delivery. To simplify the text further, distribution is herein confined to the distributing of conditioned air into an actual space, room, or enclosure, and out of that space through the return air inlets to the return delivery system.

13. Outlets. Outlets are either grilles or registers at the point of distribution supply into a space, room, or enclosure.

14. Inlets. Inlets are either grilles or registers at the point of distribution return from a supply, room, or enclosure.

15. Grille. A grille is an outlet or inlet having no damper, or air-control device.

16. Register. A register is an outlet or an inlet having a damper.

17. Throw. The distance over which air will carry, from an outlet to a point beyond the outlet face, is the throw.

18. Core Area. The core area of an outlet or an inlet is the area of that portion of the grille or register, inside the frame, through which air may flow.

19. Aspect Ratio. The aspect ratio is the ratio of the width to the height of the core area of a grille or register.

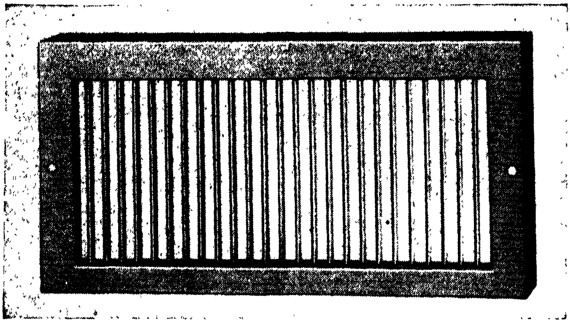


FIG. 98.—Baseboard grille. (*The Independent Register Co.*)

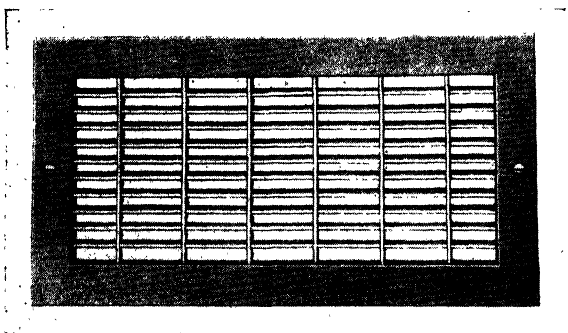


FIG. 99.—Wall grille. (*The Independent Register Co.*)

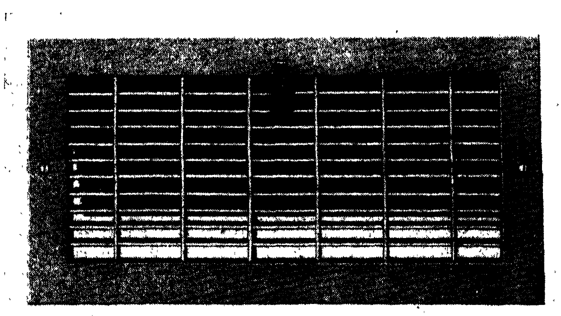


FIG. 100.—Wall (horizontal flow) register. (*The Independent Register Co.*)

20. Location. The locations of the outlet and the inlet and their relation one to the other are of vital importance.

An outlet for the supply of conditioned air to a room is best placed in the ceiling or on a side wall high enough from the floor

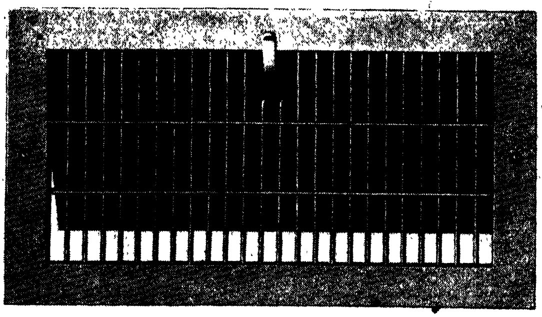


FIG. 101.—Wall (vertical flow) register. (*The Independent Register Co.*)

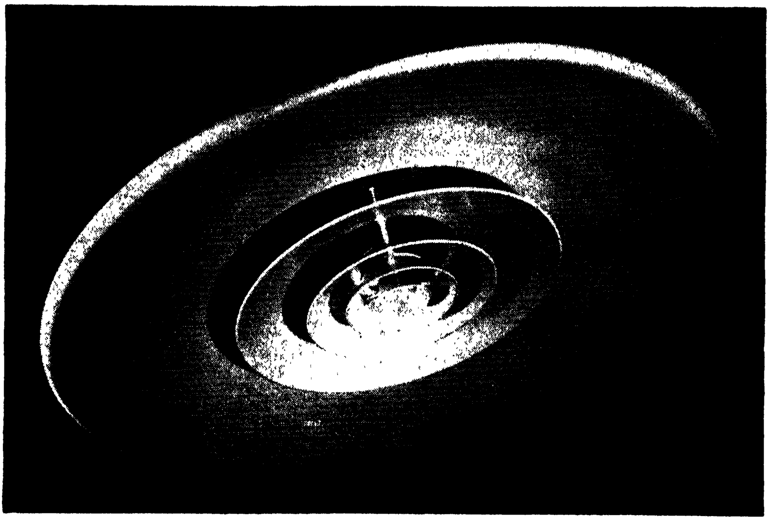


FIG. 102.—Rosette-type air-supply fitting. (*Amemostat Corporation of America.*)

to prevent the air from discharging directly upon the occupants within the enclosure. In the case of high ceilings, outlets should be placed far enough down to prevent distribution within the upper strata of unoccupied space, and to provide insulation by air stratification in this upper unused space. A simple arbitrary rule for wall outlets is not less than six feet six inches from the floor nor less than one foot six inches from the ceiling, and as low as the structural and throw requirements permit.

Supply outlets are usually placed on interior or cross partitions and rarely, if ever, on exterior walls. It should be the object of a

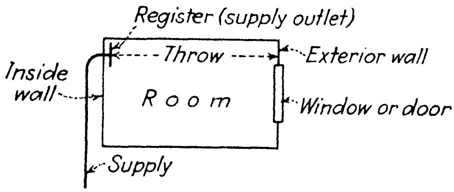


Fig. 103.

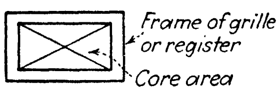


Fig. 104.

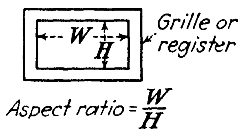


Fig. 105.

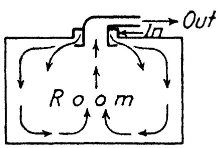


Fig. 106.

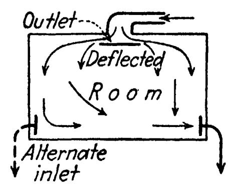


Fig. 107.

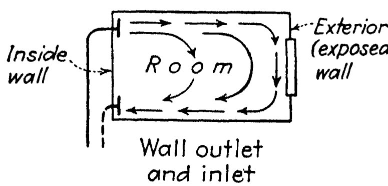


Fig. 108.

supply outlet to distribute conditioned air into a room without any unfriendly draft. Practice is to locate these outlets so that conditioned air is distributed to exposed barriers to aid in a more rapid and even balancing of heat losses or gains.

Inlets, for the return of vitiated air from individual rooms or enclosures, are placed at the beginning, or receiving end, of return air ducts. They may be either grilles or registers, depending upon control desires and economic limitations.

DIVISION II. CLEANING

1. Air Cleaning. Air cleaning is one of the common requirements of an air-conditioning system. It comprises the air itself, which is normally polluted to a degree, and the cleaning device that removes some of the particles of pollution.

2. Air Pollution. Those particles which, as impurities, pollute the air include carbon, earth, sand, ash, rubber, leather, excreta, stone, wood, rust, paper, thread, animal and vegetable matter, pollen, and the like.

3. Micron. The impurities are roughly classified according to size, the unit of measurement of which is the micron. A micron is equal to 0.001 millimeter or 1/25,000 inch.

4. Classifications. Air pollution is arbitrarily classified as:

a. Dust
b. Fumes
c. Smoke

5. Dust. Dusts are particles of solid matter from 1 to 150 microns in size.

6. Fumes. Fumes range in size from 0.1 to 1 micron.

7. Smoke. Smokes are fine soot or carbon particles mixed with other combustion products and by-products such as hydrocarbons and sulphur dioxide usually less than 0.1 micron in size.

8. Concentration. The average typical concentrations of air pollutions are

Location	*Concentration**
Rural and suburban	0.2 to 0.4
Metropolitan	0.4 to 0.8
Industrial	0.8 to 1.5
Mining	4000 to 8000

* Concentrations are in grains per 1000 cubic feet. One pound equals 7000 grains.

9. Comparison. In air of low velocity, dust tends to settle out by gravity, fumes tend to agglomerate and settle out when they become 0.1 micron or over in size, smokes tend to diffuse and remain in the air.

10. Health Angle. There are several authorities on the size of particles that are supposedly injurious to health; the sizes found in the lungs ranging from 0.1 to 10 microns, while larger particles have been found in the upper air passages.

It is claimed that most of the seasonal hay fever and much of the bronchial asthma are caused by pollens and the like, carried by the air.

11. Air Cleaners. Removal of impurities from polluted air is air cleaning. To accomplish this it is necessary to provide air filters or cleaners. It is required of air cleaners that they

a. Be efficient in the removal of harmful and objectionable impurities in the air, such as dust, dirt, pollens, bacteria.
b. Be efficient over a considerable range of air velocities.
c. Have a low frictional resistance to air flow; *i.e.*, the pressure drop across the filter should be as low as possible.
d. Have a large dust-holding capacity without excessive increase of resistance, or have ability to operate so as to keep the resistance constant automatically.
e. Be easy to clean and handle, clean themselves automatically, or else be inexpensive enough to be replaced when dirty.
f. Leave the air free from entrained moisture or charging liquids used in the cleaner.

12. Cleaner Ratings. Air cleaners, according to the ASHVE code, are rated by

a. Capacity, cubic feet per minute
b. Resistance, inches of water at capacity
c. Dust arrestance, as removal efficiency
d. Reconditioning power—for automatic filters
e. Dust-holding capacity—for nonautomatic filters

13. Cleaner Classification. Air cleaners are classified as

a. Class *A*
Automatic type
b. Class *B*
Nonautomatic
Low-resistance type
c. Class *C*
Nonautomatic
Medium-resistance type
d. Class *D*
Nonautomatic
High-resistance type

14. Automatic Cleaner. Automatic cleaners are devices using power for the automatic reconditioning of the filter medium and the maintenance of a constant resistance to air flow.

15. Nonautomatic Cleaners. Nonautomatic cleaners are devices that do not recondition the filter medium nor maintain a constant resistance to air flow.

Class *B*, Low-resistance Type. These operate at not more than 0.18 inch of water.

Class *C*, Medium-resistance Type. These operate at not more than 0.5 inch of water.

Class *D*, High-resistance Type. These will operate at 1 inch or more of water, but are rarely used in air conditioning.

16. Classification by Principle. Air cleaners may also be classified according to the principle used, as

a. Viscous filters
   1. Automatic type
   2. Unit type

b. Dry filters

c. Washers

d. Electrical precipitators

17. Viscous Automatic Filters. These filters mechanically operate in a continuous cycle comprising the cleaning of the air,

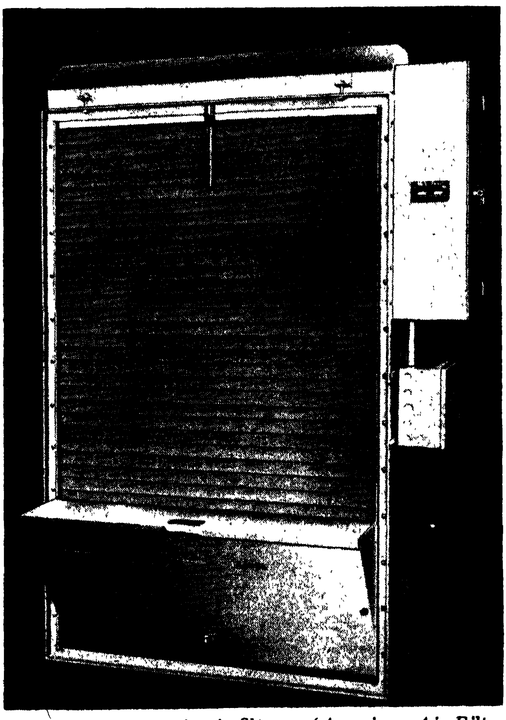


FIG. 109.—Multipanel automatic air filter. (*American Air Filter Company*.)

removal of the air-pollution particles, replenishing the viscous filter medium, and placing the effective refreshened area of the filter back into the air stream for further utilization.

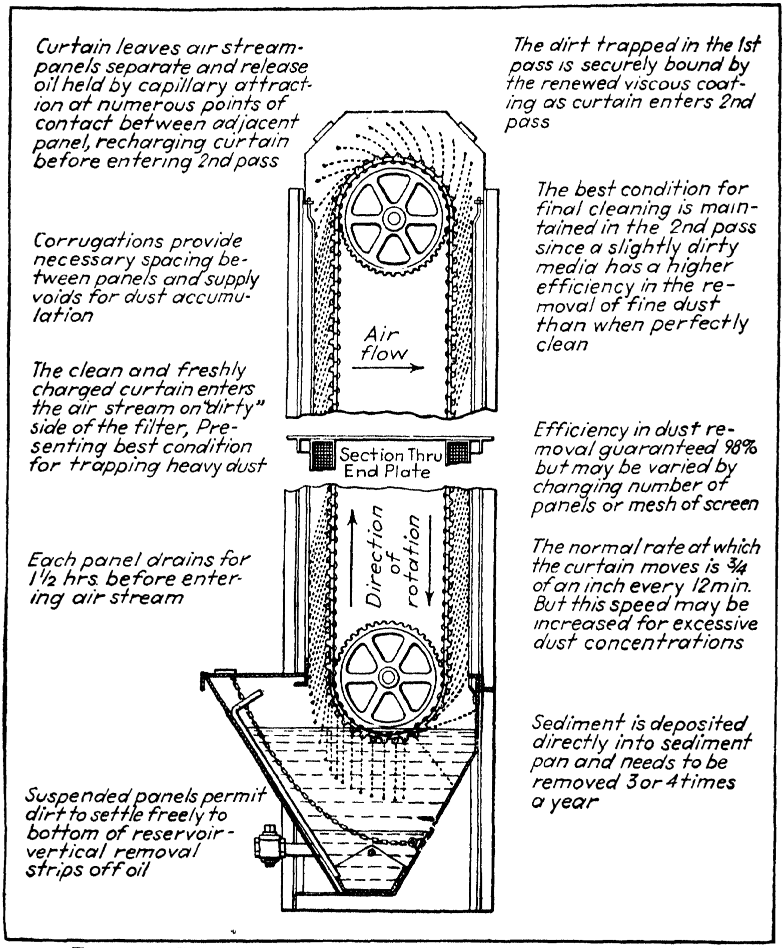


FIG. 110.—Continuous viscous filter. (*American Air Filter Company.*)

18. Viscous Unit-type Filters. Viscous unit-type air filters use a binding liquid permitting adhesive impingement, the dust being trapped and retained on the viscous-coated surfaces.

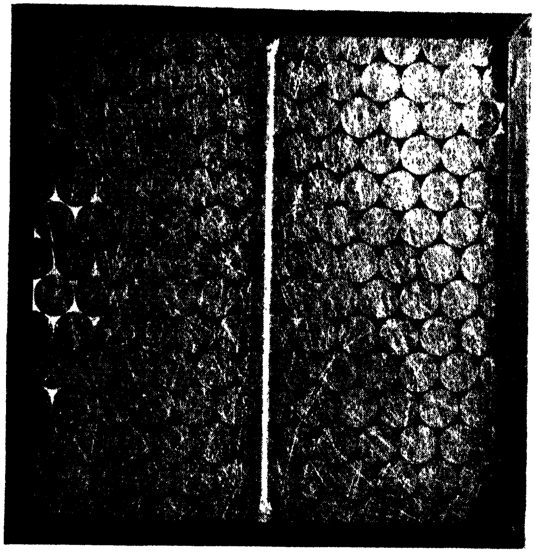


FIG. 111.—Fiberglas (viscous-replaceable) air filter. (*Owens-Corning Fiberglas Corp.*)

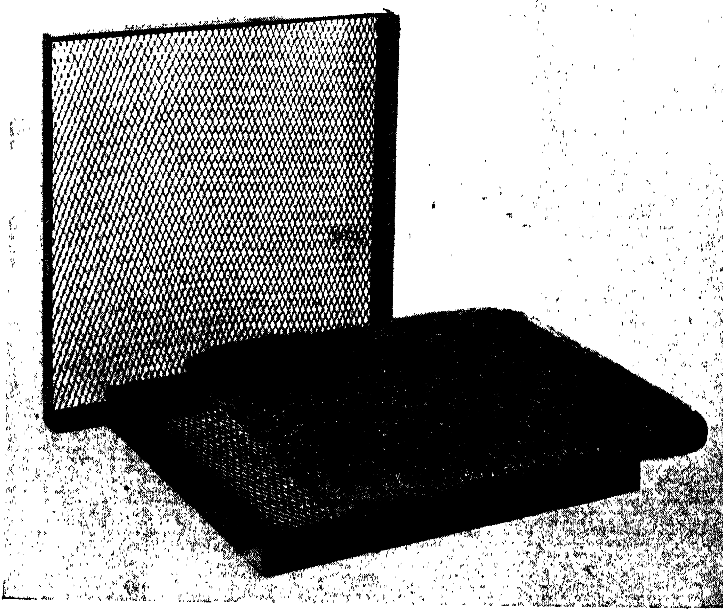


FIG. 112.– Renewable air filter. (*American Air Filter Company.*)

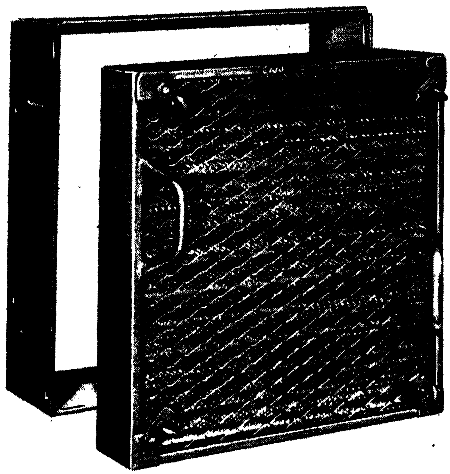


Fig. 113.—Permanent washable viscous air filter. (*American Air Filter Company.*)

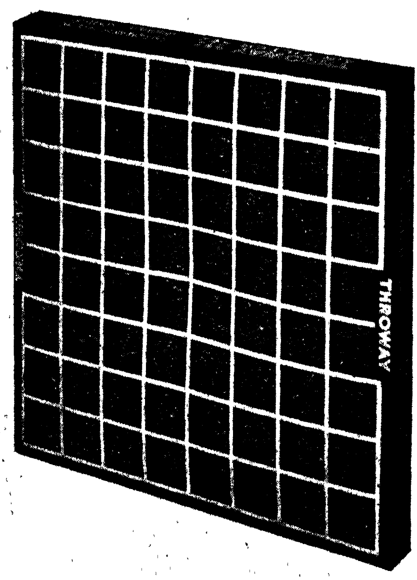


Fig. 114.—Throway air filter. (*American Air Filter Company.*)

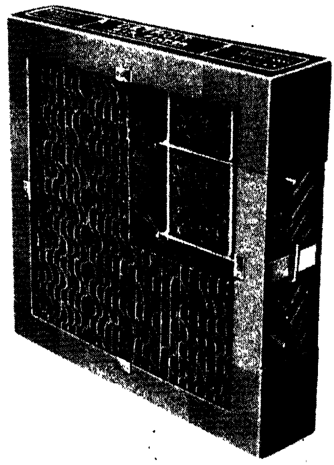


FIG. 115.—Fiber-board (viscous replaceable) air filter. (*Detroit Lubricator Co.*)

19. Dry Filters. Dry air filters are made of felt, cloth, or cellulose and depend upon the dust to impinge upon or within the filter screen.

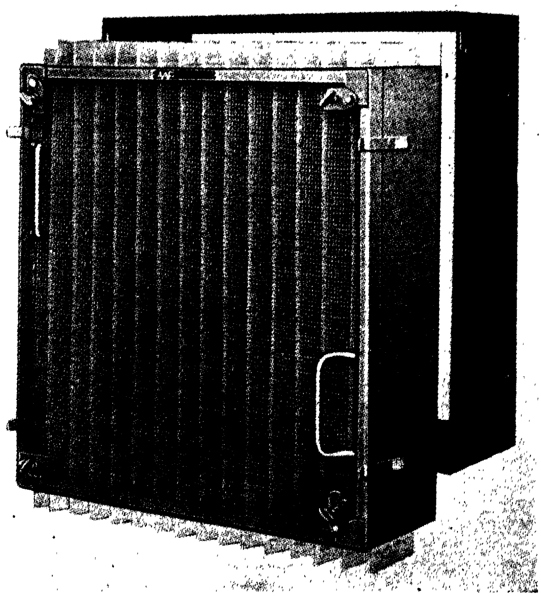


FIG. 116.—Mat air filter. (***American Air Filter Company.***)

20. Washers. Washers, described in general under dehumidification and humidification, may be utilized as air cleaners. The dust particles must be wetted or impinged upon wet surfaces to produce cleaning effect. Unfriendly fumes or gases are often cleaned from air in this manner, even to the extent of the adding of certain chemicals to the spray water to accomplish the result.

21. Electrical Precipitators. This device is described in Chap. II, section 10.

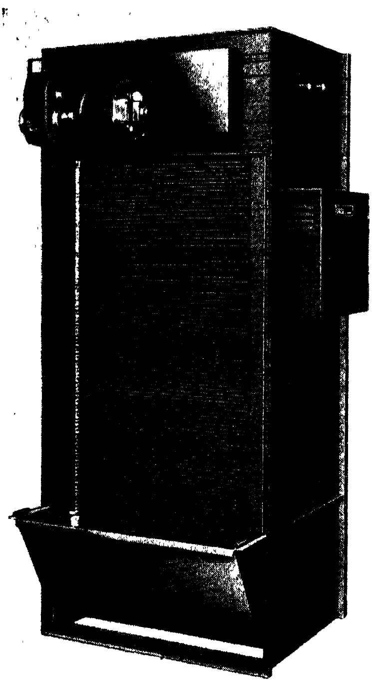


FIG. 117.—Electrical-precipitation automatic air filter. (*American Air Filter Company.*)

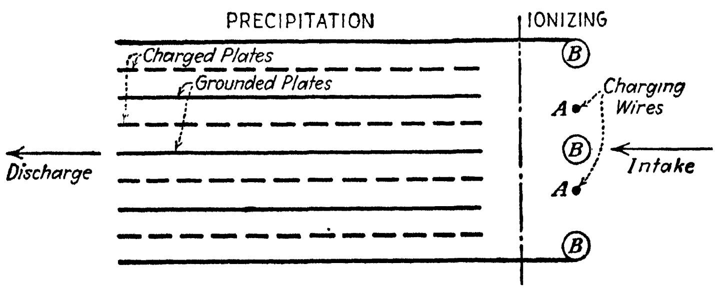


FIG. 118.—Diagram of electrostatic precipitator. (*Westinghouse Electric and Manufacturing Company.*)

DIVISION III. HEATING

1. Heating. Heating is one of the winter seasonal requirements of air conditioning. It comprises the following:

a. Fuels
b. Burners
c. Generators
d. Radiators or convectors
e. Heating coils
f. Distribution

2. Fuels. The common fuels used are

a. Coal (solid)
b. Oil (liquid)
c. Gas (gas)

The choice of any one of these fuels depends upon its

a. Availability
b. Economy
c. Cleanliness
d. Operation requirements
e. Control

3. Classification of Coals. A precise classification of coals is difficult to make, but they may be arbitrarily grouped as

a. Anthracite
b. Semianthracite
c. Bituminous
d. Semibituminous
e. Lignite
f. Coke

For those more intimately interested, reference is made to the U. S. Bureau of Mines *Bulletin* 276, and the ASHVE 1938 *Guide.*

4. Classification of Oils. Fuel oils are grossly grouped as domestic and industrial. Domestic oils are further classified as Nos. 1, 2, and 3. Industrial oils are classified as Nos. 4, 5, and 6. Since few industrial oils are used in automatic oil burners for air conditioning, only the domestic varieties will be considered.

The commercial standard fuel-oil specifications giving detailed requirements for domestic fuel oils are as given in Table *G.*

TABLE *G*.—COMMERCIAL STANDARD FUEL-OIL SPECIFICATIONS*
Detailed Requirements for Domestic Fuel Oils†

Grade of oil	Approx. B.t.u. per gallon‡	Flash point		Water and sediment, maximum per cent	Carbon residue, maximum per cent	Distillation test		Viscosity maximum
		Min., deg. Fahr.	Max., deg. Fahr.			Max., deg. Fahr.	Min., deg. Fahr.	
No. 1. Domestic fuel oil—a light distillate oil for use in burners requiring a high grade fuel	139,000	100 or legal	150	0.05	0.02	10% point 420 End point 600		
No. 2. Domestic fuel oil—a medium distillate oil for use in burners requiring a high grade fuel	141,000	125 or legal	190	0.05	0.05	10% point 440 90% point 620	End point 600	
No. 3. Domestic fuel oil—a distillate fuel oil for use in burners where a low viscosity oil is required	143,400	150 or legal	200	0.1	0.15		90% point 620	Saybolt universal at 100 70 seconds

* Adapted from "Fuel Oils," p. 2, *U. S. Department of Commerce, Bureau of Standards, Commercial Standard CS12-35*, Washington, 1935.

† Pours point maximum is 15 F. Lower or higher pour points may be specified whenever required by conditions of storage and use. However, these specifications shall not require a pour point less than 0 F. under any conditions.

‡ Government specifications do not give B.t.u. per gallon, but they are noted here for information only.

5. Classification of Gases. Fuel gases are roughly grouped as natural and artificial (or manufactured). Natural gases usually are the richer and manufactured gases the poorer in heat value.

Considerable water vapor is produced in the combustion of gases. The latent heat of condensation is included in the gross or high heat content given in the heat tables.

The representative properties of gaseous fuels, based on gas at 60 degrees Fahrenheit and thirty inches mercury pressure are:

TABLE *H*.—REPRESENTATIVE PROPERTIES OF GASEOUS FUELS*
Based on Gas at 60 Degrees Fahrenheit and 30 Inches per Hectogram

Gas	B.t.u. per cubic foot		Specific gravity, air = 1.00	Air required for combustion, cubic feet	Products of combustion				Theoretical flame temperature, degrees Fahrenheit
					Cubic feet			Ultimate CO_2 dry basis	
	High (gross)	Low (net)			CO_2	H_2O	Total with N_2		
Natural gas—California	1200	1087	0.67	11.26	1.24	2.24	12.4	12.2	3610
Natural gas—Mid-Continental	967	873	0.57	9.17	0.97	1.92	10.2	11.7	3580
Natural gas—Ohio	1130	1025	0.65	10.70	1.17	2.16	11.8	12.1	3600
Natural gas—Pennsylvania	1232	1120	0.71	11.70	1.30	2.29	12.9	12.3	3620
Retort coal gas	575	510	0.42	5.00	0.50	1.21	5.7	11.2	3665
Coke-oven gas	588	521	0.42	5.19	0.51	1.25	5.9	11.0	3660
Carbureted-water gas	536	496	0.65	4.37	0.74	0.75	5.0	17.2	3815
Blue water gas	308	281	0.53	2.26	0.46	0.51	2.8	22.3	3800
Anthracite-producer gas	134	124	0.85	1.05	0.33	0.19	1.9	19.0	3000
Bituminous-producer gas	150	140	0.86	1.24	0.35	0.19	2.0	19.0	3160
Oil gas	575	510	0.35	4.91	0.47	1.21	5.6	10.7	3725

* These data compiled from U. S. Bureau of Mines and A. S. A. sources.

6. Automatic Fuel Burners. Mechanical devices for the automatic burning of fuels are broadly classified as

a. Coal stokers (solid fuel)
b. Oil burners (liquid fuel)
c. Gas burners (gaseous fuel)

7. Stokers. Mechanical stokers automatically feed a required amount of a solid fuel, like coal, into a combustion chamber, provide a controlled supply of air for the combustion of the fuel, and may provide some means for disposing of the solid refuse or ash resulting from the combustion.

8. Classification of Stokers. Solid-fuel burners are classified as

a. Overfeed flat-grate stokers
b. Overfeed inclined-grate stokers
c. Underfeed side-cleaning stokers
d. Underfeed rear-cleaning stokers

Stokers are also grouped according to their rated coal feed per hour, as:

Class 1. Up to and including 60 pounds per hour
Class 2. From 60 to 100 pounds
Class 3. From 100 to 300 pounds
Class 4. From 300 to 1200 pounds
Class 5. Over 1200 pounds

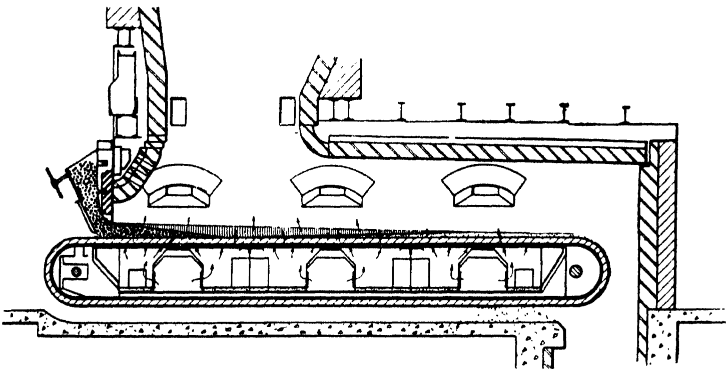


FIG. 119.—Overfeed traveling-grate stoker.

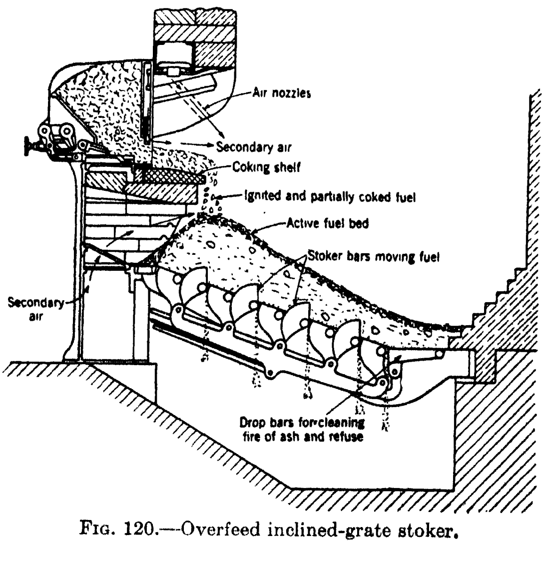


FIG. 120.—Overfeed inclined-grate stoker.

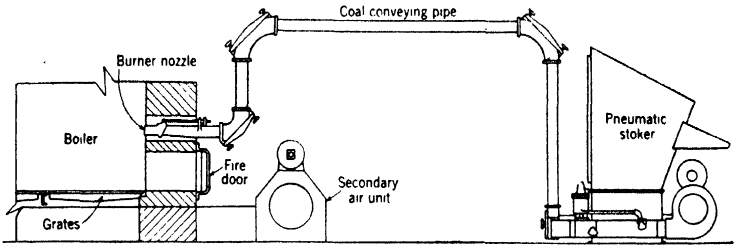


FIG. 121.—Spreader stoker, pneumatic type.

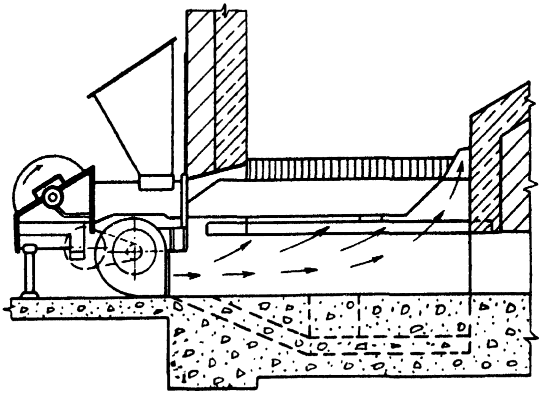


FIG. 122.—Underfeed plunger-type stoker.

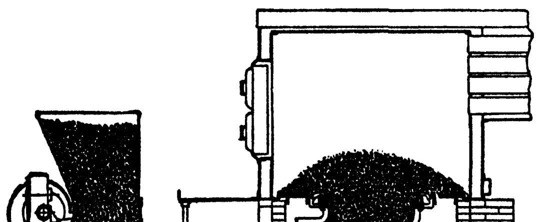


FIG. 123.—Underfeed screw stoker, hopper type.

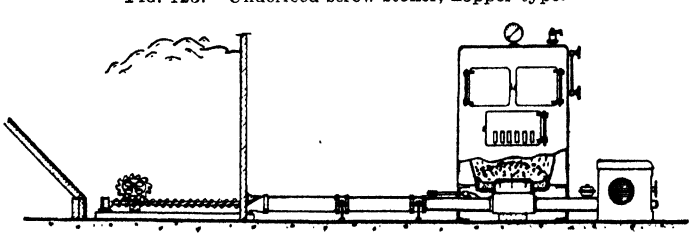


FIG. 124.—Underfeed screw stoker, bin-feed type.

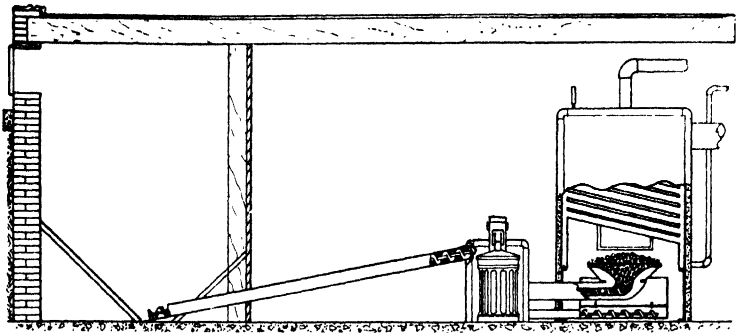


FIG. 125.—Underfeed screw stoker with automatic ash removal.

Household stokers are classified as Class 1 and Class 2. They are usually of the underfeed screw type and are subclassified as

a. Hopper type
b. Bin-feed type

Either of these types may be also classed as

a. Manual ash removal
b. Automatic ash removal

Small commercial stokers for hotels, apartments, and the like are usually under Class 3, while larger commercial jobs are found in Class 4. These types vary in classification but the majority used in air conditioning are of the underfeed type. Class 5 would rarely be found in air-conditioning systems.

9. Automatic Oil Burners. Fuel-oil burners have been grouped as commercial and domestic. Commercial burners are

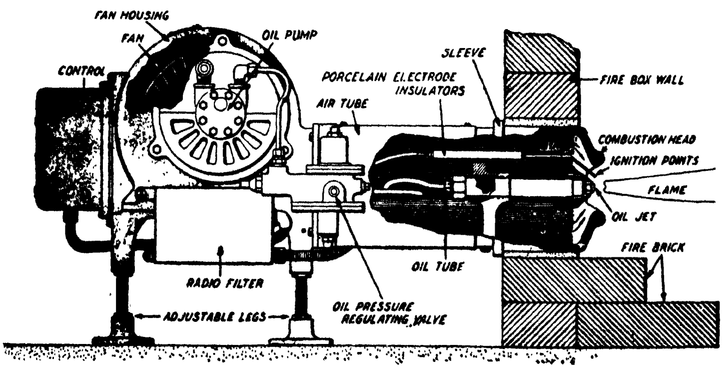


FIG. 126.—Gun-type pressure-atomizing oil burner.

generally of the nonfull automatic type. Domestic burners are used almost exclusively in air-conditioning heating. The classi-

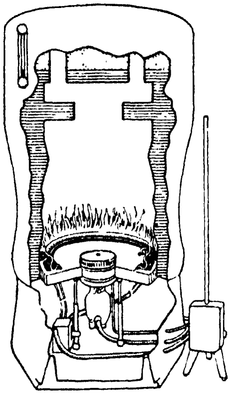


FIG. 127.—Wall-type vertical rotary burner.

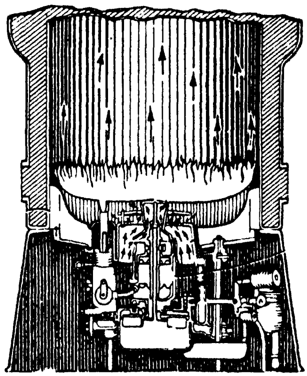


FIG. 128.—Center-flame vertical rotary burner.

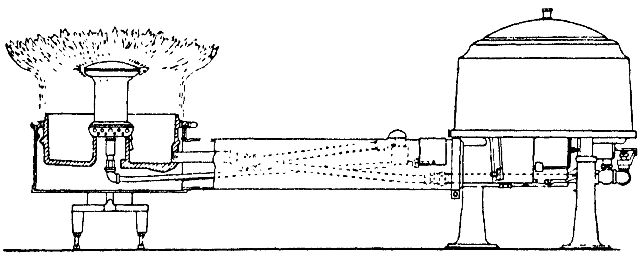


FIG. 129.—Pot-type vaporizing burner.

fication of these domestic burners varies according to several factors, as

I. Air supply
   A. Atmospheric, ordinary stack draft
   B. Mechanical, power-driven blower
   C. Combination, primary air from blower, secondary air from stack draft
II. Oil preparation
   A. Vaporizing, oil distilled on hot surface
   B. Atomizing, oil broken into fine particles
      1. Centrifugal, rotary cup or disk
      2. Pressure, oil forced through small orifice

3. Air or steam, high velocity with special nozzle
4. Combination, air and pressure

C. Dual, a combination of *B*1 and *B*2

III. Type of flame

A. Luminous, bright flame (orange)
B. Nonluminous, blue flame

IV. Method of ignition

A. Electric
1. Spark
   a. Continuous
   b. Intermittent
2. Resistance, hot wire or plate

B. Gas
1. Continuous
   a. Constant size pilot
2. Expanding
   a. Pilot expands temporarily at start of burner
3. Combination
   a. Spark lights gas, gas flame ignites oil
4. Manual
   a. Hand torch for continuously operating burners

V. Manner of operation

A. On and off, intermittent
B. High and low, continuous flame either high or low
C. Graduated continuous flame graduates from high to low and vice versa

However, the trade has classified these burners under three types, as

a. Gun or pressure
b. Rotary
c. Pot or vaporizing

10. Automatic Gas Burners. Fuel-gas burners are more numerous as to type and variety than any other automatic burners.

From an air-conditioning standpoint they may be broadly typed as

a. Gravity
b. Pressure (blast)
c. Radiant

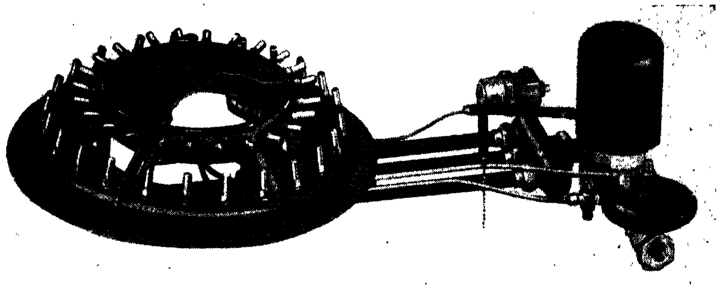


FIG. 130.—Gravity-conversion gas burner. (*Barker Gas Burner Company.*)

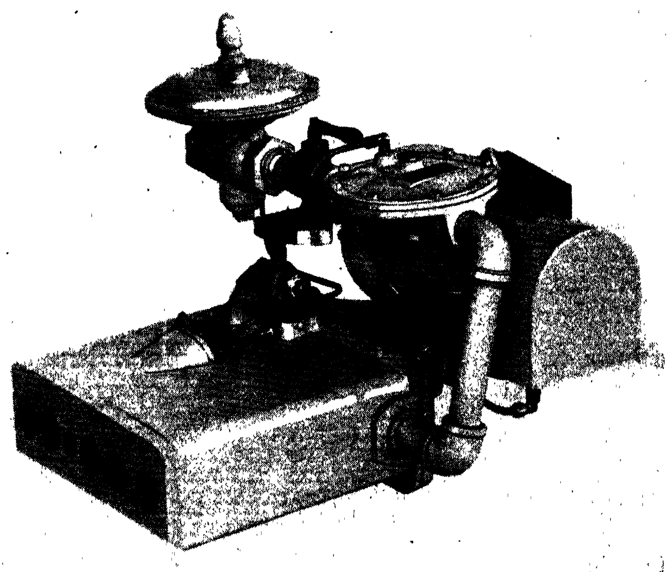


FIG. 131.—Pressure-conversion gas burner. (*National Machine Works.*)

The characteristics of the gas itself have broad control over the installation and operation of gas-burning devices.

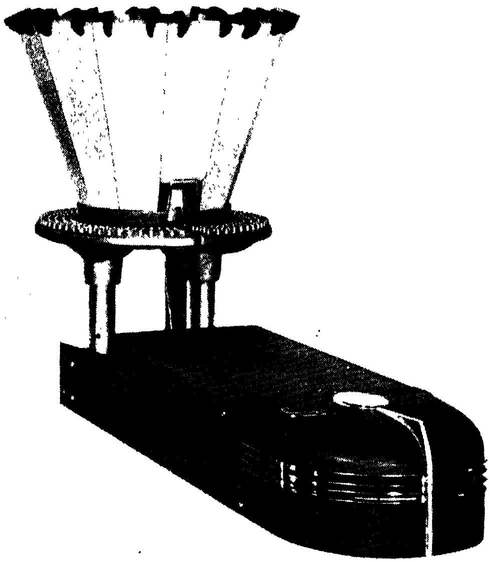


FIG. 132.—Radiant-conversion gas burner. (*The Bryant Heater Company.*)

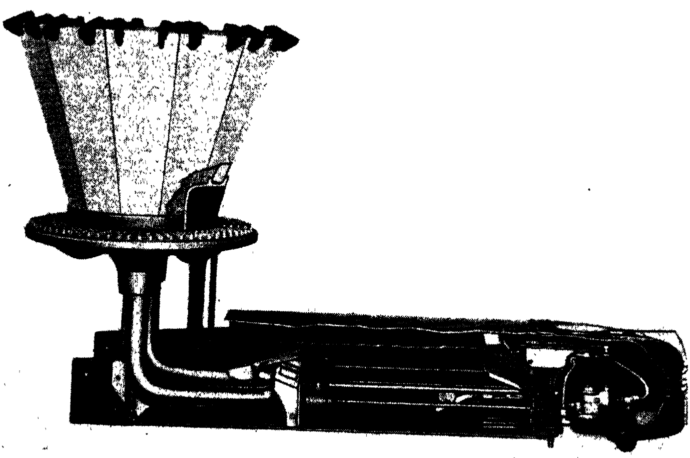


FIG. 133.—Radiant-conversion gas burner. (*The Bryant Heater Company.*)

11. Heat Generators. The generators which provide the space for and utilize the heat derived from combustion are broadly classed as

a. Furnaces
b. Boilers

12. Furnaces. The distinctive thing about a furnace is that the medium used to deliver and distribute heat from the com-

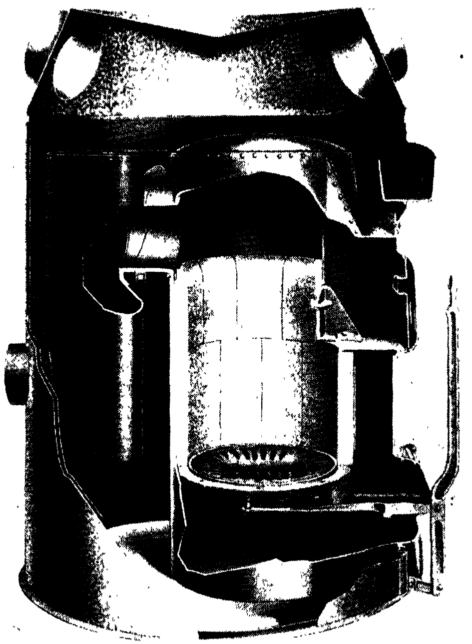


FIG. 134.—Gravity warm-air furnace. (*American Radiator & Standard Sanitary Corporation.*)

bustion chamber and any attached heat exchanger is air. Furnaces are made of cast iron or steel plate, or both.

Furnaces without fans or blowers used in heating, wherein the air circulates through the ducts within a house due solely to the rising of the heated air and the falling of the returning cooled air, are called gravity warm-air furnaces. They are not used in air conditioning.

Furnaces where the air is circulated by means of a fan or blower are called mechanical warm-air furnaces and are used in air conditioning.

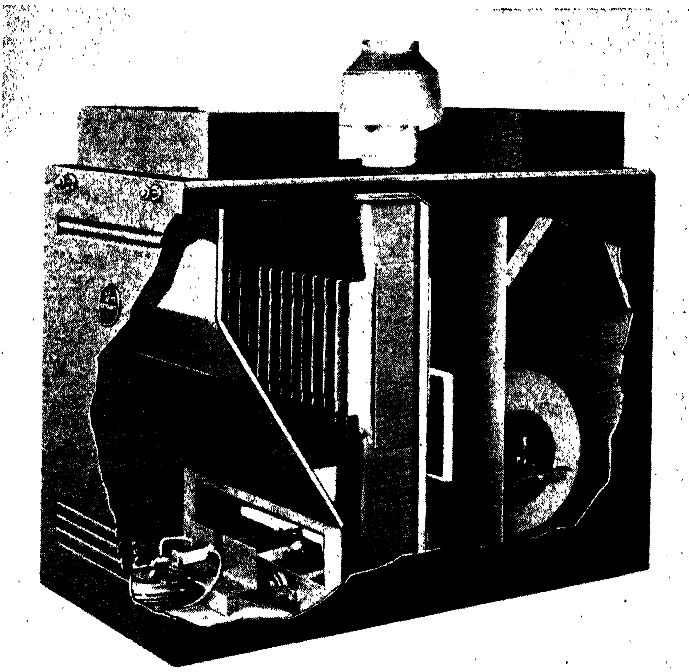


FIG. 135.—Mechanical warm-air furnace. (*The Bryant Heater Company.*)

13. Boilers. The distinctive thing about a boiler is that the medium used to deliver and distribute heat from the combustion chamber and any attached heat exchangers is water. The water as a medium may be in the state of hot water, vapor, or steam.

Boilers are designed for high-pressure and low-pressure work. Heating boilers are a low-pressure type of not over fifteen pounds working pressure. Steam from high-pressure boilers is usually reduced to low pressure for heating purposes. By slight rearrangement, a low-pressure steam boiler can be used for low-pressure hot-water heating.

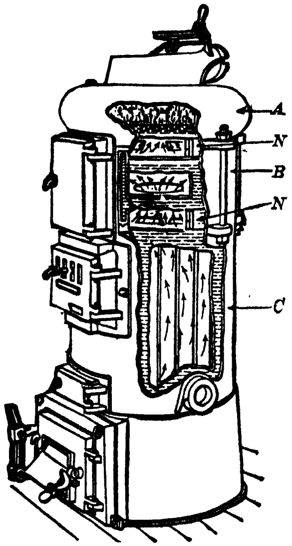


FIG. 136.—Round cast-iron boiler. (*Allen and Walker, Heating and Air Conditioning.*)

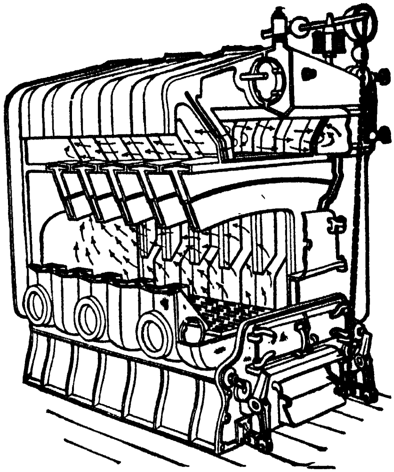


FIG. 137.—Square sectional cast-iron boiler. (*Allen and Walker, Heating and Air Conditioning.*)

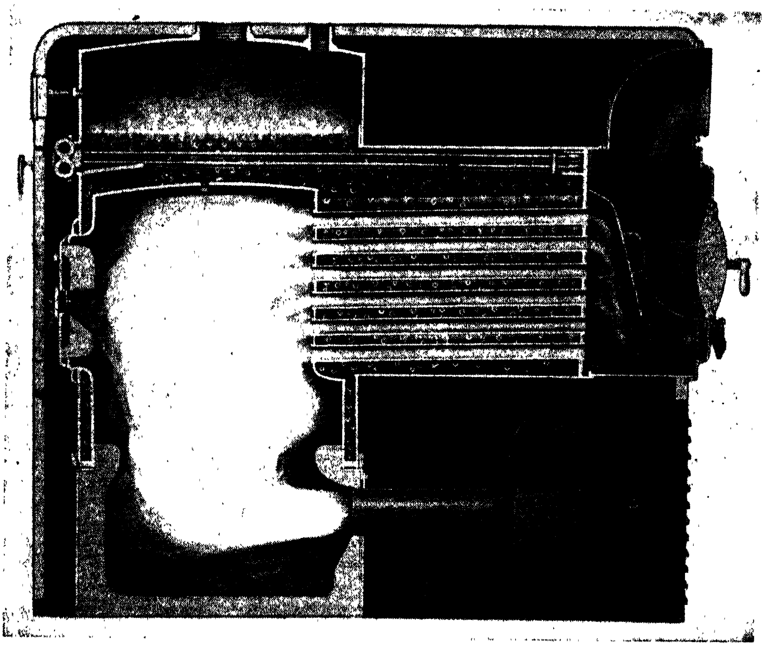


FIG. 138.—Fire-tube boiler (section). (*Fitzgibbons Boiler Company, Inc.*)

Boilers are classified as

a. Cast-iron sectional *b*. Steel fire tube *c*. Steel water tube

Cast-iron boilers are

a. Round pattern, with circular grate and horizontal sections
b. Rectangular pattern, with rectangular grate and vertical sections

Steel fire-tube boilers are constructed so that the hot gases of combustion pass through the tubes. The water surrounds the outer walls of the tubes. Steel water-tube boilers are constructed so that the water passes through the tubes. The hot gases surround and pass over the outer surfaces of the tubes.

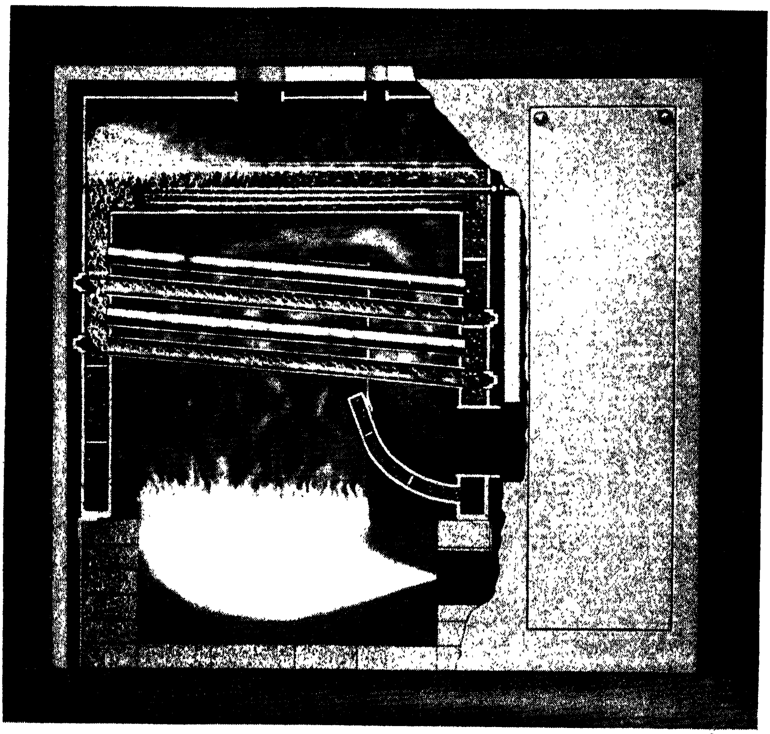


FIG. 139.—Steel water-tube boiler. (*International Boiler Company.*)

Special boilers, each with one or more distinctive features, are available; but they closely adhere, in general, to the above classified types.

14. Radiators. Radiators are generally made of cast iron, and may be classified as

a. Tubular *b.* Wall *c.* Window

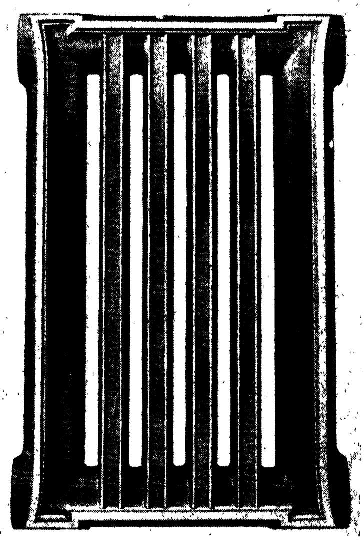


FIG. 140.—Cast-iron wall radiator. (*American Radiator & Standard Sanitary Corporation.*)

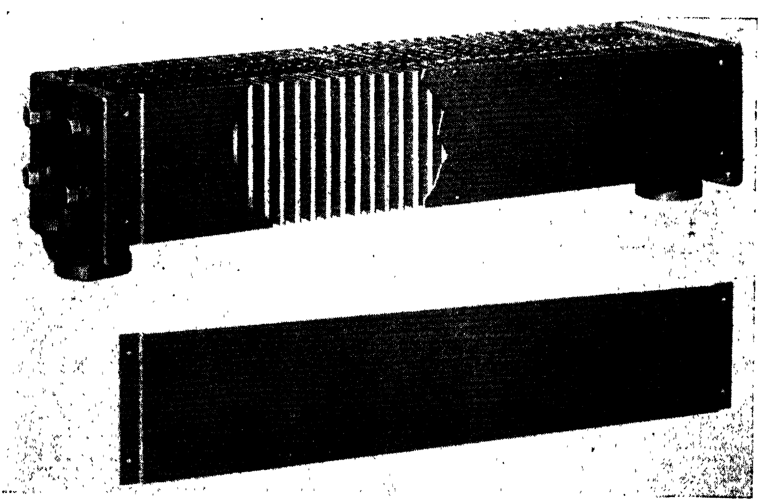


FIG. 141.—Nonferrous extended-surface convector. (*American Radiator & Standard Sanitary Corporation.*)

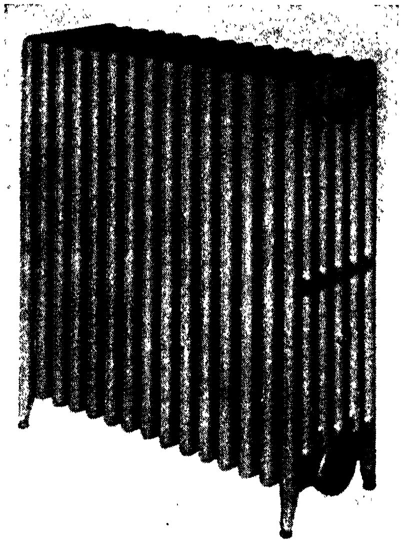


FIG. 142.—Cast-iron tubular radiator. (*American Radiator & Standard Sanitary Corporation.*)

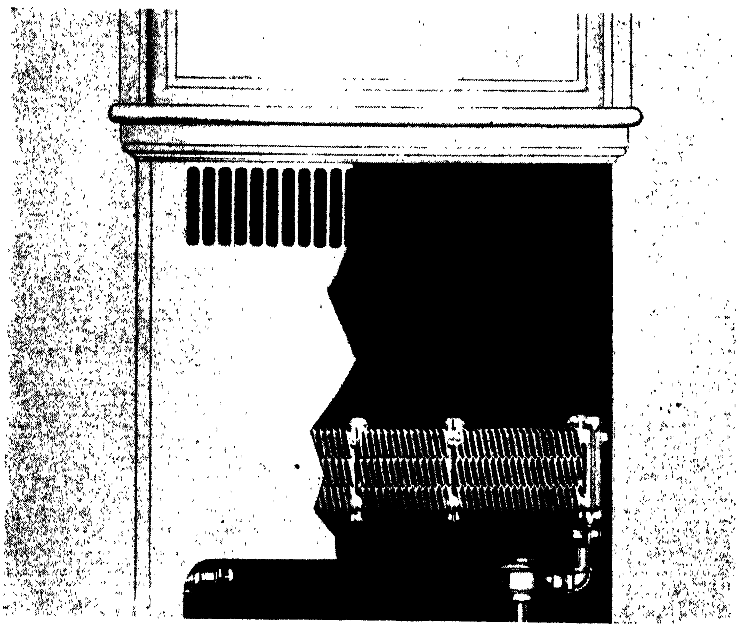


FIG. 143.—Cast-iron extended-surface convector. (*American Radiator & Standard Sanitary Corporation.*)

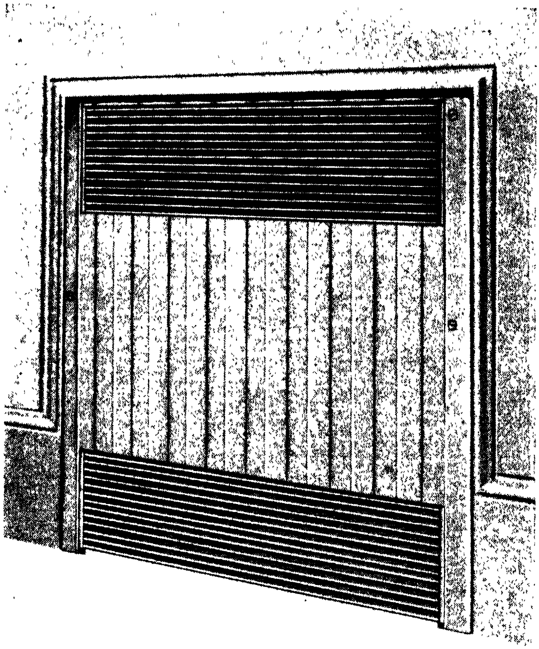


FIG. 144.—Window radiator. (*American Radiator & Standard Sanitary Corporation.*)

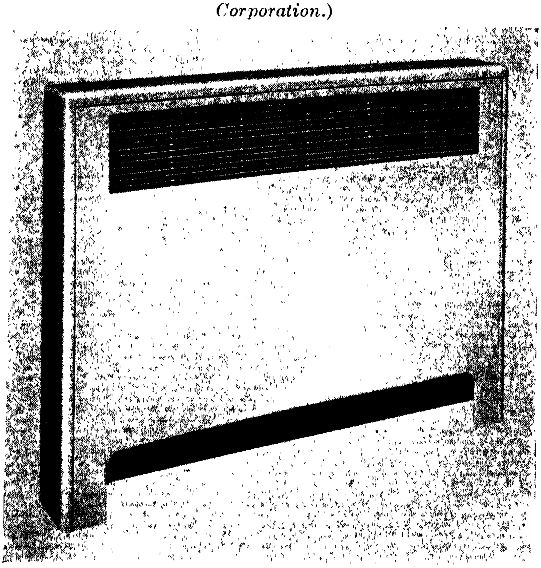


FIG. 145.—Convector enclosure. (*American Radiator & Standard Sanitary Corporation.*)

15. Convectors. Convectors may be cast-iron radiators, but there is a general trend toward extended-surface cast iron and, more particularly, toward extended-surface nonferrous metal convectors. Enclosed radiators and convectors are closely related, and the greater the relation between the extended surfaces and the air passing over them, the better the effect of heat convection.

16. Heating Coils. Heating coils, for air conditioning, like cooling coils, are more efficient and satisfactory when constructed of extended-surface tubes of selected nonferrous metals.

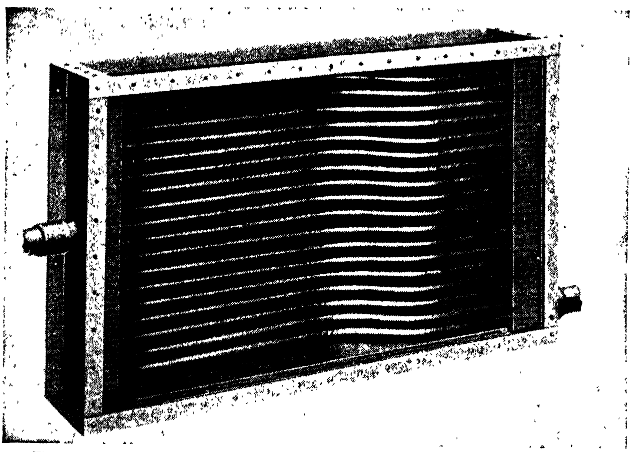


FIG. 146.—Nonferrous fin-tube unit. (*Aerofin Corporation.*)

17. Distribution. The heating mediums air, steam, and hot water are subject to varieties of distribution. Air has been described in Division I of this chapter. Hot water is rarely used in air conditioning. Two systems are used—gravity and forced circulation. Steam is grouped as gravity, vapor, or vacuum. The details of these are numerous but substantially related.

Obviously, the distribution of steam in any form, or of hot water, is accomplished through the use of piping, fittings, and valves.

18. Burner-generator Units. Combinations of fuel burners and heat generators, as so-called matched units, are

a. Stoker furnace—Fig. 147.
b. Stoker boiler—Fig. 148.

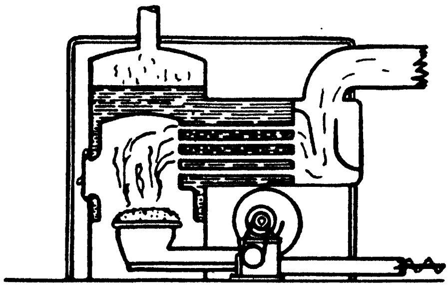


Fig. 147.—Diagram of automatic stoker-boiler. (*Fitzgibbons Boiler Company, Inc.*)

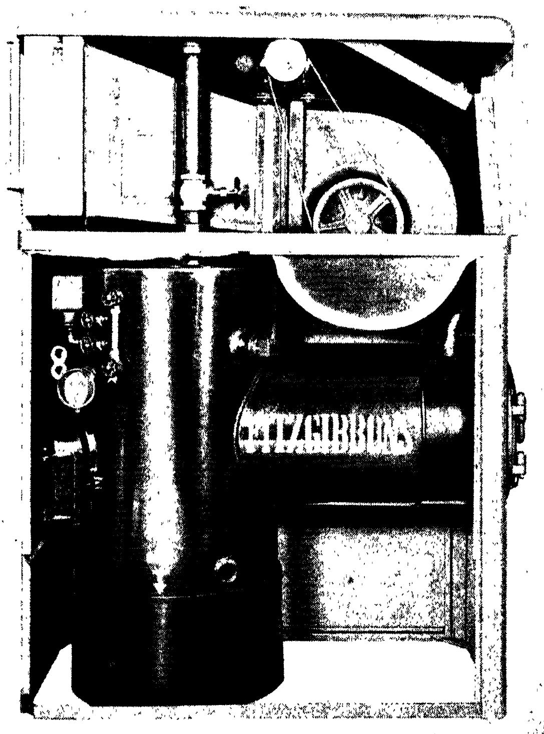


Fig. 148.—Winter air conditioner, stoker, oil, or gas fired. (*Fitzgibbons Boiler Company, Inc.*)

c. Oil-burner furnace—Fig. 149.

d. Oil-burner boiler—Fig. 150.

e. Gas-burner furnace—Fig. 151.

f. Gas-burner boiler—Fig. 152.

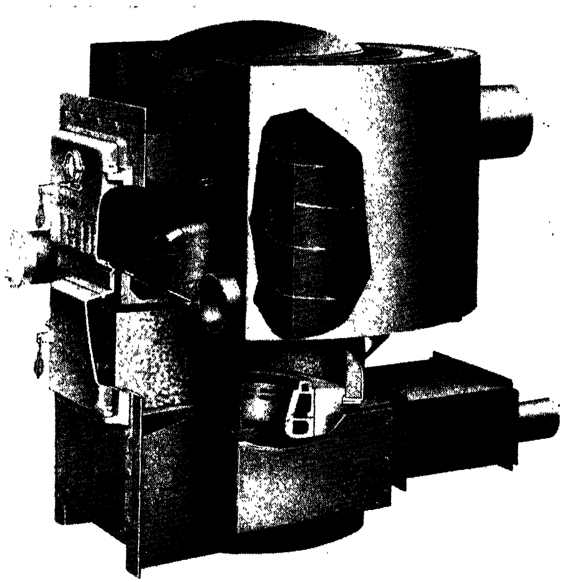


FIG. 149.—Stoker-furnace element. (*American Radiator & Standard Sanitary Corporation.*)

FIG. 150.—Iron-fireman "Deluxe Heatmaker" hopper-model stoker installed in warm-air furnace.

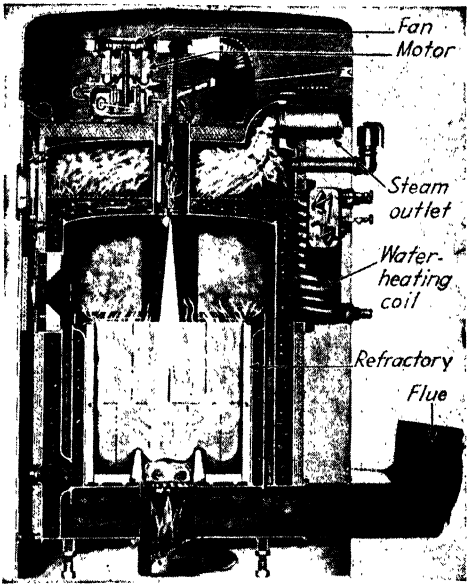


Fig. 151.—Combination oil-burner-and-boiler unit. (*General Electric Company.*)

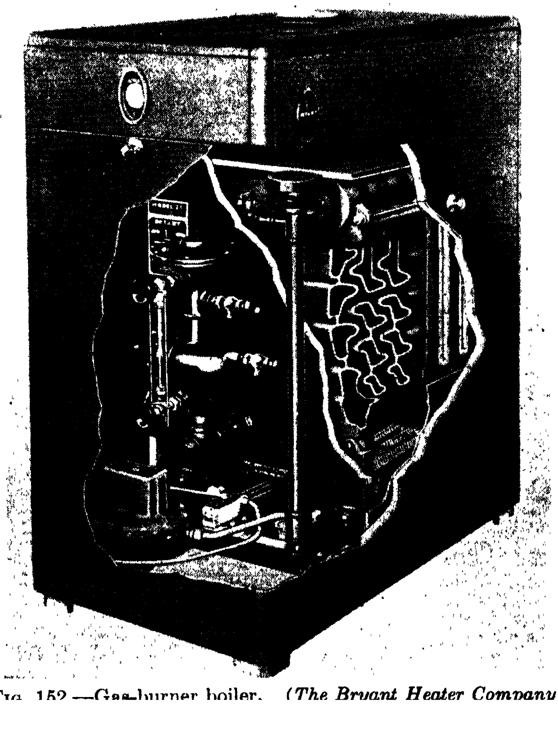


Fig. 152.—Gas-burner boiler. (*The Bryant Heater Company.*)

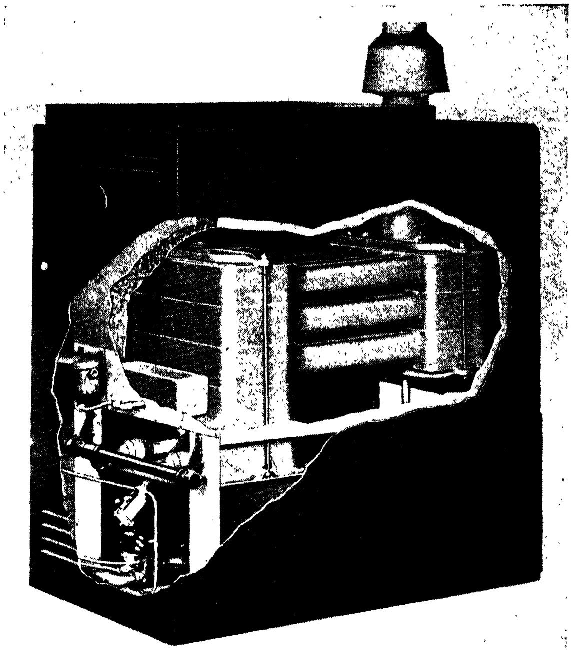


FIG. 153.—Gas-burner warm-air furnace. (*The Bryant Heater Company.*)

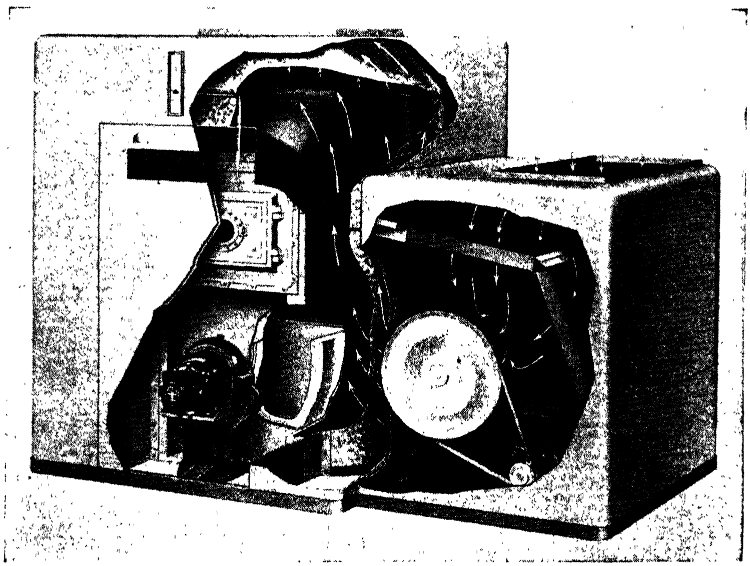


FIG. 154.—Oil-fired winter air conditioner. (*American Radiator & Standard Sanitary Corporation.*)

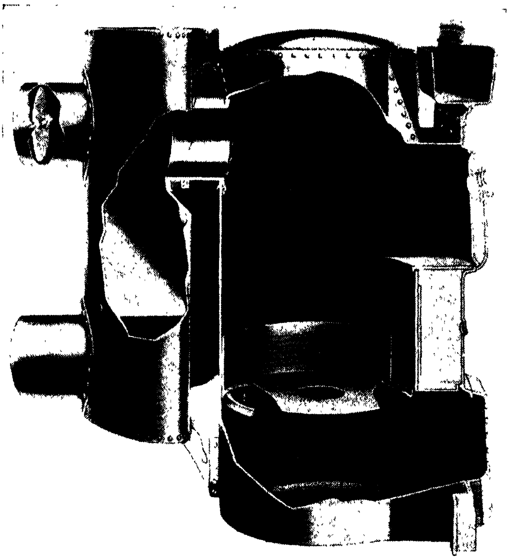
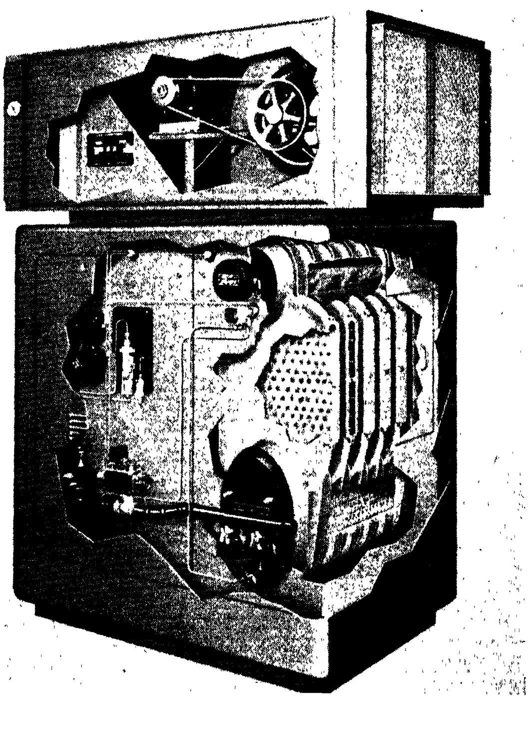


FIG. 155.—Warm-air-furnace element of rotary oil burner. (*American Radiator & Standard Sanitary Corporation.*)



DIVISION IV. COOLING AND DEHUMIDIFICATION

1. Refrigeration. It is suggested that sections 26 to 36, under Refrigeration, in Chap. III, on Heat, be reviewed.

2. Cooling. Cooling may be defined as the extraction of sensible heat from—*i.e.*, the lowering of the temperature of—a substance like air.

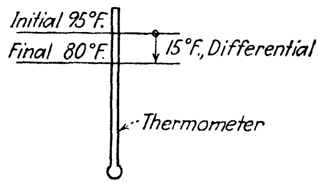


FIG. 157.

3. Dehumidification. Dehumidification may be defined as the extraction of latent heat from—*i.e.*, the lowering of the moisture content (humidity) of—a substance like air.

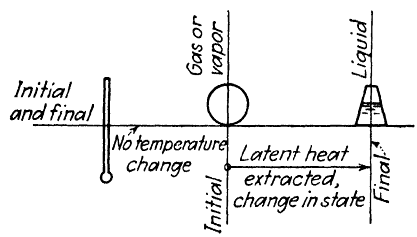


FIG. 158.

4. Load. The cooling and dehumidification load from Chap. VII, Division IV, section 32, is made up from the heat gain due to

a. Heat transmission *c.* Occupants *e.* Appliances
b. Solar radiation *d.* Infiltration

5. Cooling Methods. Cooling may be accomplished by

a. Surface cooling *b.* Spray cooling *c.* Evaporative cooling

6. Moisture Relations. Warm, partly saturated air may be cooled down to the dew point by extracting sensible heat. When cooled below the dew point, both sensible and latent heats are extracted and dehumidification accompanies cooling. Either of these conditions may be accomplished by surface cooling or spray cooling.

Warm, relatively dry air may be cooled down to the wet bulb by extracting sensible heat through humidification. The latent heat of evaporation required to vaporize the moisture of humidification is furnished by the air itself, the sensible heat being extracted from the air and converted to latent heat, with a resultant lowering of air temperature and an increase in air humidity. This condition may be accomplished by evaporative cooling.

7. Surface Cooling. In the surface cooling, the air to be cooled passes over the surface of cold metal. The cooling

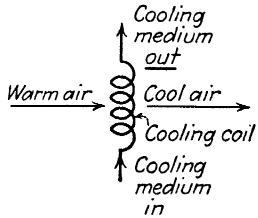


FIG. 159.

medium passes through the metal coil, while the air passes around the outside of the coil. Fig. 159.

8. Spray Cooling. In spray cooling, the air to be cooled passes through a spray of cold water. The dry bulb of the air

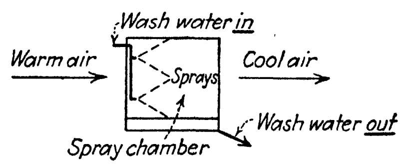


FIG. 160.

may be cooled to the wet-bulb temperature until the wet-bulb and dry-bulb temperature are alike. If wash or spray water is colder than this air-saturation or dew-point temperature, dehumidification also may be accomplished. Fig. 160.

9. Evaporative Cooling. In evaporative cooling, as in spray cooling, the air to be cooled passes through a spray of water. The air may, by humidification, be cooled to the wet-bulb temperature until the wet-bulb and dry-bulb temperatures are alike. This is known as an adiabatic saturation or heat transfer; the wet bulb and total heat remain constant, while the dew point rises and the dry bulb falls until they, as a maximum, reach the wet-bulb temperature.

10. Dehumidification Methods. Dehumidification may be accomplished by

a. Condensation *b.* Desiccation

11. Condensation. Dehumidification, as condensation, may be accomplished (usually concomitant to cooling) by

a. Surface cooling *b.* Spray cooling

The surface and the spray dehumidification are accomplished as in cooling.

12. Desiccation. Desiccation is the removal of moisture from a substance, like air. In air conditioning this is accomplished by

a. Adsorption *b.* Absorption

13. Adsorption. From a dehumidification standpoint, adsorption is the adhesion of the molecules of water vapor from air to the surfaces of solid bodies (called adsorbents) resulting in the

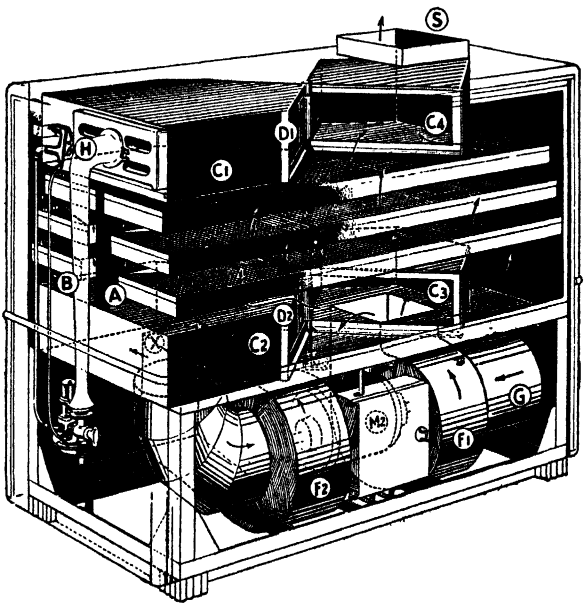


FIG. 161.—Cut-open view of silica-gel unit. (*The Bryant Heater Company.*)

concentration of the water vapor at the place of contact with the adsorbent and a reduction of the water vapor.

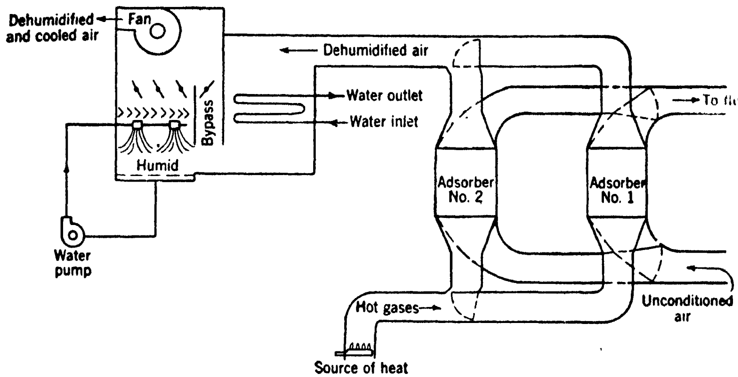


FIG. 162.—Open solid-material adsorption system. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 24.)

14. Adsorbents. The most frequently used and best known adsorbents used in air conditioning are "activated alumina," also known as aluminum oxide or alumina, and "silica gel," also known as silicon dioxide or silica.

15. Absorption. From a dehumidification standpoint, absorption is the migration of the molecules of water vapor from air

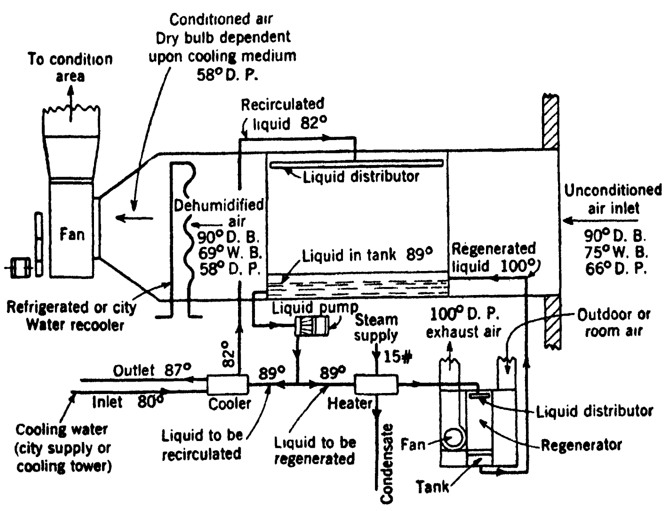


FIG. 163.—Diagram of lithium chloride absorption system. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 24.)

into a concentrated or partly concentrated brine, resulting in a dilution of the brine and a reduction of the water vapor in the air.

16. Absorbents. The most frequently used and best known absorbents used in air conditioning are ammonia, calcium chloride, and lithium chloride brines (solutions).

17. Comparisons. Adsorbents may be considered as solids and absorbents as liquids. Both can be rejuvenated and used over and over.

18. Heat of Desiccation. When water vapor is adsorbed or absorbed, the heat of vaporization or evaporation of the water vapor is released and, with the heat of mixing, increases the sensible heat of the desiccated or dried air. For comfort purposes desiccated air has to be cooled to a dry-bulb temperature within reasonable relation to the desired effective temperature.

19. Refrigeration. Surface and spray cooling may be accomplished by the use of water, ice, or volatile liquids, called refrigerants. Cold water may be produced from natural wells or melting ice, or by refrigeration.

20. Refrigeration with Water-cooling Coils. This is one of the surface-cooling methods. The sensible or latent heat (or both) passes from the air through the pipe coil into the water. All things being equal, more refrigeration may be effected by this method than by spray cooling, because of the greater temperature differential between the cooled air and the cooling water.

With a water-cooled coil, the temperature differential between the air and the water is the difference between the dry bulb of the air and the average water temperature.

With a spray cooler, or washer, the temperature differential between the air and the water is only the difference between the wet bulb of the air and the average water temperature.

The heat (sensible, latent, or both) that can be removed from air by a water-cooled coil depends upon

a. Area of the pipe and extended surfaces or fins
b. Mean temperature difference between the air and the water
c. Velocity of air over the cooling coil

Because air enters a cooling coil at a higher initial and leaves at a lower final temperature, and the cooling water enters the coil at a lower initial and leaves at a higher final temperature, the mean temperatures of both are used (as stated in *b* above).

d. Heat-transfer coefficient. The heat-transfer coefficient is rated as B.t.u. per square foot of cooling surface per degree Fahrenheit mean temperature difference, and depends upon

1. Air velocity over the coil
2. Water velocity through the coil
3. Material of which the coil is constructed
4. Surface character of the coil material

21. Refrigeration with Ice. The two methods used in refrigeration with ice for air conditioning are

a. Direct
b. Indirect

In the direct method, air is passed over the ice; the ice, at 32 degrees Fahrenheit, melts and the required latent heat of

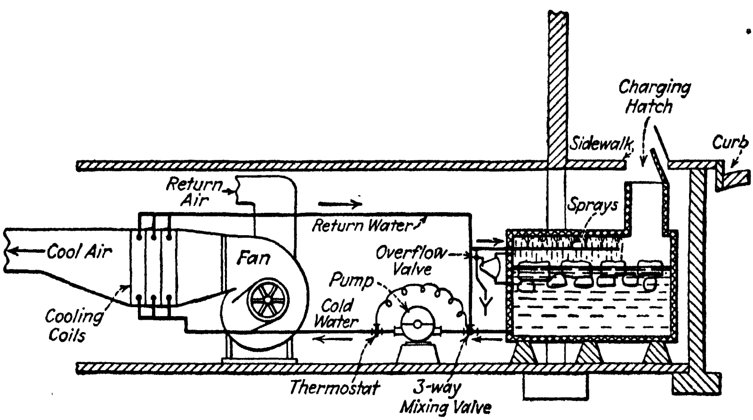


FIG. 164.—Cooling system using ice. (*Allen and Walker, Heating and Air Conditioning.*)

fusion of the ice extracts 144 B.t.u. from the air for each pound of ice melted.

In the indirect method, water is passed over the ice; the ice, at 32 degrees Fahrenheit melts and the required latent heat of fusion of the ice extracts 144 B.t.u. from the cooling water for each pound of ice melted. The cooled water is then circulated through water cooling coils, as described in section 20, and recirculated back to the ice tank for recooling. Fig. 164.

22. Refrigeration with Water Spray. Spray cooling and spray dehumidification may be effected by passing air through a water spray. If the spray water is not cooled but recirculated, the wet-bulb temperature and total heat of the air will be constant. The dry-bulb temperature will decrease and the dew-point temperature will increase, as in evaporative cooling (by humidification), until equilibrium is found at the wet-bulb temperature (which is the final dew point). Fig. 184.

But, if the spray water is cooled and recirculated and recooled, the wet-bulb temperature and total heat will theoretically first remain constant until the dew point, dry-bulb temperature, and wet-bulb temperature are alike; then the dry-bulb, wet-bulb, and dew-point readings will drop along the saturation line to a lower point, a few degrees above the temperature of the cooled spray water (dependent upon the spray, efficiency, time, air, velocity, etc.). Fig. 184.

This type of cooling and dehumidification is accomplished in washers that may also be used for winter humidification, particularly in large central systems, but the surface cooling method is the more frequently used.

23. Refrigeration with Volatiles. Probably the most common and popular method of effecting refrigeration is the more extensive use of volatile liquids, called refrigerants. The outstanding value of these refrigerants is that they can be used and reclaimed over and over again. Except for mechanical losses, these volatile liquids may be completely reclaimed in a perpetual series of operating cycles.

24. Refrigerants. Refrigerants are volatile liquids that will evaporate, compress, and condense within reasonable working temperatures and pressures. Those used in refrigeration for air conditioning, cooling, or dehumidification have been selected because of their

a. Availability
b. Cost
c. Safety
d. Stability
e. Adaptability

Some of the popular refrigerants are

a. Ammonia
b. Carbon dioxide
c. Dichlorodifluoromethane (F_{12})
d. Methyl chloride
e. Water
f. Monofluorotrichloromethane (F_{11})

25. Mechanical Refrigeration. Fundamentally, mechanical refrigeration comprises

a. An evaporator, or heat extractor
b. A refrigerant compressor
c. A condenser, or heat disposer

Since cooling and dehumidification are the extraction of sensible or latent heat (or both) from air, this heat must be extracted and disposed of in a continuous, efficient manner.

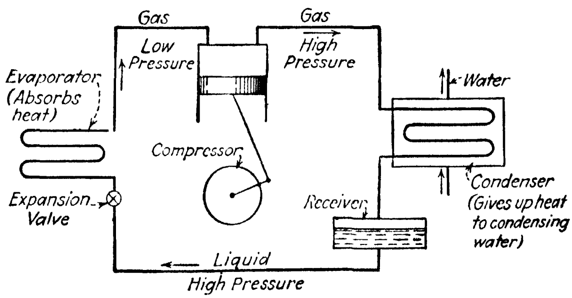


FIG. 165.—Compression-refrigeration cycle. (*Allen and Walker, Heating and Air Conditioning.*)

In mechanical refrigeration, the liquid refrigerant under relatively high pressure is allowed to expand (through an expansion valve) into the evaporator, or heat extractor. The sensible or latent heat (or both) in the air furnishes the heat of vaporization or evaporation, and the volatile liquid evaporates into the vapor or gaseous state of the refrigerant. The air has lost heat, and the refrigerant has gained it. This, as described, is a direct expansion system. Fig. 165.

In a majority of cases, for several reasons—chiefly because of refrigerant characteristics, safety measures, economy, and code requirements—the air does not pass over the direct-expansion coil.

Instead, water or some other cooling medium flows around the expansion coil, evaporator, or heat extractor (also referred to as heat exchanger) and is cooled. The cooled water, or other cooling medium is then pumped to a surface cooling coil or to a spray cooling chamber. The pressure and temperature (boiling point) of the refrigerant must be reduced below the temperature of the air, water, or other cooling medium, within the evaporator or extractor. The gaseous refrigerant, now at lower pressure but with a higher heat content, due to the heat extracted from the air (or other cooling medium), is pulled by the suction of a compressor (pump) into the compressor.

In the compressor the low-pressure gaseous refrigerant is compressed back to near its original higher pressure, but in this process the heat of compression is added to the gas (which already has the heat of extraction). The compressed hot gaseous refrigerant is forced into a condenser or heat disposer (which may be air cooled or water cooled). Other cooling mediums are sometimes used.

In the condenser, or heat disposer, the heat of extraction and the heat of compression are disposed of by passing through the walls of the condenser pipes, coils, or tubes, into the cooling medium of water, air, or the like. The water or the air used for disposing of the heat from the condenser is itself disposed of in an economical manner.

It will be observed that in mechanical refrigeration for air conditioning the refrigerant is always in one of two conditions, *i.e.*, a high-side pressure or temperature and a low-side pressure or temperature. The expansion valve is the dividing line between the two sides and the two sides are mechanically changed as to temperature and pressure at the compressor.

Also, the changes of state of the refrigerant take place at the evaporator, or heat *extractor*, where it is changed from a liquid to a gas, and at the condenser, or heat *disposer*, where it is changed back from a gas to a liquid. Fig. 165.

26. Steam-jet Refrigeration. Since all volatile liquids boil at lower temperatures when subjected to lower or reduced pressures, water will vaporize at a lower temperature under a reduced pressure or high vacuum.

Where high-pressure steam and plenty of condenser water are economically available, the steam-jet refrigerator, or water cooler, may be justified in air conditioning.

High-pressure dry saturated steam is fed into the ejector and through the booster to the surface condenser, where it is con-

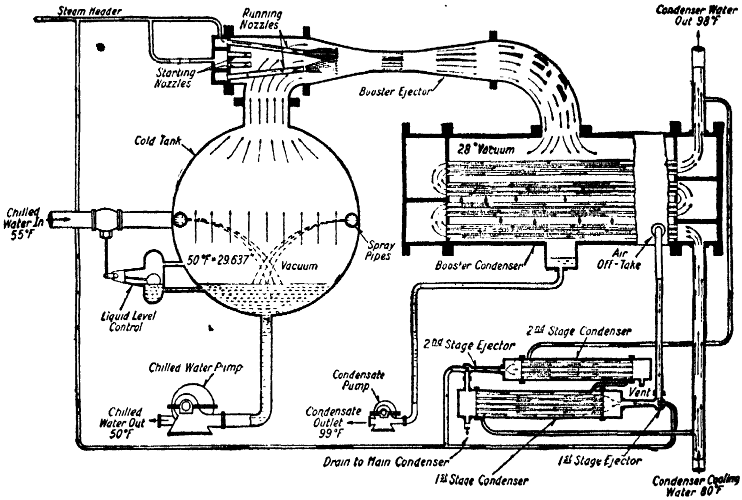


FIG. 166.—Diagram of steam-jet system. (*Westinghouse Electric and Manufacturing Company.*)

densed, producing a high vacuum in the evaporator. Water in the evaporator boils, under this high vacuum, at a low temperature (about 50 degrees Fahrenheit). The heat required to evaporate the water vapor comes from the water itself, with a resulting cooling of the water down to this boiling point. The water, cooled to about 50 degrees Fahrenheit is pumped from the evaporator to a surface cooling or spray cooling system for the summer conditioning of air. Fig. 166.

27. Compressors. Those compressors generally used in refrigeration for summer air conditioning are

a. Reciprocating
b. Centrifugal
c. Rotary
d. Steam jet

Reciprocating compressors, either vertical or horizontal are usually employed with low pressure refrigerants such as

a. Dichlorodifluoromethane (F_{12})
b. Monofluorotrichloromethane (F_{11})
c. Methyl chloride
d. Ammonia
e. Sulphur dioxide

Centrifugal compressors are generally used with

a. Monofluorotrichloromethane
b. Methylene chloride
c. Water vapor

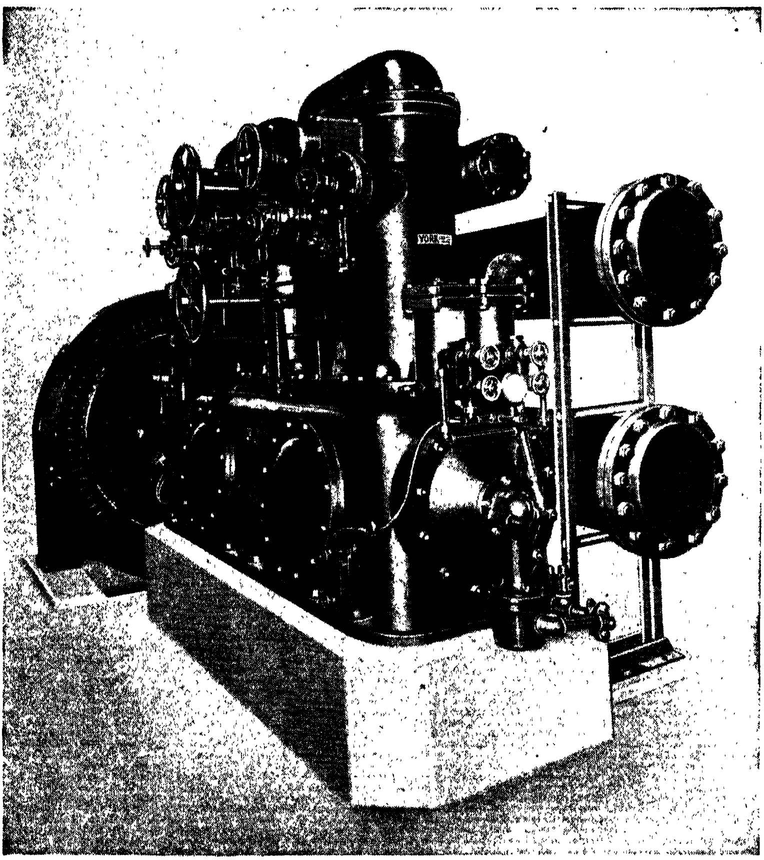


Fig. 167.—Large reciprocating condensing unit. (*York Ice Machinery Corporation.*)

Rotary compressors are not to be confused with centrifugal compressors. They are grouped into four classifications, viz:

a. Centrifugal rotary
b. Eccentric
c. Gear
d. Blade

and are being developed for use over a wide range of refrigerants.

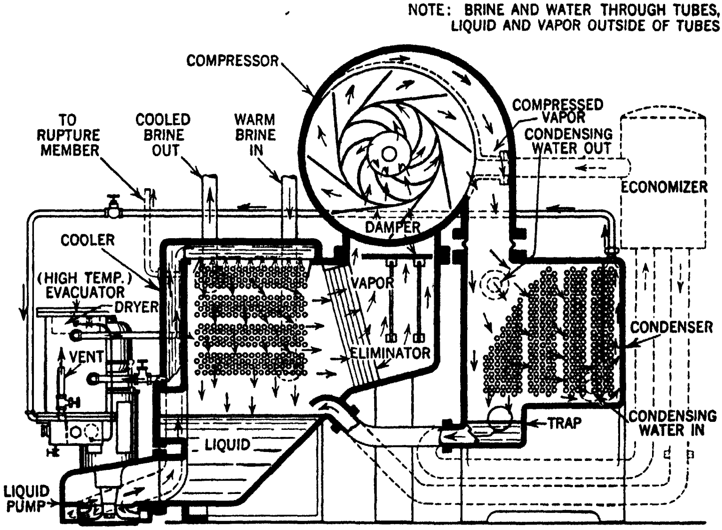


FIG. 168.—Centrifugal refrigerating unit (section). (*Carrier Corporation.*)

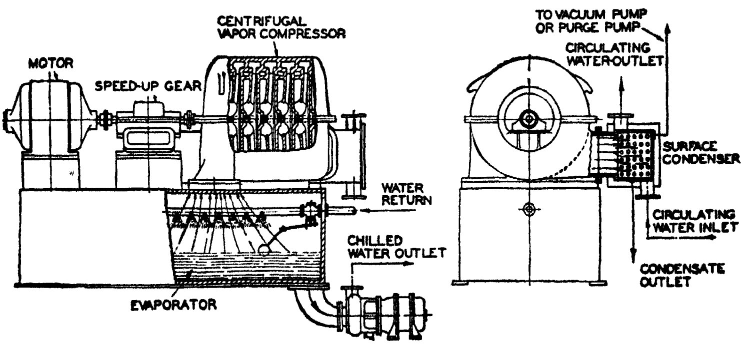


FIG. 169.—Centrifugal refrigerating unit using water vapor. (*Ingersoll Rand Company.*)

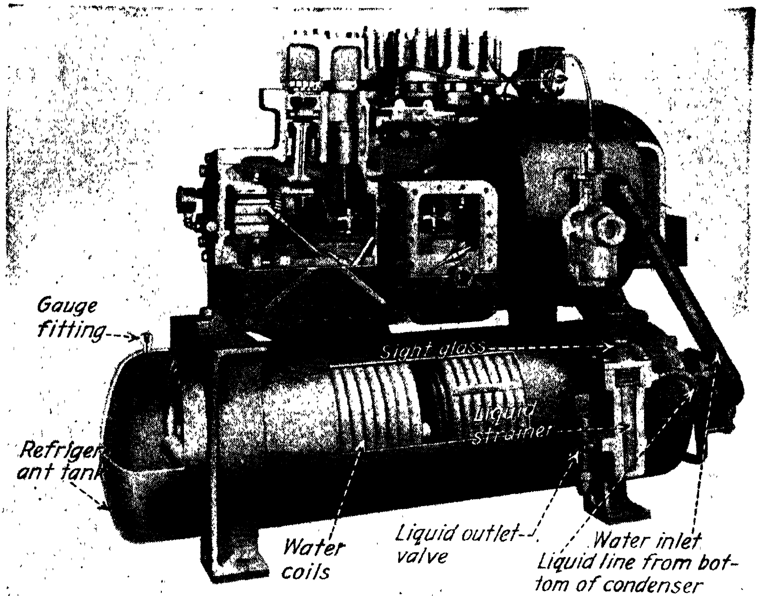


FIG. 170.—Condensing unit using coiled-tube and shell-type condenser. (*Westinghouse Electric and Manufacturing Company.*)

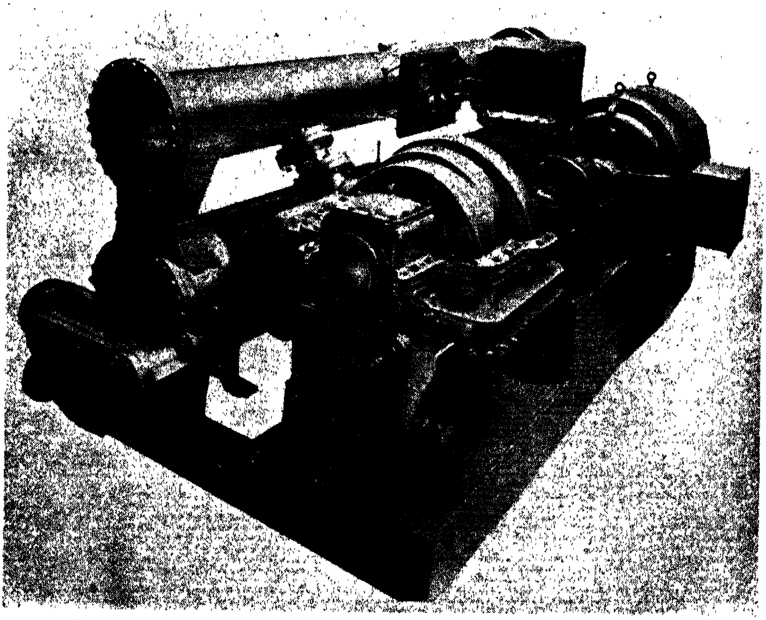


FIG. 171.—Centrifugal refrigeration unit. (*Carrier Corporation.*)

28. Cooling Coils. Cooling coils are classified as

a. Direct
b. Indirect

When the refrigerant is expanded and evaporated on one surface of the cooling metal or coil and the air is cooled or dehumidified (or both) on the other side of the same metal, the evaporator is known as a direct-expansion cooling coil.

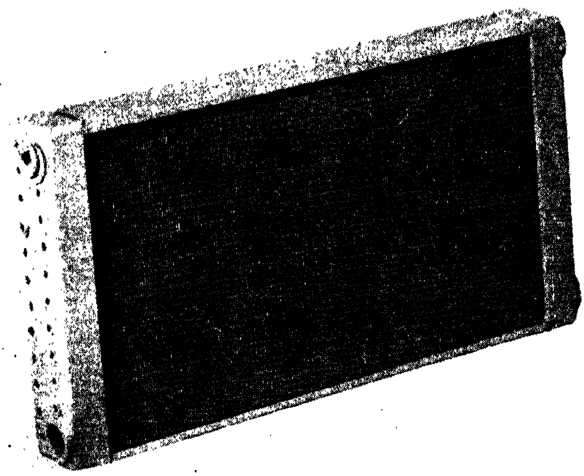


FIG. 172.—Cooling unit built especially for the circulation of water or brine. (*Young Radiator Company.*)

When cold water or brine is circulated on one surface of the cooling metal or coil and the air is cooled or dehumidified (or both) on the other side of the same metal, the heat exchanger is known as an indirect cooling coil.

29. Evaporators. Evaporators may be classified as direct expansion, because a refrigerant is always expanded and evaporated on one surface of the coil.

When the refrigerant is on one side and the cooled or dehumidified air is on the other side of the metal coil, the evaporator is the same as a direct-expansion cooling coil. But when the refrigerant is on one side and a cooling medium, like water or brine, is on the other side of the metal coil, the evaporator is like a heat exchanger and not like a direct-expansion cooling coil for air

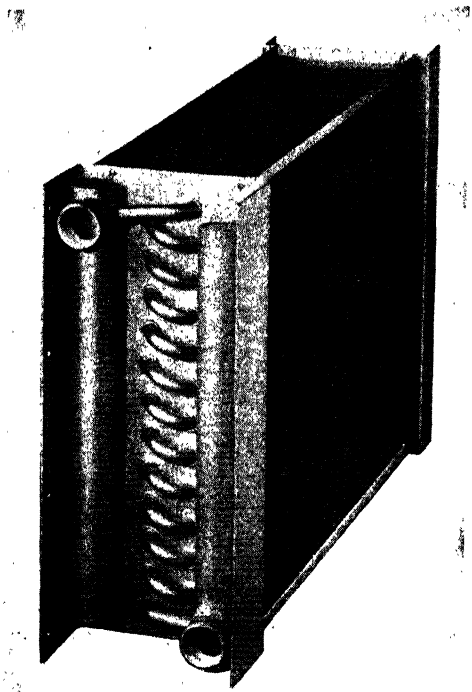
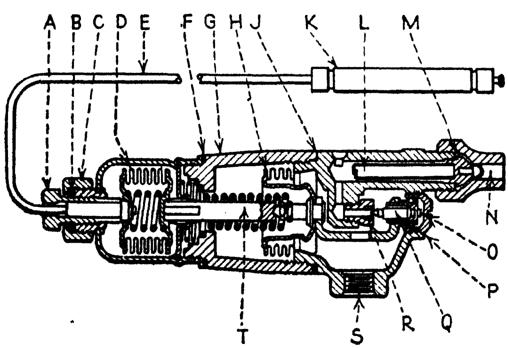


FIG. 173.—Extended-surface cooling unit made from copper fins, copper tubes, copper headers, and a steel frame. (*Young Radiator Company.*)



A Adjusting screw
B Moisturetight packing around adjusting screw
C Packing nut
D Thermostatic power element
E Flexible capillary tube
F Moisturetight joint
G Bakelite extension
H Bellows seal
J Moisturetight joint
K Thermostatic bulb
L Strainer screen
M Copper gasket
N Inlet connection for ¼-in. copper tube
O Needle swivel
P Solder-sealed plug
Q Stainless-steel needle
R Stainless-steel seat
S Outlet connection
T Bakelite push rod

FIG. 174.—Cross-sectional view of a thermostatic expansion valve. (*Detroit Lubricator Co.*)

cooling. The cooling medium is pumped to an indirect cooling coil or heat exchanger, where the air is cooled or dehumidified.

30. Condensers. Condensers may be cooled by water or by air.

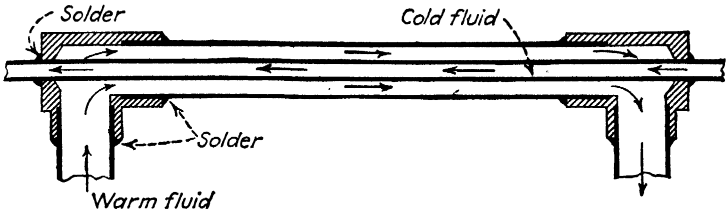


FIG. 175.—Simple counterflow heat exchanger. (*Holmes, Air Conditioning in Summer and Winter.*)

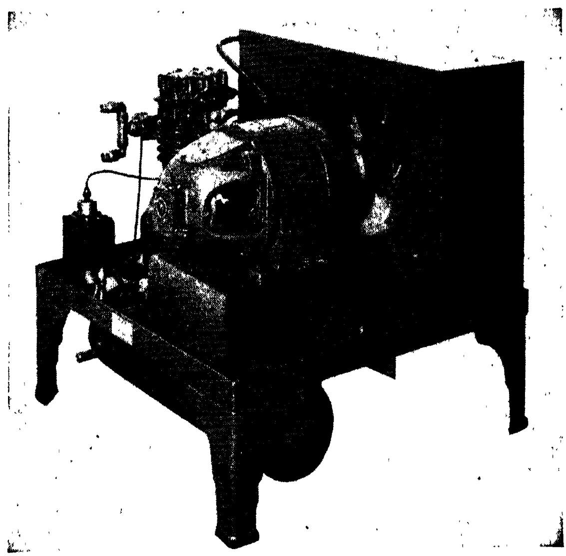


FIG. 176.—Condensing unit with air-cooled condenser and fan. (*Westinghouse Electric and Manufacturing Company.*)

Water-cooled condensers are usually of the double-pipe or the shell-and-tube type. In the double-pipe type, the condenser water passes through the inner pipe and the refrigerant within the concentric annular ring between the two pipes.

Better efficiencies and effects are obtained by counterflow of the water and the refrigerant. In the shell-and-tube type, the water flows through the tubes and the refrigerant flows around the tubes and within the shell.

Air-cooled condensers are sometimes used on small-tonnage units (usually under three tons) when cooling or condensing water is economically or practically prohibited. In the air-

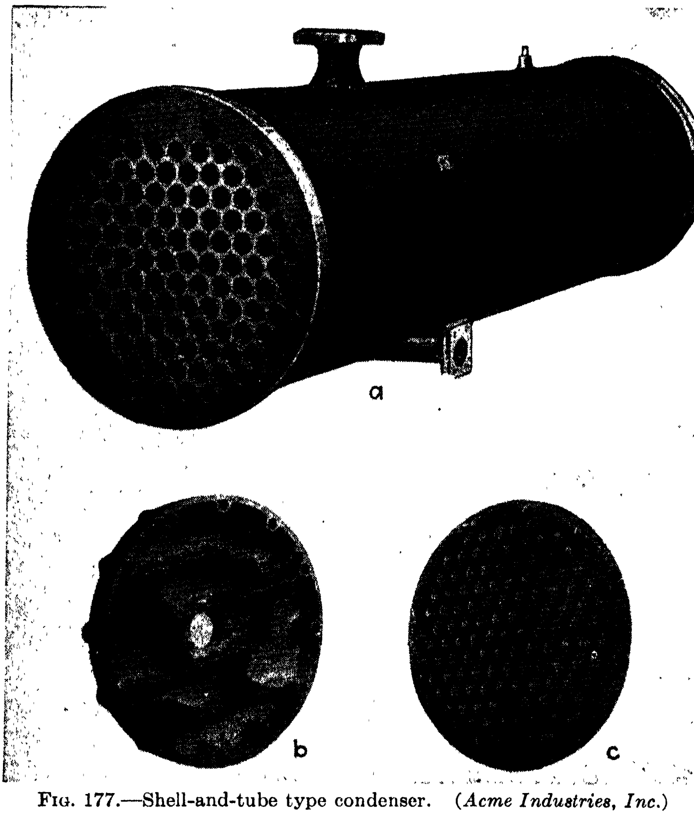


FIG. 177.—Shell-and-tube type condenser. (*Acme Industries, Inc.*)

cooled condenser, the refrigerant flows through the coil (usually an extended-surface type) and air is blown over the coil surfaces. They are practically the reverse of an air-cooling or dehumidifying coil.

31. Evaporative Condensers. Where natural and satisfactory well water is not available or reliable, or where city water is

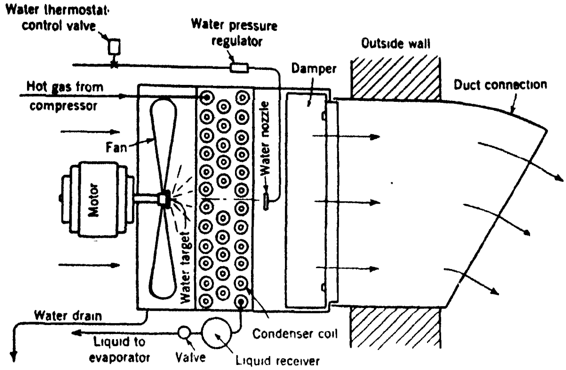


FIG. 178.—Diagram of evaporative condenser. (*From Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 24.)

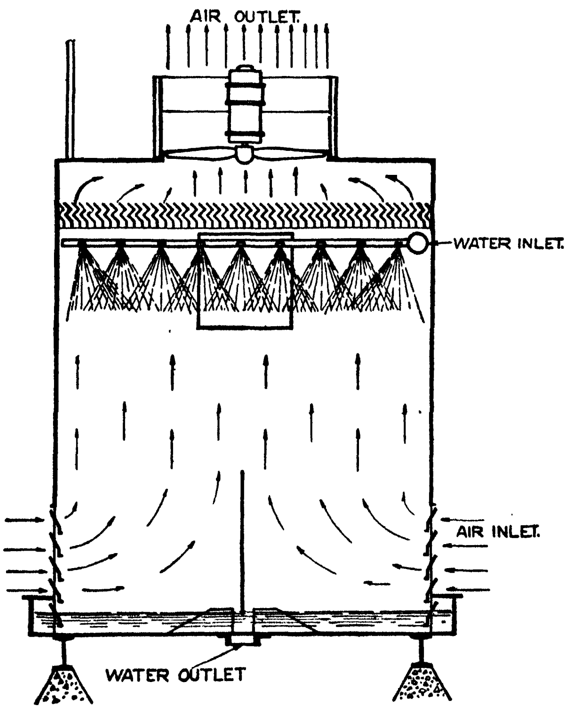


FIG. 179.—Mechanical-draft cooling tower. (*Binks Manufacturing Company.*)

prohibitive because of cost, ordinance, unreliability, or unavailability, evaporative condensers may be used to good operating and economic advantage.

FIG. 180.—An outdoor spray-cooling pond. (*Binks Manufacturing Company.*)

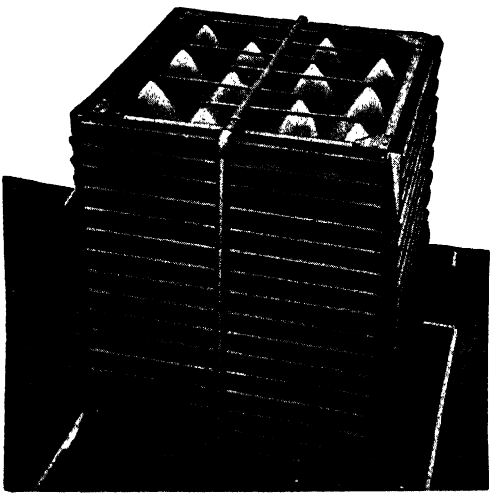


FIG. 181.—Atmospheric cooling tower. (*Binks Manufacturing Company.*)

32. Closed Absorption System. Certain refrigerants may be absorbed by affinitive absorbents. Such a refrigeration system is classified as a refrigerant-absorbent or closed absorption system. Although several such refrigerant-absorbent combinations are known, the practical one, capable of use in air conditioning, is the ammonia-water combination. The advantage, if any, of this system is the lack of moving parts, except for

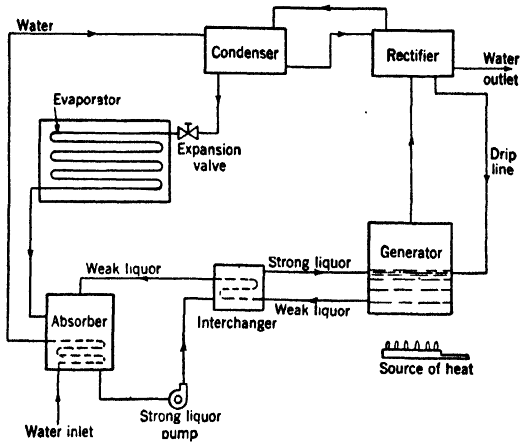


FIG. 182.—Closed absorption system. (*Heating Ventilating Air Conditioning Guide* 1938, *Chapter* 24.)

pumps. The system is best described in the accompanying diagrammatic illustration. Fig. 182.

33. Washers. Washers have been described in previous divisions and sections.

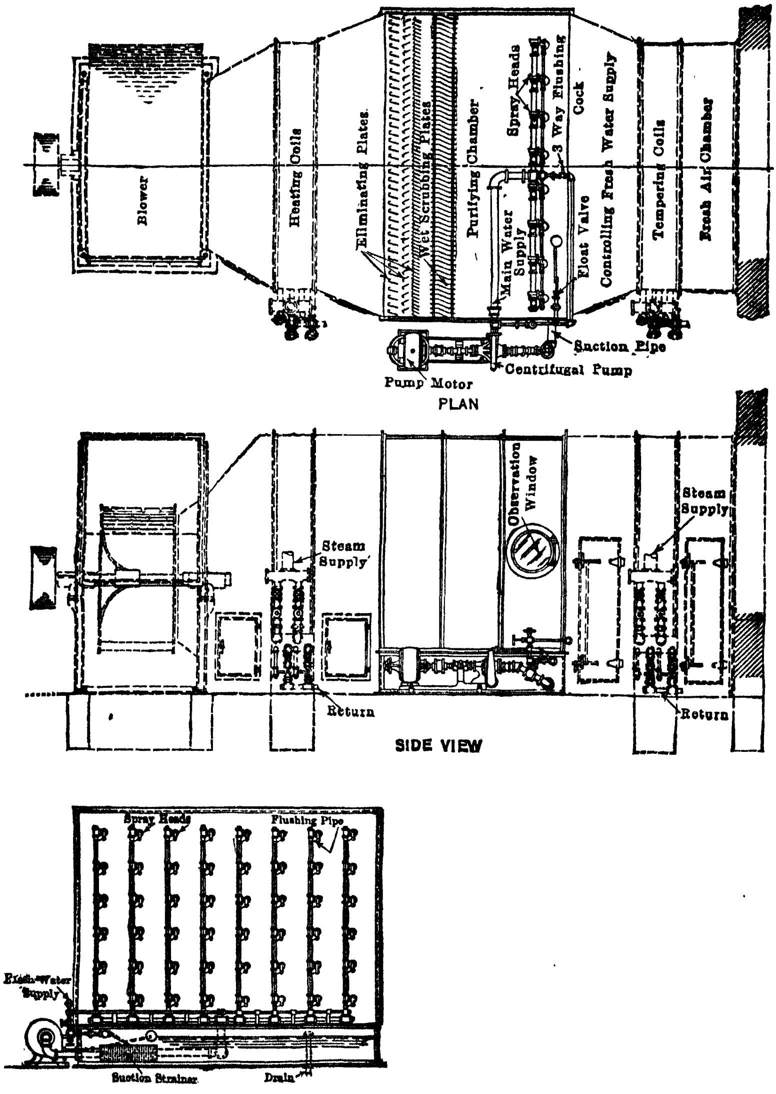
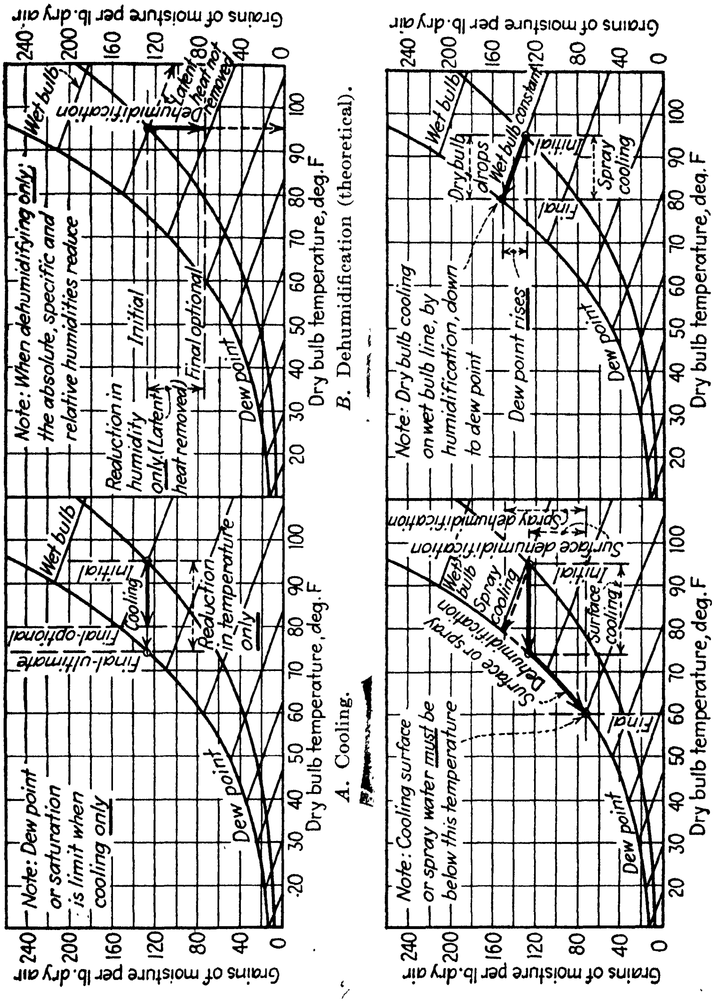


FIG. 183.—Air washer. (*Allen and Walker, Heating and Air Conditioning.*)



A. Cooling.

B. Dehumidification (theoretical).

C. Cooling and dehumidification.

D. Cooling by humidification.

FIG. 184.

DIVISION V. HUMIDIFICATION

1. Humidification. Humidification (the adding of moisture to the air) is a seasonal requirement of air conditioning. In the winter the outside air, because of its lower temperature, has very low absolute or specific humidities. When it is introduced into the enclosure or house as heated air, the relative humidity is very low, introducing conditions unfavorable to olfactory and pulmonary organs of the body and to the propagation of body heat, all of which are unfriendly to health, comfort, and convenience.

Winter air should be humidified to bring the relation of the inside temperature and humidity (or the dry- and wet-bulb temperatures) within the accepted effective temperatures and comfort conditions for winter operation.

It has been shown in Division IV of this chapter that humidification may be used to effect cooling, through so-called evaporative cooling.

2. Heat Relation. When air is humidified, the heat of vaporization must be added. This heat may be added to the spray water before actual humidification or it may be the sensible heat from the air transformed to the latent heat of evaporation or humidification.

3. Humidifiers. Humidifiers, for the adding of water vapor to air, may be classified as

a. Direct—spray into the room
b. Indirect—introducing moistened air
c. Combined

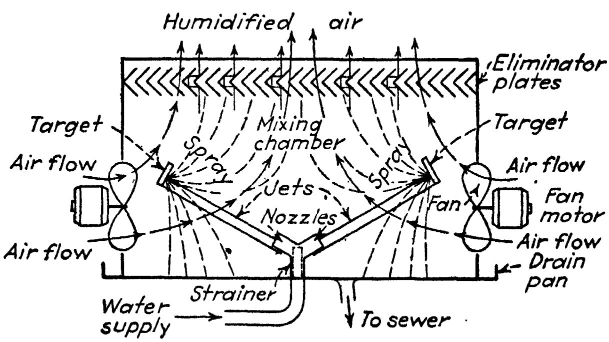


FIG. 185.—Impact humidifier nozzles in an air conditioner. (*Westinghouse Electric and Manufacturing Company.*)

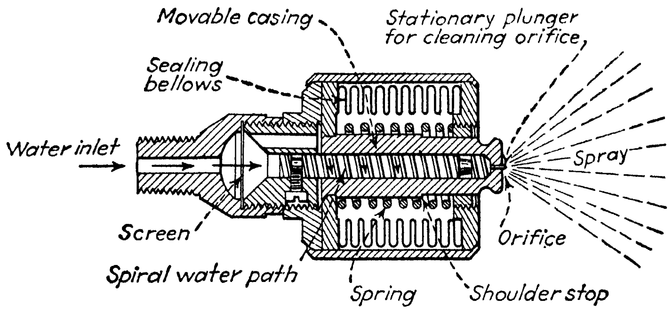


FIG. 186.—Self-cleaning hydraulic-separation humidifier nozzle. Nozzle is shown in "off" position. When water pressure is turned on, movable casing is forced out against shoulder and orifice is opened. When water pressure is again turned off, casing recedes and plunger cleans orifice. (*Rega Manufacturing Company.*)

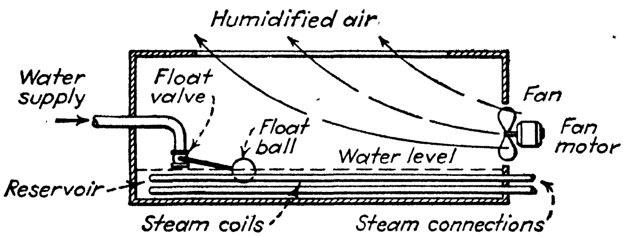


FIG. 187.—Forced-evaporation humidifier. (*Holmes, Air Conditioning in Summer and Winter.*)

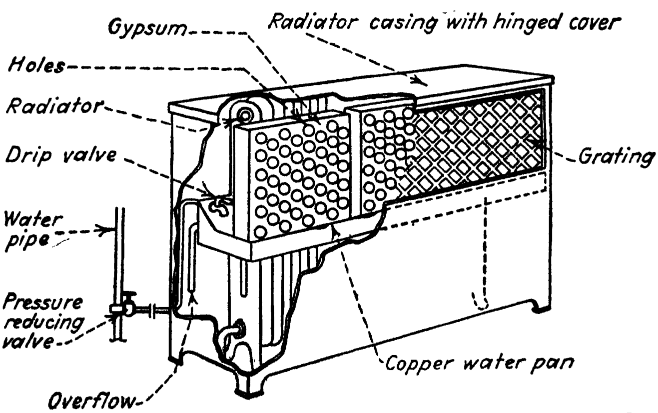


FIG. 188.—Capillary-type humidifier. (*Blom-Gamarra Humidifier, Inc.*)

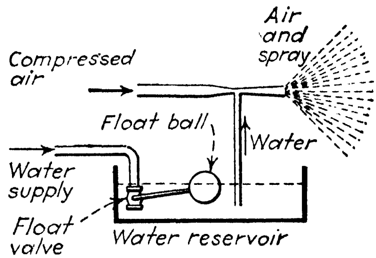


FIG. 189.—Atomization humidifier. (*Holmes, Air Conditioning in Summer and Winter.*)

4. Washers. Washers may be considered in the indirect class of humidifiers or dehumidifiers. The humidification of air

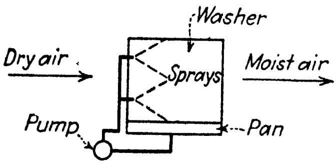


FIG. 190.

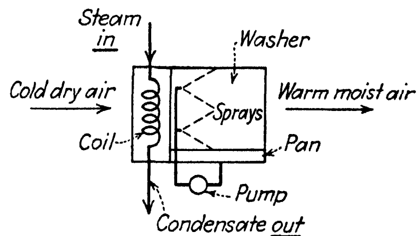


FIG. 191.

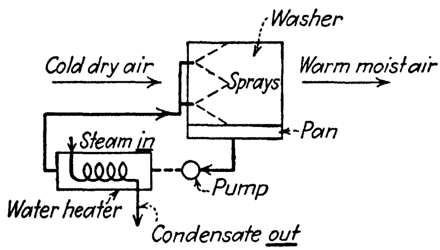
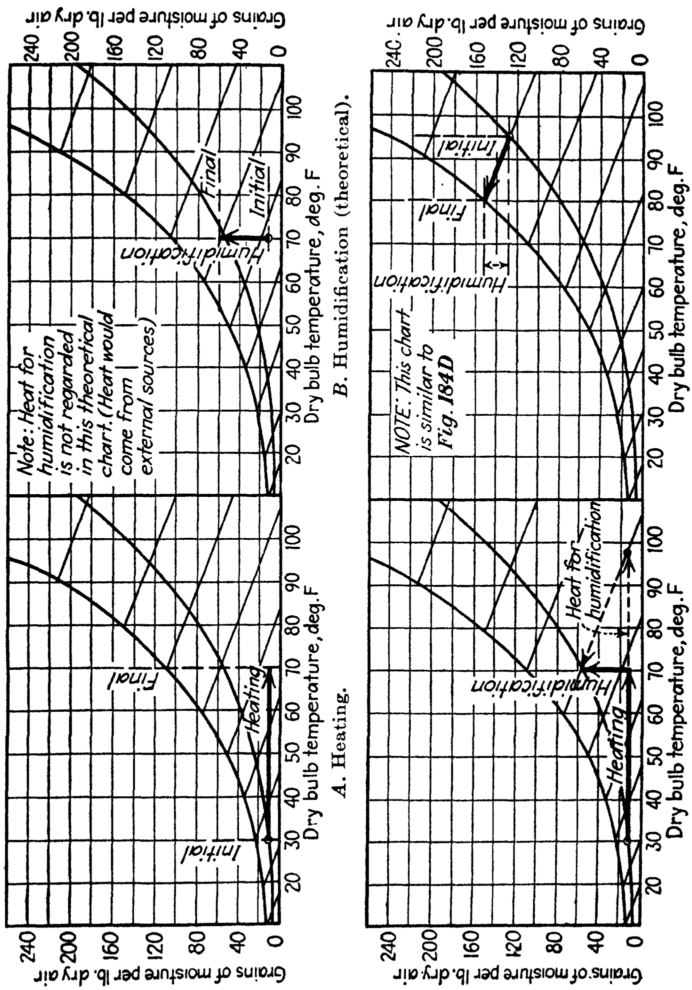


FIG. 192.

within a washer may be effected by

a. Use of recirculated spray water without prior treatment of the entering air—Fig. 190.
b. Preheating the entering air and then washing it with recirculated spray water—Fig. 191.
c. Using heated spray water—Fig. 192.

5. Preheaters and Reheaters. Preheaters are frequently used to increase the dry bulb of the entering air in order that greater humidification may be effected. They are also used to prevent



A. Heating.

B. Humidification (theoretical).

C. Heating and humidification.

D. Humidification (cooling).

FIG. 193.

freezing within the humidifier or washer; air below 35 degrees Fahrenheit should never enter a washer. Fig. 193.

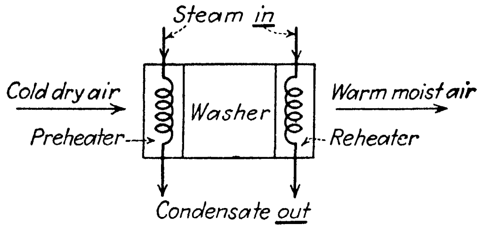


FIG. 194.

Reheaters are frequently used to increase the dry-bulb temperature above the near-dew-point temperature of the leaving air. This may be applied for summer or winter conditioning or for humidification or dehumidification, as conditions require.

DIVISION VI. UNITS

1. Units. In addition to the self-contained and semicontained units described in the general division of this chapter, there are several functional units which fill one or more of the requirements

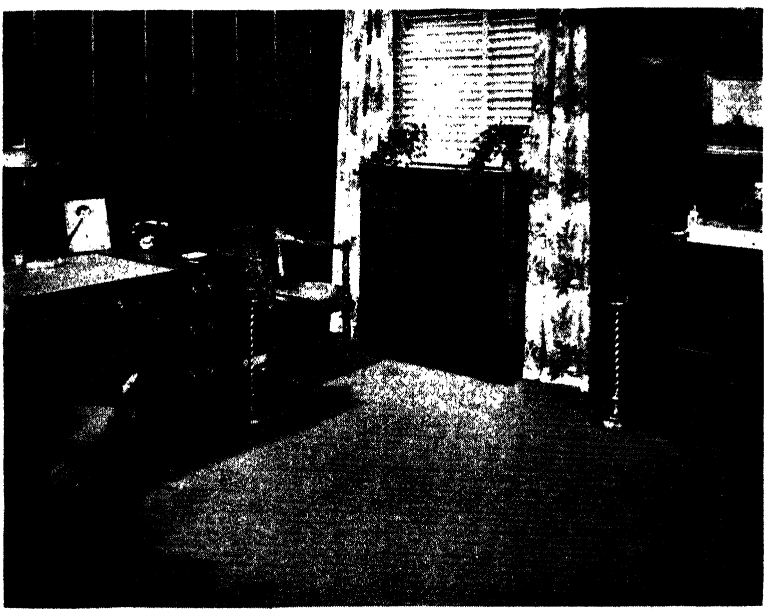


FIG. 195.—Air-cooled summer (unit) conditioner. (*American Radiator & Standard Sanitary Corporation.*)

of air conditioning, and which have a definite place in the practical solution of economic problems, although frequently short

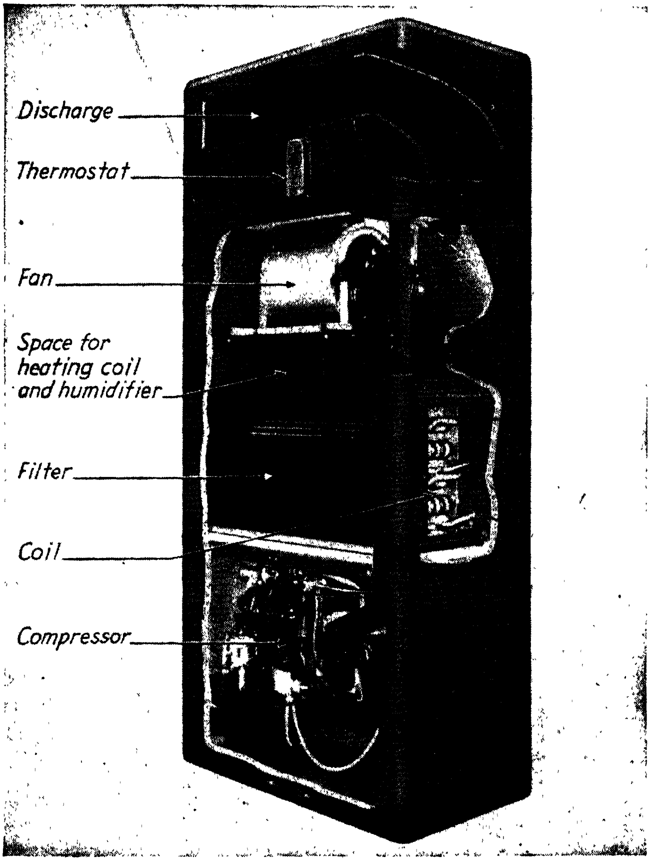


FIG. 196.—Self-contained store-type unit. (*Kelvinator Corporation.*)

of the real meaning of air conditioning. Those units, common to the industry, are

a. Blower (or fan) units
b. Cleaning units
c. Quiet units
d. Unit heaters
e. Unit coolers
f. Unit humidifiers
g. Unit ventilators

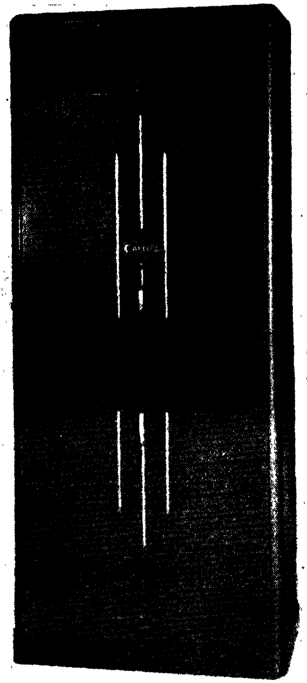


FIG 197.—Water-cooled summer (unit) conditioner. (*Carrier Corporation.*)

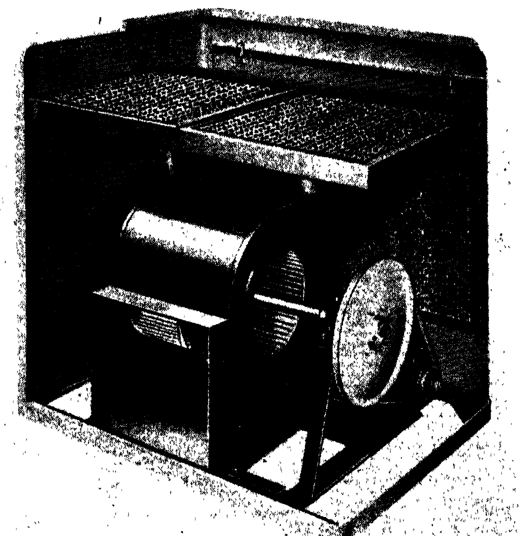


FIG. 198.—Blower filter unit. (*American Radiator & Standard Sanitary Corporation.*)

2. Blower (or Fan) Units. For the supplying, circulating, or exhausting of air from an enclosure, fan or blower units, with or without accessory cleaning devices, are available. They are frequently housed in casings, some of which are styled or finished to fit in with surrounding wall finishes or furnishings.

3. Cleaning Unit. A cleaning unit is generally combined with a blower or fan, and frequently with a silencer, to reduce sound and maintain quiet within the enclosure.

4. Quiet (Sound Reduction) Units. To lower the ingress of outside sound into an enclosure, silencer units, usually provided with blowers or fans and frequently with cleaning devices, are available in casings that are well styled and well finished.

5. Unit Heaters. Unit heaters may best be thought of as mechanical convection heaters. Such a unit comprises a heating

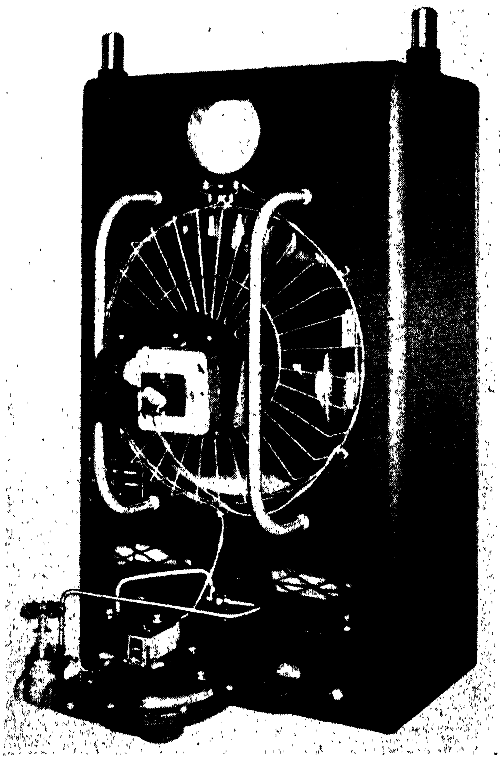


FIG. 199.—Unit gas-fired heater. (*The Bryant Heater Corporation.*)

element and a blower or fan within some form of common enclosure. It is claimed that unit heaters are especially desirable because they

a. Circulate air at a relatively rapid rate without objectionable draft
b. Maintain a more uniform temperature between floor and ceiling, thereby reducing this usually objectionable differential
c. Direct the heated air
d. Reduce the cold air stratum at the floor level
e. Reduce the cost of installation by reducing the number of heaters (compared to radiators and convectors) and the piping
f. Produce economical operation

Obviously, these claims are open to discussion, while their success depends upon application that must come from broad training and experience. It is also to be observed that the physical claims having to do with health, comfort, and convenience may also be obtained with a properly designed central system.

6. Unit Coolers. Unit coolers may best be thought of as mechanical convection coolers. Such a unit comprises a cooling

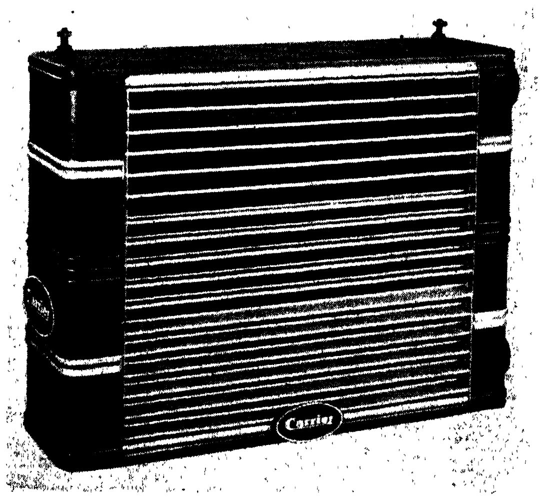


FIG. 200.—Unit cooler. (*Carrier Corporation.*)

element and a blower or fan within some form of common enclosure. Unit coolers are generally similar to unit heaters, except for the use of a cooling instead of a heating element. The cooling element is usually an indirect-type cooling coil using water or the like as a cooling medium, although direct-expansion cooling coil and brine-spray unit coolers are available.

Somewhat similar claims are made for unit coolers as for unit heaters. Unit coolers may also be utilized for the additional attendant dehumidification, but special drip pans and waste lines must be provided, and there is the danger that the water-vapor condensate will be carried by the air discharge into the conditioned space.

7. Unit Humidifiers. There are several types of unit humidifiers for the provision of water vapor or moisture within the

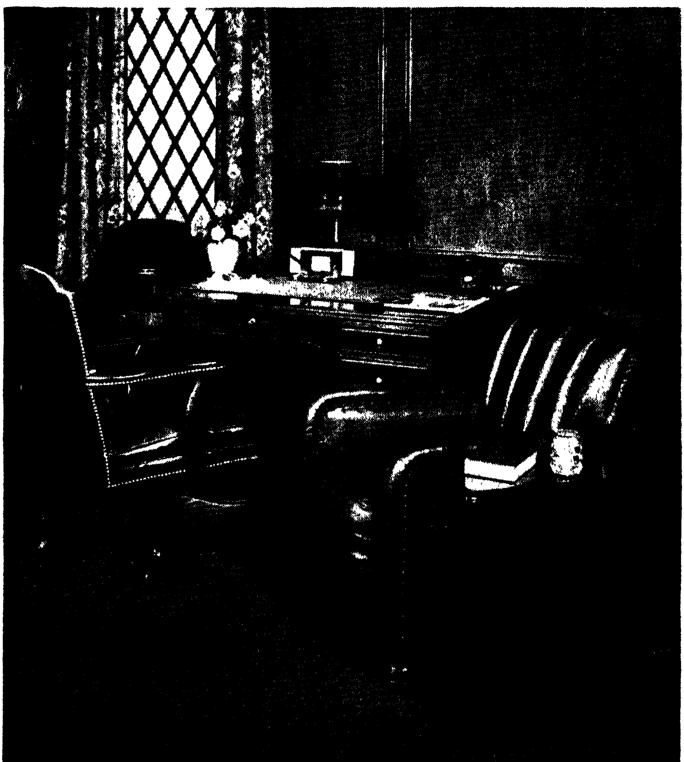


FIG. 201.—Unit humidifier (cabinet type). (*American Radiator & Standard Sanitary Corporation.*)

drier air of an enclosure. They may range from a simple pan or receptacle containing water, to a well-styled, well-finished unit housing a blower or fan, a water receptacle, and a heating element (to provide the heat of evaporation).

8. Unit Dehumidifiers. The use of unit dehumidifiers for comfort alone is rare. They may more generally be considered as adaptable to material processing or preservation, *i.e.*, industrial conditioning. They may be of the surface-cooling type similar to unit coolers, or of the desiccating or drying-agent type.

9. Unit Ventilators. A unit ventilator is usually a winter air-conditioning unit, without the humidifier. It usually com-

FIG. 202.—Unit ventilator with cleaner and silencer. (*American Radiator & Standard Sanitary Corporation.*)

prises a casing that houses a blower or fan and a heating element, together with dampers for the control of the mixtures of outside make-up and inside recirculated air.

10. Unit Conditioners. Unit air conditioners have been described in the general division of this chapter, section 7, under Self-contained System.

DIVISION VII. AUTOMATIC CONTROLS

1. Automatic Controls. Referring to the general division of this chapter, it is observed that Controls heads the list of the functional requirements. It is safe to say that air-conditioning fundamentals depend upon the control of circulating air and what we do to that air.

Controls are not accessories to an air-conditioning system; they are the brain, nerve, and muscle of the system—the thinking and activating part.

2. Requirements. Automatic controls may be required to establish and maintain

a. Conditions
b. Safety
c. Economy

3. Purpose. The prime purpose of automatic controls is to establish and maintain the required functional conditions of an air-conditioning system. The common functional requirements of cleaning and sound control (maintenance of quiet) are either built into the system or manually controlled. The most important common requirement, and the one demanding automatic control, is circulation.

The seasonal requirements of heating, cooling, humidification, and dehumidification all need automatic control.

4. Safety. Safety controls are intended to prevent temperature, pressures, or volumes above or below prescribed limits of safe operation.

5. Economy. Economy controls are intended to prevent the operation of any apparatus beyond the limits required and to save in fuel, power, or the like.

6. Indications vs. Control. The suffix "meter" means to measure or indicate, while "stat" means to control, maintain, or make static (stationary). For example, a thermo *meter* indicates the intensity of heat or temperature, and a thermo *stat* controls the intensity or temperature.

7. Classes. Controls may be thought of as the

a. Thinker (or teller)
b. Helper (or booster)
c. Doer (or operator)

The "thinker," such as a thermostat (corresponding to the human sense of feeling), is sensitive to a change in conditions and tells the "helper" or the "doer" what is needed.

The "helper," such as a relay or a lever, is sensitive to the story told by the "thinker" and, because the "thinker" is sometimes too weak to pass on the story direct to the "doer" or is itself incapable of doing what is needed, the "helper" boosts the weaker signal of the "thinker," so that the "doer" will know what is needed.

The "doer," such as a motor or a solenoid, operates a valve, a damper, or the like, and actually turns on or off the heating or cooling, humidifying, or dehumidifying medium or the air-circulating blower or fan, and does so at the will of the "thinker" and frequently with the aid of the "helper."

8. Systems. Control systems are generally classified as

a. Pneumatic *b.* Electrical
c. Self-contained

9. Functions. Controls are required, automatically to establish and maintain predetermined

a. Temperature *b.* Humidity
c. Air circulation *d.* Pressure

10. Temperature. Temperatures, either winter or summer (as dry-bulb temperatures), are maintained or controlled by thermostats.

11. Thermostats. Thermostats, for the control of dry-bulb temperatures, are available in four different types, *viz.*

a. Bourdon tube *b.* Charged bellows
c. Bimetallic *d.* Mercury column

12. Bourdon-tube Thermostats. This type uses a curved hollow tube connected through a capillary tube to a bulb. The bulb is filled with a selected volatile liquid. When the temperature increases, the liquid evaporates and the gas from the liquid fills the capillary and the curved tube, the pressure of the gas—following Boyle's law—being in direct proportion to the temper-

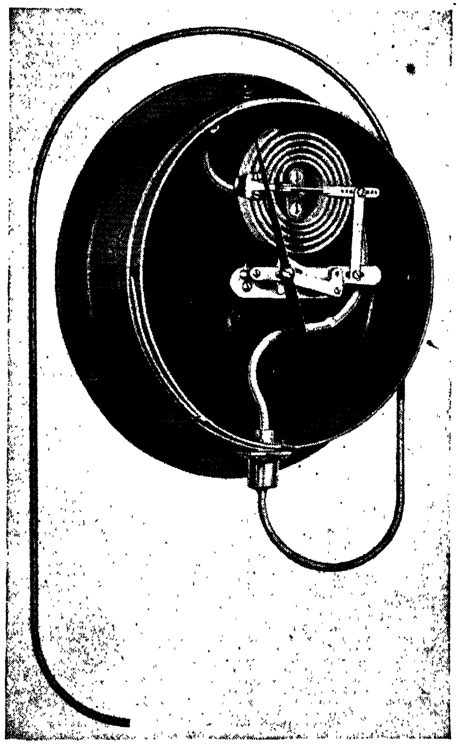


FIG. 203.—Bourdon-tube-type thermostat. (*Taylor Instrument Companies.*)

ature. The increase in pressure has a tendency to straighten the curved tube. This movement actuates a gear train and electric switch or a slide wire to tell the "helper" to boost the message to the "doer."

13. Charged-bellows Thermostat. This type uses a bellows partly filled with volatile liquid, or a bellows attached by a tube to a bulb charged with a volatile liquid, operating similarly to the Bourdon-tube type. The movement of the bellows, expanding under the gaseous pressure increase, induced by an increase in temperature, will tell the "helper" to boost the message, or directly tell the "doer," and in some cases, do the actuating of the damper, valve, or the like, itself.

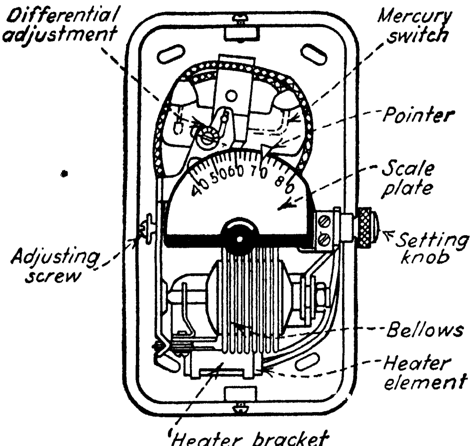


FIG. 204.—Charged-bellows thermostat. (*Minneapolis-Honeywell Regulator Company.*)

14. Bimetallic Thermostat. This type uses a bimetallic element, consisting of two dissimilar metals, each with a different

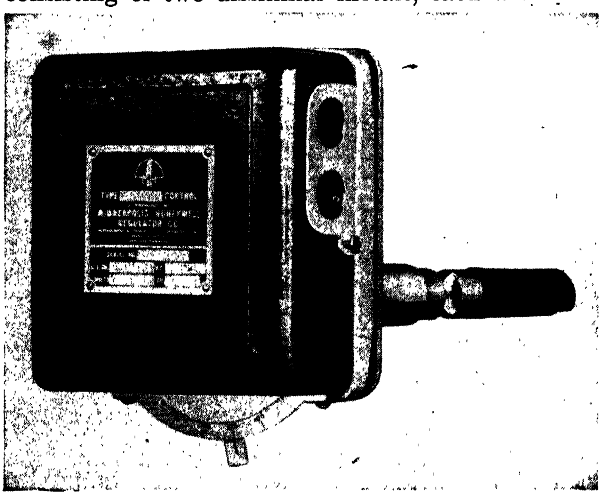


FIG. 205.—Insertion thermostat with helical bimetal coil. (*Minneapolis-Honeywell Regulator Company.*)

rate of expansion; the two metals are welded together. An increase in temperature causes one of the metals to expand more rapidly than the other, and this results in a distortion of the strip or element. These bimetallic elements are originally formed in straight, helical coil, or spiral coil form. The movement of the element, induced by a change in temperature, may be utilized to make an electrical contact, to operate a switch or a slide wire to tell the "helper" to boost the message to the "doer."

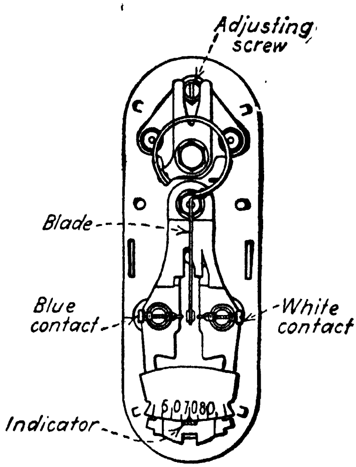


FIG. 206.—Room thermostat with spiral bimetal strip. (*Minneapolis-Honeywell Regulator Company.*)

15. Mercury-column Thermostat. This type uses a large bulb or reservoir filled with mercury, a short tube, and a small

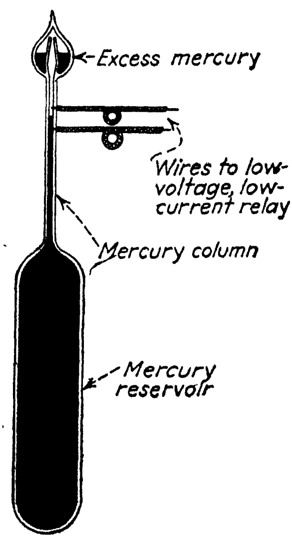


FIG. 207.—Mercury-column thermostat. (*Holmes, Air Conditioning in Summer and Winter.*)

excess-mercury bulb at the top of the tube. Wire electrodes are sealed into the tube at a predetermined spacing and connected to extension wires leading to a relay. An increase in temperature causes the mercury to expand and rise in the short, narrow tube and make contact with the two electrodes, thereby closing the "telling" circuit. This type is used for delicate or sensitive operation under low voltage and low current. The telling circuit connects to a relay or "helper," which boosts the message to the "doer."

16. Humidity. Relative humidity is controlled by a humidistat.

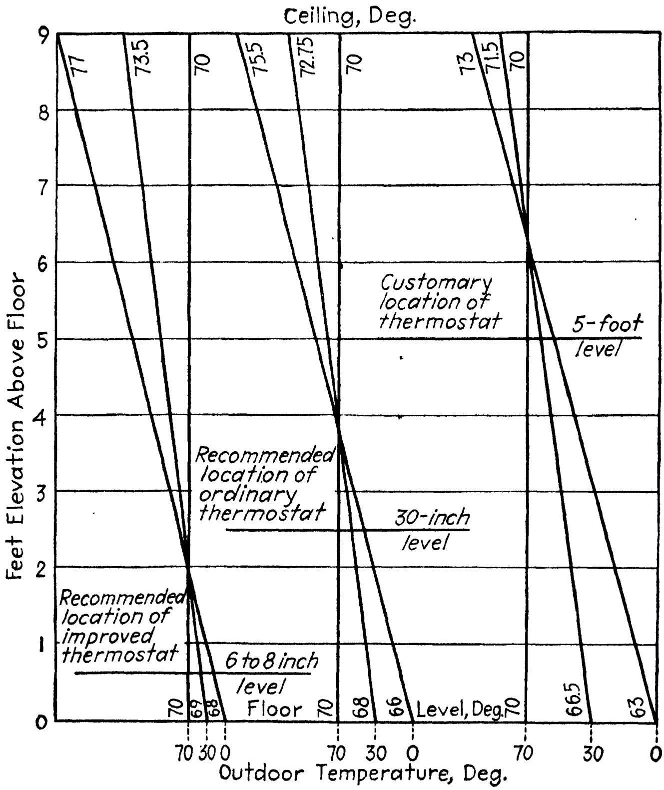


FIG. 208.—Effect of thermostat location upon air temperature at various levels in a room. (*Data from laboratory tests run by the Penn Electric Switch Company.*)

17. Humidistat. Humidistats, as control devices for relative humidity, are very delicate in their operation and as "thinkers" need the aid of "helpers" to boost their "telling" to the "doer."

For winter air conditioning they will energize an electric circuit and tell the "helper" what is needed. Then the "helper" will tell the "doer" what to do. The "doer" will open or close a solenoid or a magnet water valve controlling the pressure or flow in a spray humidifier, start or stop the agitator and fan on a mechanical separation humidifier, or start and stop the pump on a washer-type humidifier.

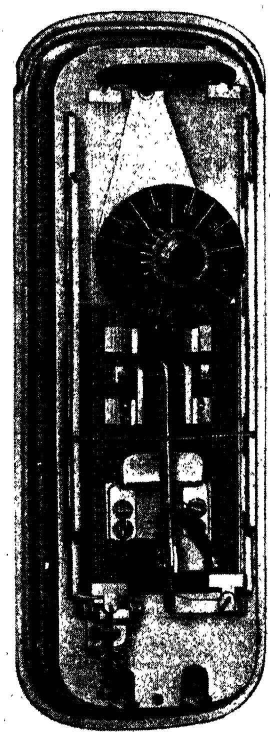


FIG. 209.—Human-hair room humidistat. (*Julien P. Freiz & Sons, Inc.*)

For summer air conditioning they will likewise energize an electric circuit and tell the "helper" what is needed, and the "helper" will tell the "doer" what to do. The "doer" will open or close a solenoid or magnet valve controlling the pressure or volume of water to the dehumidifying coil, start or stop the pump on a washer-type dehumidifier, start or stop a refrigeration machine, open and close dampers at a dehumidifying coil or washer, or start and stop a fan and operate dampers at an adsorption-type dehumidifier.

Fundamentally, a humidistat is a moisture or water-vapor element sufficiently sensitive to expand or contract with small variations in relative humidity. This expansion or contraction is translated by mechanical means, such as a lever, into a more extensive motion, to operate an electric switch or electrical contacts.

There are several kinds of humidistats, such as

a. Human hair
b. Treated paper
c. Wood

The most sensitive, durable, and popular humidistat is the human-hair type. Paper, specially treated, is sometimes used. Pearwood is but infrequently used as a humidistat element.

18. Special Thermostats. In addition to the four fundamental types of thermostats just described, there are several special or augmented types, generally known as

a. Anticipating
b. Accelerating
c. Protective
d. Effective temperature
e. Compensated
f. Zone
g. Insertion or immersion
h. Surface

19. Anticipating Thermostat. Considerable air-conditioning apparatus operates on an "on-and-off" cycle. Frequently the time lag results in an overrun of the system, resulting in undesirable fluctuations or differentials. One of the controls devised to overcome such difficulty is the anticipating thermostat.

This type is a regular thermostat to which has been added a small electrically energized heating element. When the room or enclosure temperature drops, the thermostat "calls" for heat, contact is made by the "thinker," and the "helper" and "doer" start the production of heat.

All heating systems, because of the materials used in their construction, tend to store up heat. This stored heat, unless properly controlled, will put too much heat into the enclosure. But, when the anticipating thermostat calls for heat, the built-in heating element caused the thermostat to heat itself at a faster rate than the enclosure or room air will do.

As a result, the thermostat is "satisfied" with heat before the room or enclosure is, the heating apparatus is shut off ahead of the room air satisfaction, and the stored heat brings the room air to the desired level without any apparent "overshooting." Room temperatures may be held as close as ½ degree Fahrenheit variation with an anticipating thermostat, whereas a 5 degrees Fahrenheit differential is not uncommon with an ordinary room thermostat, particularly with a warm-air furnace heat generator.

20. Accelerating Thermostat. It is a common practice, particularly at night, to slow down the operation of a winter air conditioner by setting the thermostat at a lower demand temperature.

During this period of slowed-down operation the enclosure and the objects within the enclosure become colder. Because of the time lag, due to inertia, the enclosure and furnishings take some time to rise to the speeded-up and more normal temperatures of the winter morning or daytime demand.

To offset this difficulty, an accelerating thermostat is used. This type is like the anticipating thermostat but, if allowed to operate on "anticipation," the thermostat would shut off the heating mechanism too soon. To accelerate the heating of a colder enclosure, an additional contact is provided so that the room air induces the thermostat action until the room air is up to the higher daytime thermostat setting, after which the accelerating effect ceases and the anticipation effect takes charge.

21. Protective Thermostats. This type is usually of the insertion or immersion type and is principally used to protect the apparatus and provide safety to the equipment, the enclosure, and the people. A protective thermostat should always be provided (usually an insertion type) in the bonnet of a warm-air furnace to stop or start a fuel burner, open or close the draft dampers, or control the blower operation.

Similarly, a protective thermostat should be provided for a steam or hot-water boiler, to protect against too high or too low a pressure or temperature, and to control the fuel burner and drafts.

Such thermostats should be installed, usually as insertion types, in air ducts. At the outside air inlet, one should be provided to protect the preheating coil; another should be provided to protect the washer (when used) from freezing. Still others should be provided in ducts to rooms, to control the air passing into the rooms, especially in preventing cold air from entering during the winter season.

Another protective thermostat may be used to activate a fire-alarm system, comprising the alarm, fire dampers, and blower or fan shut-off.

22. Effective-temperature Thermostat. Referring to Chap. VII, Division I, under People, it is observed that optimum, or best, comfort conditions are based upon effective temperature.

These effective temperatures may be converted to related dry-bulb temperatures and relative humidity. Normally, a

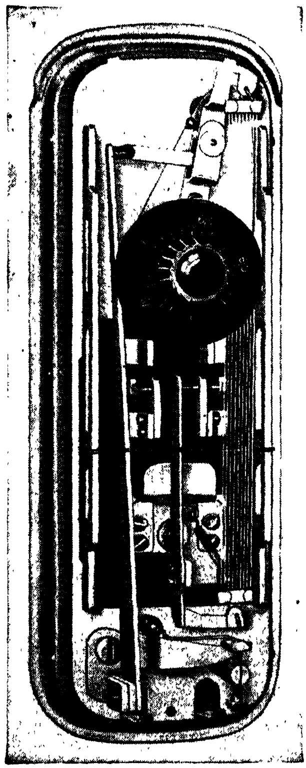


FIG. 210.—View of the interior of an effective-temperature control instrument. (*Julien P. Friez & Sons, Inc.*)

thermostat and a humidistat are used to maintain the optimum comfort. A combination control, comprising both a thermostat and humidistat, is available under the name of effective-temperature thermostat, and may be used for either winter or summer inside effective-temperature control.

23. Compensated Control. This type is a combination of temperature and humidity control for winter and summer conditioning. In the winter, it maintains an effective temperature indoors related to the varying outdoor dry-bulb temperature, increasing the inside effective temperature as the outside dry-bulb temperature decreases and decreasing the inside effective temperature as the outside dry-bulb temperature increases. In the summer, it maintains an inside dry-bulb temperature related to the outside dry-bulb temperature, to prevent shock, approximating the required relations shown between outside design dry-bulb temperature and inside effective temperatures (with the related dry-bulb temperature) as shown in Fig. 68.

24. Special Humidistats. Wet-bulb and dew-point humidistats also are available.

25. Wet-bulb Humidistat. An augmented psychrometer, controlling the dry-bulb and the wet-bulb temperatures will maintain the relative humidity for the specific dry bulb. Room air is circulated over the wet bulb for more accurate maintenance.

26. Dew-point Humidistat. This type is frequently referred to as a window thermostat or humidistat. Its purpose is to maintain the humidity within a room so that there will be no condensation on the cold inside surface of the window glass. Since the inside air is cooled at this windowpane surface, it approaches its dew point. This type lowers the relative humidity and increases the dry bulb to maintain air within an enclosure the dew point of which is slightly above the temperature of the air at the inside windowpane surface.

27. Other Thermostats. The inversion or immersion types are used to insert into ducts or into steam or water, for the control of their temperatures.

Surface thermostats are often used on existing hot-water heating systems to obviate the more costly insertion type.

28. Combinations. Combinations of these and more complicated "thinkers," "helpers," and "doers" are too numerous to attempt in this text. The reliable control manufacturers cooperate very closely, either directly or through their distribution channels, in matters of special control combinations. There is also a tendency to provide all-package control combinations for fuel burners, heat generators, refrigeration machines, winter and summer conditioners.

APPENDIX

CONTENTS

TABLE 1.—WINTER INSIDE DRY-BULB TEMPERATURES USUALLY SPECIFIED*,†

Type of building	Degrees Fahrenheit	Type of building	Degrees Fahrenheit
Schools:		Theaters:	
Classrooms	70–72	Seating space	68–72
Assembly rooms	68–72	Lounge rooms	68–72
Gymnasiums	55–65	Toilets	68
Toilets and baths	70		
Wardrobe and locker rooms	65–68	Hotels:	
Kitchens	66	Bedrooms and baths	70
Dining and lunchrooms	65–70	Dining rooms	70
Playrooms	60–65	Kitchens and laundries	66
Natatoriums	75	Ballrooms	65–68
		Toilets and service rooms	68
Hospitals:			
Private rooms	70–72	Homes	70–72
Private rooms (surgical)	70–80	Stores	65–68
Operating rooms	70–95	Public buildings	68–72
Wards	68	Warm-air baths	120
Kitchens and laundries	66	Steam baths	110
Toilets	68	Factories and machine shops	60–65
Bathrooms	70–80	Foundries and boiler shops	50–60
		Paintshops	80

* From Chapter 7, *Heating Ventilating Air Conditioning Guide*, 1938.

† The most comfortable dry-bulb temperature to be maintained depends on the relative humidity and air motion. These three factors considered together constitute what is termed the "effective temperature."

TABLE 2.—PROPERTIES OF SATURATED WATER VAPOR WITH AIR AT LOW TEMPERATURES*,†—PART I

Temperature, degrees Fahrenheit	Pressure of saturated vapor × 10^{-5}		Weight of saturated vapor				Volume in cu. ft. barometer, 29.92 in. Hg		Heat content per lb.		
	In. of Hg	Lb. per sq. in.	Per cu. ft.		Per lb. of dry air		Of 1 lb. of dry air	Of 1 lb. of dry air + vapor to saturate it	Dry air, °F. datum	Vapor, 32°F. datum	Dry air with vapor to saturate it
			Lb. × 10^{-5}	Grains	Lb. × 10^{-5}	Grains					
−60	101.4	49.808	0.20993	0.01470	2.108	0.14756	10.07	10.07	−14.48	1032.2	−14.46
−59	108.8	53.443	0.22469	0.01573	2.262	0.15834	10.09	10.09	−14.23	1032.7	−14.21
−58	116.3	57.127	0.23958	0.01677	2.418	0.16926	10.12	10.12	−13.99	1033.1	−13.97
−57	124.8	61.302	0.25645	0.01795	2.595	0.18165	10.14	10.14	−13.75	1033.6	−13.72
−56	133.4	65.526	0.27344	0.01914	2.773	0.19411	10.17	10.17	−13.50	1034.0	−13.47
−55	143.0	70.242	0.29239	0.02047	2.973	0.20811	10.19	10.19	−13.26	1034.5	−13.23
−54	153.0	75.154	0.31207	0.02184	3.181	0.22267	10.22	10.22	−13.02	1034.9	−12.99
−53	163.5	80.311	0.33267	0.02329	3.399	0.23793	10.24	10.24	−12.78	1035.4	−12.74
−52	174.9	85.911	0.35499	0.02485	3.636	0.25452	10.27	10.27	−12.53	1035.8	−12.49
−51	187.0	91.854	0.37862	0.02650	3.888	0.27216	10.29	10.29	−12.29	1036.3	−12.25
−50	199.9	98.191	0.40376	0.02826	4.156	0.29092	10.32	10.32	−12.05	1036.7	−12.01
−49	213.0	104.63	0.42917	0.03004	4.428	0.30996	10.34	10.34	−11.81	1037.2	−11.76
−48	227.9	111.94	0.45808	0.03207	4.738	0.33166	10.37	10.37	−11.57	1037.6	−11.52
−47	243.1	119.41	0.48744	0.03412	5.054	0.35378	10.40	10.40	−11.32	1038.1	−11.27
−46	259.5	127.47	0.51905	0.03633	5.395	0.37765	10.42	10.42	−11.08	1038.5	−11.02
−45	276.7	135.92	0.55213	0.03865	5.753	0.40271	10.45	10.45	−10.84	1039.0	−10.78
−44	295.0	144.90	0.58722	0.04111	6.133	0.42931	10.47	10.47	−10.60	1039.4	−10.54
−43	314.7	154.58	0.62493	0.04375	6.543	0.45801	10.50	10.50	−10.35	1039.9	−10.28
−42	335.3	164.70	0.66426	0.04650	6.971	0.48797	10.52	10.52	−10.11	1040.3	−10.04
−41	357.6	175.65	0.70672	0.04947	7.435	0.52045	10.55	10.55	−9.872	1040.8	−9.795
−40	380.3	186.80	0.7498	0.05249	7.907	0.55349	10.57	10.57	−9.629	1041.2	−9.547
−39	405.5	199.18	0.7976	0.05583	8.431	0.59017	10.60	10.60	−9.388	1041.7	−9.300
−38	431.2	211.81	0.8461	0.05922	8.965	0.62755	10.62	10.62	−9.146	1042.1	−9.053
−37	459.2	225.56	0.8989	0.06292	9.548	0.66836	10.65	10.65	−8.905	1042.6	−8.805
−36	488.4	239.90	0.9538	0.06677	10.16	0.71120	10.67	10.67	−8.663	1043.0	−8.557
−35	519.5	255.18	1.0122	0.07085	10.80	0.75600	10.69	10.69	−8.422	1043.5	−8.309
−34	552.4	271.34	1.0738	0.07517	11.49	0.80430	10.72	10.72	−8.180	1043.9	−8.060
−33	586.5	288.09	1.1374	0.07962	12.20	0.85400	10.75	10.75	−7.939	1044.4	−7.812
−32	623.7	306.36	1.2067	0.08447	12.97	0.90790	10.77	10.77	−7.698	1044.8	−7.562
−31	661.8	325.08	1.2774	0.08942	13.76	0.96320	10.80	10.80	−7.457	1045.3	−7.313

−30	701.0	344.33	1.3499	0.09449	14.58	1.0206	10.82	10.82	−7.216	1045.7	−7.064
−29	742.2	364.57	1.4260	0.09982	15.43	1.0801	10.85	10.85	−6.975	1046.2	−6.814
−28	791.2	388.64	1.5166	0.10616	16.45	1.1515	10.87	10.87	−6.734	1046.6	−6.562
−27	841.0	413.10	1.6083	0.11258	17.49	1.2243	10.90	10.90	−6.493	1047.1	−6.310
−26	892.1	438.20	1.7021	0.11914	18.55	1.2985	10.92	10.92	−6.251	1047.5	−6.057
−25	946.4	464.87	1.8016	0.12611	19.68	1.3776	10.95	10.95	−6.011	1048.0	−5.805
−24	1003.0	492.67	1.9049	0.13334	20.86	1.4602	10.97	10.97	−5.770	1048.4	−5.551
−23	1064.0	522.64	2.0162	0.14113	22.13	1.5491	11.00	11.00	−5.529	1048.9	−5.297
−22	1126.0	553.09	2.1287	0.14901	23.42	1.6394	11.02	11.02	−5.288	1049.3	−5.042
−21	1192.0	585.51	2.2484	0.15739	24.79	1.7353	11.05	11.05	−5.047	1049.8	−4.787
−20	1262.0	619.89	2.3750	0.16625	26.25	1.8375	11.07	11.07	−4.807	1050.2	−4.531
−19	1337.0	656.73	2.5105	0.17574	27.81	1.9467	11.10	11.10	−4.566	1050.7	−4.274
−18	1416.0	695.54	2.6527	0.18569	29.45	2.0615	11.13	11.13	−4.325	1051.1	−4.015
−17	1496.0	734.84	2.7963	0.19574	31.12	2.1784	11.15	11.15	−4.085	1051.6	−3.758
−16	1584.0	778.06	2.9542	0.20679	32.96	2.3065	11.18	11.18	−3.844	1052.0	−3.497
−15	1675.0	822.76	3.1168	0.21818	34.84	2.4388	11.20	11.21	−3.604	1052.5	−3.237
−14	1772.0	870.41	3.2899	0.23029	36.86	2.5802	11.23	11.24	−3.363	1052.9	−2.975
−13	1874.0	920.51	3.4714	0.24300	38.98	2.7286	11.25	11.26	−3.123	1053.4	−2.712
−12	1980.0	972.58	3.6596	0.25617	41.19	2.8833	11.28	11.29	−2.883	1053.8	−2.449
−11	2093.0	1028.1	3.8599	0.27019	43.54	3.0478	11.30	11.31	−2.642	1054.3	−2.183
−10	2210.0	1085.6	4.0666	0.28466	45.98	3.2186	11.33	11.34	−2.402	1054.7	−1.917
−9	2335.0	1147.0	4.2871	0.30009	48.58	3.4006	11.35	11.36	−2.162	1055.2	−1.649
−8	2463.0	1209.8	4.5120	0.31584	51.25	3.5875	11.38	11.39	−1.921	1055.6	−1.380
−7	2502.0	1229.0	4.5734	0.32014	52.06	3.6442	11.40	11.41	−1.681	1056.1	−1.131
−6	2745.0	1348.3	5.0066	0.35046	57.12	3.9984	11.43	11.44	−1.441	1056.5	−0.8375
−5	2898.0	1423.5	5.2738	0.36917	60.30	4.2210	11.45	11.46	−1.201	1057.0	−0.5636
−4	3055.0	1500.6	5.5473	0.38831	63.57	4.4499	11.48	11.49	−0.9604	1057.4	−0.2882
−3	3222.0	1582.6	5.8379	0.40865	67.05	4.6935	11.50	11.51	−0.7203	1057.9	−0.01098
−2	3397.0	1668.6	6.1414	0.42990	70.69	4.9483	11.53	11.54	−0.4802	1058.3	+0.2679
−1	3580.0	1758.5	6.4583	0.45208	74.50	5.2150	11.55	11.57	−0.2401	1058.8	+0.5487
0	3773.0	1853.3	6.7914	0.47500	78.52	5.5000	11.58	11.59	0	1059.2	+0.8317

* Compiled by W. M. Sawdon, vapor pressures converted from *International Critical Tables.*

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TABLE 2.—PROPERTIES OF SATURATED WATER VAPOR WITH AIR, 0 TO 200°F.*—PART II

Temperature, degrees Fahrenheit	Pressure of saturated vapor		Weight of saturated vapor				Volume in cu. ft. barometer, 29.92 in. Hg		Heat content per lb.		
	In. of Hg	Lb. per sq. in.	Per cu. ft.		Per lb. of dry air		Of 1 lb. of dry air	Of 1 lb. of dry air + vapor to saturate it	Dry air °F. datum	Vapor 32°F. datum	Dry air with vapor to saturate it
			Lb.	Grains	Lb.	Grains					
0	0.03773	0.01853	0.000067914	0.475	0.0007852	5.50	11.58	11.59	0.0000	1059.2	0.8317
1	0.03975	0.01963	0.000071395	0.500	0.0008275	5.79	11.60	11.62	0.2401	1059.7	1.117
2	0.04186	0.02056	0.000075021	0.525	0.0008714	6.10	11.63	11.64	0.4801	1060.1	1.404
3	0.04409	0.02166	0.000078851	0.552	0.0009179	6.43	11.65	11.67	0.7201	1060.6	1.694
4	0.04645	0.02282	0.000082890	0.580	0.0009671	6.77	11.68	11.70	0.9601	1061.0	1.986
5	0.04886	0.02400	0.000087005	0.609	0.001017	7.12	11.70	11.72	1.200	1061.5	2.280
6	0.05144	0.02527	0.000091399	0.640	0.001071	7.50	11.73	11.75	1.440	1061.9	2.577
7	0.05412	0.02658	0.000095955	0.672	0.001127	7.89	11.75	11.77	1.680	1062.4	2.877
8	0.05692	0.02796	0.00010070	0.705	0.001186	8.30	11.78	11.80	1.920	1062.8	3.180
9	0.05988	0.02941	0.00010572	0.740	0.001247	8.73	11.80	11.83	2.160	1063.3	3.486
10	0.06295	0.03092	0.00011090	0.776	0.001311	9.18	11.83	11.85	2.400	1063.7	3.795
11	0.06618	0.03251	0.00011634	0.814	0.001379	9.65	11.86	11.88	2.640	1064.2	4.108
12	0.06958	0.03418	0.00012206	0.854	0.001450	10.15	11.88	11.91	2.880	1064.6	4.424
13	0.07309	0.03590	0.00012794	0.896	0.001523	10.66	11.91	11.93	3.120	1065.1	4.742
14	0.07677	0.03771	0.00013410	0.939	0.001600	11.20	11.93	11.96	3.359	1065.5	5.064
15	0.08067	0.03963	0.00014062	0.984	0.001682	11.77	11.96	11.99	3.599	1066.0	5.392
16	0.08469	0.04160	0.00014732	1.031	0.001766	12.36	11.98	12.01	3.839	1066.4	5.722
17	0.08895	0.04369	0.00015440	1.081	0.001855	12.99	12.00	12.04	4.079	1066.9	6.058
18	0.09337	0.04586	0.00016174	1.132	0.001947	13.63	12.03	12.07	4.319	1067.3	6.397
19	0.09797	0.04812	0.00016935	1.185	0.002043	14.30	12.06	12.09	4.559	1067.8	6.741
20	0.1028	0.05050	0.00017747	1.242	0.002144	15.01	12.08	12.12	4.798	1068.2	7.088
21	0.1078	0.05295	0.00018564	1.299	0.002250	15.75	12.11	12.15	5.038	1068.7	7.443
22	0.1132	0.05560	0.00019439	1.361	0.002361	16.53	12.13	12.18	5.278	1069.1	7.802
23	0.1186	0.05826	0.00020335	1.423	0.002476	17.33	12.16	12.20	5.518	1069.6	8.166
24	0.1244	0.06111	0.00021276	1.489	0.002596	18.17	12.18	12.23	5.758	1070.0	8.536
25	0.1304	0.06405	0.00022255	1.558	0.002722	19.05	12.21	12.26	5.998	1070.5	8.912
26	0.1366	0.06710	0.00023278	1.629	0.002853	19.97	12.23	12.29	6.237	1070.9	9.292
27	0.1432	0.07034	0.00024342	1.704	0.002991	20.94	12.26	12.32	6.477	1071.4	9.682
28	0.1500	0.07368	0.00025445	1.781	0.003133	21.93	12.28	12.34	6.717	1071.8	10.075
29	0.1571	0.07717	0.00026597	1.862	0.003283	22.99	12.31	12.37	6.957	1072.3	10.477

30	0.1645	0.08080	0.00027797	1.946	0.003439	24.07	12.33	12.40	7.197	1072.7	10.886
31	0.1722	0.08458	0.00029043	2.033	0.003601	25.21	12.36	12.43	7.437	1073.2	11.302
32	0.1803	0.08856	0.00030343	2.124	0.003771	26.40	12.38	12.46	7.677	1073.6	11.726
33	0.1879	0.09230	0.00031471	2.203	0.003931	27.52	12.41	12.49	7.917	1074.1	12.139
34	0.1957	0.09610	0.00032690	2.288	0.004094	28.66	12.43	12.51	8.157	1074.5	12.556
35	0.20360	0.1000	0.0003394	2.376	0.004262	29.83	12.46	12.54	8.397	1075.0	12.979
36	0.21195	0.1041	0.0003527	2.469	0.004438	31.07	12.48	12.57	8.636	1075.4	13.409
37	0.22050	0.1083	0.0003662	2.563	0.004618	32.33	12.51	12.60	8.876	1075.9	13.845
38	0.22925	0.1126	0.0003799	2.660	0.004803	33.62	12.53	12.63	9.116	1076.3	14.285
39	0.23842	0.1171	0.0003943	2.760	0.004996	34.97	12.56	12.66	9.356	1076.8	14.736
40	0.24778	0.1217	0.0004090	2.863	0.005194	36.36	12.59	12.69	9.596	1077.2	15.191
41	0.25755	0.1265	0.0004243	2.970	0.005401	37.80	12.61	12.72	9.836	1077.7	15.657
42	0.26773	0.1315	0.0004401	3.081	0.005616	39.31	12.64	12.75	10.08	1078.1	16.13
43	0.27832	0.1367	0.0004566	3.196	0.005840	40.88	12.66	12.78	10.32	1078.6	16.62
44	0.28911	0.1420	0.0004735	3.315	0.006069	42.48	12.69	12.81	10.56	1079.0	17.11
45	0.30031	0.1475	0.0004909	3.436	0.006306	44.14	12.71	12.84	10.80	1079.5	17.61
46	0.31191	0.1532	0.0005088	3.562	0.006553	45.87	12.74	12.87	11.04	1079.9	18.12
47	0.32393	0.1591	0.0005274	3.692	0.006808	47.66	12.76	12.90	11.28	1080.4	18.64
48	0.33635	0.1652	0.0005465	3.826	0.007072	49.50	12.79	12.93	11.52	1080.8	19.16
49	0.34917	0.1715	0.0005663	3.964	0.007345	51.42	12.81	12.96	11.76	1081.3	19.70
50	0.36241	0.1780	0.0005866	4.106	0.007626	53.38	12.84	12.99	12.00	1081.7	20.25
51	0.37625	0.1848	0.0006078	4.255	0.007921	55.45	12.86	13.02	12.23	1082.2	20.80
52	0.39051	0.1918	0.0006296	4.407	0.008226	57.58	12.89	13.06	12.47	1082.6	21.38
53	0.40496	0.1989	0.0006516	4.561	0.008534	59.74	12.91	13.09	12.71	1083.1	21.95
54	0.42003	0.2063	0.0006746	4.722	0.008856	61.99	12.94	13.12	12.95	1083.5	22.55
55	0.43570	0.2140	0.0006984	4.889	0.009192	64.34	12.96	13.15	13.19	1084.0	23.15
56	0.45179	0.2219	0.0007228	5.060	0.009536	66.75	12.99	13.19	13.43	1084.4	23.77
57	0.46828	0.2300	0.0007477	5.234	0.009890	69.23	13.01	13.22	13.67	1084.9	24.40
58	0.48538	0.2384	0.0007735	5.415	0.01026	71.82	13.04	13.25	13.91	1085.3	25.05
59	0.50310	0.2471	0.0008003	5.602	0.01064	74.48	13.06	13.29	14.15	1085.8	25.70
60	0.52142	0.2561	0.0008278	5.795	0.01103	77.21	13.09	13.32	14.39	1086.2	26.37
61	0.54035	0.2654	0.0008562	5.993	0.01144	80.08	13.11	13.35	14.63	1086.7	27.06
62	0.55970	0.2749	0.0008852	6.196	0.01186	83.02	13.14	13.39	14.87	1087.1	27.76
63	0.57985	0.2848	0.0009153	6.407	0.01229	86.03	13.16	13.42	15.11	1087.6	28.48
64	0.60042	0.2949	0.0009460	6.622	0.01274	89.18	13.19	13.46	15.35	1088.0	29.21
65	0.62179	0.3054	0.0009778	6.845	0.01320	92.40	13.21	13.49	15.59	1088.5	29.96
66	0.64378	0.3162	0.0010105	7.074	0.01368	95.76	13.24	13.53	15.83	1088.9	30.73
67	0.66638	0.3273	0.0010440	7.308	0.01417	99.19	13.26	13.57	16.07	1089.4	31.51
68	0.68980	0.3388	0.0010816	7.571	0.01468	102.8	13.29	13.60	16.31	1089.8	32.31
69	0.71382	0.3506	0.0011140	7.798	0.01520	106.4	13.31	13.64	16.55	1090.3	33.12

* Compiled by W. M. Sawdon, vapor pressures converted from *International Critical Tables.*

TABLE 2.—PROPERTIES OF SATURATED WATER VAPOR WITH AIR, 0 TO 200°F.*—PART II.—(*Continued*)

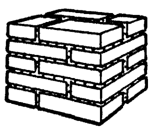
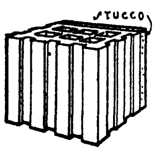
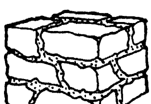
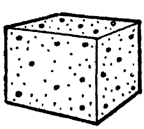
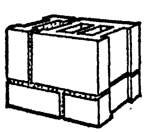
Temperature, degrees Fahrenheit	Pressure of saturated vapor		Weight of saturated vapor				Volume in cu. ft. barometer, 29.92 in. Hg		Heat content per lb.		
	In. of Hg	Lb. per sq. in.	Per cu. ft.		Per lb. of dry air		Of 1 lb. of dry air	Of 1 lb. of dry air + vapor to saturate it	Dry air °F. datum	Vapor 32°F. datum	Dry air with vapor to saturate it
			Lb.	Grains	Lb.	Grains					
70	0.73866	0.3628	0.0011507	8.055	0.01574	110.2	13.34	13.68	16.79	1090.7	33.96
71	0.76431	0.3754	0.0011884	8.319	0.01631	114.2	13.37	13.71	17.03	1091.2	34.83
72	0.79058	0.3883	0.0012269	8.588	0.01688	118.2	13.40	13 75	17.27	1091.6	35.70
73	0.81766	0.4016	0.0012667	8.867	0.01748	122.4	13.42	13.79	17.51	1092.1	36.60
74	0.84555	0.4153	0.0013075	9.153	0.01809	126.6	13.44	13.83	17.75	1092.5	37.51
75	0.87448	0.4295	0.0013497	9.448	0.01873	131.1	13.47	13.87	17.99	1093.0	38.46
76	0.90398	0.4440	0.0013927	9.749	0.01938	135.7	13.49	13.91	18.23	1093.4	39.42
77	0.93452	0.4590	0.0014371	10.06	0.02005	140.4	13.52	13.95	18.47	1093.9	40.40
78	0.96588	0.4744	0.0014825	10.38	0.02075	145.3	13.54	13.99	18.71	1094.3	41.42
79	0.99825	0.4903	0.0015295	10.71	0.02147	150.3	13.57	14.03	18.95	1094.8	42.46
80	1.0316	0.5067	0.0015777	11.04	0.02221	155 5	13.59	14.08	19.19	1095.2	43.51
81	1.0661	0.5236	0.0016273	11.39	0.02298	160.9	13 62	14.12	19.43	1095.7	44.61
82	1.1013	0.5409	0.0016781	11.75	0.02377	166.4	13.64	14.16	19.67	1096.1	45.72
83	1.1377	0.5588	0.0017304	12.11	0.02459	172.1	13.67	14.21	19.91	1096.6	46.88
84	1.1752	0.5772	0.0017841	12.49	0.02543	178.0	13.69	14.26	20.15	1097.0	48.05
85	1.2135	0.5960	0.0018389	12.87	0.02629	184.0	13.72	14.30	20.39	1097.5	49.24
86	1.2527	0.6153	0.0018950	13.27	0.02718	190.3	13.74	14.34	20.63	1097.9	50.47
87	1.2933	0.6352	0.0019531	13.67	0.02810	196.7	13.77	14.39	20.87	1098.4	51.74
88	1.3346	0.6555	0.0020116	14.08	0.02904	203.3	13.79	14.44	21.11	1098.8	53.02
89	1.3774	0.6765	0.0020725	14.51	0.03002	210.1	13.82	14.48	21.35	1099.3	54.35
90	1.4211	0.6980	0.0021344	14.94	0.03102	217.1	13.84	14.53	21.59	1099.7	55.70
91	1.4661	0.7201	0.0021982	15.39	0.03205	224.4	13.87	14.58	21.83	1100.2	57.09
92	1.5125	0.7429	0.0022634	15.84	0.03312	231.8	13.89	14.63	22.07	1100.6	58.52
93	1.5600	0.7662	0.0023304	16.31	0.03421	239.5	13.92	14.69	22.32	1101.1	59.99
94	1.6088	0.7902	0.0023992	16.79	0.03535	247.5	13.94	14.73	22.56	1101.5	61.50
95	1.6591	0.8149	0.0024697	17.28	0.03652	255.6	13.97	14.79	22.80	1102.0	63.05
96	1.7108	0.8403	0.0025425	17.80	0.03772	264.0	13.99	14.84	23.04	1102.4	64.62
97	1.7638	0.8663	0.0026164	18.31	0.03896	272.7	14.02	14.90	23.28	1102.9	66.25
98	1.8181	0.8930	0.0026925	18.85	0.04024	281.7	14.04	14.95	23.52	1103.3	67.92
99	1.8741	0.9205	0.0027700	19.39	0.04156	290.9	14.07	15.01	23.76	1103.8	69.63

100	1.9316	0.9487	0.0028506	19.95	0.04293	300.5	14.10	15.07	24.00	1104.2	71.40
101	1.9904	0.9776	0.0029316	20.52	0.04433	310.3	14.12	15.12	24.24	1104.7	73.21
102	2.0507	1.0072	0.0030156	21.11	0.04577	320.4	14.15	15.18	24.48	1105.1	75.06
103	2.1128	1.0377	0.0031017	21.71	0.04726	330.8	14.17	15.25	24.72	1105.6	76.97
104	2.1763	1.0689	0.0031887	22.32	0.04879	341.5	14.20	15.31	24.96	1106.0	78.92
105	2.2414	1.1009	0.0032786	22.95	0.05037	352.6	14.22	15.37	25.20	1106.5	80.93
106	2.3084	1.1338	0.0033715	23.60	0.05200	364.0	14.25	15.44	25.44	1106.9	83.00
107	2.3770	1.1675	0.0034650	24.26	0.05368	375.8	14.27	15.50	25.68	1107.4	85.13
108	2.4473	1.2020	0.0035612	24.93	0.05541	387.9	14.30	15.57	25.92	1107.8	87.30
109	2.5196	1.2375	0.0036603	25.62	0.05719	400.3	14.32	15.64	26.16	1108.3	89.54
110	2.5939	1.274	0.0037622	26.34	0.05904	413.3	14.35	15.71	26.40	1108.7	91.86
111	2.6692	1.311	0.0038669	27.07	0.06092	426.4	14.37	15.78	26.64	1109.2	94.21
112	2.7486	1.350	0.0039729	27.81	0.06292	440.4	14.39	15.85	26.88	1109.6	96.70
113	2.8280	1.389	0.0040816	28.57	0.06493	454.5	14.42	15.93	27.12	1110.1	99.20
114	2.9094	1.429	0.0041911	29.34	0.06700	469.0	14.45	16.00	27.36	1110.5	101.76
115	2.9929	1.470	0.0043047	30.13	0.06913	483.9	14.47	16.08	27.60	1111.0	104.40
116	3.0784	1.512	0.0044208	30.95	0.07134	499.4	14.50	16.16	27.84	1111.4	107.13
117	3.1660	1.555	0.0045372	31.76	0.07361	515.3	14.52	16.24	28.08	1111.9	109.92
118	3.2576	1.600	0.0046620	32.63	0.07600	532.0	14.55	16.32	28.32	1112.3	112.85
119	3.3492	1.645	0.0047846	33.49	0.07840	548.8	14.57	16.41	28.56	1112.8	115.80
120	3.4449	1.692	0.0049115	34.38	0.08093	566.5	14.60	16.50	28.80	1113.2	118.89
121	3.5406	1.739	0.005040	35.28	0.08348	584.4	14.62	16.58	29.04	1113.7	122.01
122	3.6404	1.788	0.005173	36.21	0.08616	603.1	14.65	16.68	29.28	1114.1	125.27
123	3.7422	1.838	0.005311	37.18	0.08892	622.4	14.67	16.77	29.52	1114.6	128.63
124	3.8460	1.889	0.005450	38.15	0.09175	642.3	14.70	16.87	29.76	1115.0	132.06
125	3.9519	1.941	0.005590	39.13	0.09466	662.6	14.72	16.96	30.00	1115.5	135.59
126	4.0618	1.995	0.005734	40.14	0.09770	683.9	14.75	17.06	30.24	1115.9	139.26
127	4.1718	2.049	0.005882	41.17	0.1008	705.6	14.77	17.17	30.48	1116.4	143.01
128	4.2858	2.105	0.006031	42.22	0.1040	728.0	14.80	17.27	30.72	1116.8	146.87
129	4.4039	2.163	0.006188	43.32	0.1074	751.8	14.83	17.38	30.96	1117.3	150.96
130	4.5220	2.221	0.006344	44.41	0.1107	774.9	14.85	17.49	31.20	1117.7	154.93
131	4.6441	2.281	0.006504	45.53	0.1143	800.1	14.88	17.61	31.45	1118.2	159.26
132	4.7703	2.343	0.006671	46.70	0.1180	826.0	14.90	17.73	31.69	1118.6	163.68
133	4.8986	2.406	0.006839	47.87	0.1218	852.6	14.93	17.85	31.93	1119.1	168.24
134	5.0289	2.470	0.007010	49.07	0.1257	879.9	14.95	17.97	32.17	1119.5	172.89
135	5.1633	2.536	0.007185	50.30	0.1297	907.9	14.98	18.10	32.41	1120.0	177.67
136	5.2997	2.603	0.007364	51.55	0.1339	937.3	15.00	18.23	32.65	1120.4	182.67
137	5.4402	2.672	0.007547	52.83	0.1382	967.4	15.03	18.36	32.89	1120.9	187.80
138	5.5827	2.742	0.007732	54.12	0.1427	998.9	15.05	18.50	33.13	1121.3	193.14
139	5.7293	2.814	0.007923	55.46	0.1473	1031.1	15.08	18.65	33.37	1121.8	198.61

* Compiled by W. M. Sawdon, vapor pressures converted from *International Critical Tables.*

TABLE 3.—COEFFICIENTS OF TRANSMISSION

Coefficients are expressed in B.t.u. per hour per square foot per degree are based on a wind

Typical construction	Type of wall	Thickness of masonry, inches	Wall no.
	Solid brick: Based on 4-in. face brick and the remainder common brick.	8 12 16	1 2 3
 	Hollow tile: Stucco exterior finish The 8-in. and 10-in. tile figures are based on two cells in the direction of flow of heat. The 12-in. tile is based on three cells in the direction of flow of heat. The 16-in. tile consists of one 10-in. tile and one 6-in. tile· each having two cells in the direction of heat flow.	8 10 12 16	4 5 6 7
	Limestone or sandstone	8 12 16 24	8 9 10 11
	Concrete: These figures may be used with sufficient accuracy for concrete walls with stucco exterior finish.	6 10 16 20	12 13 14 15
	Hollow cinder blocks: Based on one air cell in direction of heat flow	8 12	16 17
	Hollow concrete blocks: Based on one air cell in direction of heat flow	8 12	18 19

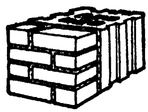
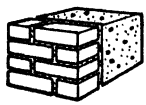
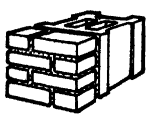
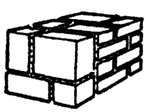
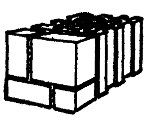
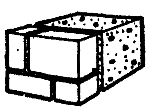
† Based on the actual thickness of 2-in. furring strips.

(U) of Masonry Walls*—Interior Finish
Fahrenheit difference in temperature between the air on the two sides and velocity of 15 miles per hour

Uninsulated walls						Insulated walls					
Plain walls—no interior finish	Plaster (½ in.) on walls	Plaster on wood lath, furred	Plaster (¾ in.) on metal lath, furred	Plaster (½ in.) on plasterboard (⅜ in.), furred	Decorated building board (½ in.) without plaster, furred	Plaster (½ in.) on rigid insulation (½ in.), furred	Plaster (½ in.) on rigid insulation (1 in.), furred	Plaster (½ in.) on corkboard (1½ in.) set in cement mortar (½ in.)	Plaster (¾ in.) on metal lath attached to furring strips—furred space (over ¾-in. wide) faced one side with bright aluminum foil	Plaster on metal lath attached to furring strips (2 in.†), rock wool fill (1⅝ in.†)‡	Plaster (¾ in.) on metal lath attached to furring strips (2 in.†), flexible insulation (½ in.) between furring strips (one air space)
0.50	0.46	0.30	0.32	0.30	0.23	0.22	0.16	0.14	0.23	0.12	0.20
0.36	0.34	0.24	0.25	0.24	0.19	0.19	0.14	0.12	0.19	0.11	0.17
0.28	0.27	0.20	0.21	0.20	0.17	0.16	0.13	0.11	0.17	0.10	0.15
0.40	0.37	0.26	0.27	0.26	0.20	0.20	0.15	0.13	0.20	0.11	0.18
0.39	0.37	0.26	0.27	0.26	0.20	0.19	0.15	0.13	0.20	0.11	0.18
0.30	0.29	0.22	0.22	0.22	0.17	0.17	0.13	0.12	0.17	0.10	0.16
0.25	0.24	0.19	0.19	0.19	0.15	0.15	0.12	0.11	0.15	0.097	0.14
0.71	0.64	0.37	0.39	0.37	0.26	0.25	0.18	0.15	0.26	0.13	0.23
0.58	0.53	0.33	0.34	0.33	0.24	0.23	0.17	0.14	0.24	0.13	0.21
0.49	0.45	0.30	0.31	0.30	0.22	0.22	0.16	0.14	0.22	0.12	0.20
0.37	0.35	0.25	0.26	0.25	0.20	0.19	0.15	0.13	0.20	0.11	0.18
0.79	0.70	0.39	0.42	0.39	0.27	0.26	0.19	0.16	0.27	0.13	0.23
0.62	0.57	0.34	0.37	0.34	0.25	0.24	0.18	0.15	0.25	0.13	0.22
0.48	0.44	0.29	0.31	0.29	0.22	0.21	0.16	0.14	0.22	0.12	0.20
0.41	0.39	0.27	0.28	0.27	0.21	0.20	0.15	0.13	0.21	0.12	0.18
0.42	0.39	0.27	0.28	0.27	0.21	0.20	0.16	0.13	0.21	0.12	0.19
0.37	0.35	0.25	0.26	0.25	0.19	0.19	0.15	0.13	0.19	0.11	0.17
0.56	0.52	0.32	0.34	0.32	0.24	0.23	0.17	0.14	0.24	0.12	0.21
0.49	0.46	0.30	0.32	0.30	0.23	0.22	0.16	0.14	0.23	0.12	0.20

‡ A waterproof membrane should be provided between the outer material and the insulation fill to prevent possible wetting by absorption and a subsequent lowering of efficiency.

TABLE 4.—COEFFICIENTS OF TRANSMISSION (U) OF MASONRY
Coefficients are expressed in B.t.u. per hour per square foot per degree and are based on a wind

Typical construction	Type of wall		Wall no.
	Facing	Backing	
	4-in. brick veneer§	6 in. 8 in. 10 in. 12 in. hollow tile‡	20 21 22 23
	4-in. brick veneer§	6 in. 10 in. 16 in. concrete	24 25 26
	4-in. brick veneer§	8 in. 12 in. cinder blocks‖	27 28
	4-in. brick veneer§	8 in. 12 in. concrete blocks‖	29 30
	4-in. cut-stone veneer§	8 in. 12 in. 16 in. common brick	31 32 33
	4-in. cut-stone veneer§	6 in. 8 in. 10 in. 12 in. hollow tile‡	34 35 36 37
	4-in. cut-stone veneer§	6 in. 10 in. 16 in. concrete	38 39 40

 From *A.S.H.V.E. Guide*, 1935, Chapter 5.
† Based on the actual thickness of 2-in. furring strips.
‡ The 6-in., 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.

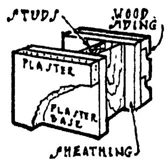
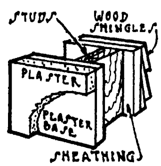
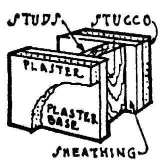
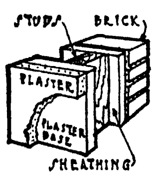
WALLS WITH VARIOUS TYPES OF VENEER*—INTERIOR FINISH
Fahrenheit difference in temperature between the air on the two sides
velocity of 15 miles per hour

Uninsulated walls					Insulated walls						
Plain walls—no interior finish	Plaster (½ in.) on walls	Plaster on wood lath, furred	Plaster (¾ in.) on metal lath, furred	Plaster (½ in.) on plasterboard (⅜ in.), furred	No plaster—decorated rigid or building-board interior finish (½ in.), furred	Plaster (½ in.) on rigid insulation (½ in.), furred	Plaster (½ in.) on rigid insulation (1 in.), furred	Plaster on corkboard (1½ in.) set in cement mortar (½ in.)	Plaster on metal lath (¾ in.) attached to furring strips, furred space (over ¾-in. wide) faced one side with bright aluminum foil	Plaster (¾ in.) on metal lath attached to furring strips (2 in.†), rock wool fill (1⅝ in.†)¶	Plaster (¾ in.) on metal lath attached to furring strips (2 in.†), flexible insulation (½ in.) between furring strips (one air space)
0.36	0.34	0.24	0.25	0.24	0.19	0.19	0.16	0.13	0.19	0.11	0.17
0.34	0.33	0.24	0.25	0.24	0.19	0.18	0.14	0.12	0.19	0.11	0.17
0.34	0.32	0.23	0.24	0.23	0.19	0.18	0.14	0.12	0.19	0.11	0.17
0.27	0.26	0.20	0.21	0.20	0.16	0.16	0.13	0.11	0.16	0.10	0.15
0.57	0.53	0.33	0.35	0.33	0.24	0.23	0.17	0.14	0.24	0.13	0.21
0.48	0.45	0.30	0.31	0.30	0.22	0.22	0.16	0.14	0.22	0.12	0.20
0.39	0.37	0.26	0.27	0.26	0.20	0.19	0.15	0.13	0.20	0.11	0.18
0.35	0.33	0.24	0.25	0.24	0.19	0.18	0.14	0.12	0.19	0.11	0.17
0.31	0.30	0.22	0.23	0.22	0.18	0.17	0.14	0.12	0.18	0.11	0.16
0.44	0.42	0.28	0.30	0.28	0.21	0.21	0.16	0.13	0.21	0.12	0.19
0.40	0.38	0.26	0.28	0.26	0.20	0.20	0.15	0.13	0.20	0.11	0.18
0.37	0.35	0.25	0.26	0.25	0.19	0.19	0.15	0.13	0.19	0.11	0.17
0.28	0.27	0.21	0.21	0.21	0.17	0.16	0.13	0.12	0.17	0.10	0.15
0.23	0.22	0.18	0.18	0.18	0.15	0.14	0.12	0.11	0.15	0.095	0.14
0.37	0.35	0.25	0.26	0.25	0.20	0.19	0.15	0.13	0.20	0.11	0.18
0.36	0.34	0.24	0.25	0.24	0.19	0.19	0.15	0.13	0.19	0.11	0.17
0.35	0.33	0.24	0.25	0.24	0.19	0.18	0.14	0.12	0.19	0.11	0.17
0.28	0.26	0.20	0.21	0.20	0.17	0.16	0.13	0.11	0.17	0.10	0.15
0.61	0.56	0.34	0.36	0.34	0.25	0.24	0.18	0.15	0.25	0.13	0.22
0.51	0.47	0.31	0.32	0.31	0.23	0.22	0.17	0.14	0.23	0.12	0.20
0.41	0.38	0.26	0.28	0.26	0.20	0.20	0.15	0.13	0.21	0.11	0.18

§ Calculations include cement mortar (½ in.) between veneer or facing and backing.
‖ Based on one air cell in direction of heat flow.
¶ A waterproof membrane should be provided between the outer material and the insulation fill to prevent possible wetting by absorption and a subsequent lowering of efficiency.

TABLE 5.—COEFFICIENTS OF TRANSMISSION (*U*) OF VARIOUS

These coefficients are expressed in B.t.u. per hour per square foot per degree and are based on a wind

Typical construction	Exterior finish	Type of sheathing	Wall no.
	Wood siding or clapboard	1-inch wood‡	41
		½-inch rigid insulation	42
		½-inch plasterboard	43
	Wood shingles	1-inch wood§	44
		½-inch rigid insulation‖	45
		½-inch plasterboard‖	46
	Stucco	1-inch wood‡	47
		½-inch rigid insulation	48
		½-inch plasterboard	49
	Brick¶ veneer	1-inch wood§	50
		½-inch rigid insulation	51
		½-inch plasterboard	52

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† These coefficients may also be used with sufficient accuracy for plaster on wood lath or plaster on plasterboard.

‡ Based on the actual width of 2 by 4 studding, namely, 3⅝ in.

TYPES OF FRAME CONSTRUCTION*—INTERIOR FINISH
Fahrenheit difference in temperature between the air on the two sides
velocity of 15 miles per hour

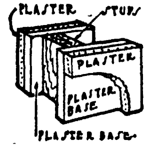
No insulation between studding							Insulation between studding		
Plaster on wood lath on studding	Plaster (¾ in.) on metal lath on studding	Plaster (½ in.) on plasterboard (⅜ in.) on studding	Plaster (½ in.) on rigid insulation (½ in.) on studding	Plaster (½ in.) on rigid insulation (1 in.) on studding)	Plaster (½ in.) on corkboard (1½ in.) on studding	No plaster, decorated rigid or building-board interior finish (½ in.)	Plaster (¾ in.) on metal lath, stud space faced one side with bright aluminum foil	Plaster (¾ in.) on metal lath† on studding, rock wool fill (3⅝ in.‡) between studding**	Plaster (¾ in.) on metal lath† on studding, flexible insulation (½ in.) between studding and in contact with sheathing
0.25	0.26	0.25	0.19	0.15	0.11	0.19	0.19	0.061	0.17
0.23	0.24	0.23	0.18	0.14	0.11	0.18	0.18	0.060	0.17
0.31	0.33	0.31	0.22	0.17	0.13	0.23	0.23	0.064	0.20
0.25	0.26	0.25	0.19	0.15	0.11	0.19	0.19	0.061	0.17
0.19	0.20	0.19	0.15	0.12	0.10	0.16	0.16	0.057	0.14
0.24	0.25	0.24	0.19	0.15	0.11	0.19	0.19	0.061	0.17
0.30	0.31	0.30	0.22	0.16	0.12	0.22	0.22	0.064	0.20
0.27	0.29	0.27	0.20	0.16	0.12	0.21	0.21	0.062	0.19
0.40	0.43	0.40	0.26	0.19	0.14	0.28	0.28	0.067	0.24
0.27	0.28	0.27	0.20	0.15	0.12	0.21	0.21	0.062	0.18
0.25	0.26	0.25	0.19	0.15	0.11	0.19	0.20	0.061	0.18
0.35	0.37	0.35	0.24	0.18	0.13	0.25	0.25	0.066	0.22

§ Yellow pine or fir—actual thickness about $^{25}/_{32}$ in.
‖ Furring strips between wood shingles and sheathing.
¶ Small air space and mortar between building paper and brick veneer neglected.
** A waterproof membrane should be provided between the outer material and the insulation fill to prevent possible wetting by absorption and a subsequent lowering of efficiency.

TABLE 6.—COEFFICIENTS OF TRANSMISSION (U) OF FRAME INTERIOR WALLS AND PARTITIONS*

Coefficients are expressed in B.t.u. 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

TYPICAL CONSTRUCTION



Type of wall	Wall no.	Single partition (finish on one side of studding)	Double partition (Finished on both sides of studding): Air space between studding	Flaked gypsum fill† between studding	Rock-wool fill† between studding	½-inch flexible insulation between studding (one air space)	Stud space faced one side with bright aluminum foil
Wood lath and plaster on studding	53	0.62	0.34	0.11	0.065	0.21	0.24
Metal lath and plaster‡ on studding	54	0.69	0.39	0.11	0.066	0.23	0.26
Plasterboard (⅜ inch) and plaster§ on studding	55	0.61	0.34	0.10	0.065	0.21	0.24
½-inch rigid insulation and plaster§ on studding	56	0.35	0.18	0.083	0.056	0.14	0.15
1-inch rigid insulation and plaster§ on studding	57	0.23	0.12	0.066	0.048	0.097	0.10
1½-inch corkboard and plaster§ on studding	58	0.16	0.081	0.052	0.040	0.070	0.073
2-inch corkboard and plaster§ on studding	59	0.12	0.063	0.045	0.035	0.057	0.059

 From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† Thickness assumed 3⅝ in.

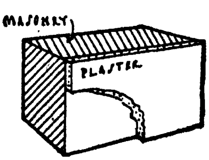
‡ Plaster on metal lath assumed ¾ in. thick.

§ Plaster assumed ½ in. thick.

TABLE 7.—COEFFICIENTS OF TRANSMISSION (U) OF MASONRY PARTITIONS*

Coefficients are expressed in B.t.u. 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

TYPICAL CONSTRUCTION



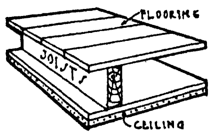
Type of wall	Wall no.	Plain walls (no plaster)	Walls plastered on one side	Walls plastered on both sides
4-in. hollow clay tile	60	0.45	0.42	0.40
4-in. common brick	61	0.50	0.46	0.43
4-in. hollow gypsum tile	62	0.30	0.28	0.27
2-in. solid plaster	63	....	....	0.53

 From *A.S.H.V.E. Guide*, 1935, Chapter 5.

TABLE 8.—COEFFICIENTS OF TRANSMISSION (U) OF FRAME-CONSTRUCTION FLOORS AND CEILINGS*

Coefficients are expressed in B.t.u. 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

TYPICAL CONSTRUCTION



Type of ceiling	Insulation between joists	Wall no.	Type of flooring: No flooring	Yellow pine flooring† on joists	Yellow pine flooring on rigid insulation (½ in.) on joists	Maple or oak flooring‡ on yellow pine subflooring† on joists	¼-in. battleship linoleum on yellow pine flooring†
No ceiling	None	1	....	0.46	0.27	0.34	0.34
Metal lath and plaster (¾ in.)	None	2	0.69	0.30	0.21	0.25	0.25
Wood lath and plaster	None	3	0.62	0.28	0.20	0.24	0.24
Plasterboard (⅜ in.) and plaster (½ in.)	None	4	0.61	0.28	0.20	0.24	0.23
Rigid insulation (½ in.) and plaster (½ in.)	None	5	0.35	0.21	0.16	0.18	0.18
Metal lath and plaster	Flexible§ insulation (½ in.)	6	0.24	0.16	0.13	0.15	0.15
Metal lath and plaster	Rigid insulation§ (½ in.)	7	0.26	0.17	0.14	0.15	0.15
Metal lath and plaster	Bright aluminum foil‖	8	0.59	0.22	0.16	0.19	0.19
Metal lath and plaster	Rock-wool fill (3⅝ in.)	9	0.067	0.063	0.058	0.060	0.060
Corkboard (1½ in.) and plaster (½ in.)	None	10	0.16	0.12	0.10	0.11	0.11
Corkboard (2 in.) and plaster (½ in.)	None	11	0.12	0.10	0.087	0.094	0.094

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† Thickness assumed to be $^{25}/_{32}$ in.

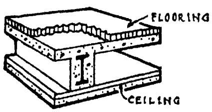
‡ Thickness assumed to be $^{13}/_{16}$ in.

§ Based on one air space with no flooring, and two air spaces with flooring. The value of U will be the same if insulation is applied to underside of joists and separated from lath and plaster ceiling by 1-in. furring strips.

‖ Air space faced on one side with bright aluminum foil.

TABLE 9.—COEFFICIENTS OF TRANSMISSION (U) OF CONCRETE-CONSTRUCTION FLOORS AND CEILINGS*

Coefficients are expressed in B.t.u. 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



TYPICAL CONSTRUCTION	Thickness of concrete, inches	Wall no.	Type of flooring: No flooring, bare† concrete	Yellow pine flooring‡ on wood sleepers embedded in concrete§	Maple or oak flooring‖ on yellow pine subflooring‡ on wood sleepers embedded in concrete	Tile or terrazzo¶ flooring on concrete	¼-inch battleship linoleum directly on concrete
Type of Ceiling			A	B	C	D	E
No ceiling	4	1	0.65	0.40	0.31	0.61	0.44
	6	2	0.59	0.37	0.30	0.56	0.41
	8	3	0.53	0.35	0.28	0.51	0.38
	10	4	0.49	0.33	0.27	0.47	0.36
½-inch plaster applied directly to underside of concrete	4	5	0.59	0.38	0.30	0.56	0.41
	6	6	0.54	0.35	0.28	0.52	0.38
	8	7	0.50	0.33	0.27	0.47	0.36
	10	8	0.45	0.32	0.26	0.44	0.34
Suspended or furred metal lath and plaster (¾ in.) ceiling	4	9	0.37	0.28	0.23	0.36	0.29
	6	10	0.35	0.26	0.22	0.34	0.28
	8	11	0.33	0.25	0.21	0.32	0.27
	10	12	0.32	0.24	0.21	0.31	0.25
Suspended or furred ceiling of plasterboard (⅜ in.) and plaster (½ in.)	4	13	0.35	0.26	0.22	0.34	0.28
	6	14	0.33	0.25	0.21	0.32	0.26
	8	15	0.31	0.24	0.21	0.30	0.25
	10	16	0.30	0.23	0.20	0.29	0.24
Suspended or furred ceiling of rigid insulation (½ in.) and plaster (½ in.)	4	17	0.24	0.20	0.17	0.24	0.21
	6	18	0.23	0.19	0.17	0.23	0.20
	8	19	0.22	0.18	0.16	0.22	0.19
	10	20	0.22	0.18	0.16	0.21	0.19
Plaster (½ in.) on corkboard (1½ in.) set in cement mortar (½ in.) on concrete	4	21	0.15	0.13	0.12	0.14	0.14
	6	22	0.14	0.13	0.12	0.14	0.13
	8	23	0.14	0.12	0.11	0.14	0.13
	10	24	0.14	0.12	0.11	0.14	0.13

 From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† The figures in Column A may be used with sufficient accuracy for concrete floors covered with carpet.

‡ Thickness of yellow pine flooring assumed to be $^{25}/_{32}$ in.

§ The figures in Column B may be used with sufficient accuracy for maple or oak flooring‖ applied directly over the concrete on wood sleepers.

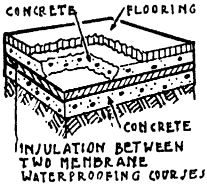
‖ Thickness of maple or oak flooring assumed to be $^{13}/_{16}$ in.

¶ Thickness of tile or terrazzo assumed 1 in.

TABLE 10.—COEFFICIENTS OF TRANSMISSION (*U*) OF CONCRETE FLOORS ON GROUND WITH VARIOUS TYPES OF FINISH FLOORING*,||

Coefficients are expressed in B.t.u. per hour per square foot per degree Fahrenheit difference in temperature between the ground and the air over the floor, and are based on still-air (no wind) conditions

TYPICAL CONSTRUCTION



Type and thickness of insulation	Thickness of concrete, inches	Wall no.	Type of finish flooring				
			No flooring, bare concrete	Yellow pine flooring† on wood sleepers resting on concrete	Maple or oak flooring‡ on yellow pine subflooring on wood sleepers resting on concrete	Tile or terrazzo§ on concrete	¼-in. battleship linoleum directly on concrete
None	4	1	1.07	0.35	0.28	0.98	0.60
	6	2	0.90	0.33	0.27	0.84	0.54
	8	3	0.79	0.32	0.26	0.74	0.50
	10	4	0.70	0.30	0.25	0.66	0.46
None§	4	5	0.66	0.29	0.24	0.63	0.44
	8	6	0.54	0.27	0.23	0.52	0.39
1-inch rigid insulation§	4	7	0.22	0.16	0.14	0.22	0.19
1-inch rigid insulation§	8	8	0.21	0.15	0.13	0.20	0.18
2-inch corkboard§	4	9	0.12	0.099	0.093	0.12	0.11
2-inch corkboard§	8	10	0.12	0.096	0.090	0.12	0.11

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† Assumed 25/32 inch thick.

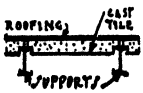
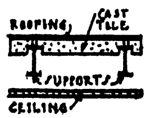
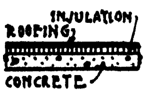
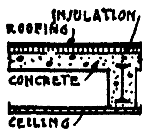
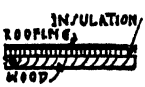
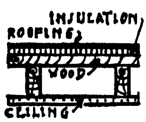
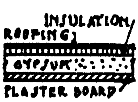
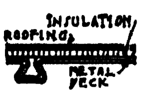
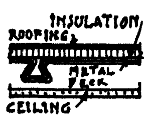
‡ Assumed 13/16 inch thick.

§ Assumed 1 inch thick.

|| The figures for Nos. 5 to 10, inclusive, include 3-inch cinder concrete placed directly on the ground. The insulation is applied between the cinder concrete and the stone concrete. Usually the insulation is protected on both sides by a waterproof membrane, but this is not considered in the calculations.

TABLE 11.—COEFFICIENTS OF TRANSMISSION (U) OF VARIOUS

Coefficients are expressed in B.t.u. per hour per square foot per degree are based on an outside wind

Typical construction: Without ceilings	Typical construction: With metal lath and plaster ceilings	Type of roof deck	Thickness of roof deck, *inches*	Wall no.
		Precast cement tile	1⅝	1
		Concrete Concrete Concrete	2 4 6	2 3 4
		Wood Wood Wood Wood	1† 1½† 2† 4†	5 6 7 8
		Gypsum fiber concrete‡ (2 inches) on plasterboard (⅜ inch) Gypsum fiber concrete‡ (3 inches) on plasterboard (⅜ inch)	2⅜ 3⅜	9 10
		Flat metal roofs: Coefficient of transmission of bare corrugated iron (no roofing) is 1.50 B.t.u. per hour per square foot of projected area per degree Fahrenheit difference in temperature, based on an outside wind velocity of 15 miles per hour		11

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† Nominal thicknesses specified—actual thicknesses used in calculations.

‡ Gypsum fiber concrete—87½ per cent gypsum, 12½ per cent wood fiber.

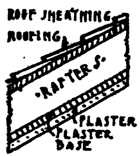
Types of Flat Roofs Covered with Built-up Roofing*
Fahrenheit difference in temperature between the air on the two sides and velocity of 15 miles per hour

Without ceiling—underside of roof exposed									With metal lath and plaster ceilings§						
No insulation	Rigid insulation (½ in.)	Rigid insulation (1 in.)	Rigid insulation (1½ in.)	Rigid insulation (2 in.)	Corkboard (1 in.)	Corkboard (1½ in.)	Corkboard (2 in.)	No insulation	Rigid insulation (½ in.)	Rigid insulation (1 in.)	Rigid insulation (1½ in.)	Rigid insulation (2 in.)	Corkboard (1 in.)	Corkboard (1½ in.)	Corkboard (2 in.)
0.84	0.37	0.24	0.18	0.14	0.22	0.16	0.13	0.43	0.26	0.19	0.15	0.12	0.18	0.14	0.11
0.82	0.37	0.24	0.17	0.14	0.22	0.16	0.13	0.42	0.26	0.19	0.15	0.12	0.18	0.14	0.11
0.72	0.34	0.23	0.17	0.13	0.21	0.16	0.12	0.40	0.25	0.18	0.14	0.12	0.17	0.13	0.11
0.64	0.33	0.22	0.16	0.13	0.21	0.15	0.12	0.37	0.24	0.18	0.14	0.11	0.17	0.13	0.11
0.49	0.28	0.20	0.15	0.12	0.19	0.14	0.12	0.32	0.21	0.16	0.13	0.11	0.15	0.12	0.10
0.37	0.24	0.18	0.14	0.11	0.17	0.13	0.11	0.26	0.19	0.15	0.12	0.10	0.14	0.11	0.095
0.32	0.22	0.16	0.13	0.11	0.16	0.12	0.10	0.24	0.17	0.14	0.11	0.097	0.13	0.11	0.092
0.23	0.17	0.14	0.11	0.096	0.13	0.11	0.091	0.18	0.14	0.12	0.10	0.087	0.11	0.096	0.082
0.40	0.25	0.18	0.14	0.12	0.17	0.13	0.11	0.27	0.19	0.15	0.12	0.10	0.14	0.12	0.097
0.32	0.22	0.16	0.13	0.11	0.15	0.12	0.10	0.23	0.17	0.14	0.11	0.097	0.13	0.11	0.091
0.95	0.39	0.25	0.18	0.14	0.23	0.17	0.13	0.46	0.27	0.19	0.15	0.12	0.18	0.14	0.11

§ These coefficients may be used with sufficient accuracy for wood lath and plaster, or plasterboard and plaster ceilings. It is assumed that there is an air space between the underside of the roof deck and the upper side of the ceiling.

TABLE 12.—COEFFICIENTS OF TRANSMISSION (U) OF PITCHED ROOFS*,†

Coefficients are expressed in B.t.u. 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 miles per hour

Typical construction	Type of roofing and roof sheathing	Insulation between roof rafters	No.	Type of ceiling (Applied directly to roof rafters)								
				No ceiling, rafters exposed	Metal lath and plaster (¾ in.)	Plasterboard (⅜ in.) and plaster (½ in.)	Wood lath and plaster	Rigid insulation (½ in.)	Rigid insulation (½ in.) and plaster (½ in.)	Rigid insulation (1 in.) and plaster (½ in.)	Corkboard (1½ in.) and plaster (½ in.)	Corkboard (2 in.) and plaster (½ in.)
	Wood shingles on wood strips†	None	1	0.46	0.30	0.29	0.29	0.22	0.21	0.16	0.12	0.10
		½ inch flexible‡	2	....	0.17	0.16	0.16	0.14	0.13	0.11	0.091	0.079
		1 inch flexible‡	3	....	0.13	0.12	0.12	0.11	0.11	0.092	0.078	0.069
		Bright aluminum foil**	4	....	0.22	0.21	0.21	0.17	0.17	0.13	0.10	0.085
		3⅝ inch rock wool‖	5	....	0.063	0.062	0.062	0.058	0.058	0.053	0.048	0.044
	Asphalt shingles, rigid asbestos shingles, composition roofing, or slate or tile roofing§ on wood sheathing¶	None	6	0.56	0.34	0.32	0.32	0.24	0.23	0.17	0.13	0.11
		½ inch flexible‡	7	....	0.18	0.17	0.17	0.14	0.14	0.12	0.094	0.089
		1 inch flexible‡	8	....	0.13	0.13	0.13	0.11	0.11	0.095	0.080	0.071
		Bright aluminum foil**	9	....	0.24	0.23	0.23	0.18	0.18	0.14	0.11	0.093
		3⅝ inch rock wool‖	10	....	0.065	0.064	0.064	0.060	0.059	0.054	0.049	0.045

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.
† Numbers 6 to 10, inclusive, based on ½-in. thick slate.
‡ Based on 1 by 4 in. strips spaced 2 in.
§ Figures based on two air spaces. Insulation may also be applied to under side of roof rafters with furring strips between.
‖ Roofing felt between roof sheathing and slate or tile neglected in calculations.
¶ Assumed 3⅝ in. thick based on the actual width of 2 by 4 in. rafters.
** Sheathing assumed ²⁵⁄₃₂ in. thick.
†† Air space faced on one side with bright aluminum foil.

TABLE 13.—COEFFICIENTS OF TRANSMISSION (U) OF DOORS, WINDOWS, AND SKYLIGHTS*

Coefficients are based on a wind velocity of 15 miles per hour and are expressed in B.t.u. per hour per square foot per degree Fahrenheit difference in temperature between the air inside and outside of the door, window, or skylight

A. Windows and skylights

	U
Single	1.13†,§
Double	0.45†
Triple	0.281†

B. Solid wood doors‡,§

Nominal thickness, inches	Actual thickness, inches	U
1	25/32	0.69
1¼	1 1/16	0.59
1½	1 5/16	0.52
1¾	1⅜	0.51
2	1⅝	0.46
2½	2⅛	0.38
3	2⅝	0.33

* Copyright, American Society of Heating and Ventilating Engineers. From *A.S.H.V.E. Guide*, 1935, Chapter 5.

† See *Heating, Ventilating and Air Conditioning*, by Harding and Willard, rev. ed., 1932.

‡ Computed using $C = 1.15$ for wood; $f_i = 1.65$ and $f_o = 6.0$.

§ 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 B.t.u. per hour per square foot per degree difference between inside and outside air temperatures.

TABLE 14.—CLIMATIC CONDITIONS COMPILED FROM WEATHER BUREAU RECORDS*,†

State or province	City	Average temperature, Oct. 1 to May 1	Lowest temperature ever reported	Average wind velocity, December, January, February, miles per hour	Direction of prevailing wind, December, January, February
Alabama	Mobile	58.9	− 1	10.4	N
	Birmingham	53.8	−10	8.5	N
Arizona	Phoenix	59.5	12	6.4	E
	Flagstaff	35.8	−25	7.8	SW
Arkansas	Fort Smith	50 4	−15	8.1	E
	Little Rock	51.6	−12	8.7	NW
California	San Francisco	54.2	27	7.6	N
	Los Angeles	58.5	28	6.3	NE
Colorado	Denver	38.9	−29	7.5	S
	Grand Junction	38.9	−21	5.3	NW
Connecticut	New Haven	38.4	−15	9.7	N
District of Columbia	Washington	43.4	−15	7.1	NW
Florida	Jacksonville	62.0	10	9.2	NE
Georgia	Atlanta	51.5	− 8	12.1	NW
	Savannah	58.5	8	9.5	NW
Idaho	Lewiston	42.3	−23	5.3	E
	Pocatello	35.7	−28	9.6	SE
Illinois	Chicago	36.4	−23	12.5	W
	Springfield	39.8	−24	10.1	NW
Indiana	Indianapolis	40.3	−25	11.5	SW
	Evansville	45.1	−16	9.8	S
Iowa	Dubuque	33.9	−32	7.1	NW
	Sioux City	32.6	−35	11.6	NW
Kansas	Concordia	39.8	−25	8.1	S
	Dodge City	41.4	−26	9.8	NW
Kentucky	Louisville	45.3	−20	9.9	SW
Louisiana	New Orleans	61.6	7	8.8	N
	Shreveport	56.2	− 5	8.9	SE
Maine	Eastport	31.5	−23	12.0	W
	Portland	33.8	−21	9.2	NW
Maryland	Baltimore	43.8	− 7	7.8	NW
Massachusetts	Boston	38.1	−18	11.2	W
Michigan	Alpena	29.6	−28	12.4	W
	Detroit	35.8	−24	12.7	SW
	Marquette	28.3	−27	11.1	NW
Minnesota	Duluth	24.3	−41	12.6	SW
	Minneapolis	29.4	−33	11.3	NW
Mississippi	Vicksburg	56.8	− 1	8.3	SE
Missouri	St. Joseph	40.7	−24	9.3	NW
	St. Louis	43.6	−22	11.6	S
	Springfield	44.3	−29	10.8	SE
Montana	Billings	34.0	−49	....	W
	Havre	27.6	−57	9.5	SW
Nebraska	Lincoln	37.0	−29	10.5	S
	North Platte	35.4	−35	8.5	W
Nevada	Tonopah	39.4	−10	10.0	SE
	Winnemucca	37.9	−28	8.7	NE
New Hampshire	Concord	33.3	−35	6.6	NW
New Jersey	Atlantic City	41.6	− 9	15.9	NW
New Mexico	Santa Fe	38.3	−13	7.8	NE
New York	Albany	35.2	−24	8.1	S
	Buffalo	34.8	−20	17.2	W
	New York	40.7	−14	17.1	NW
North Carolina	Raleigh	50.0	− 2	8.2	SW
	Wilmington	54.2	5	8.5	SW
North Dakota	Bismarck	24.6	−45	9.1	NW
	Devils Lake	20.3	−44	10.6	W
Ohio	Cleveland	37.2	−17	13.0	SW
	Columbus	39.9	−20	12.0	SW
Oklahoma	Oklahoma City	47.9	−17	12.0	N
Oregon	Baker	35.2	−24	6.9	SE
	Portland	46.1	− 2	7.5	S
Pennsylvania	Philadelphia	42.7	− 6	11.0	NW
	Pittsburgh	41.0	−20	11.7	W

TABLE 14.—CLIMATIC CONDITIONS COMPILED FROM WEATHER BUREAU RECORDS.*,†—(*Continued*)

State or province	City	Average temperature, Oct. 1 to May 1	Lowest temperature ever reported	Average wind velocity, December, January, February, miles per hour	Direction of prevailing wind, December, January, February
Rhode Island	Providence	37.2	−17	12.8	NW
South Carolina	Charleston	57.4	7	10.6	SW
	Columbia	54.0	− 2	8.1	NE
South Dakota	Huron	28.2	−43	10.6	NW
	Rapid City	33.4	−34	8.2	W
Tennessee	Knoxville	47.9	−16	7.8	SW
	Memphis	51.1	− 9	9.7	S
Texas	El Paso	53.5	− 5	10.4	NW
	Fort Worth	55.2	− 8	10.4	NW
	San Antonio	60.6	4	8.0	NE
Utah	Modena	36.3	−24	8.8	W
	Salt Lake City	40.0	−20	6.7	SE
Vermont	Burlington	31.5	−29	11.8	S
Virginia	Norfolk	49.3	2	12.5	N
	Lynchburg	46.8	− 7	7.1	NW
	Richmond	47.0	− 3	7.9	SW
Washington	Seattle	44.8	3	11.3	SE
	Spokane	37.7	−30	7.1	SW
West Virginia	Elkins	39.4	−28	6.6	W
	Parkersburg	42.6	−27	7.5	SW
Wisconsin	Green Bay	30.0	−36	10.4	SW
	La Crosse	31.7	−43	7.3	S
	Milwaukee	33.4	−25	11.5	W
Wyoming	Sheridan	30.7	−41	6.0	NW
	Lander	30.0	−40	5.0	SW
Alberta	Edmonton	23.0	−57	6.5	SW
British Columbia	Victoria	43.9	− 1.5	12.5	N
	Vancouver	42.0	2	4.5	E
Manitoba	Winnipeg	17.5	−47	10.0	NW
New Brunswick	Fredericton	27.0	−35	9.6	NW
Nova Scotia	Yarmouth	35.0	−12	14.2	NW
Ontario	London	32.6	−27	10.3	SW
	Ottawa	26.5	−34	8.4	NW
	Port Arthur	22.4	−37	7.8	NW
	Toronto	32.9	−26.5	13.0	SW
Prince Edward Island	Charlottetown	29.0	−27	9.4	SW
Quebec	Montreal	27.8	−29	14.3	SW
	Quebec	24.2	−34	13.6	SW
Saskatchewan	Prince Albert	15.8	−70	5.1	W
Yukon	Dawson	2.1	−68	3.7	S

* From Chapter 7, *Heating, Ventilating Air Conditioning Guide*, 1938.
† United States data from U. S. Weather Bureau. Canadian data from Meteorological Service of Canada.

TABLE 15.—DESIGN DRY- AND WET-BULB TEMPERATURES, WIND VELOCITIES, AND WIND DIRECTIONS FOR JUNE, JULY, AUGUST, AND SEPTEMBER*

State	City	Design, dry bulb	Design, wet bulb	Summer wind velocity, miles per hour	Prevailing summer wind direction
Alabama	Birmingham	95	78	5.2	S
	Mobile	95	80	8.6	SW
Arizona	Phoenix	105	76	6.0	W
Arkansas	Little Rock	95	78	7.0	NE
California	Los Angeles	90	70	6.0	SW
	San Francisco	90	65	11.0	SW
Colorado	Denver	95	64	6.8	S
Connecticut	New Haven	95	75	7.3	S
Delaware	Wilmington	95	78	9.7	SW
District of Columbia	Washington	95	78	6.2	S
Florida	Jacksonville	95	78	8.7	SW
	Tampa	94	79	7.0	E
Georgia	Atlanta	95	75	7.3	NW
	Savannah	95	78	7.8	SW
Idaho	Boise	95	65	5.8	NW
Illinois	Chicago	95	75	10.2	NE
	Peoria	95	76	8.2	S
Indiana	Indianapolis	95	76	9.0	SW
Iowa	Des Moines	95	77	6.6	SW
Kansas	Wichita	100	75	11.0	S
Kentucky	Louisville	95	76	8.0	SW
Louisiana	New Orleans	95	79	7.0	SW
Maine	Portland	90	73	7.3	S
Maryland	Baltimore	95	78	6.9	SW
Massachusetts	Boston	92	75	9.2	SW
Michigan	Detroit	95	75	10.3	SW
Minnesota	Minneapolis	95	75	8.4	SE
Mississippi	Vicksburg	95	78	6.2	SW
Missouri	Kansas City	100	76	9.5	S
	St. Louis	95	78	9.4	SW
Montana	Helena	95	67	7.3	SW
Nebraska	Lincoln	95	75	9.3	S
Nevada	Reno	95	65	7.4	W
New Hampshire	Manchester	90	73	5.6	NW
New Jersey	Trenton	95	78	10.0	SW

TABLE 15.—DESIGN DRY- AND WET-BULB TEMPERATURES, WIND VELOCITIES, AND WIND DIRECTIONS FOR JUNE, JULY, AUGUST, AND SEPTEMBER.*—(*Continued*)

State	City	Design, dry bulb	Design, wet bulb	Summer wind velocity, miles per hour	Prevailing summer wind direction
New Mexico	Santa Fe	90	65	6.5	SE
New York	Albany	92	75	7.1	S
	Buffalo	93	75	12.2	SW
	New York	95	75	12.9	SW
North Carolina	Asheville	90	75	5.6	SE
	Wilmington	95	79	7.8	SW
North Dakota	Bismarck	95	73	8.8	NW
Ohio	Cleveland	95	75	9.9	S
	Cincinnati	95	78	6.6	SW
Oklahoma	Oklahoma City	101	76	10.1	S
Oregon	Portland	90	65	6.6	NW
Pennsylvania	Philadelphia	95	78	9.7	SW
	Pittsburgh	95	75	9.0	NW
Rhode Island	Providence	93	75	10.0	NW
South Carolina	Charleston	95	80	9.9	SW
	Greenville	95	76	6.8	NE
South Dakota	Sioux Falls	95	75	7.6	S
Tennessee	Chattanooga	95	77	6.5	SW
	Memphis	95	78	7.5	SW
Texas	Dallas	100	78	9.4	S
	Galveston	95	80	9.7	S
	San Antonio	100	78	7.4	SE
	Houston	95	78	7.7	S
	El Paso	100	69	6.9	E
Utah	Salt Lake City	95	67	8.2	SE
Vermont	Burlington	90	73	8.9	S
Virginia	Norfolk	95	78	10.9	S
	Richmond	95	78	6.2	SW
Washington	Seattle	85	65	7.9	S
	Spokane	90	65	6.5	SW
West Virginia	Parkersburg	95	75	5.3	SE
Wisconsin	Madison	95	75	8.1	SW
	Milwaukee	95	75	10.4	S
Wyoming	Cheyenne	95	65	9.2	S

* From Chapter 8, *Heating, Ventilating Air Conditioning Guide*, 1938.

TABLE 16.—INFILTRATION THROUGH WINDOWS*
Expressed in cubic feet per foot of crack per hour†

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‡	3.3	8.2	14.0	20.2	27.2	34.6
	Around frame in masonry wall—calked‡	0.5	1.5	2.6	3.8	4.8	5.8
	Around frame in wood frame construction‡	2.2	6.2	10.8	16.6	23.0	30.3
	Total for average window, non-weatherstripped, 1/16-inch crack and 3/64-inch clearance.§ Includes wood frame leakage‖	6.6	21.4	39.3	59.3	80.0	103.7
	Ditto, weatherstripped‖	4.3	15.5	23.6	35.5	48.6	63.4
	Total for poorly fitted window, non-weatherstripped, 3/32-inch crack and 3/32-inch clearance.¶ Includes wood frame leakage‖	26.9	69.0	110.5	153.9	199.2	249.4
	Ditto, weatherstripped‖	5.9	18.9	34.1	51.4	70.5	91.5
Double-hung metal windows**	Nonweatherstripped, locked	20	45	70	96	125	154
	Nonweatherstripped, unlocked	20	47	74	104	137	170
	Weatherstripped, unlocked	6	19	32	46	60	76
Rolled section steel sash windows¶¶	Industrial pivoted,†† 1/16-inch crack	52	108	176	244	304	372
	Architectural projected, 1/32-inch crack‡‡	15	36	62	86	112	139
	Architectural projected, 3/64-inch crack‡‡	20	52	88	116	152	182
	Residential casement, 1/64-inch crack§§	6	18	33	47	60	74
	Residential casement, 1/32-inch crack§§	14	32	52	76	100	128
	Heavy casement section, projected, 1/64-inch crack‖‖	3	10	18	26	36	48
	Heavy casement section, projected, 1/32-inch crack‖‖	8	24	38	54	72	92
Hollow metal, vertically pivoted window**		30	88	145	186	221	242

 From Chapter 6, *Heating, Ventilating Air Conditioning Guide*, 1938.

† The values given in this table 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 at the end of this chapter.

‡ 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.

§ 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.

‖ 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.

¶ A 3/32-in. crack and clearance represents a poorly fitted window, much poorer than average.

** Windows tested in place in building.

†† Industrial pivoted window generally used in industrial buildings. Ventilators horizontally pivoted at center or slightly above, lower part swinging out.

‡‡ Architectural projected made of same sections as industrial pivoted except that outside framing member is heavier, and 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.

§§ 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.

‖‖ 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.

¶¶ 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.

TABLE 17.—INFILTRATION THROUGH OUTSIDE DOORS FOR COOLING LOADS*,†
Expressed in cubic feet per minute per person in room

Application	Pair 36-in. Swinging Doors, Single Entrance‡
Bank	7.5
Barbershop	4.5
Broker's office	7.0
Candy and soda	6.0
Cigar store	25.0
Department store	8.0
Dress shop	2.5
Drugstore	7.0
Furrier	2.5
Hospital room	3.5
Lunchroom	5.0
Men's shop	3.5
Office	3.0
Office building	2.0
Public building	2.5
Restaurant	2.5
Shoe store	3.5

* From Chapter 6, *Heating, Ventilating Air Conditioning Guide*, 1938.
† For doors located in only one wall or where doors in other walls are of revolving type.
‡ Vestibules with double pair of swinging doors, infiltration may be assumed 75 per cent of swinging door values.
Infiltration for 72 in. revolving doors may be assumed 60 per cent of swinging door values.

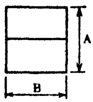
TABLE 18.—AIR CHANGES TAKING PLACE UNDER AVERAGE CONDITIONS EXCLUSIVE OF AIR PROVIDED FOR VENTILATION*

Kind of Room or Building	Number of Air Changes Taking Place per Hour
Rooms, 1 side exposed	1
Rooms, 2 sides exposed	1½
Rooms, 3 sides exposed	2
Rooms, 4 sides exposed	2
Rooms with no windows or outside doors	½ to ¾
Entrance halls	2 to 3
Reception halls	2
Living rooms	1 to 2
Dining rooms	1 to 2
Bathrooms	2
Drugstores	2 to 3
Clothing stores	1
Churches, factories, lofts, etc	½ to 3

* From Chapter 6, *Heating, Ventilating Air Conditioning Guide*, 1938.

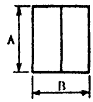
TABLE 19.—GLASS AREA AND LENGTH OF CRACK DOUBLE-HUNG AND CASEMENT WINDOWS

Double-hung



Legend

Casement



A = height of double-hung window
B = width of casement window

A = height of casement window
B = width of double-hung window

	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9
1	1 / 5	1½ / 6	2 / 7	2½ / 8	3 / 9	3½ / 10	4 / 11	4½ / 12	5 / 13	5½ / 14	6 / 15	6½ / 16	7 / 17	7½ / 18	8 / 19	8½ / 20	9 / 21
1½	1½ / 6½	2 / 7½	3 / 8½	4 / 9½	4½ / 10½	5 / 11½	6 / 12½	7 / 13½	7½ / 14½	8 / 15½	9 / 16½	10 / 17½	10½ / 18½	11 / 19½	12 / 20½	13 / 21½	13½ / 22½
2	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12	7 / 13	8 / 14	9 / 15	10 / 16	11 / 17	12 / 18	13 / 19	14 / 20	15 / 21	16 / 22	17 / 23	18 / 24
2½	2½ / 9½	4 / 10½	5 / 11½	6 / 12½	7½ / 13½	9 / 14½	10 / 15½	11 / 16½	12½ / 17½	14 / 18½	15 / 19½	16 / 20½	17½ / 21½	19 / 22½	20 / 23½	21½ / 24½	22½ / 25½
3	3 / 11	4½ / 12	6 / 13	7½ / 14	9 / 15	10½ / 16	12 / 17	13½ / 18	15 / 19	16½ / 20	18 / 21	19½ / 22	21 / 23	22½ / 24	24 / 25	25½ / 26	27 / 27
3½	3½ / 12½	5 / 13½	7 / 14½	9 / 15½	10½ / 16½	12 / 17½	14 / 18½	16 / 19½	17½ / 20½	19 / 21½	21 / 22½	23 / 23½	24½ / 24½	26 / 25½	28 / 26½	30 / 27½	31½ / 28½
4	4 / 14	6 / 15	8 / 16	10 / 17	12 / 18	14 / 19	16 / 20	18 / 21	20 / 22	22 / 23	24 / 24	26 / 25	28 / 26	30 / 27	32 / 28	34 / 29	36 / 30
4½	4½ / 15½	7 / 16½	9 / 17½	11 / 18½	13½ / 19½	16 / 20½	18 / 21½	20 / 22½	22½ / 23½	25 / 24½	27 / 25½	29 / 26½	31½ / 27½	34 / 28½	36 / 29½	38½ / 30½	40½ / 31½
5	5 / 17	7½ / 18	10 / 19	12½ / 20	15 / 21	17½ / 22	20 / 23	22½ / 24	25 / 25	27½ / 26	30 / 27	32½ / 28	35 / 29	37½ / 30	40 / 31	42½ / 32	45 / 33
5½	5½ / 18½	8 / 19½	11 / 20½	14 / 21½	16½ / 22½	19 / 23½	22 / 24½	25 / 25½	27½ / 26½	30 / 27½	33 / 28½	36 / 29½	38½ / 30½	41 / 31½	44 / 32½	47 / 33½	49½ / 34½
6	6 / 20	9 / 21	12 / 22	15 / 23	18 / 24	21 / 25	24 / 26	27 / 27	30 / 28	33 / 29	36 / 30	39 / 31	42 / 32	45 / 33	48 / 34	51 / 35	54 / 36
6½	6½ / 21½	10 / 22½	13 / 23½	16 / 24½	19½ / 25½	23 / 26½	26 / 27½	29 / 28½	32½ / 29½	36 / 30½	39 / 31½	42 / 32½	45½ / 33½	49 / 34½	52 / 35½	55½ / 36½	58½ / 37½
7	7 / 23	10½ / 24	14 / 25	17½ / 26	21 / 27	24½ / 28	28 / 29	31½ / 30	35 / 31	38½ / 32	42 / 33	45½ / 34	49 / 35	52½ / 36	56 / 37	59½ / 38	63 / 39
7½	7½ / 24½	11 / 25½	15 / 26½	19 / 27½	22½ / 28½	26 / 29½	30 / 30½	34 / 31½	37½ / 32½	41 / 33½	45 / 34½	49 / 35½	52½ / 36½	56 / 37½	60 / 38½	64 / 39½	67½ / 40½
8	8 / 26	12 / 27	16 / 28	20 / 29	24 / 30	28 / 31	32 / 32	36 / 33	40 / 34	44 / 35	48 / 36	52 / 37	56 / 38	60 / 39	64 / 40	68 / 41	72 / 42
8½	8½ / 27½	13 / 28½	17 / 29½	21½ / 30½	25½ / 31½	30 / 32½	34 / 33½	38½ / 34½	42½ / 35½	47 / 36½	51 / 37½	55½ / 38½	59½ / 39½	64 / 40½	68 / 41½	72½ / 42½	76½ / 43½
9	9 / 29	13½ / 30	18 / 31	22½ / 32	27 / 33	31½ / 34	36 / 35	40½ / 36	45 / 37	49½ / 38	54 / 39	58½ / 40	63 / 41	67½ / 42	72 / 43	76½ / 44	81 / 45

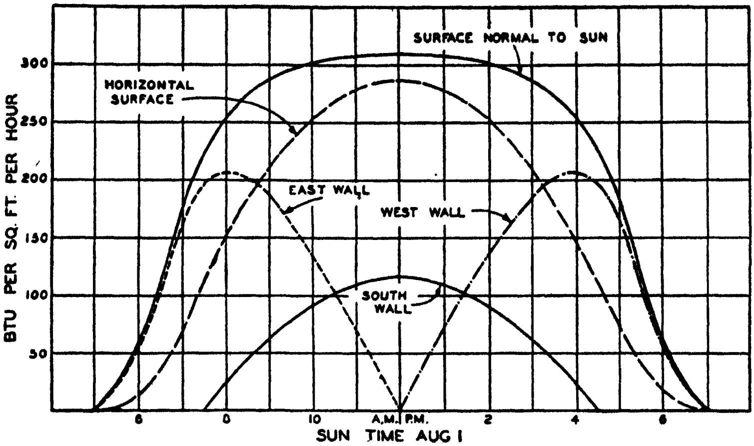


FIG. 211.

TABLE 20a.—SOLAR RADIATION IMPINGING AGAINST WALLS HAVING SEVERAL ORIENTATIONS AND A HORIZONTAL SURFACE, AND THE RADIATION TRANSMITTED THROUGH GLASS FOR THE SAME ORIENTATIONS

For 30-degree latitude on July 21, in B.t.u. per square foot per hour

Sun time	Northeast		East		Southeast		South		Southwest		West		Northwest		Horizontal surface	
	I	*I*I_G	*I*	I_G	*I*	I_G	*I*	I_G	*I*	I_G	*I*	I_G	*I*	I_G	*I*	I_G
4:59	0	0	0	0	0	0									0	0
5:00	1	0.9	1	0.9	0.3	0.2									0.01	0.005
6:00	47	41	51	44	24	17									9	5
7:00	136	106	160	140	90	68									68	47
8:00	151	122	205	177	136	105									147	116
9:00	127	91	189	156	140	104	8	1							214	182
10:00	79	47	141	103	122	85	31	12							265	231
11:00	21	6	78	45	85	52	45	21							296	261
12:00					36	15	50	24	36	15					305	269
1:00							45	21	85	52	78	45	21	6	296	261
2:00							31	12	122	85	141	103	79	47	265	231
3:00							8	1	140	104	189	156	127	91	214	182
4:00									136	105	205	177	151	122	147	116
5:00									90	68	160	140	136	106	68	47
6:00									24	17	51	44	47	41	9	5
7:00									0.3	0.2	1	0.9	1	0.9	0.01	0.005
7:01									0	0	0	0	0	0	0	0

TABLE 20b.—SOLAR RADIATION IMPINGING AGAINST WALLS HAVING SEVERAL ORIENTATIONS AND A HORIZONTAL SURFACE, AND THE RADIATION TRANSMITTED THROUGH GLASS FOR THE SAME ORIENTATIONS

For 35-degree latitude on July 21, in B.t.u. per square foot per hour

Sun time	Northeast		East		Southeast		South		Southwest		West		Northwest		Horizontal surface	
	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G
4:46	0	0	0	0	0	0									0	0
5:00	9	8	9	8	3	2									0 01	0 [illegible]
6:00	67	58	72	63	35	26									15	8
7:00	142	120	174	152	103	78									77	53
8:00	150	120	209	181	145	114									151	120
9:00	118	83	191	157	154	118	26	8							214	181
10:00	60	32	143	104	139	101	55	27							264	230
11:00	2	0.1	75	43	103	67	72	41							291	256
12:00					55	28	78	46	55	28					300	265
1:00							72	41	103	67	75	43	2	0.1	291	256
2:00							55	27	139	101	143	104	60	32	264	230
3:00							26	8	154	118	191	157	118	83	214	181
4:00									145	114	209	181	150	120	151	120
5:00									103	78	174	152	142	120	77	53
6:00									35	26	72	63	67	58	15	8
7:00									3	2	9	8	9	8	0.01	0 007
7:14									0	0	0	0	0	0	0	0

TABLE 20c.—SOLAR RADIATION IMPINGING AGAINST WALLS HAVING SEVERAL ORIENTATIONS AND A HORIZONTAL SURFACE, AND THE RADIATION TRANSMITTED THROUGH GLASS FOR THE SAME ORIENTATIONS

For 40-degree latitude on July 21, in B.t.u. per square foot per hour

Sun time	Northeast		East		Southeast		South		Southwest		West		Northwest		Horizontal surface	
	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G
4:31	0	0	0	0	0	0									0	0
5:00	14	12	14	12	5	3									1	0.2
6:00	72	63	80	70	40	29									19	11
7:00	143	120	180	158	112	87									82	57
8:00	143	111	211	182	155	124	8	2							152	121
9:00	104	69	192	158	168	133	46	22							213	178
10:00	46	22	143	104	156	117	77	45							258	225
11:00			75	43	121	83	95	60	15	4					284	249
12:00					73	42	103	67	73	42					293	258
1:00					15	4	95	60	121	83	75	43			284	249
2:00							77	45	156	117	143	104	46	22	258	225
3:00							46	22	168	133	192	158	104	69	213	178
4:00							8	2	155	124	211	182	143	111	152	121
5:00									112	87	180	158	143	120	82	57
6:00									40	29	80	70	72	63	19	11
7:00									5	3	14	12	14	12	1	0.2
7:29									0	0	0	0	0	0	0	0

TABLE 20*d*.—SOLAR RADIATION IMPINGING AGAINST WALLS HAVING SEVERAL ORIENTATIONS AND A HORIZONTAL SURFACE, AND THE RADIATION TRANSMITTED THROUGH GLASS FOR THE SAME ORIENTATIONS

For 45-degree latitude on July 21, in B.t.u. per square foot per hour

Sun time	Northeast		East		Southeast		South		Southwest		West		Northwest		Horizontal surface	
	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G	I	I_G
4:26	0	0	0	0	0	0									0	0
5:00	25	22	24	21	9	6									2	0 7
6:00	89	77	99	88	52	39									26	15
7:00	149	125	194	170	125	99									90	63
8:00	140	109	219	189	171	139	22	8							156	123
9:00	92	58	194	160	183	148	65	36							210	177
10:00	33	13	144	106	171	134	98	63							251	217
11:00			75	43	139	101	121	83	32	13					274	240
12:00					91	67	128	90	91	67					282	247
1:00					32	13	121	83	139	101	75	43			274	240
2:00							98	63	171	134	144	106	33	13	251	217
3:00							65	36	183	148	194	160	92	58	210	177
4:00							22	8	171	139	219	189	140	109	156	123
5:00									125	99	194	170	144	125	90	63
6:00									52	39	99	88	89	77	26	15
7:00									9	6	24	21	25	22	2	0 7

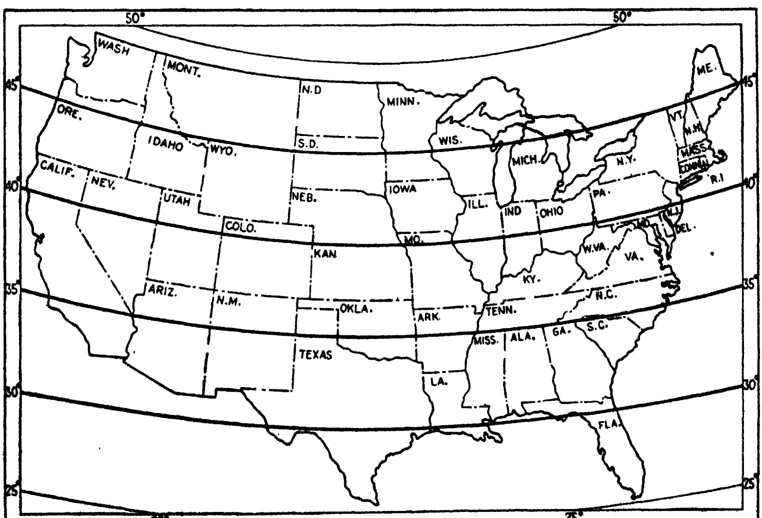


FIG. 212.—Outside dry-bulb temperatures in the United States for cooling estimates.

TABLE 21.—SUN EFFECT—LATITUDES NORTH
(To be used with Tables 20*a* to 20*d* and Fig. 213)

State	City	Use latitude, degrees
Alabama	Birmingham	35
	Mobile	30
Arizona	Phoenix	35
Arkansas	Little Rock	35
California	Los Angeles	35
	San Francisco	40
Colorado	Denver	40
Connecticut	New Haven	40
Delaware	Wilmington	40
District of Columbia	Washington	40
Florida	Jacksonville	40
	Tampa	30
Georgia	Atlanta	35
	Savannah	30
Idaho	Boise	45
Illinois	Chicago	40
	Peoria	40
Indiana	Indianapolis	40
Iowa	Des Moines	40
Kansas	Wichita	40
Kentucky	Louisville	40
Louisiana	New Orleans	30
Maine	Portland	45
Maryland	Baltimore	40
Massachusetts	Boston	40
Michigan	Detroit	40
Minnesota	Minneapolis	45
Mississippi	Vicksburg	30
Missouri	Kansas City	40
	St. Louis	40
Montana	Helena	45
Nebraska	Lincoln	40
Nevada	Reno	40
New Hampshire	Manchester	45
New Jersey	Trenton	40
New Mexico	Sante Fe	35
New York	Albany	45
	Buffalo	45
	New York	40
North Carolina	Asheville	35
	Wilmington	35
North Dakota	Bismarck	45
Ohio	Cleveland	40
	Cincinnati	40
Oklahoma	Oklahoma City	35
Oregon	Portland	45
Pennsylvania	Philadelphia	40
	Pittsburgh	40
Rhode Island	Providence	40
South Carolina	Charleston	30
	Greenville	35
South Dakota	Sioux Falls	45
Tennessee	Chattanooga	35
	Memphis	35
Texas	Dallas	35
	Galveston	30
	San Antonio	30
	Houston	30
	El Paso	30
Utah	Salt Lake City	40
Vermont	Burlington	45
Virginia	Norfolk	35
	Richmond	35
Washington	Seattle	45
	Spokane	45
West Virginia	Parkersburg	40
Wisconsin	Madison	45
	Milwaukee	45
Wyoming	Cheyenne	40

TABLE 22.—SOLAR ABSORPTION COEFFICIENTS FOR DIFFERENT BUILDING MATERIALS

Surface Material	Absorption Coefficient (a)
Very light-colored surfaces:	
White stone	
Very light-colored cement	0.4
White or light cream-colored paint	
Medium dark surfaces:	
Asbestos shingles	
Unpainted wood	
Brown stone	
Brick and red tile	0.7
Dark-colored cement	
Stucco	
Red, green, or gray paint	
Very dark-colored surfaces:	
Slate roofing	
Tar roofing materials	0.9
Very dark paints	

TABLE 23.—SOLAR RADIATION TRANSMITTED THROUGH BARE AND SHADED WINDOWS

Type of appurtenance	Finish facing sun	Per cent delivered to room*
Bare window glass	....	0.97
Canvas awning	Plain	0.28
Canvas awning	Aluminum	0.22
Inside shade, fully drawn	Aluminum	0.45
Inside shade, one-half drawn	Buff	0.68
Inside Venetian blind, fully covering window, slats at 45 degrees	Aluminum	0.58
Outside Venetian blind, fully covering window, slats at 45 degrees	Aluminum	0.22

* Expressed in decimals.

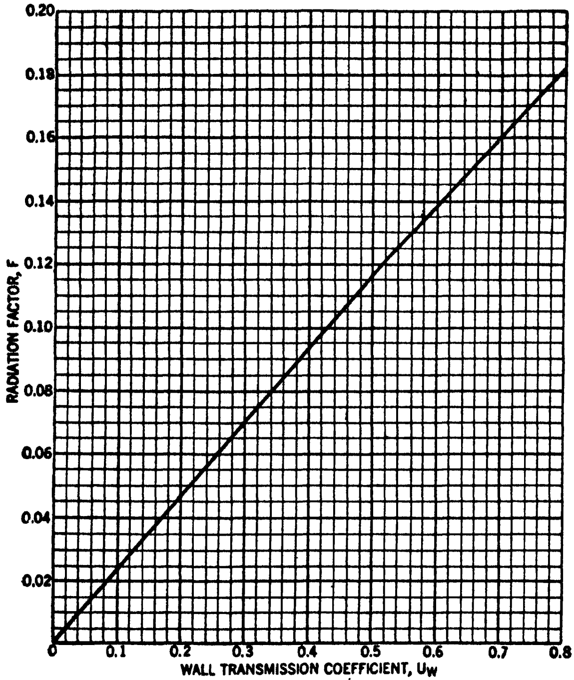


FIG. 213.—Solar-radiation factors.

TABLE 24.—HEAT GAIN FROM VARIOUS SOURCES

Source	B.t.u. per hour		
	Sensible	Latent	Total
Electric heating equipment			
Electrical equipment—dry heat—no evaporated water	100 %	0 %	100 %
Electric oven—baking	80 %	20 %	100 %
Electric equipment—heating water—stewing, boiling, etc	50 %	50 %	100 %
Electric lights and appliances per watt (dry heat)	3.4	0	3.4
Electric lights and appliances per kilowatt (dry heat)	3413	0	3413
Electric motors per horsepower	2546	0	2546
Electric toasters or electric griddles	90 %	10 %	100 %
Coffee urn—large, 18 inches diameter—single drum	2000	2000	4000
Coffee urn—small, 12 inches diameter—single drum	1200	1200	2400
Coffee urn—approximate connected load per gallon of capacity	600	600	1200
Electric range—small burner	*	*	3400
Electric range—large burner	*	*	7500
Electric range—oven	8000	2000	10000
Electric range—warming compartment	1025	0	1025
Steam table—per square foot of top surface	300	800	1100
Plate warmer—per cubic foot of volume	850	0	850
Baker's oven—per cubic foot of volume	3200	1300	4500
Frying griddles—per square foot of top surface	*	*	4600
Hot plates—per square foot of top surface	*	*	9000
Hair dryer in beauty parlor—600 watts	2050	0	2050
Permanent wave machine in beauty parlor—24–25-watt units	2050	0	2050
Gas-burning equipment			
Gas equipment—dry heat—no water evaporated	90 %	10 %	100 %
Gas-heated oven—baking	67 %	33 %	100 %
Gas equipment—heating water—stewing, boiling, etc	50 %	50 %	100 %
Stove, domestic type—no water evaporated—per medium size burner	9000	1000	10000
Gas heated oven—domestic type	12000	6000	18000
Stove, domestic type—heating water—per medium-size burner	5000	5000	10000
Residence gas range—giant burner (about 5½ inches diameter)	*	*	12000
Residence gas range—medium burner (about 4 inches diameter)	*	*	10000
Residence gas range—double oven (total size 18 x 18 x 22 inches, high)	*	*	18000
Residence gas range—pilot	*	*	250
Restaurant range—4 burners and oven	*	*	100000
Cast-iron burner—low flame—per hole	*	*	100
Cast-iron burner—high flame—per hole	*	*	250
Simmering burner	*	*	2500
Coffee urn—large, 18 inches diameter—single drum	5000	5000	10000
Coffee urn—small, 12 inches diameter—single drum	3000	3000	6000
Coffee urn—per gallon of rated capacity	500	500	1000
Egg boiler—per egg compartment	2500	2500	5000
Steam table or serving table—per square foot of top surface	400	900	1300
Dish warmer—per squre foot of shelf	540	60	600

TABLE 24.—HEAT GAIN FROM VARIOUS SOURCES.—(*Continued*)

Source	B.t.u. per hour		
	Sensible	Latent	Total
Gas-burning equipment—(*Continued*)			
Cigar lighter—continuous flame type	2250	250	2500
Curling iron heater	2250	250	2500
Bunsen type burner—large—natural gas	*	*	5000
Bunsen type burner—large—artificial gas	*	*	3000
Bunsen type burner—small—natural gas	*	*	3000
Bunsen type burner—small—artificial gas	*	*	1800
Welsbach burner—natural gas	*	*	3000
Welsbach burner—artificial gas	*	*	1800
Fish-tail burner—natural gas	*	*	5000
Fish-tail burner—artificial gas	*	*	3000
Lighting fixture outlet—large, 3-mantle 480 candlepower	4500	500	5000
Lighting fixture outlet—small, 1-mantle 160 candlepower	2250	250	2500
One cubic foot of natural gas generates	900	100	1000
One cubic foot of artificial gas generates	540	60	600
One cubic foot of producer gas generates	135	15	150
Steam-heated equipment			
Steam heated surface not polished—per square foot of surface	330	0	330
Steam heated surface polished—per square foot of surface	130	0	130
Insulated surface, per square foot	80	0	80
Bare pipes, not polished per square foot of surface	400	0	400
Bare pipes, polished per square foot of surface	220	0	220
Insulated pipes, per square foot	110	0	110
Coffee urn—large, 18 inches diameter—single drum	2000	2000	4000
Coffee urn—small, 12 inches diameter—single drum	1200	1200	2400
Egg boiler—per egg compartment	2500	2500	5000
Steam table—per square foot of top surface	300	800	1100
Miscellaneous			
Heat liberated by food per person, as in a restaurant	30	30	60
Heat liberated from hot water used direct and on towels per hour—barber shops	100	200	300

* Per cent sensible and latent heat depends upon use of equipment; dry heat, baking, or boiling.

TABLE 25.—TYPICAL NOISE LEVELS

Rooms	Noise level in decibels to be anticipated		
	Minimum	Representative	Maximum
Sound-film studios	10	14	20
Radio-broadcasting studios	10	14	20
Planetarium	15	20	25
Residence, apartments, etc	25	35	40
Theaters, legitimate	25	30	35
Theaters, motion picture	30	35	40
Auditoriums, concert halls, etc	25	30	40
Churches	25	30	35
Executive offices, acoustically treated private offices	25	33	40
Private offices, acoustically untreated	35	45	50
General offices	45	55	60
Hospitals	25	40	55
Classrooms	30	35	45
Libraries, museums, art galleries	30	40	45
Public building, courthouses, post offices, etc	45	55	60
Small stores	40	50	60
Upper floors department stores	40	50	55
Stores, general, including main floor department stores	50	60	70
Hotel dining rooms	40	50	60
Restaurants and cafeterias	50	60	70
Banking rooms	50	55	60
Factories	60	70	80
Office machine rooms	60	70	80
Vehicles			
Railroad coach	60*	70	80
Pullman car	55*	65	75
Automobile	50	65	80
Vehicular tunnel	75	85	95
Airplane	80	85	100

* For train standing in station a level of about 45 decibels is the maximum which can ordinarily be tolerated.

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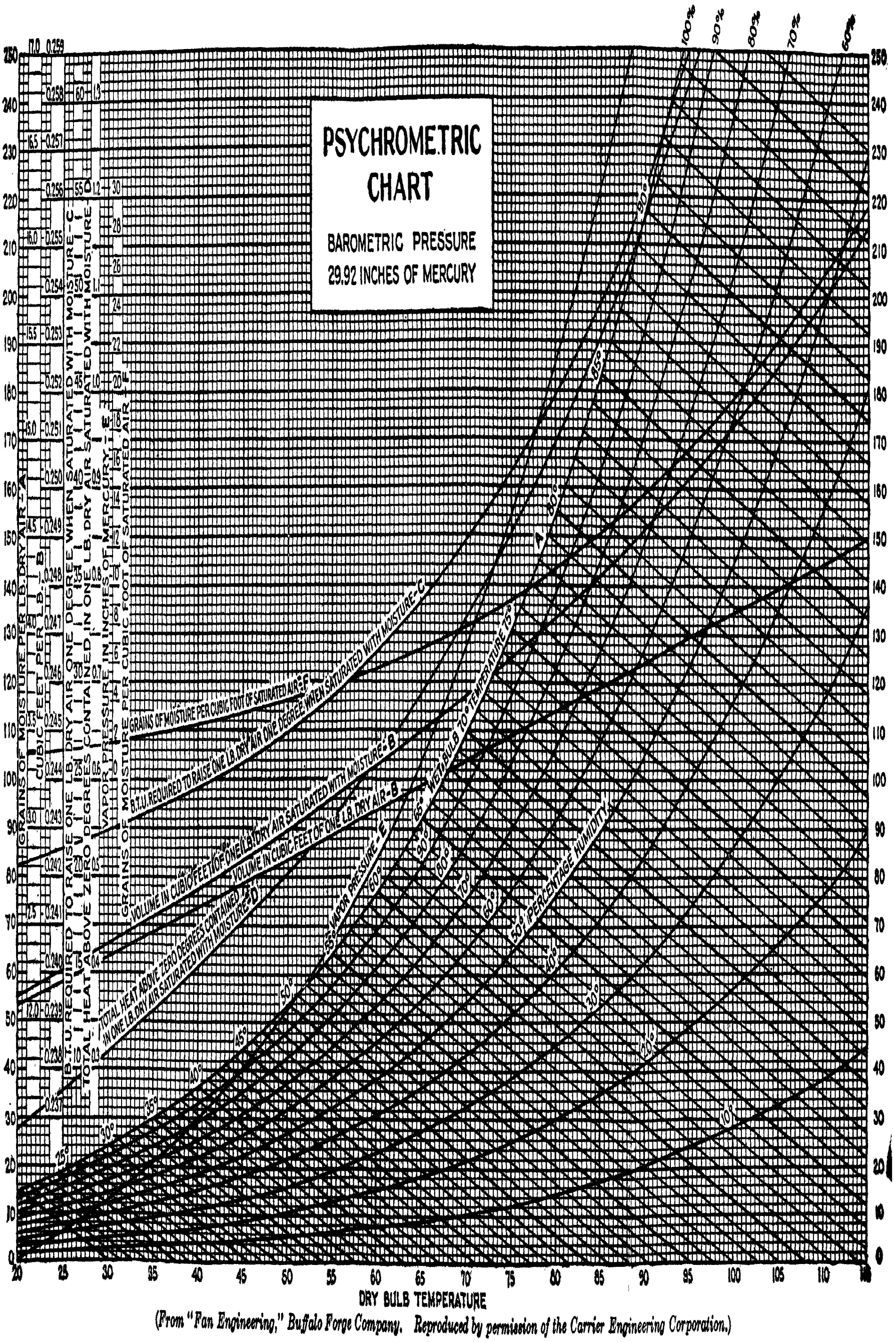

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