# CONTROLLED HUMIDITY IN INDUSTRY

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BY

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WITH FOREWORD BY

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# FOREWORD.

THE importance of air conditioning to the textile industries needs no emphasis, but it may not be generally realised that it has an interest also for those concerned with the maturing of tobacco, the manufacture of chocolates and of photographic films, and the preservation of museum specimens, to mention a few applications.

The Research Control Committee of the Wool Industries Research Association is doing a public service in allowing the publication of this book by one of its staff, Dr. Marsh. In it will be found a survey of the instruments and plants used for controlling humidity in industry, and it should prove of help to those wishing to keep abreast of recent advances in the technology of "air conditioning."

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*May*, 1935.

# PREFACE.

The object of this book is to review the question of the control of humidity under industrial conditions, and the principles of the instruments and plants used for the purpose. It is intended to be of service to manufacturers, engineers and research workers by setting out what has been accomplished in the variation and control of humidity.

The manufacture of the plant described is a very specialised branch of engineering and cannot be carried out successfully except by specialists in this line. No attempt, therefore, has been made here to give details of the methods of manufacture or of the means by which the dimensions of the plants required to suit particular conditions are determined, the latter being a matter for the maker of each type of plant decided from practical experience. There are also many subjects closely allied to humidity problems, such as heating, drying and air filtering, which are also beyond the scope of the present work.

The author's thanks are due to the manufacturers of the various plants and instruments described for the necessary information and illustrations. In every case the photographs or the blocks showing plant have been supplied by the makers of the plant, with the exception of Fig. 34, which is published by courtesy of the *Journal of Scientific Instruments.*

The permission of the Research Control Committee of the Wool Industries Research Association to write this book is also gratefully acknowledged.

M. C. M.

Leeds, *May*, 1935.

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# CONTROLLED HUMIDITY IN INDUSTRY

## CHAPTER I.

### THE IMPORTANCE OF HUMIDITY IN INDUSTRY.

ALTHOUGH water vapour is usually considered to be one of the minor constituents of the atmosphere, it is of greater interest to the manufacturer than any other constituent. In the past the natural humidity has been a great factor in determining the most suitable locality for the manufacture of textile and other materials. It has brought great prosperity to certain districts, while on the other hand, a deficiency or excess of humidity has banned industries from other climates. Local atmospheric conditions are, however, no longer such a dominant factor, for if industrial conditions call for it, the quantity of water vapour can be increased or decreased, and this is often done with great economic advantage. The purpose of this book is to survey the fundamental facts about atmospheric humidity and to describe how it can be measured and recorded, increased or decreased, and automatically controlled.

It is interesting first to review very briefly how other properties of air, both chemical and physical, are changed and controlled on a commercial scale. The relative quantities of the main constituents, nitrogen and oxygen, are rarely varied and then only for medical purposes on a very small scale. With carbon dioxide the general problem is to reduce its quantity (except in such special cases as apple storage) and although this could be effected by chemical absorption, it is generally done by the introduction of fresh air. One main reason for this is that an abnormal amount of carbon dioxide is usually present as a waste product of life or combustion and is consequently associated with a slight decrease in the amount of oxygen. Dust is removed from air by filtration, according to its nature and the amount present. Water vapour is therefore the only constituent of air whose quantity is varied and controlled on a commercial scale.

Of the physical properties of atmospheres, the most obvious one is temperature. The heating of air has been carried out since the earliest history of man, but methods of heating and cooling air are the subjects of much research and development work at the present time. The recent introduction of "unit heaters" and of the system of heating by high pressure water, shows that advance has not yet ceased. Instruments for the control of temperature are also in a state of active development.

Another physical property of air to be considered is that of the velocity of movement, which has a physiological importance. No case is known in which density and pressure of the air are varied for their own sakes except in very specialised circumstances, such as in tunnelling work.

In controlling industrial atmospheric conditions, it is therefore necessary to consider three main factors :—

1. Quantity of water vapour present, *i.e.* the humidity.
2. Temperature.
3. Air velocity, involving generally air change, *i.e.* the introduction of fresh air to replace that already present.

These three are very intimately connected with each other and while this survey treats mainly of humidity, the other two factors are of necessity considered where they are relevant. The problems of humidity, its measurement, variation and control, are matters which are little understood by those who are not connected with the manufacture of plant or instruments for these purposes. There has been a tendency in the past to regard humidity as something intangible and it is to be regretted that some manufacturers of humidifiers and similar plant do not seem to have been at all anxious to remove this belief. The subject has therefore been greatly neglected or considered to be only of academic interest.

The following sections attempt to show that the question of humidity is one of great practical industrial importance, and that in some cases the advantages are so great that the initial outlay and running costs of a humidity controlling plant are amply repaid.

The first factor to be considered may well be that of the material used. It is generally recognised in all industries using hygroscopic materials (which include many manufactured foodstuffs, textiles, paper, leather, etc.) that there are good and bad working days, depending on the weather conditions prevailing. Air conditioning plant manufacturers claim that it is possible to reproduce the best conditions every day of the year, thus resulting in higher rates of production and a better product. The benefit of the elimination of the effects of weather on some industrial processes is so obvious that it need not be stressed further.

Another advantage from the point of view of the material is that the production of dust, lint or " fly " is generally a minimum when the optimum humidity for ease of working is maintained. Thus waste and the deposition of dirt in undesirable places are reduced. Similarly, in the storage of hygroscopic materials, it is possible to maintain them at any desired moisture content without the risk of its becoming too high and causing mildew. In such an application the benefit of running the plant night and day is obvious.

It is a well-known fact that under certain atmospheric conditions, some industrial processes, such as textile and celluloid film manufacture, are rendered very difficult

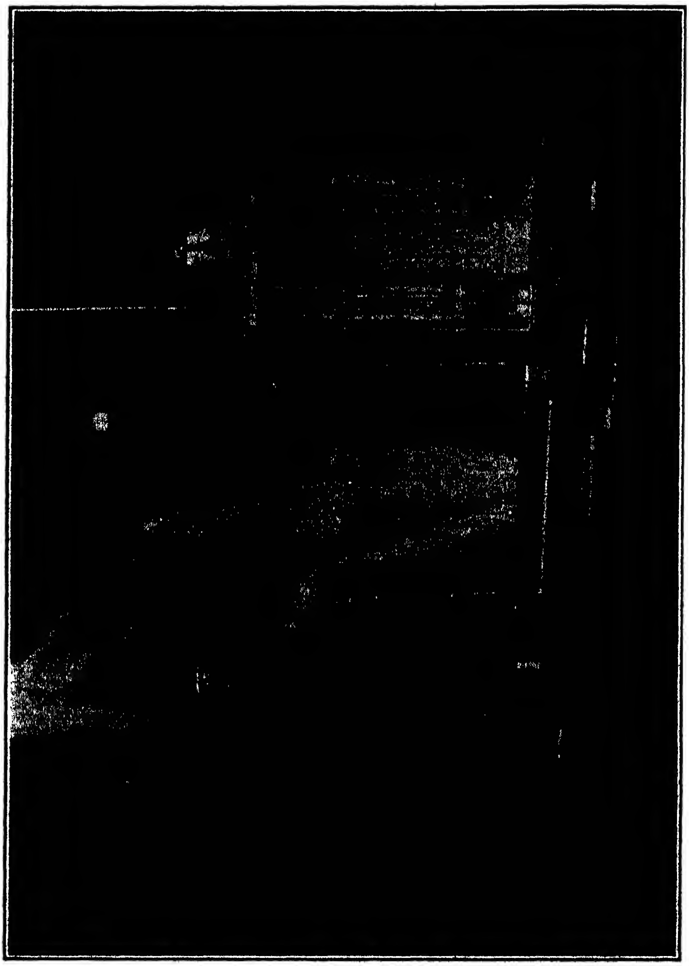


FIG. 1.—Electrified Wool Clinging to the Leather of a Worsted Gill-box.

owing to electrification. As such conditions are approached, the quality of the work must suffer, even if electrification is only slight. When it becomes severe processes are sometimes brought to a complete standstill (see Fig. 1). It has been definitely proved that electrification can be entirely removed in all cases by increasing the humidity. The electrical resistance of, for example, textile fibres, decreases very rapidly with increase of humidity, as is indicated by the curve in Fig. 2 obtained by Marsh and Earp (*Trans. Faraday Soc.*, 1933, **29**, 173), for a wool fibre. From this curve it will be seen that the resistance decreases to one-

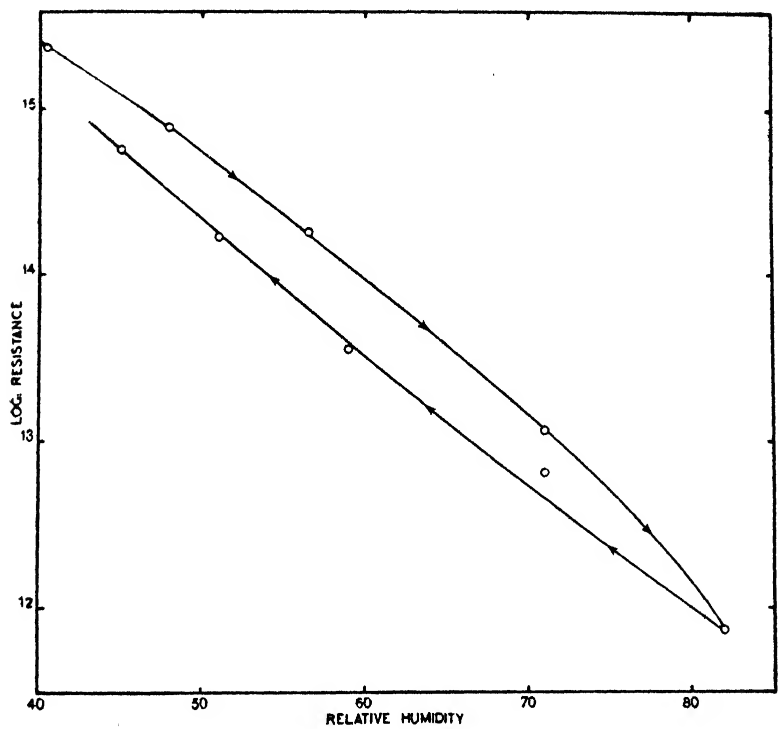



FIG. 2.—Curve showing the Relation between the Electrical Resistance of Wool and the Relative Humidity of the Air in Equilibrium with it.

thousandth of the value at 45 per cent. R.H. when the humidity is raised to 80 per cent. R.H. When the resistance of the material is low, the charges escape before they become large enough to produce harmful effects.

Another interesting example occurred in a process in which rubber mixed with an inflammable solvent had to be passed between rollers. When the humidity was low, the rubber became electrified and the resulting sparks set fire to the solvent vapour. This trouble has been completely eliminated by humidification of the atmosphere.

In general the weight, dimensions and other physical properties of hygroscopic substances change with variations of the atmosphere and especially with humidity. Where the weight or size of the product is to be determined with accuracy, these variations may have very serious consequences. An example of this is found in multi-colour printing, where it is essential that all the impressions in the various colours should register exactly. The paper is located in the machine by its edges, so that if expansion or contraction has occurred, there will be imperfection in the register. This has been overcome in many modern printing works by the maintenance of constant humidity conditions.

Another example is found in the production of textile yarns which have to have definite "counts" (length per unit weight) within narrow limits when they contain a certain percentage of water. Adjustments of the machines to compensate for variations in the product which are really due to humidity changes must necessarily introduce irregularity in the yarn. In practice it is obvious that the only satisfactory way to achieve the best results is to keep the humidity as constant as possible.

A further purpose served by controlled atmospheres is the production of conditions for human comfort. Whilst this is done to some extent in manufacturing concerns for the benefit of the work-people, and for the increasing of production, its greatest application is in public buildings such as cinemas, theatres, hotels, hospitals and large stores. The most comfortable conditions vary with the type of building, the season of the year and other factors, but it may be taken in general that they are approximately 35-50 per cent. relative humidity and a temperature of 65-70° F. In a well-filled building, for instance a cinema, the heat and moisture given off by the people is always sufficient to raise both the temperature and humidity to a considerable extent. Cooling and drying of the atmosphere therefore are both necessary, especially in summer when a comfortable atmosphere is a great attraction. Under such conditions, however, the temperature must not be so low as to produce a cold shock on entering the building. For comfort purposes, the plants used are generally of the central station air conditioning type and although these are costly, their increasing use shows that they are a profitable investment, since they serve also to give heating, ventilation and air washing service for the building.

An extension of "comfort" work, which is hardly industrial but of great interest, is the preparation of atmospheres for medical purposes. The "bronchitis kettle" has been well known for a long time, and certain climates are found beneficial for certain diseases of the respiratory system. It is possible therefore that research would prove that there is an optimum humidity for the treatment of such diseases. Preliminary results from America point to interesting developments along these lines.

With these examples in mind it is hard to think of an industry which is completely independent of humidity conditions. Even in the iron industry it has been found worth while to dry the air supplied to blast furnaces. It should, therefore, be a matter of considerable interest to every manufacturer to enquire whether there is any point in his processes where the control of humidity would be an advantage.

It is essential also to review the objections which have been raised against humidification of indoor atmospheres. It must be admitted that very high humidities are not comfortable and tend to produce a feeling of fatigue, especially at fairly high temperatures. This sensation of discomfort disappears after a time spent under the same atmospheric conditions, and after a few weeks will hardly be noticed at all. The "stuffy" feeling can, however, be greatly reduced by causing an adequate movement of the air. This can often be brought about by the humidifying devices themselves, if they are provided with fans. Otherwise, circulating fans can be installed.

Objections are also often raised, especially by the operatives, to humidification on the grounds that it is injurious to health. This subject has been investigated in relation to cotton weaving by the Industrial Fatigue Research Board of the Medical Research Council. The investigation is detailed in a very clear and interesting report by Dr. A. Bradford Hill, entitled "Artificial Humidification in the Cotton Weaving Industry—its Effect upon Sickness Rates of Weaving Operatives" (Industrial Fatigue Research Board of the Medical Research Council, *Report No.* 48, 1927). It is sufficient here to quote a few sentences from the conclusions reached by Dr. Hill, but the whole Report is worthy of close study not only for the results obtained, but for the masterly way in which a difficult statistical problem has been handled. He says (pp. 71-73):—

"The trade organisations of the operatives have for many years opposed these methods of increasing the humidity in the mills, one of the grounds for their objections being a belief that the relatively hot and humid atmosphere is deleterious to health and causes a high sickness incidence in the humid sheds . . . The operatives are still dissatisfied with the conditions and require the total abolition of all artificial humidification. Such a step, in the opinion of the employers, would seriously impair production of certain types of cloth.

"The investigation . . . was designed to test the operatives' contention that artificial humidification is responsible for excess rates of sickness in the humid as compared with the non-humid sheds. A sample of mills of each type was chosen and the sickness experience of all the weavers within these mills was obtained for the year 1st August, 1925 to 31st July, 1926. This sickness was related to the environment in which the weaver was at work during the year . . . The sickness of, in all, some 20,000 weavers was investigated.

"A year's investigation of the sickness incidence found in all the humid sheds and that found in the non-humid sheds reveals no significant difference between the two, either in number of days of sickness experienced, in number of claims made, or in number of persons suffering from one or more sicknesses during the year of investigation . . .

"Analysis of the sickness, town by town, produces a similar result, *i.e.* the humid sheds are not found to possess a higher sickness incidence than the non-humid sheds . . .

"The classification of mills as humid and non-humid makes no allowance for the variations within these groups. To take this into account, wet and dry bulb temperature readings were obtained from each mill over a period of five months in the year of investigation. The mills were then classified according to these readings, and the sickness experience related to their dry bulb, wet bulb, relative humidity, physiological saturation deficit, and combinations of these variables. Although the groups thus obtained were often too small to give reliable results when taken alone, the rates were sufficiently consistent to make it justifiable to state that no significant difference in the sickness incidence was present within the range of variation found to exist. In addition no difference was found between the extremes in the humid group and the extremes in the non-humid group . . .

"Analysis, involving rather small figures, according to the *nature* of the incapacity suffered in the two environments, yielded no evidence of any consistent or distinct differences in the distribution of specific sickness as between humid and non-humid sheds."

It is clear from these facts that high humidities have no deleterious effect on the operatives. No similar complaints of harmful effects from low humidities have been recorded.

# CHAPTER II.

## FUNDAMENTALS OF HUMIDITY.

BEFORE going into methods of measuring, varying and controlling humidity, it may be profitable to recall a few fundamental facts about humidity which are of industrial importance.

As already pointed out, air ordinarily contains water vapour. According to Dalton's law of partial pressures, each gas in such a mixture exerts a pressure independent of the others. Thus in any given space, each gas is at the same density and exerts the same pressure as if it occupied the whole space alone. The water vapour in air therefore exerts a pressure which depends on the amount present. As the quantity of water vapour increases the pressure also increases until it reaches a maximum value corresponding to the vapour pressure over liquid water at the same temperature. In this state the air is said to be saturated and the vapour pressure is called the saturation or maximum vapour pressure. The saturation vapour pressure of water increases rapidly with temperature as will be seen from the following brief table :—

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (° C.) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Temp. (° F.) | 32 | 50 | 68 | 86 | 104 | 122 | 140 | 158 | 176 | 194 | 212 |
| Maximum Vapour Pressure of Water (mm. of mercury) | 4·6 | 9·2 | 17·5 | 31·7 | 55·1 | 92·3 | 149·2 | 233·5 | 355·1 | 525·8 | 760·0 |

In general the actual vapour pressure of water in air is not equal to the saturation vapour pressure and the ratio of the former to the latter is known as the *relative humidity.* This is usually expressed as a percentage and hence an alternative term *percentage humidity* is sometimes used.

If the effect of heating a given volume of air containing water vapour but no free water be considered, it will be seen that this will result in a decrease in relative humidity since the vapour pressure of water will increase proportionally to the absolute temperature, while the saturation pressure increases much more rapidly. Similarly, if air is heated at constant pressure, which is the more usual case, the vapour pressure of water will remain constant as long as no water is evaporated or condensed, while the saturation vapour pressure will increase. It may therefore be taken that when air is heated the relative humidity is lowered and when it is cooled the relative humidity is increased.

While from a scientific point of view, vapour pressure is the best method of defining the amount of water contained in air, from an engineering point of view it is more useful to know the actual weight of water contained in unit volume of air. This is known as the *absolute humidity* and is expressed in grains per cubic foot on the British system of units and grammes per cubic metre on the metric system. As water vapour obeys Boyle's law approximately, its pressure is proportional to the reciprocal of the volume of a given mass, and therefore to the density. Thus within the limits of accuracy of this law, the absolute humidity is proportional to the vapour pressure. Another interesting consequence of water vapour obeying Boyle's law, is that at a given temperature the saturation absolute humidity is independent of the pressure.

Relative humidity may now be alternatively defined as the ratio of the actual absolute humidity to the absolute humidity of air when in equilibrium with liquid water at the same temperature. This definition is based on the weights of water in a given volume of air. A still further definition is similar but defines relative humidity as the weight of water per pound of air divided by the saturation weight of water per pound of air. In the last definition it should be stated whether the air is wet or dry.

There are thus four possible definitions for relative humidity, but when it is realised that in any given case the differences between the values given by the various methods of definition are far smaller than the errors in the best methods of measuring relative humidity, the matter is of small concern. It is clear, however, that as accuracy of measurement increases, the differences may become significant.

It is *relative* humidity rather than the *absolute* humidity which is the important factor in practical work, and for human comfort. This will, therefore, be the main term referred to in all further discussion, and unless " humidity " is definitely described as " absolute " it may be assumed that " relative " humidity is signified.

To take a practical example, the following figures calculated from Hartshorne's tables show the relative and absolute humidities corresponding to wool with a regain of $18\frac{1}{4}$ per cent. (*i.e.* containing $18\frac{1}{4}$ per cent. of water calculated on the dry weight) at temperatures from 50-90° F.

| Temperature (°F.) | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|
| Relative Humidity (per cent.) | 69 | 71 | 73 | 75 | 77 |
| Absolute Humidity (grains/cu. foot.) | 2·8 | 4·1 | 5·9 | 8·3 | 11·4 |

It is therefore clear that in the wool industries the determination of the relative rather than the absolute humidity is of greater importance.

Tables of absolute humidities such as that just quoted, and other similar data, give very little idea of the actual quantities of air and water involved in any scheme involving the change of the hygrometric state of the air. It is of interest therefore, to calculate a concrete example. For this purpose, a "unit" volume of 10,000 cu. ft. is convenient. The volumes of rooms used for industrial purposes will vary from this volume up to about one hundred times this size, while testing rooms will be of the order of one-tenth of this volume. Calculations for any building can therefore be readily made from this unit. A temperature of 70° F. will be assumed and a barometric pressure of 29·9 inches (760 mm.) of mercury.

Under these conditions perfectly dry air has a density of 0·0750 lb. per cu. ft. This value decreases regularly as air absorbs water until at saturation it is 0·0743 lb. per cu. ft. The total weight of air in the "unit" volume, therefore, varies from 750 lbs. at 0 per cent. relative humidity to 743 lbs. at 100 per cent. R.H. Intermediate values are given in the table overpage.

The weight of water required to saturate this volume of air at 70° F. is 11·4 lbs. which is only 1·53 per cent. of the weight of the air. It will therefore be seen that, under normal conditions, the percentage of weight of water in air is very small indeed. Also the weight of water required to increase the relative humidity by 1 per cent. is only 0·114 lb. or 1·82 ozs. Thus the evaporation of 1 pint of water is enough to raise the relative humidity of 10,000 cu. ft. of air by 11 per cent. The effect on the relative humidity of changing the temperature by 10° F. either way, and figures relevant to the above calculation, are given in the table overpage.

Psychrometric charts giving very full particulars of the properties of air which are of interest to air conditioning engineers were introduced in America by Carrier in 1911. These charts are too complicated to be included here, but will be found with explanations in "*Air Conditioning*" by Moyer and Fittz (McGraw-Hill).

It must be remembered that from a room which is at a higher humidity than outside, there will always be a leakage of air and therefore of water vapour. This will be greatly increased if fresh air is brought in by means of a fan. Water may also be absorbed by hygroscopic substances (*e.g.* textile materials, woodwork, etc.) in the room. Any humidifying plant in addition to supplying the quantity

**Table showing Properties of 10,000 cu. ft. of Air at 70° F.**

**(Pressure 29·9″ of Mercury).**

| Relative Humidity, Per cent. | 0 | 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|---|
| Vapour pressure of water (inches of mercury) . . . | 0 | 0·146 | 0·296 | 0·441 | 0·590 | 0·736 |
| Absolute humidity (grains per cubic foot) | 0 | 1·6 | 3·2 | 4·8 | 6·4 | 8·0 |
| Density (lbs. per cubic foot) . . . | 0·0750 | 0·0748 | 0·0747 | 0·0746 | 0·0744 | 0·0743 |
| Weight of 10,000 cu. ft. (lbs.) . . . | 750 | 748 | 747 | 746 | 744 | 743 |
| Weight of water present (lbs.) . . | 0 | 2·3 | 4·6 | 6·8 | 9·1 | 11·4 |
| Percentage weight of water . . . | 0 | 0·31 | 0·61 | 0·91 | 1·22 | 1·53 |
| R.H. if temp. lowered to 60° F. (per cent.) . | 0 | 31 | 56 | 84 | Supersa | turated. |
| R.H. if temp. raised to 80° F. (per cent.) . | 0 | 14 | 29 | 43 | 58 | 73 |

of water indicated in the above table for the raising of the humidity, will therefore have to supply further amounts to make up for leakage and absorption. This extra amount of moisture may become very important when the relative merits of steam and water spray humidification are in question. Each pound of steam in cooling from boiling point to 70° F. will give to the room 67 British thermal units, whereas if water spray humidification is used, each pound of water evaporated absorbs 1053 British thermal units, thus giving a cooling effect.

A few terms which occur in the discussion of humidity questions may usefully be defined at this juncture.

**Dry Bulb Temperature** is the temperature of the air as ordinarily measured.

**Wet Bulb Temperature** is the reading given by a thermometer whose bulb is covered by a wet cloth. As this reading depends on the construction of the thermometer and the velocity and barometric pressure of the air passing over it, besides the humidity of the air, it is not a very exact term. It must therefore be taken as applying to the instrument and conditions under discussion.

**Bulb Difference** is the difference in temperature shown by the wet and dry bulbs.

**Dew Point.**—When air is cooled sufficiently it falls to a temperature at which it is saturated and deposits dew on solid surfaces. This temperature is called the " dew point."

**Effective Temperature.**—The " effective temperature " has been defined as " the degree of warmth as felt by the human body " and attempts to combine in one figure the effects of temperature, humidity and air movement. It can only be determined in the first place by carrying out physiological measurements on human beings under various conditions. The effective temperature thus varies with the amount of clothing and the degree of activity of the subject. Most of the work on this subject has been carried out at the Laboratory of the American Society of Heating and Ventilating Engineers, whose publications should be consulted for further details.

**Equivalent Temperature.**—The "equivalent temperature" of an environment is defined as that temperature of a uniform enclosure in which, in still air, a sizable black body at 75° F. would lose heat at the same rate as in the environment. Humidity has little effect on equivalent temperature, which is generally measured by an instrument known as a "eupatheoscope," to be described later. (For further details see the Department of Scientific and Industrial Research *Building Research Technical Paper No.* 13, "The Equivalent Temperature of a Room and its Measurement," H.M. Stationery Office.)

It can also be measured by means of two special katathermometers one silvered and one black (Dufton, *Journ. of Hygiene*, 1933, **33**, 349). The cooling times are converted to equivalent temperatures by means of a nomogram. Later a special stop watch dial was designed to allow the conversion to be done in an even simpler manner (Dufton, *Journ. of Hygiene*, 1933, **33**, 474).

## CHAPTER III.

## INDUSTRIAL METHODS OF MEASURING RELATIVE HUMIDITY.

THERE is no simple way of measuring humidity which is at the same time accurate, reliable and convenient. A great need exists, therefore, for an apparatus which can be relied on for accuracy, which will not change with time, and which will give direct readings. From the practical point of view, however, good, accurate instruments do exist, even if they are slightly inconvenient to use. It is this slight inconvenience in taking readings and obtaining values which has seemingly caused the consideration of humidity problems to be ignored in industry, since humidity variations often go unnoticed. The common types of humidity measuring apparatus of various kinds are readily available. The degree of reliability and accuracy, however, depends greatly on the price and the maker. In this treatise, methods of hygrometry of general industrial application are discussed. Laboratory and specialised industrial methods will be found in the literature of the subject (see Bibliography) and especially in the Department of Scientific and Industrial Research publication "*The Measurement of Humidity in Closed Spaces.*"

### Wet and Dry Bulb Thermometers.

1. **Mercury-in-Glass Type.**—This is the hygrometer most commonly used in factories, since it is required by the Factory Acts that two such instruments shall be placed in any room which is artificially humidified. In its unventilated form it is, however, not a reliable instrument when

accuracy is important. It consists of two mercury-in-glass Fahrenheit thermometers, usually with spherical bulbs (Fig. 3), one of which is covered with muslin and is provided with a wick dipping into a water reservoir which keeps the

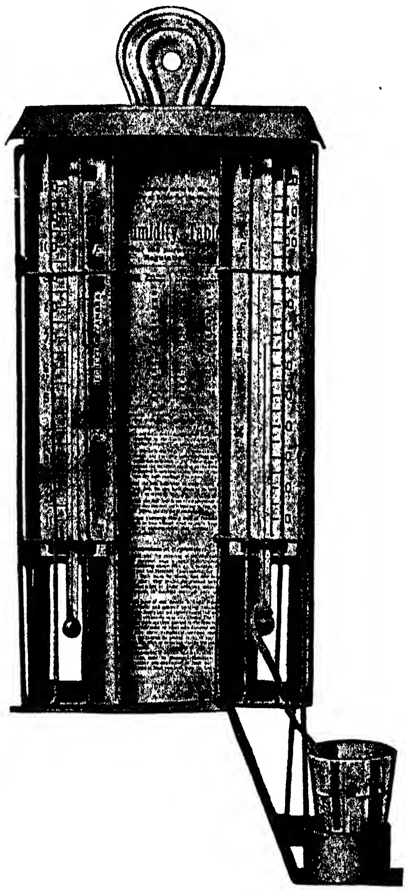


FIG. 3.—Wet and Dry Bulb Hygrometer (Type approved by Home Office).

muslin wet. Water then evaporates off the muslin at a rate depending on the relative humidity of the air. The latent heat required for this evaporation is obtained mainly from the bulb of the thermometer and in consequence this indicates a lower temperature than the dry one. The "bulb difference" is then a measure of the relative humidity, which is determined by reference to tables.

These instruments need regular attention to ensure results which are of any value. The effect of neglect is that a humidity is indicated which is too high. The best instructions for the use of the wet and dry bulb hygrometer are those given by the Home Office in connection with the regulations for humidified factories. These are as follows :—

"The standardised wet and dry bulb hygrometers should be so fixed about 4½ ft. above the floor as to be easily read, and should not be on a hot or damp wall. The bulbs should be at least 3½ ins. apart The water reservoir should be on the side away from the dry bulb, and either have a very small aperture for the wick, or (better) be provided with a copper cover having such an aperture.

"Next to accuracy, legibility is of first importance. The scale should be open (allowing of readings to half a degree) and clearly marked, and should range from about 40° to about 110°. The column of mercury or spirit should not be too fine.

"The water in the reservoir, and the muslin coat of the wet bulb, need frequent renewal. The reservoir should be kept supplied with pure soft water, such as rain or distilled water. (If hard water be used, the muslin becomes clogged and the readings exaggerate the indication of humidity.)

"The muslin and wick as a rule need renewal at least every fortnight and more often if they become dirty or clogged. The renewal, which should be done outside working hours, is effected as follows :—A piece of wet thin muslin (a fine bleached India muslin is suitable) is fitted closely round the bulb and secured in position by a wetted thread of soft coarse bleached knitting cotton (*e.g.* No. 4) tied firmly but not tightly round the neck of the bulb, preferably in a slip knot. The two ends of the thread are then carried as a wick into the reservoir."

It will be noted that standardised thermometers are specified. The only legal standardising authority in Great Britain is the National Physical Laboratory, which will test thermometers and supply a certificate for a small charge. The instruments thus tested have a monogram of the letters *N.P.L.*, followed by the year, etched on them. It is strongly advised that all wet and dry bulb hygrometers should be tested thus before purchase, whether they are to be used for official purposes or not, as the accuracy of the thermometers is a vital factor.

It is possible to use a wet and dry bulb instrument when the wet bulb is frozen. Special precautions which have to be taken will be found in the books of tables. This, of course, applies only to outdoor observations.

The tables generally used in Great Britain for this type of wet and dry bulb hygrometer are "*Hygrometric Tables Adapted for the Use of the Dry and Wet Bulb Thermometer,*" by James Glaisher, F.R.S. (published by Taylor & Francis, London). These are based on comparisons with Daniell's dew point hygrometer, at the Royal Observatory, Greenwich, between 1841 and 1854, combined with others at high temperatures made in India and at low and medium temperatures at Toronto. While Daniell's hygrometer is not the best of its type, Glaisher's results are accurate enough for many purposes at ordinary temperatures and humidities. The Humidity Tables mentioned in the Factory and Workshop Acts are based on his figures. More convenient arrangements of his results have been published, but are not easily available.

Several instruments are now produced, in which tables are replaced by a series of curves inscribed on a vertical cylinder. By rotating this cylinder to a point on a scale corresponding to the dry bulb temperature, the relative humidity or dew point is indicated directly by the height of the wet bulb thermometer with reference to the curves.

The Meteorological Office issues tables (*M.O.* 265) for use with wet and dry bulb thermometers exposed in Stevenson screens out of doors. The introduction to these says :—

"The tables are not suitable for use with thermometers exposed indoors, for example, in factories or store-rooms, unless precautions are taken to secure adequate motion of the air over the thermometers by fanning or otherwise."

This raises a very difficult question. Glaisher's tables are for "still air," which, if it is realised in practice, means that the sample of air the hygrometer measures may not be the same as the rest of the room. The Meteorological Office tables are for "light airs." It is well known that the bulb difference varies with air velocity over the bulbs, so that in view of the draughts, etc. in mills, the indication of the ordinary wet and dry bulb hygrometers can often only be taken as approximate.

2. **Ventilated Mercury-in-Glass Type.**—The rather unsatisfactory state of affairs due to the effect of air velocity

Fig. 4.—"Whirling" or "Sling" Psychrometer.

on the wet bulb reading of an ordinary wet and dry bulb hygrometer has led to the extensive use of "ventilated hygrometers." It is found that as the air velocity over the bulb increases at any fixed temperature and humidity, the bulb difference increases until the air velocity is about 10 ft. or three metres per second. Above this value it is practically constant. The ventilated type of instrument uses this fact.

In the "*Sling*" or "*Whirling*" *Psychrometer* (Fig. 4) the thermometers are rotated, thus causing a stream of air to flow over the bulbs. This instrument is adopted as the standard for measurement of humidity in the U.S. Weather Bureau. The following instructions for its preparation are taken from their psychrometric tables

("*Psychrometric Tables*," Washington Government Printing Office) supplied for use with the "sling" instrument :—

"The instrument consists of a pair of thermometers provided with a handle, which permits the thermometers to be whirled rapidly, the bulbs being thereby strongly affected by the temperature of and the moisture in the atmosphere. The bulb of the lower of the two thermometers is covered with thin muslin, which is wet at the time when observation is made.

"*The Wet Bulb:* It is important that the muslin covering for the wet bulb be kept in good condition. The evaporation of the water from the muslin always leaves in its meshes a small quantity of solid material, which sooner or later somewhat stiffens the muslin so that it does not readily take up water. This will be the case if the muslin does not readily become wet after being dipped in water. On this account it is desirable to use water which is as pure as possible, and also to renew the muslin from time to time, according to instructions given.

"*To Make an Observation:* The so-called wet bulb is thoroughly saturated with water by dipping it into a small cup or wide-mouthed bottle. The thermometers are then whirled rapidly for 15 or 20 seconds, stopped and quickly read, the wet bulb first. This reading is kept in mind, the psychrometer immediately whirled again, and a second reading taken. This is repeated three or four times, or more if necessary, until at least two successive readings of the wet bulb are found to agree very closely, thereby showing that it has reached its lowest temperature.

"When the air temperature is near the freezing point it very often happens that the temperature of the wet bulb will fall several degrees below freezing point, but the water will remain in the liquid state. No error results from this, provided the minimum temperature is reached. If, however, as frequently happens, the water suddenly freezes, a larger amount of heat is liberated and the temperature of the wet bulb immediately becomes 32°. In such cases it is necessary to continue the whirling until the ice-covered bulb has reached a minimum temperature.

"*Whirling and Stopping the Psychrometer:* It is impossible effectually to describe these movements. The arm is held with the forearm about horizontal and the hand well in front. A peculiar swing starts the thermometers whirling and afterwards the motion is kept up by only a slight but very regular action of the wrist in harmony with the whirling thermometers. The rate should be a natural one, so as to be easily and regularly maintained. If too fast, or irregular, the thermometers may be jerked about in a violent and dangerous manner.

"The stopping of the psychrometer, even at the very highest rates, can be perfectly accomplished in a single revolution.

"*Exposure:* While the psychrometer will give quite accurate indications, even in the bright sunshine, yet observations so made are not without some error, and, where greater accuracy is desired, the psychrometer should be whirled in the shade. In all cases, there should be perfectly free circulation of the air, and the observer should face the wind, whirling the psychrometer in front of his body. It is a good plan while whirling to step back and forth a few steps further to prevent the presence of the observer's body from giving rise to erroneous observations.

"*Preparation of Wet-bulb Thermometers:* Certain precautions must be observed in preparing and fitting muslin covering of the wet bulb, as follows:—

(*a*) Fine, preferably loosely woven, muslin is best, and if new material is used, it must first be thoroughly washed with water to remove all sizing as far as possible.

(*b*) The covering must be carried up on the stem of the thermometer above the bulb a distance so that the stem near the bulb, as well as the bulb itself, is cooled by the evaporation.

(*c*) The muslin must be thoroughly wetted when a new piece is to be applied to the bulb, and fitted in the manner explained above."

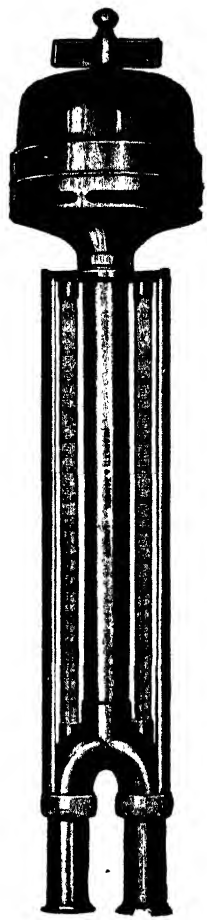


FIG. 5.—Assmann Psychrometer.

Another ventilated mercury-in-glass instrument is the *Assmann Psychrometer* (Fig. 5). This is regarded as the best hygrometer produced at present and the standard instrument for checking purposes. A constant current of air is drawn over the bulbs by a fan driven by a clockwork or electric motor. The bulbs are surrounded by highly polished metal sheaths, so that the instrument is unaffected by heat radiated by the sun or other hot bodies. The tables used with it are practically identical with those used for the "Sling" instrument. The best tables are the "*Aspirations Psychrometer Tafeln*" issued by the Prussian Meteorological

Institute. These tables originally covered the range up to 40° C. (104° F.), but this range has been extended recently by Awbery and Griffiths (*Proc. Phys. Soc.*, 1932, **44**, 132) up to 100° C. (212° F.). The usefulness of this instrument is therefore greatly enhanced.

Special forms of this instrument can be made. One form was designed by Dr. Ezer Griffiths of the National Physical Laboratory, for investigating the humidity in rooms, cold stores, etc. Air is withdrawn from the room along an insulated duct in which are wet and dry bulb thermometers. The thermometers can therefore be situated at any convenient place outside the room and readings thus taken in comfort.

3. **Mercury-in-Steel Thermometers.**—It is a short step from a mercury-in-glass to a mercury-in-steel thermometer. This consists of a steel bulb and capillary tube filled with mercury and connected to a pressure measuring device of the Bourdon tube type, calibrated in temperatures. The capillary tube is so fine that normally it introduces no appreciable error, but if a great length is necessary a compensating device can be used. The steel bulb thermometers have the advantage of robustness, great accuracy and permanency. The bulbs are, however, apt to be heavy for the amount of surface exposed and should be chosen to secure a maximum surface area per unit volume. It should always be arranged that the bulbs are in an air stream with a minimum velocity of 10 feet per second. Assmann tables may then be used to calculate humidity, but for the most accurate work, the wet bulb reading should be checked by the wet bulb of an Assmann instrument.

Mercury-in-steel thermometers may be made self-recording and consequently a continuous record of the wet and dry bulb temperatures can be obtained. (Fig. 6).

An instrument has been designed by R. G. Bateson, of the Forest Products Research Laboratory, to give direct humidity readings (*Journ. Sci. Instr.*, 1932, **9**, 94.) Wet and dry bulb mercury-in-steel thermometers cause the movement of two racks which are connected by a mechanism

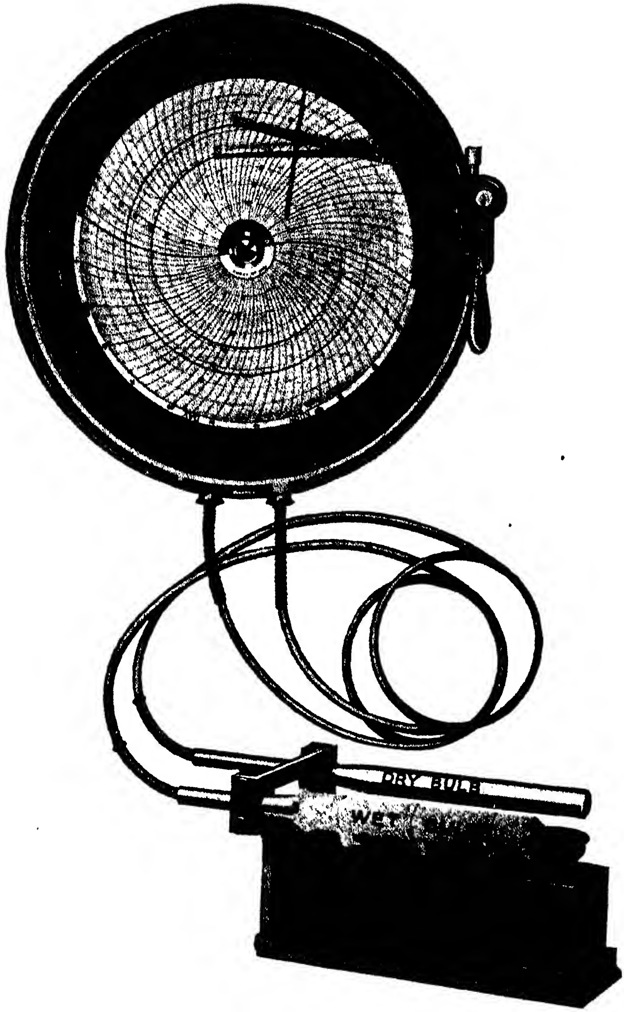



FIG. 6.—Wet and Dry Bulb Recording Hygrometer.
(Mercury-in-steel type thermometers.)

to a pointer moving over a scale calibrated in relative humidity. The mechanism is based on a well-known nomogram for converting wet and dry bulb readings to relative humidity.

4. **Bi-Metallic Thermometers.**—Indicators and recorders using bi-metallic spirals are made, but it is stated that the wet bulb indication cannot be relied upon owing to the difficulty of surrounding the spiral with a film of moisture.

5. **Electrical Resistance Thermometers.**—The use of electrical methods for measuring humidity has the advantage of indicating and recording at a distance, if desired. Readings at several scattered points may be taken on one recording instrument. It has been shown that satisfactory results cannot be obtained by merely providing a wet covering for a standard "bulb."

Considerable attention has been given during the last few years to the electrical method for the direct determination of humidity and it is now proposed to describe three instruments for this purpose. It will be realised that, owing to the character of their construction, such instruments cannot be produced cheaply.

In the *Cambridge Humidity Indicator and Recorder*, the sensitive element comprises two identical long spirals of platinum wire encased within a sheathing of special construction, the arrangement being such as to secure exceptionally rapid response to changes in temperature, and the elimination of errors due to conduction of heat along the supports of the usual type of bulb. One of the spirals serves to measure the "dry bulb" temperature, whilst the other is fitted with a fabric sleeving which is thoroughly wetted before use. In this way a large evaporative surface is obtained in intimate contact with a thermometer element of small total mass. Tests have proved that for any given humidity this form of thermometer element gives a greater temperature difference between the wet and dry thermometers than is otherwise obtained. The two thermometers are mounted together, on a common shaft which is extended to form a convenient handle, as shown in Fig. 7. They are connected to an indicator mounted in a portable case which also accommodates a switch, a rheostat and the battery for supplying current in the Wheatstone bridge circuit.

When the switch is set to "Temperature," the dry thermometer only is connected up, and the temperature is

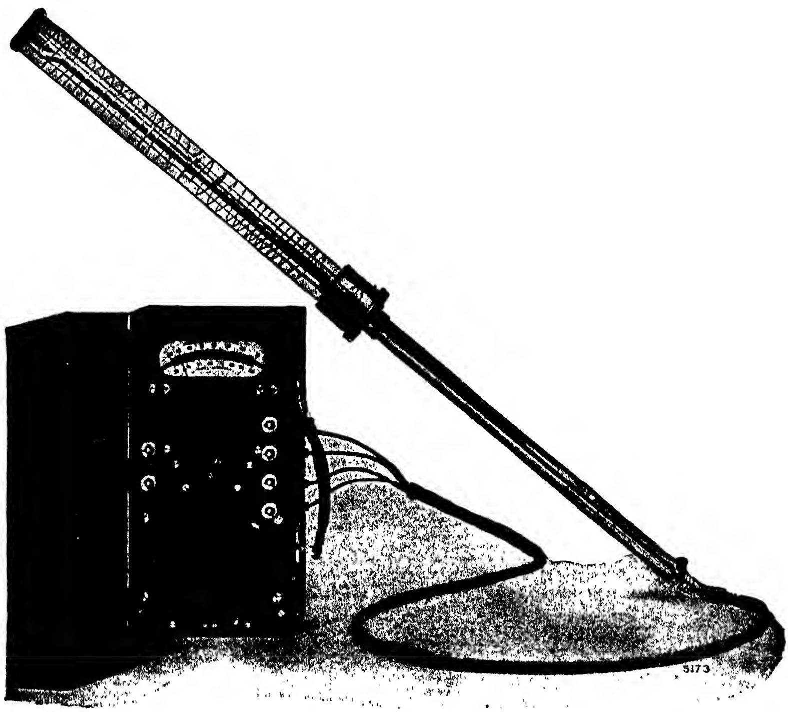


FIG. 7.—Cambridge Humidity Indicator.

read on the lower scale of the indicator. By rotating a large circular dial concentric with the switch so that the scale around this dial is set to this temperature, a rheostat in the Wheatstone bridge circuit is adjusted so as to introduce automatically the necessary correction in the humidity readings for that temperature. The switch is then turned to the "Humidity" position, when both wet and dry thermometers are connected up in such a way that the galvanometer pointer is controlled by the difference in the two temperatures. Since the galvanometer sensitivity has previously been adjusted by the rheostat in relation to the dry bulb temperature, the deflection can be read directly on the upper scale of the indicator, in terms of percentage relative humidity.

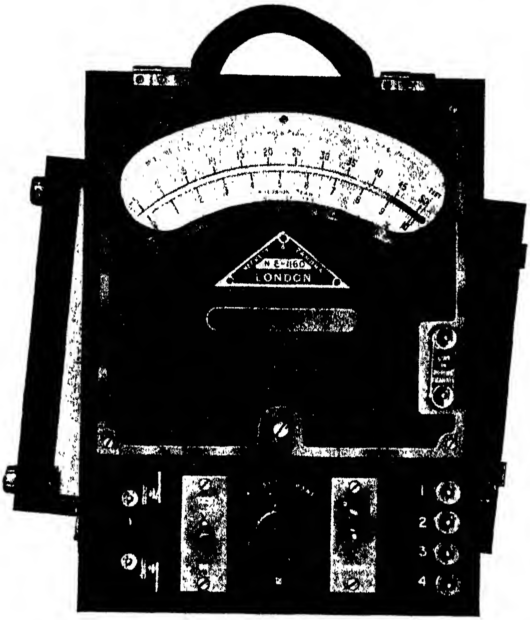
A recording outfit is also made, in which the correction for variations in the dry bulb temperature is automatically effected by means of an independent relay mechanism, thus enabling the recorder chart to be calibrated to read directly in terms of percentage relative humidity.

In the *Negretti and Zambra Thermocouple Wet and Dry Bulb Hygrometer* (Fig. 8), designed by Dr. Ezer Griffiths of the National Physical Laboratory, the bulb difference is measured by thermocouples mounted on a cylindrical glass former, one series of junctions being covered by muslin which is wetted from time to time. The dry bulb temperature is measured by means of a nickel resistance thermometer which, with the thermocouples, is situated in a stream of air moving with considerable velocity. The bulb difference and dry bulb temperature are shown on the same calibrated indicator. This is provided with a change-over switch for the two readings, and the necessary dry battery. A "test" switch and rheostat allow corrections to be made for the variations of voltage of the battery.

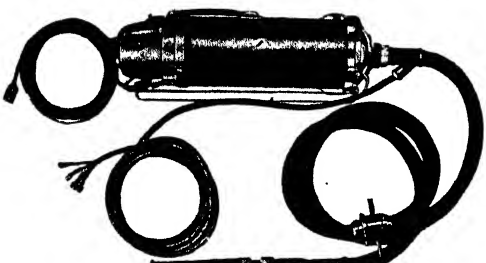
While this instrument could be used in any situation, it has been specially designed for measuring the humidity in cooled holds of ships. For this purpose, the couples and resistance coil are carried in a tube attached to the end of a hose-pipe connected to a suction fan, the wiring being situated inside the tube. The fan and indicator are situated at a convenient position and the measuring end of the hose is lowered into the hold through suitable orifices.

The *Siemens Humidity Meter* gives readings of relative humidity directly. Three electrical resistance thermometers are used in this instrument, two being the usual wet and dry bulbs and the third a further dry bulb, whose purpose is to convert the bulb difference given by the other two

Wet and dry thermocouples and resistance thermometer.




Indicator with change-over and test switches.



Suction fan and hose (on smaller scale).

FIG. 8.—Negretti and Zambra Thermocouple Wet and Dry Bulb Hygrometer. (Designed by Dr. Ezer Griffiths of the National Physical Laboratory.)

bulbs into a relative humidity scale. A special type of measuring system is employed, embodying a double or "cross-coil" indicating galvanometer connected to a double Wheatstone bridge. The thermometers are contained in a "transmitter" (Fig. 9) containing an electric fan (*f*) which draws the air under test over the two dry bulbs (*c*) and then over the wet bulb (*d*), kept moist by a stocking dipping into a trough of water (*b*). If the air is moving rapidly and a fairly steady pressure is available, the fan may be omitted, whilst if the air is very hot the fan is fitted in a

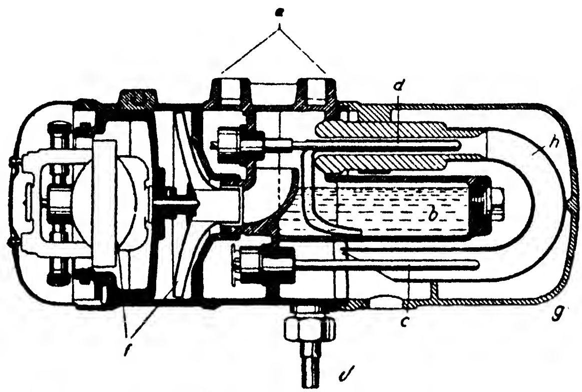



FIG. 9.—Siemens Humidity Meter (Sectional diagram of "transmitter").

cool place and connection made to the transmitter by a pipe line. The indicators or recorders may serve a number of points and the same apparatus can measure dry bulb temperature as well as humidity without the use of further thermometers. The whole apparatus may be worked from the electric mains.

### Hygroscopic Methods.

These methods depend on the change of dimensions (usually length) and weight of hygroscopic substances when in equilibrium with atmospheres of different relative humidities. The most common form of instrument uses the change of length of hair, goldbeater's skin, animal and vegetable membranes or textile fibres with changes in relative humidity. Temperature changes of normal magnitude, however, have little effect upon these materials. The substances when thoroughly cleaned to remove grease, afford a basis for the manufacture of indicating and recording instruments which read the relative humidity directly, independently of temperature. Numerous instruments of this type have been made. Unfortunately the accuracy of such instruments is not very great, as there is often considerable lag and, when they are exposed to high or low humidities, or when they suffer sudden changes of humidity, the setting is changed. It has been shown recently (*D.S.I.R. Food Investigation Special Report No.* 8 (Revised Edition, 1933)) that goldbeater's skin has a very small lag and that horse hair maintains its calibration better than other substances. If, however, extreme accuracy is not required and changes of humidity are only moderate, this type of instrument can be quite useful, but should be checked against a standard hygrometer at frequent intervals. Recording instruments of this type show the variations of humidity in controlled rooms efficiently. It is found that, under such conditions, the length of the sensitive element remains constant and thus small variations from the standard humidity are faithfully shown. This property also enables these hygroscopic substances to be used for control purposes.

Figs. 10 and 11 show typical indicating and recording instruments. Such instruments are not usually suitable for distance indication or recording, but this function may be obtained if desired. In the *Casartelli Distance Hygrometer*, the changes in length of a hygroscopic element move a shutter thus varying the amount of light falling on a light sensitive cell of a special type. The current passing through the cell is read off on a galvanometer which can be calibrated in terms of humidity. Another instrument which is available for distance work is the *Cambridge Humidity Indicator* or *Recorder*. This utilises a strip of goldbeater's skin, held under a tension at which it is found to give repeatable indications. The ends of the strip are attached to a flat spring at one end of a fixed frame, the strip being passed over a roller at the other end

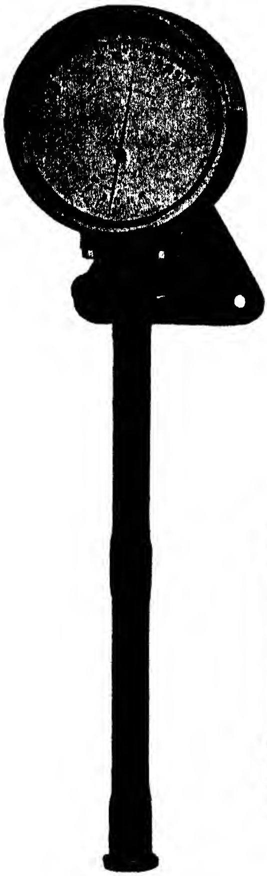


FIG. 10.—Hair Hygrometer.

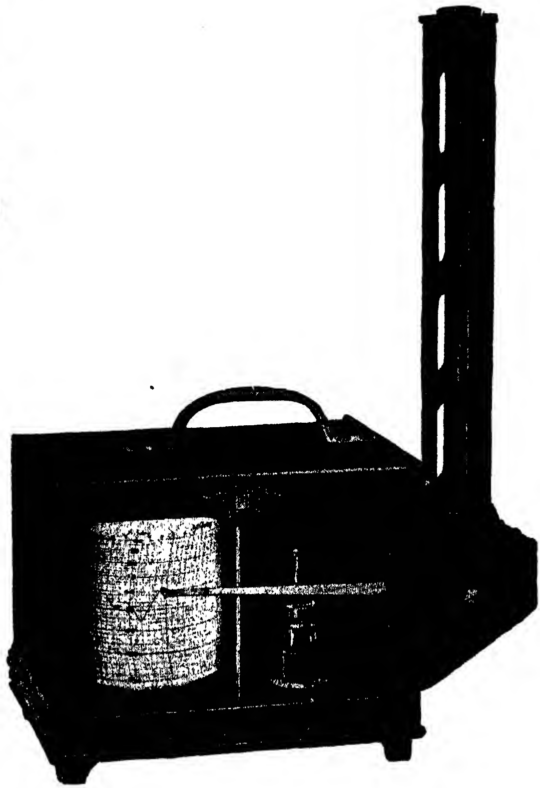


FIG. 11.—Recording Hair Hygrometer.

of the frame. This roller is connected to a Shakespear electrical micrometer, by means of which the extensions of the goldbeater's skin are shown on a thread recorder or indicator calibrated to read directly in terms of relative humidity, the usual range being 30-100 per cent. The recorder can thus be installed some distance away from the position at which the humidity measurements are being taken.

Hygroscopic measuring instruments are available for measuring the humidity of the air inside piles of paper, bales of wool and cotton, etc. This humidity will give an indication of the moisture content of the material. The sensitive element is enclosed in a strong tube of a length and cross-section suitable for the particular material which it has to penetrate in the *Cambridge* and *Casella* instruments. In the one made by *Negretti and Zambra,* the element is inside the instrument case and so arranged that air from inside the bale or pile can be aspirated over it by means of a rubber bulb.

The change of weight of hygroscopic substances is an obvious way of measuring humidity and has been used considerably. Recently Mellanby (*Journ. Sci. Instr.*, 1933, **10**, 349) has described a hygrometer on this principle consisting of a small piece of paper attached to a torsion balance which is calibrated in terms of relative humidity. There is, however, a hysteresis effect which causes the weight for a given humidity approached from high values to be different from that obtained when the approach is from low ones. The paper is ordinarily maintained in an atmosphere with a relative humidity of 40 per cent., and the change of weight noted when it is moved to the atmosphere to be measured.

## Dew Point.

The dew point method of determining humidity involves the cooling of a polished surface until dew is deposited on it. Its temperature so attained is that at which the air would be saturated. From tables, the vapour pressure or absolute humidity can easily be deduced. If the air temperature is known, the relative humidity is readily calculated. The general form of dew point apparatus is shown in Fig. 12.

The dew point method can, however, hardly be classed as an industrial method. A full description of the method and its variations for special circumstances, and of devices

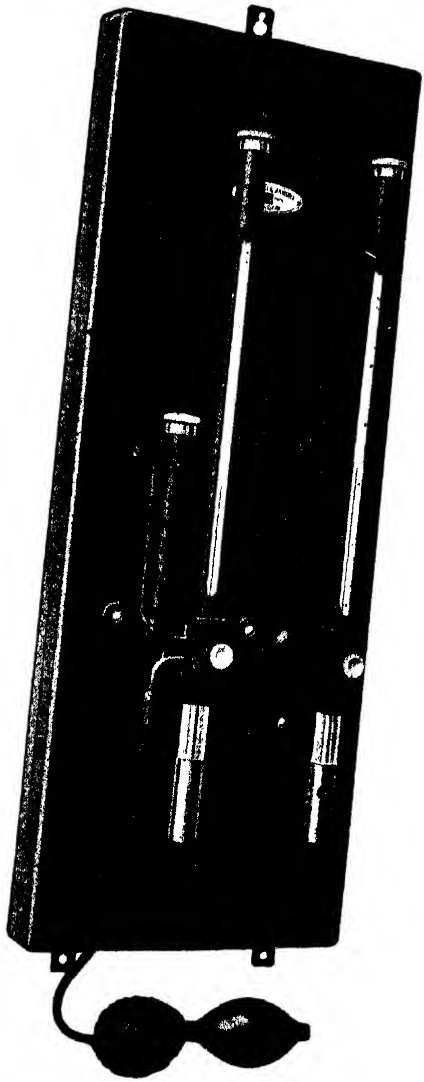


FIG. 12.—Dew Point Apparatus.

for making it less dependent on the observer, will be found in "The Measurement of Humidity in Closed Spaces" (*D.S.I.R. Food Investigation Special Report No.* 8 (Revised Edition, 1933)). Moss (*Proc. Phys. Soc.*, 1934, **46,** 450) has recently designed an instrument in which the formation of dew is very easily detected. By means of a photoelectric cell device he can keep the surface of a stainless steel mirror at the dew point. Such developments will be watched with great interest.

### Other Methods.

In the chemical absorption method of humidity measurement, a known volume of air is drawn over some weighed absorbent substance and hence the weight of water in that volume of air determined. This determination can also be done volumetrically, but in either case it is slow and tedious, and is only used as an ultimate standard for the checking of the industrial types of instruments.

Three other methods of measuring humidity on commercial lines are of special interest in that they make direct use of physical properties of the air which vary with humidity. They are thus independent of the evaporation from a wet bulb, a process which is very complicated and only understood empirically, or of the rather variable physical properties of hygroscopic substances such as hair. They offer the best approach to an ideal method of measuring humidity. The results are strictly in terms of absolute humidity, but conversion to relative humidity is easy if the temperature is known. As they depend on indirect means of measuring the actual composition of the air, they will, however, be rendered inaccurate if impurities are present to any appreciable extent. The cost of these instruments is also very much higher than that of the simple types of hygrometer, though not much higher than the more involved ones such as the electrical resistance type. These methods will now be described.

**The A.E.G.-Muirhead "Ranarex" Gravitometer** measures the density of the air in question by comparison with that of air at the same temperature and pressure which has been thoroughly dried. Since water vapour has a density of 62 per cent. of that of air, the density of the humid air will be an indication of the amount of water contained in it. The method of measuring density is aerodynamical in principle and makes use of the fact that the torque produced in a stationary fan by another fan on the same axis and running at a constant high speed is proportional to the density of the air. Two such units revolving in opposite directions are provided, one in the humid air and the other in air which has been dried by passing it over an absorbent substance. Precautions are taken that both samples of air are at the same temperature.

A linkage mechanism between the stationary fans moves a pointer and operates a recorder according to the ratio of the two densities. The rotating fans also serve to draw a continuous stream of air through the apparatus and therefore its action is continuous and automatic. The instrument is calibrated in absolute humidity, but a special scale is provided so that relative humidity can be read off if the air temperature is known.

**The Fagelston Continuous Gas Indicator** also employs a stream of humid air and a stream of dried air, and makes use of the difference in both density and viscosity. The two streams are drawn first through capillary tubes, then through wider tubes of negligible resistance to air flow and finally through fine orifices into a common chamber which is kept at a low pressure by means of a pump. The two wider tubes are connected by a sensitive manometer. The fall in pressure along the capillaries depends on the viscosity, while that through the orifices depends on the density. Since the total fall in pressure is the same for both streams and since the humid and dry air have different viscosities and densities, a pressure difference will be shown on the manometer, which can be calibrated in terms of absolute humidity.

The third method depends on the differences of the thermal conductivities of humid and dry air. The change in conductivity with humidity is very small, but accurate comparative methods are available, based on the difference in temperature of similar wires heated by a constant current when situated in gases of different conductivities. This is the same principle as that of the "Katharometer" described by Shakespear and Daynes (*Proc. Roy. Soc.*, 1920, **A97**, 273) for the detection of small quantities of hydrogen in air.

An instrument recently designed by Walker ("*Instruments*," 1933, **6**, 184) for recording the humidities in cable storage rooms, is essentially a Wheatstone bridge whose four arms consist of fine platinum wires mounted axially in tubes. The air to be analysed passes first through two tubes containing two opposite arms of the bridge, then through a drier and finally through tubes containing the other two arms in series. The tubes are actually formed by drilling holes in a block of metal. All four wires are heated by a constant current and if the composition of the air were the same in the four tubes all would be at the same temperature. The moist air has, however, a higher thermal conductivity than the drier air and thus conducts more heat from the wires. This lowers their temperature, consequently varying their resistance and unbalancing the Wheatstone bridge by an amount which is measured by a sensitive recording potentiometer, which can be calibrated in terms of humidity. With this arrangement, variations of composition other than those of humidity do not alter the recorder. It is essential to control the heating current and the temperature of the walls of the tubes very closely indeed. By changing the sensitivity of the circuit it is possible to alter the range of the instrument to any desired extent.

### *Related Instruments.*

**The *Katathermometer.***—This instrument has been designed by Professor Sir Leonard Hill for the measurement of the comfort of any atmosphere. Though it is not truly an instrument for measuring humidity, it may justifiably be noted here. It is essentially an alcohol thermometer with a large bulb of about 25 sq. cm. surface area. On the stem are two marks, one corresponding to 100° F. and the other to 95° F., the mean being very close to normal body temperature. The bulb is placed in warm water at about 110° F. until the liquid is well above the upper mark, then removed and wiped perfectly dry. The time in seconds for the liquid to fall between the two marks is noted. The first reading is always neglected and the mean of the next five taken. Marked on the instrument is a "factor" which when divided by the time in seconds, gives the "cooling power" in millicalories per sq. cm. per second. The "cooling power" thus obtained is that due to radiation and convection and is also dependent on air velocity.

The Katathermometer can also be used with a wet sleeve on the bulb. The method of use is exactly the same and thus adds heat loss by evaporation to those mentioned above. The results are, therefore, affected by the humidity of the air.

When used in air at high temperatures, the cooling time of the ordinary Katathermometer is very long and another instrument has therefore been introduced in which the cooling range is 130° F. to 125° F. In this instrument the liquid is coloured blue instead of red to prevent confusion.

Both Katathermometers can be used to measure air velocities and are very useful for this purpose for measuring low velocities. Particulars of this use are given by Angus ("*Engineering*," 1932, **133**, 281) who gives a nomograph calculated by Soper for both instruments connecting

Kata-factor, cooling time and temperature with cooling power and air velocity.

The Katathermometer is greatly used in the physiological study of ventilation and humidity conditions suitable for various purposes. Although it does not give results which are simply interpreted in terms of temperature, humidity and air velocity, it gives values which have apparently a close relation to human comfort, and therefore to the "effective" temperature. An automatic recording model has been made and this is now being developed in a form suitable for industrial use.

**The Eupatheoscope.**—The purpose of this instrument is to measure and record a quantity analogous to the physiological sensation induced by a cool environment. It is essentially a black-painted hollow copper cylinder, 22 inches high and 7½ inches in diameter, heated to 75° F., the loss of heat from which is recorded and scaled in degrees of "equivalent temperature." The temperature is maintained by heating lamps controlled by a thermostat and relay. Part of the heating current heats a mercury thermometer which is embedded in an insulator to cause its rate of change of reading to be slow and thus to prevent "hunting" when the current is switched on and off frequently. For recording purposes the thermometer is replaced by a thermocouple, and the calibration is in terms of "equivalent temperature." (For a full description see *D.S.I.R. Building Research Technical Paper No.* 13—H.M. Stationery Office.)

**"Rate of Drying" Meter.**—This instrument, designed by Rendall, is a differential air thermometer with one bulb covered by a wet sleeve. The indications will clearly be affected by the relative humidity and the velocity of air movement, as in the case of the Katathermometer. The calibration is usually descriptive in character.

## CHAPTER IV.

## METHODS OF INCREASING HUMIDITY.

The process of increasing the relative humidity of the atmosphere in a room is extremely simple in principle, namely to introduce water vapour. This is usually effected by the evaporation of a relatively small amount of water. Thus it was an old practice in textile mills to sprinkle water on the floor when electrification was prevalent.

A method of humidification which has been considerably used in the past, especially in the cotton weaving sheds of Lancashire, is the steam jet. A series of low pressure steam pipes is installed above the machines and provided with orifices at suitable intervals, each being controlled by a small tap. This system is very simple and cheaply installed. It puts water vapour into the air as distinct from a spray. The great objection to it, however, is that it has a heating as well as a humidifying effect, since the vapour is supplied at a temperature above boiling point. This may be advantageous in winter but in summer this rise of temperature is undesirable and may become so great that the relative humidity will actually fall. On the other hand a humidifier using water always has a distinct cooling effect which is often very useful. Another objection to steam humidification is that unless very pure water is used in the boilers, it is liable to give an unpleasant odour to the air. The steam method of humidification is therefore rapidly becoming obsolete. It survives, however, in a modified form as an auxiliary in some humidifiers working mainly with water jets. Owing to the coldness of the water and the further cooling due to evaporation, sometimes these humidifying devices have difficulty in maintaining the humidity in very cold weather and steam jets are provided to assist, with considerable advantage.

A humidifier is, therefore, a piece of apparatus which, when supplied with water, gives off into the atmosphere water vapour. However, almost all the simple types merely aim at converting the water into a fine spray and rely on this evaporating before it comes into contact with any solid object such as roof members, machines or the floor. This is an important point to remember when re-arrangements or alterations are being carried out in a humidified room. There is also always a risk with simple humidifiers that dirt or damage to them may cause the spray to become less fine, so that water is precipitated in undesirable places. The ideal humidifying plant is one that delivers air of high humidity, free from even the smallest droplets, into the room.

The purity of the water supplied to humidifiers should be of a high order and at least equal to that of drinking water. Various disinfectant preparations are sold for adding to the water. These may have some slight germicidal effect but it cannot be complete. The psychological effect on the workers should however be good.

For the consideration of the different types of humidifiers it is convenient to divide them into four classes. The distinctions between these are often not well defined, but there are certain general features which enable such classification to be made. The four types are as follows :—

(1) *Simple Spray Type*, which gives a fine spray of water from a specially designed jet.

(2) *Enclosed Spray Type*, in which water spray is inside a casing and induces a flow of air through the apparatus.

(3) *Simple Ventilating or Plenum Type*, which consists of a spray producing mechanism through which air is

driven by a fan. Distribution is usually by a trunking system.

(4) *Central Station or Air Conditioning Type,* which involves a large air-washing chamber followed by spray eliminators. These deliver to the room air, heated if necessary, which has been saturated at a definite temperature. As this type of plant has other applications besides humidification, it is described in a separate chapter later.

The first three types will now be considered in detail and their advantages and disadvantages compared. Details of the special features of the various makes will also be given. It will only be possible to consider British makes of plant in any detail. Many plants are produced in other countries, especially in America, one or two of these, which are readily available, being mentioned later. Much of the pioneer work in connection with humidification and air conditioning has been done in America, owing to the great differences between summer and winter climatic conditions, which make the use of such plants almost imperative.

## Simple Spray Type.

The spray type of humidifier is the simplest and the least expensive of humidifiers using water, both in initial cost and in running and maintenance. It is relatively easy to install and there are no large diameter air trunks to cut off the illumination from windows or artificial light in the roof. Compressed air and water pipes leading to small spray heads suitably distributed about the area to be humidified are the prime necessities. By this system it is possible to put a large amount of water into the air easily, and if required, certain parts of a room may be given a higher or lower humidity than others by regulating the distribution of the spray heads.

One great criticism which has been directed against this system and with undoubted justification in some instances, is that the humidity produced is not uniform. In the line of the jet of spray it will be high, while in other places it will be much lower. There are, however, several ways in which this may be largely overcome. The first is by providing an ample number of spray heads working at moderate outputs rather than a few widely scattered working at full capacity. Secondly, a separate means may be provided for the circulation of the air. In rooms containing much shafting and belting running at high speeds this may be unnecessary, but if these are absent a trunk system may be installed in order to cause air movement. A solution on these lines is afforded by carrying out the heating by "unit" heaters, which will provide a good circulation. This type of heater, which is usually slung from the roof, is a steam radiator through which air is blown by an electric fan. If, however, the unit heaters are to be controlled by a thermostat, this should regulate the steam supply and not stop and start the motor. In this way circulation is assured whether the heating is on or off. It is also possible in some cases to use the draught induced by the spray and further to arrange that all the sprays co-operate in a definite scheme of circulation.

A unit designed for the purpose of causing movement and consequently mixing of air is the *Angus* jet tube. It consists of a small centrifugal fan, generally motor driven, to which is attached a metal duct terminating in a narrow orifice. The air is thus driven in a nearly horizontal stream above the heads of the operatives, the inclination and volume of the stream being variable. Eddies are caused by this device and the air thoroughly mixed. The jet tube is also very efficient in removing the "stuffy" feeling from an atmosphere of high humidity.

A spray system is also used sometimes to assist a central station system and results in considerable economy in the cost of the latter. This is especially the case where the central station system has to give high humidities in rooms where there are considerable sources of heat. This application will be better understood when air-conditioning plants have been considered.

The principle of the spray head is very simple. Air issuing from a jet causes a partial vacuum in the neighbourhood, and this effect is used to draw up water which is then atomised by the air. The water level is maintained at a definite distance below the air jet so that, if the compressed air fails, there shall be no dripping of water. Every spray head can be turned in any desired direction and is provided with valves so that it can be regulated or cut out of the system as desired. This is in addition to the general control of the system, which may be either by hand or by automatic control and which is usually effected by cutting off the water supply and draining the pipe line.

An air compressor at some central position is necessary in the spray system. It is generally provided with an air cooler and filter to remove dust and oil. Also there is often an automatic valve which prevents water being supplied until there is sufficient air pressure to cause good atomisation.

**Andrew, "Aquair," "Twone" and "Park Spray" Humidifiers.**—Four well-known makes of plant operating on the spray system and involving the features already mentioned are the Andrew (Fig. 13), "Aquair" (Fig. 14), "Twone" (Fig. 15) and "Park Spray Turbo Humidifier" of American origin. The makers of the first of these claim that they can humidify a space of only 18 inches between the top of stored bales and the ceiling without either becoming wet. The output of water is, of course, less in this case than in normal circumstances.

**"Textile" Humidifier.**—Considerable interest attaches to the "Textile" system which operates on the spray principle. The latest spray heads of this system (Fig. 16) are provided with " push-buttons " at the rear by means of which needles are passed through both the air and water jets and thus instantly dislodge any dirt which may be present.

The makers of this system are now making a unit heater

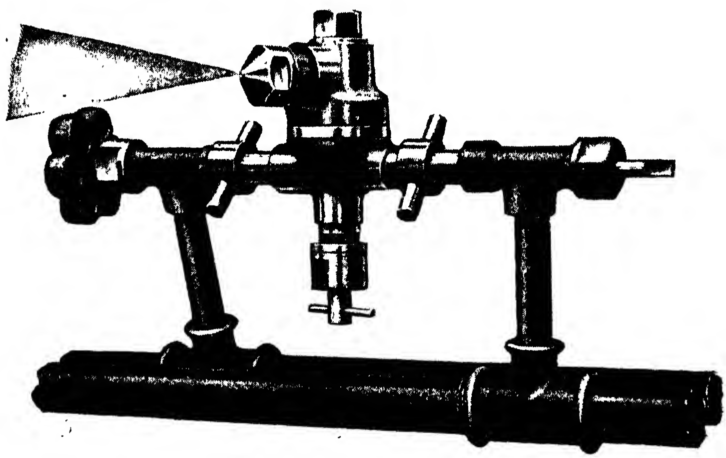


Fig. 13.—Andrew Spray Head.


Fig. 14.—" Aquair " Spray Head.

Fig. 15.—" Twone " Spray Head.

in front of which are fixed four spray heads, the heater and jets being controlled automatically by a thermostat and humidity control respectively if desired. The condensation from the heater is used in the sprays which, working with warm water, are more effective and have less cooling effect, both of which are desirable conditions. When the heating is not required the steam supply is cut off so that there is now no condensed water and the sprays are fed with cold water from the mains. The great advantage of this arrangement is, however, the constant positive circulation of the humidified air by the fan associated with the unit heater. It is also possible for these units to have an arrange-

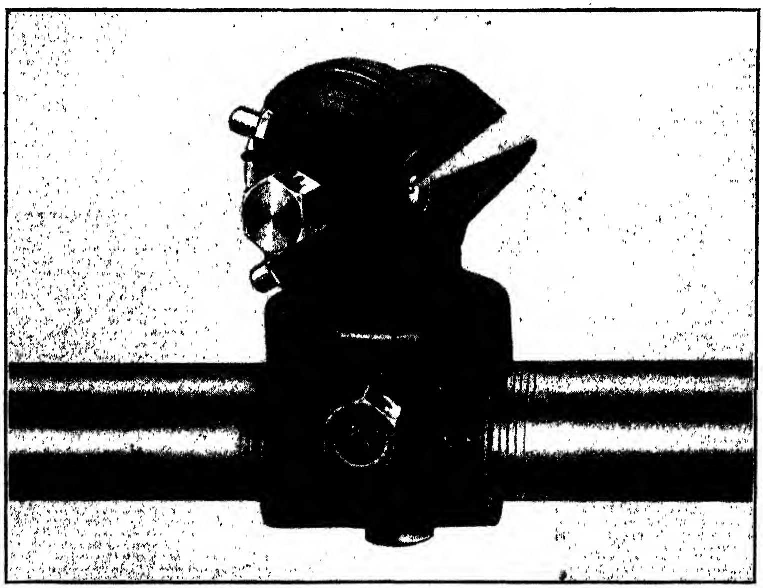


FIG. 16.—" Textile " Spray Head.

ment of dampers whereby inside or outside air can be circulated, thus providing facilities for increased ventilation or cooling.

This firm also advises the use of a ventilation system in conjunction with its spray humidifiers and for this purpose has developed a fabric trunking which is rather unusual and therefore interesting. The trunk is made of a woven material and is supported by a light steel framework. When not in use it lies in the bottom of the framework, but when delivering air assumes a circular cross-section. The makers claim the following advantages for this fabric tube over the normal sheet metal trunks :—

1. It acts as a "fog filter," *i.e.* removes the dirt associated with fog from the air as it enters the room.
2. It gives very uniform diffusion of air everywhere at low velocities.
3. It can be used on a recirculation system in the room to remove dust and lint from the air. Large volumes of fresh air therefore are unnecessary, with a consequent saving of heating costs. The cleaned air is arranged to flow from the ceiling to the floor, thus preventing dust from rising.

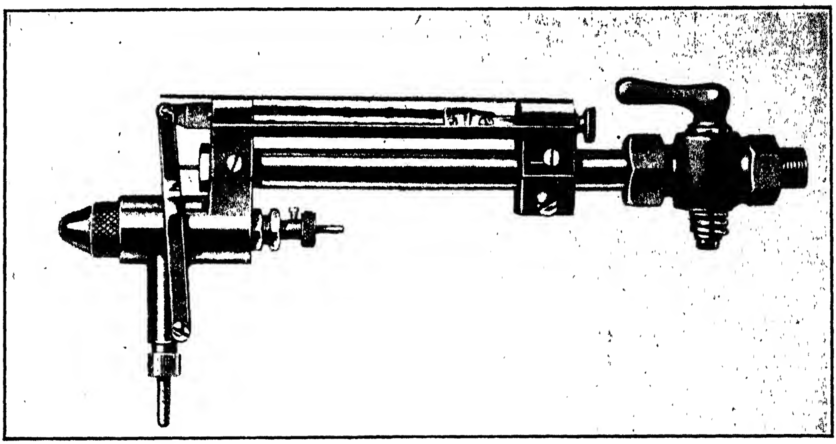


FIG. 17.—"Aerograph" Spray Head.

4. When the tube is deflated after use the dirt falls to the bottom and is eventually carried to the far end from which it can be emptied at intervals. Thorough cleaning is therefore not often necessary.
5. A length of fabric tube may be coupled to the front of a unit heater working in a dusty atmosphere without lowering its efficiency, and thus the continual stirring up of dust is prevented.
6. In damp atmospheres condensation sometimes occurs on sheet metal trunks and for this reason they usually have trays beneath them. The fabric trunk is all at the temperature of the air it is distributing and condensation is therefore much less likely.

**"Aerograph" Humidifier.**—The chief feature of interest of the "Aerograph" spray head is the incorporation of an automatic control in its construction (Fig. 17). Compressed air at a pressure of 50 lbs. per sq. in. is supplied to the head through a valve which is controlled by a sensitive element, which consists of jointed pieces of fibre from the outer covering of the ovular bracts of coniferous trees.

**Sharman Humidifier.**—In this humidifier, which is of recent introduction, compressed air as an atomising medium is replaced by steam at a pressure of about 30-50 lbs. per sq. inch. The steam issues from four jets arranged round a

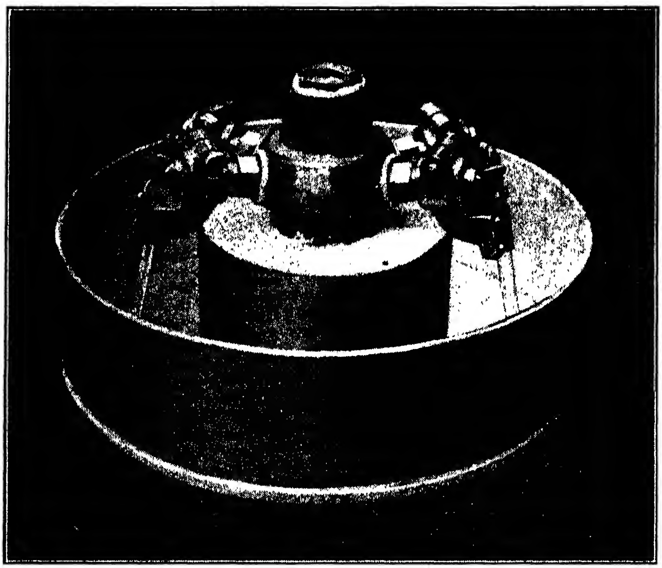


FIG. 18.—Sharman Humidifier.

central chamber (Fig. 18) and in so doing draws up water from an annular tank through four glass tubes provided with fine nozzles. In this way the water is very thoroughly atomised, but it is very important that the steam should be dry. Control is effected by turning off the steam and no water can drip when the steam is off, as it is maintained at a constant height in all the annular tanks by means of a ball valve in a central supply cistern.

One disadvantage of this humidifier is that part (stated to be about one-third) of the moisture given off is in the form of steam and therefore the cooling effect will be less than for a compressed air type spray humidifier.

**"International" Humidifier.**—This is very different from the humidifiers already described. The atomisation is brought about by mechanical means instead of by compressed air or steam. A vertical cylinder contains a rotating unit consisting of tubular arms mounted on a hollow spindle rotated at high speed. Water, whose level controls the output and is maintained by a ball valve, is drawn up the spindle and thrown out of the arms, thus being atomised. The spindle may be driven from the line shafting or by separate motor as desired. Portable, self-contained and fixed models are available. In the fixed type, the water is supplied from a common constant level tank to all humidifiers in the system. It is claimed that the rotating arms act as a fan for spreading the spray, but owing to the construction of the machine this effect can only be small. Portable machines of this type are, however, sometimes useful in humidifying small dry areas in an emergency.

## Enclosed Spray Type.

The characteristic of this type of humidifier is that a stream of air is induced through the humidifier without the use of a fan. Generally water supplied from a central pump at a high pressure issues from an atomising jet inside a cylinder in such a way as to bring about this movement of air. Only a small portion of the water is delivered to the room, the rest being returned by a drain to a filter and thus to the feed tank for further use. Owing to the large quantity of water passing, the air is cooled (unless hot water is specially used to prevent this), and it is also washed to some extent. Each humidifier can be controlled separately by hand, while general control, either manual or automatic, is effected by a valve in the high pressure water supply pipe.

This type has the advantage over the simple spray type that there is a definite cleaning of the air which passes through the humidifier, but it is more expensive. The flow of air through these humidifiers is often stressed, but it is very doubtful whether, in most situations, there are enough changes of the air per hour to be of real value unless a large number of units be installed. The induced air current, even if sufficient, may very easily form a closed circuit in the neighbourhood of each humidifier and thus leave the rest of the room unaffected except by diffusion. This may give rise to a great lack of uniformity of humidity.

Care is needed with this type of humidifier to keep the parts responsible for the atomisation of the water clean and in good condition, otherwise "spitting" may occur with consequent damage to machinery and materials below.

**"Vortex" Humidifier.**—A very widely used humidifier of this type is the "Vortex" (Fig. 19). A central pump delivers clean filtered water to these humidifiers at a pressure of 135 lbs. per sq. inch. Inside the top of each unit, which is in the form of a vertical cylinder, is a jet of $\frac{1}{16}$ inch diameter, through which the water issues at the rate of about 960 lbs. per hour. Immediately on leaving the orifice the stream of water impinges on the head of a pin and is broken up into the form of a hollow cone. This cone of moving water induces the air flow and effects the washing. The atomised water leaves the base of the cylinder in a horizontal direction, while the rest is caught by a tray and carried away by a drain. This water, returned by the waste pipe, is passed through two screens between which are packed small lumps of coke. In this way the dust is removed and the water delivered to the feed tank for further use.

If desired the "Vortex" humidifier can be fitted with a tube passing through the roof or through a window or wall so that either inside or outside air can be drawn through the cylinder.

Each " Vortex " unit has a filter which is automatically flushed every time the system is stopped. This is brought about by causing the high pressure water to entrap and compress some air in a spherical air vessel which clearly will also contain some water. When the pressure in the

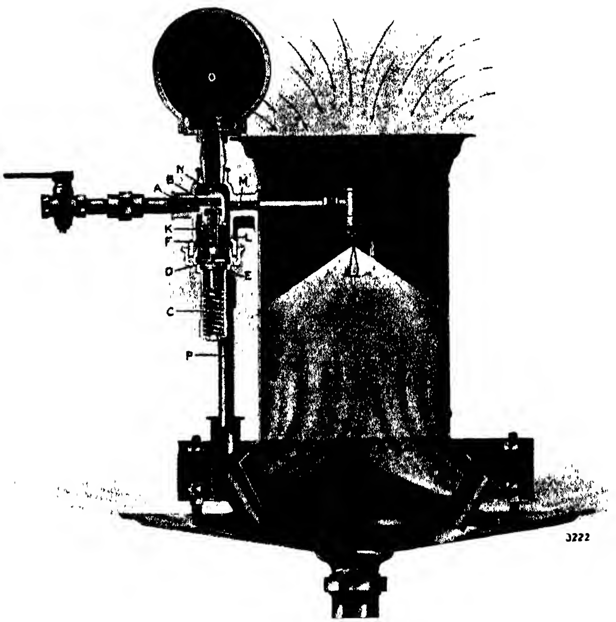


FIG. 19.—" Vortex " Humidifier.

supply pipe is cut off, a spring-loaded valve allows the air to expel the water through the filter in the direction opposite to the normal flow and thus to wash accumulated dirt away into the return pipe. This pipe can be flushed when necessary by high pressure water admitted from the supply pipe through a hand valve.

The jet and pin of these humidifiers used to be of gun-metal and nickel respectively, but are now made of

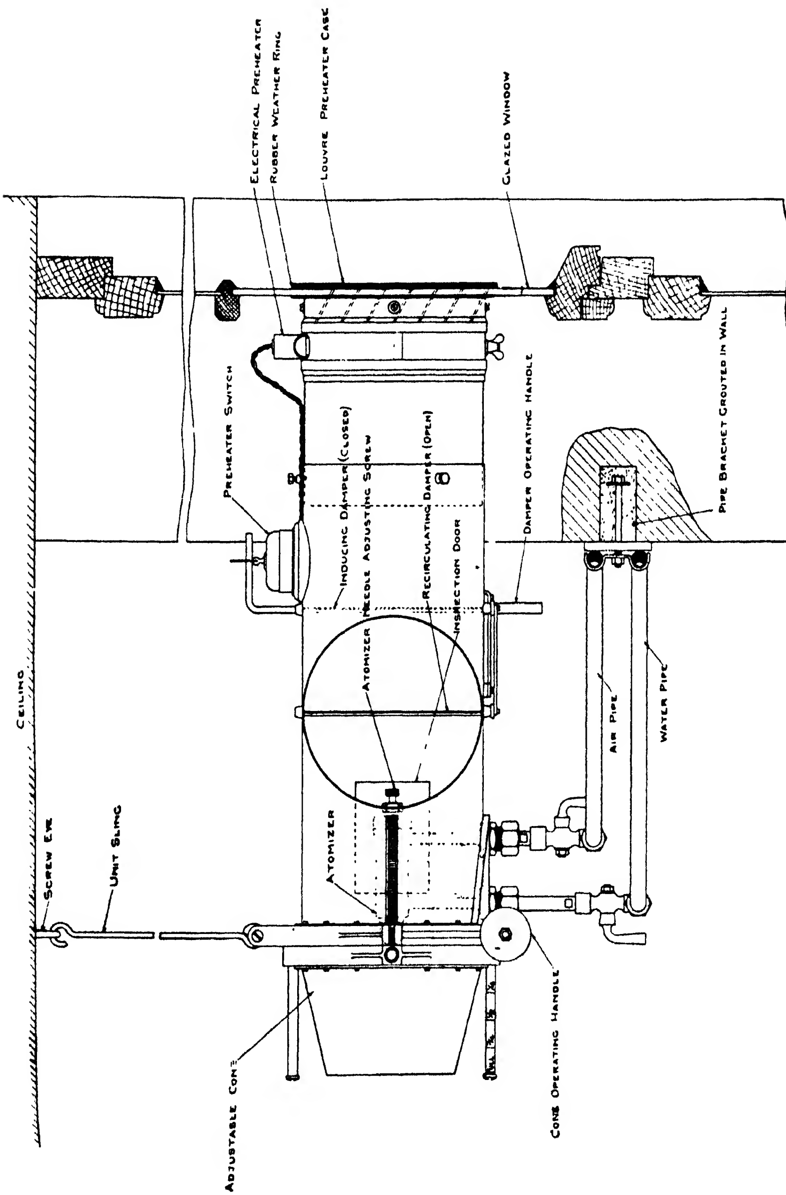



FIG. 20.—" Aerozon " Humidifier.

rustless steel and consequently have a much longer life. They are very easily replaced when necessary.

**"Cyclone" Humidifier.**—The "Cyclone" unit humidifier is a simple unit working on the same principle but without the flushing arrangements. The makers prefer to fit their other types mentioned later and only supply this when price is the first consideration.

**"Park Spray" Humidifier.**—One of the American "Park Spray" humidifiers is also of this type but the makers prefer the "high duty" or "centrifugal" types described later.

**"Aerozon" Humidifier.**—This type is somewhat different from those already described. The cylinder is horizontal and the atomisation of the water is brought about by compressed air, which also induces the flow of air through the apparatus (Fig. 20). The cylinders are 7 inches in diameter and 30 inches long, the front end, from which the spray emerges, being in the form of a truncated cone, which can if necessary be made adjustable to vary the induction of air. Two types are made, the ventilating units being arranged to recirculate or to draw in fresh air in any desired ratio. The circulating type can only stir up the air in the room. It may, however, be fixed on to the trunk of a forced ventilating system. Electric heaters and filters can be combined with the units if required.

Under normal conditions, one "Aerozon" unit is sufficient for 6,000 cu. ft. and National Physical Laboratory tests show that it would then give a complete air change in 1-1½ hours.

**"British" Humidifier.**—In the "British" system (based on that of Messrs. Kestner & Neu, of Lille) trunking is used to distribute the air (Fig. 21). This is connected to a "generator" which is a slightly conical metal duct containing a number of high-pressure water atomisers of different types, each having its special function. The atomisers cause a flow of air into the trunking and are so placed that their action is cumulative. Surplus water leaves the air while it is passing through the duct. The air can be drawn either from inside or outside the room according to the position of dampers, thus giving ventilation or recirculation as desired.

If ventilation is required without humidification, a special atomiser facing the reverse direction is brought into play. This causes air to be drawn into the duct and

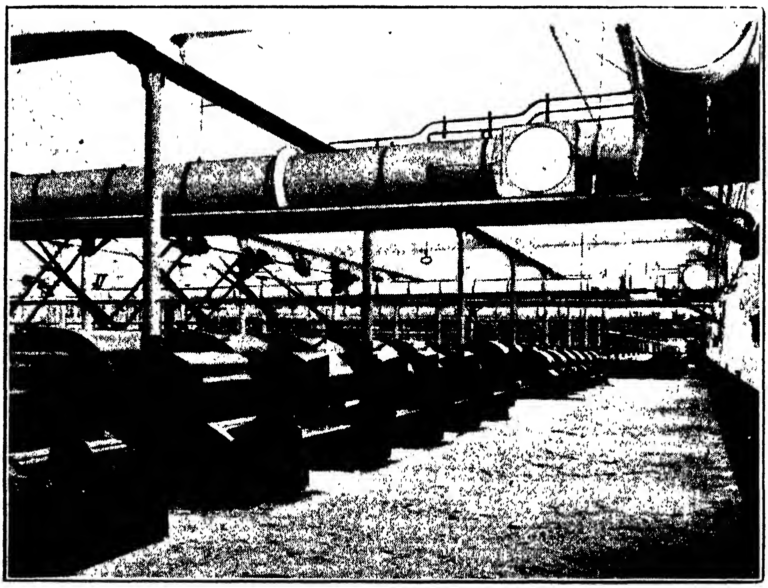


FIG. 21.—"British" Humidifying Plant.

recirculated or discharged outside the building, in which case fresh air is drawn in through doors and windows. This humidifier has many features in common with some of those described in the next section.

## Simple Ventilating Type.

The humidifiers of the simple ventilating type have, as a common distinguishing feature, a fan for the movement of air. As a consequence some are provided with a trunk system for distributing the air which comes from the fan and humidifying device. If necessary, several units are installed in large rooms and it is therefore possible to give somewhat different humidities in different parts of the room or to correct for local effects. It is possible also to do this on a smaller scale with a humidifier having a trunking system by suitably arranging the orifices.

In most cases a heater is easily incorporated in the construction and it can be helped by using steam instead of water for humidifying. There is also a certain amount of air washing as the air passes through the humidifier. Control is effected by cutting off the water and the humidifying steam (if any) from the machine when the humidity is too high.

The great advantage of this type over those already detailed is that large volumes of air can be brought into the room or merely recirculated. This gives good ventilation and a uniformity of humidity throughout the area served. It occupies no floor space as the whole apparatus can be slung from the roof. One disadvantage which is often stressed against this system is that the large ducts necessary obstruct the access of light to the machines. By careful designing, however, this defect can be largely eliminated.

Of all the simple types of humidifier this is probably the best in principle and is worthy of consideration in any proposed humidification scheme. Those provided with trunks will be considered first.

**"Cyclone" Humidifier.**—The "Cyclone" humidifier is composed essentially of a centrifugal fan, which delivers air into a long duct, and the spray producing devices. These consist of a number of specially designed jets, steam jets being also provided to blow into the ducts directly. (Fig. 22). Outside air can be drawn in past a steam heating coil or air from the room can be used. After passing through the sprays, the air passes through eliminators which remove the suspended moisture.

The makers of this plant have expressed a definite preference for a central station type of air conditioning plant wherever possible.

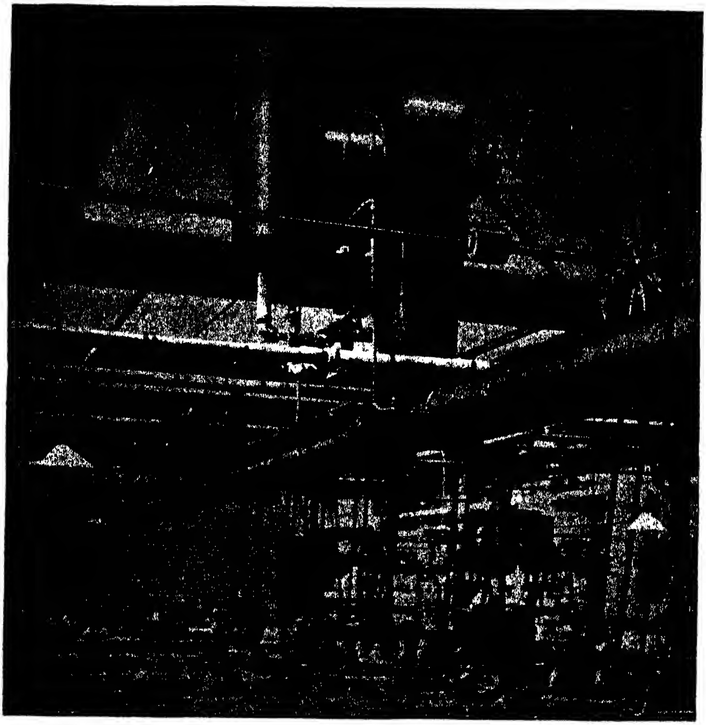


FIG. 22.—" Cyclone " Humidifier.

**" Venti - Humid " Humidifier.**—The " Venti - Humid " system uses a combined steam and water spraying nozzle for humidifying the air before it passes to the trunk. The orifices from which the air and surplus water escape are situated along the bottom of the trunk. A trough below serves to catch the water and to deflect the air horizontally in both directions.

**Musgrave Humidifier.**—In the Musgrave system heated air is blown into the room through ducts in which are fitted water and steam sprays as required.

**"Airton" Humidifier.**—The "Airton" humidifier, which is no longer being produced, is very similar to the foregoing types but the spray is formed by a number of metal discs revolving at a high speed and just dipping into water.

The humidifiers in this group which are not provided with trunking usually have a fan of the propeller type directly producing a movement of the air and thus distributing the spray effectively.


FIG. 23.—"Low-Zone" Humidifier.

**"Low-Zone" Humidifier.**—This humidifier is very like some of the enclosed spray type in appearance. (Fig. 23). Arranged round a vertical cylinder *externally* is a number of spray heads which eject atomised water radially. Air is drawn up the cylinder by an electric fan and is deflected by a cover so that it is also delivered radially at the top. This assists in the distribution of the moisture and will tend to reduce the effect of local air circuits. The atomisation is by compressed air but only at a low pressure (15 lbs. per sq. inch).

Another form of this humidifier is available in which a second impeller, fitted to the opposite end of the motor shaft, brings in fresh air through a steam heater coil and any desired mixture of fresh and room air can be obtained.

**Unit Air Conditioner.**—The principle on which this unit works is the same as the large central station air conditioning plants. Air is drawn in at the base of a tower through a spray chamber and eliminators and after passing over a heater is ejected into the room. (Fig. 24). When necessary, three such units are placed together and driven by a common fan motor and only have one pump. Hand or automatic control is effected in the same way as in the large air conditioning plants to be described later.

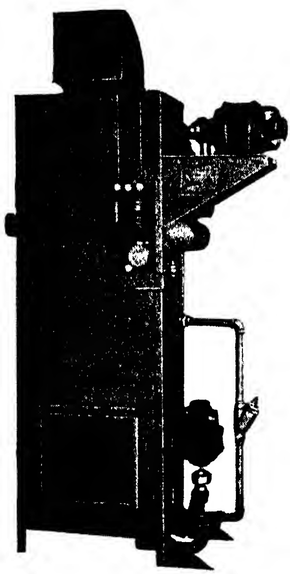


Fig. 24.—Unit Air Conditioner.

**Brecknell, Munro & Rogers Humidifier.**—This humidifier employs a spray head somewhat similar to the simple spray type of plant. The air is compressed by bellows which are incorporated in the humidifier and are operated by a cam driven by an electric motor through a gear box. The motor also drives a large fan behind the spray head. This humidifier is controlled by starting and stopping the motor either by a switch or an automatic control. These humidifiers are in service chiefly in the tobacco industry, but this model is now superseded by this firm's Sharman type with steam atomisation.

**Bahnson Humidifier.**—The Bahnson humidifier, which is of American origin, consists of a small electric motor with a horizontal shaft, on one end of which is mounted a conical disc and on the other a fan ; surrounding the circumference of the disc are several hundred teeth. (Fig. 25). Hot or cold water is fed by gravity through a pipe to the centre of the revolving disc and is thrown by centrifugal force from the rim against the teeth. It is thus broken into a fine spray so that it can be blown from the front of the machine by the fan. Excess of water is removed by a drain. One interesting feature of this humidifier is that each unit is

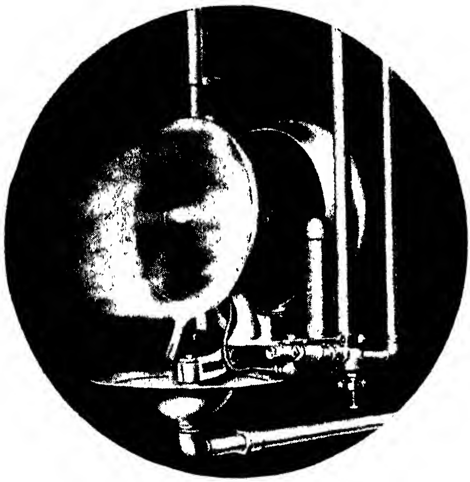


FIG. 25.—Bahnson Humidifier.

fitted with an automatic control consisting of a strip of hygroscopic material (a special paper) which throttles the water supply when the humidity tends to become too great. Bahnson humidifiers are often fitted with a length of trunking to give better distribution of the spray.

**" Park Spray " Humidifiers.**—There are three humidifiers of this make to be mentioned here. They have found a large application in different industries in America. The first is a " high duty " humidifier very similar to the enclosed spray heads with a vertical cylinder, but provided with a fan to assist in the circulation of air through the cylinder. Next is a centrifugal type with a horizontal disc driven by a motor which also drives an air fan. Only 20 per cent. of the water is evaporated, the remainder serving to remove dirt and lint. If, however, the air is very clean a third apparatus similar to the second is available in which a constant level of water is maintained in the bottom of the humidifier ; thus all the water being supplied is evaporated.

## CHAPTER V.

## METHODS OF DECREASING RELATIVE HUMIDITY.

WHILST there are few industrial buildings fitted with dehumidifying plant, the subject of decreasing the relative humidity of air is one of great importance since it enters into all drying problems. The subject of drying is too large to be discussed here in detail, but the production of a suitable atmosphere for this purpose is considered.

There are four methods of decreasing humidity which are of importance :—

1. Heating the air, thus lowering the relative humidity.
2. Absorption of the water by a hygroscopic substance, which is rejected when exhausted.
3. Adsorption of the water by a substance which can be regenerated for further use.
4. Air conditioning methods which involve cooling the air so that it loses moisture and then reheating to the desired temperature.

These will now be discussed briefly in greater detail.

**Heating.**—This method is only of use when the temperature is of little importance compared with the relative humidity. In most cases of drying this condition holds and it is therefore found that almost all drying processes are carried on at higher than normal temperatures.

**Hygroscopic Absorption.**—This method is of use where an increase of temperature is not allowable and relatively small volumes of air have to be dehumidified. Solid calcium chloride is very often used as the absorbing substance owing to its low price. As it absorbs water, a solution is formed on the surface of the lumps. This drips off and then leaves a fresh surface for absorption. It can be suitably arranged that the solution drains away and thus the calcium chloride removes itself as it becomes exhausted. This method is used in drying towers for lowering the humidity in small laboratories and testing rooms. In larger plants use is sometimes made of a spray of strong calcium chloride brine. Sulphuric acid also absorbs water well, but is little used outside the laboratory owing to the danger of corrosive spray from it.

**Regenerated Adsorbers.**—The best known substance of this type is Silica Gel, although a form of alumina has been recently suggested for the same purpose. Silica Gel is a hard, glassy material with the appearance of clean quartz sand. Chemically it is pure silica, but owing to the special processes by which it is made from sodium silicate, it has a porous structure which enables it to take up 40 per cent. of its own weight of water without appearing to be wet or increasing in volume. When heated it gives off the water and can be thus used again any number of times without loss of efficiency. In practice it is arranged in three or four adsorbing units available in one plant (Fig. 26). One or two are used for adsorbing water from the air stream, which should be previously filtered. Another is at the same time undergoing regeneration ready for further adsorbing. The change over is effected at specified intervals, by the operation of a hand wheel or by a purely automatic apparatus. A valuable paper by Lees ("*Engineering,*" 1932, **134,** 458), published recently, makes it unnecessary to go into further detail here.

This system has proved to be of great value in works producing cables, transformers and other electrical apparatus where it is essential that the insulation should be kept in a very dry state. It has even been successfully applied to the drying of blast for iron furnaces, and is certainly the best system when very dry air is required. If, however, less dry air is required, untreated air can be mixed with it in any desired proportion.

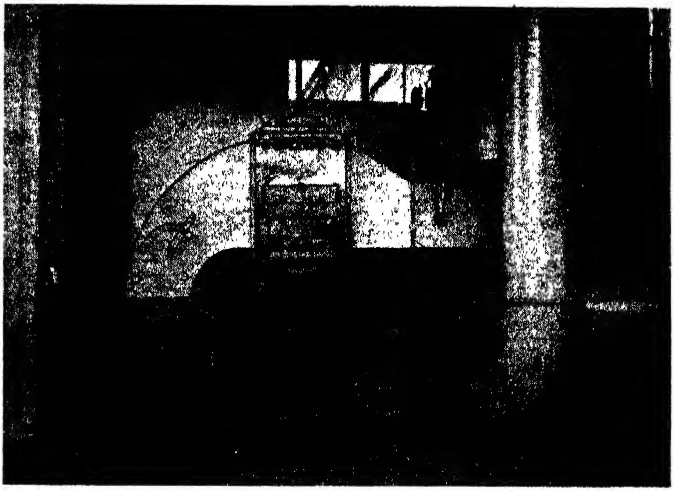


FIG. 26.—Silica Gel Plant installed adjacent to a store room in a chocolate factory (160,000 c. ft. capacity). The plant maintains the humidity in the store between 40 and 45 per cent. by drawing approximately 900 c.ft./m. out of the store at one end, passing it through the adsorbers and back to the store at the other end. It is fully automatic and controlled entirely by an electrical contact hair hygrometer located in the store. Activation (drying out the gel) is accomplished by hot air heated in a gilled tube steam heater, plainly shown in front of the plant.

The plant consists of 4 adsorbers and the change from activation to adsorption is done by continuously rotating valves which in turn direct the air to be dried and the air for activation over the several adsorbers.

**Air Conditioning Methods.**—A normal type of air conditioning plant is used for this purpose, but the spray water is cooled by means of a refrigerator. The principles of this method are dealt with fully in the next section.

# CHAPTER VI.

## CENTRAL STATION OR AIR CONDITIONING PLANTS.

The plants which have been discussed previously are designed with the object of correcting humidity by the direct addition or removal of water vapour. This function is independent of the heating system and generally makes little attempt to cope with temperature changes. Some heating can be effected in humidifiers by the use of hot water or steam, or by fitting heaters in the ventilating types, while cooling will always occur when there is evaporation of water owing to the absorption of latent heat. Provision is also sometimes made for drawing in air from outside, but even in automatically controlled plants the change over from inside to outside air is almost always made by hand. It may be said that, in general, these simple plants attempt to correct humidity with little regard to temperature and may also include some other function which is more or less independent of the main purpose of the plant.

The object of air-conditioning plants is to deliver at every point air which has been washed free from solid impurities at the desired temperature and humidity, with the correct amount of air movement. The principle on which they work is, briefly, that air is saturated with water at such a temperature that, when it is subsequently heated to room temperature, it will have the correct relative humidity. This process may be humidification or dehumidification according to circumstances. This type of plant serves for both purposes. The air may also be heated or cooled and washed. It will be seen therefore that an air conditioning plant may be designed to undertake a wide range of duties in a very complete manner.

The mode of action of an air conditioning plant can be seen by reference to Fig. 27. Air enters the plant from the right-hand end either through fresh or return air dampers (not shown in diagram). In some plants it then passes through a preliminary or tempering heater H, which is provided to prevent very cold air entering the plant and causing freezing of the water. This, however, is not always necessary. The air then enters a chamber which is filled with a dense spray produced by a number of jets J. These are supplied by a pump with water drawn from the base of the chamber through a filter. In some plants the sprays are in the same direction as the air flow and in others in the reverse direction, while still others have sprays in both directions as shown in Fig. 27. Baffle plates are sometimes provided at the forward end of this chamber to prevent the escape of the spray. In this chamber the air is saturated, cooled and washed. Its velocity during this process should be about 500 ft. per minute. Next it passes through tortuous passages between metal "scrubber" plates S. Any solid matter which has been wetted by the spray impinges on these plates, is caught and washed down by a continuous stream of water into the bottom of the spray chamber. A further set of similar plates with projecting edges E, but having no stream of water, called the eliminator plates, are next encountered, which finally remove every trace of suspended water. The main heater M and the fan F, which is the driving force of the whole circulating system, come next and so the air passes back by means of ducts into the room. If the air temperature is to be high, the main heaters are situated beyond the fan, so keeping the fan bearings cool. Further constructional details of these plants and modifications for special purposes will be found in "*Air Conditioning*" by Moyer and Fittz.

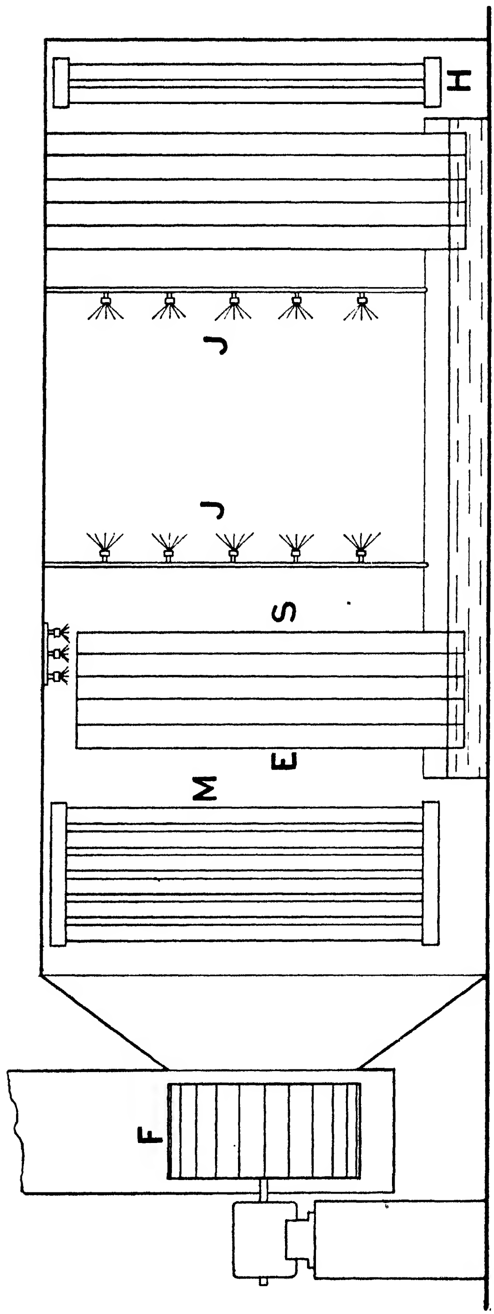



FIG. 27.—Diagram showing the Lay-out of a Central Station Air Conditioning Plant.

Various systems of control are possible with a plant of such versatile capabilities. The simplest and most usual is a "dew point" thermostat just beyond the spray chamber, which controls the relative amounts of inside and fresh air or the spray water heaters in such a way as to keep the spray temperature constant. Another thermostat in the room controls the quantity of air supplied and the steam supplied to the heater. Many other forms can be devised to meet any special set of circumstances and any change of weather conditions without any human intervention. Compressed air is generally used in this type of plant as the link between the sensitive control instruments and the valves or dampers to be regulated. It is provided by a small compressor driven from some convenient shaft in the plant.

When air is saturated, as in this type of plant, without the addition or removal of heat, it is cooled by the water evaporated (by absorption of latent heat) to a temperature which is known as the "temperature of adiabatic saturation." Carrier in 1911 (*Amer. Soc. Mech. Eng.*, 1911, **33,** 1005) and Carrier and Lindsay in 1924 (*Amer. Soc. Mech. Eng.*, 1924, **46,** 739) have published results showing that this adiabatic saturation temperature has the same value as the wet bulb temperature of a ventilated psychrometer and they have therefore been considered to be identical. This has never had a really sound theoretical basis and has been challenged recently by Sherwood and Comings (*Trans. Amer. Inst. Chem. Eng.*, 1932, **28,** 88), who have experimented with bulbs wetted by other liquids as well as water. Their conclusions are that while the adiabatic saturation temperature and wet bulb temperature are not identical and generally have different values, for the case of water vapour in air they may be taken as the same, especially at moderate and high relative humidities. It is therefore permissible in air conditioning work to use and speak of the wet bulb temperature when the adiabatic saturation temperature is really meant.

Air is thus cooled in passing through the saturating chamber of an air conditioning plant. This process, which is known as "evaporative cooling" makes it possible to keep the temperature inside a building lower than that outside. It is also possible to remove from the building the heat produced by the operatives, by the friction of the machines and the heat received through the walls from the sun or warm air outside, all of which would tend to raise the inside temperature above that outside.

The size of an air conditioning plant working on evaporative cooling is usually determined by the maximum cooling effect required in summer. This can often be greatly reduced by the introduction of suitable heat insulation, especially inside the roof. If this is insufficient another method is to keep a film of cold water running over the roof in hot weather or to flood a flat roof. Another way which cuts down the cost of an air conditioning plant, is to combine it with a simple spray system, especially for correcting local hot, dry regions. The disadvantages of the simple spray are largely eliminated by the good circulation of the other plant, while its capability of putting out large amounts of water spray for evaporation will often enable the central station plant to be reduced considerably in size.

The effect of cooling the air will be to raise the relative humidity and thus give conditions which are far more comfortable than would be produced by simple humidification of the hot air. As, in general, the wet bulb temperature outside is lower than that inside, it represents the normal limits of cooling and is reached when all outside air is used. When the air passes back into the building from the plant, the adiabatic saturation temperature becomes the new dew point temperature and the wet bulb temperature will be slightly higher than before. Thus with evaporative cooling, the air conditioning plant has acted as a combined humidifier, air cooler and air washer. Of course, if desired, the heaters are operated and the air can be heated instead of cooled. With a plant working on evaporative cooling it is only necessary to recirculate the spray water, adding only sufficient to make up that lost by evaporation. It is withdrawn from the base of the spray chamber, thoroughly filtered and pumped back to the jets at a pressure of 20-30 lbs. per sq. in. Heaters are included in this circuit if high dew points are necessary.

As already mentioned, it is possible to use the same type of plant for dehumidification if necessary. In this case it is necessary, instead of recirculating the spray water, to have a large supply of water cold enough to cool the air to the temperature of the required dew point and thus condense water from the air. The type of spray used for this purpose is often designed to give smaller drops of water which are more efficient in cooling. The supply of cold water can frequently be obtained from deep wells but it is more general to install a refrigerating plant to cool the water. This greatly increases the cost of an installation. Normal types of refrigerating plant are often used, but certain makers have developed special designs. The normal types make use of ammonia, carbon dioxide, sulphur dioxide or certain organic compounds as refrigerants. The general method is to cool brine which is in turn used to cool the water supplied to the spray. Lees ("*Engineering*," 1932, **134,** 458) has pointed out that the refrigeration load can be made lighter and the efficiency increased by using a heat interchanger so that the cooled, dried air leaving the dehumidifier is warmed by and cools the moist air entering the plant.

An interesting method of cooling water, which has been recently used in America, especially in connection with air conditioning plants on railway trains, may be noted. The water is contained in a vessel and the space above it is evacuated by means of a high pressure steam ejector. The water is thus caused to boil under the reduced pressure and so to lose latent heat. As the vapour is removed continuously, cooling is only limited by the vacuum which can be conveniently produced.

For small installations when cooling is only required in extremely hot weather, ice often provides the cheapest method of doing this. The first cost of the plant is very low, but the operating costs are higher than with the self-contained plants already described.

The cost of an air conditioning plant is always high, but when it is remembered that if it is employed, heating or cooling, ventilating, humidifying or dehumidifying and air washing plants are not separately required, its cost is not excessive. It is a great advantage when the plant and building are designed simultaneously. Ducts can then often be situated in the spaces between ceilings and floors or in hollow walls, thus eliminating unsightly lines of trunks, which may obstruct light. Distributing points may then be towers built up from the floor or combined with pillars or even with ornamental features. On the other hand, slight alterations to the design of a building can often reduce the cost of the plant greatly. The architect should pay great attention to thermal insulation, air-tightness and similar factors which, if inadequate, can put a large and unnecessary burden on the installation. It should be noticed that a central station plant can be used to condition more than one room where each room may have a different relative humidity as long as the dew point is constant throughout. Mixing of conditioned air with outside or recirculated air in varying proportions may also offer possibilities in some cases.

The air conditioning type of plant has found a very large and satisfactory application in "comfort" work, that is the production of comfortable atmospheres in theatres, cinemas and other public buildings. Besides ordinary industrial uses they are often used also in drying plants where very precise conditions are necessary. In this last application they are valuable in giving a definite flow

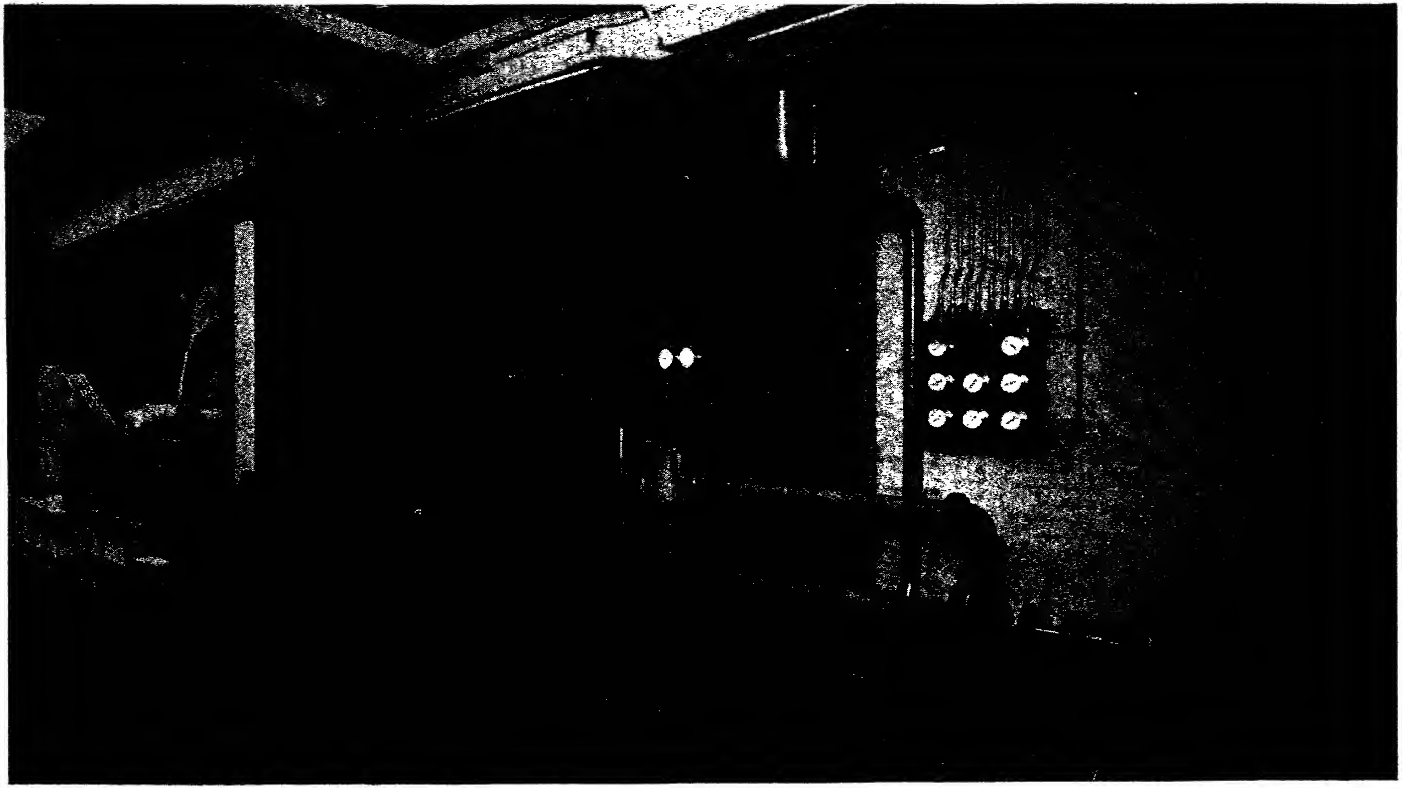


FIG. 28.—A typical Carrier Air Conditioning Plant in the basement of a large building.

of air over the substance to be dried, thus removing water vapour as quickly as it is produced.

In turning now to the various individual makers of plant, the *Carrier* plant merits initial mention, since much of the pioneer work on air conditioning was done by W. H. Carrier in America. This plant (Fig. 28) has found very wide application both in industrial and "comfort" work and the makers are prepared to give a definite guarantee of performance. To do this a complete survey of the building is made, and local meteorological conditions observed. From experience it is possible to calculate with considerable accuracy the size of the plant required.

For use with the Carrier plants, when acting as dehumidifiers a centrifugal refrigerating machine has been developed. Methylene chloride is employed as a refrigerant since it has a high thermodynamic efficiency, is non-poisonous and non-explosive. The machine occupies relatively little floor space and operates under a vacuum, thus removing the danger of bursts and explosions. The response of the machine to varying load is very rapid and it is therefore particularly suitable for air conditioning work. Reciprocating parts are avoided and the centrifugal compressor can be driven by an electric motor or steam turbine.

Other makes of plant which follow the general lines just indicated are the "*Cyclone*" (Fig. 29), "*Sirocco*," *Andrew*, *Sturtevant*, *Chapman*, *Hall & Kay*, *Gorford*, "*A.C.C.*," "*Standard*," "*Park Spray*," and *Ogden*. It is not to be inferred that all of these are identical in design and construction. For instance, the last mentioned had as many components as possible outside the machine in order to give good accessibility. The return water is also visible outside the machine so that samples may be taken at any time. Simpler central station plants are the *Hall & Kay* (older pattern), *Sutcliffe* and "*Champion*."

An entirely different type of central station plant which employs no jets or sprays is the *Heenan* "Cooler" (Fig. 30).

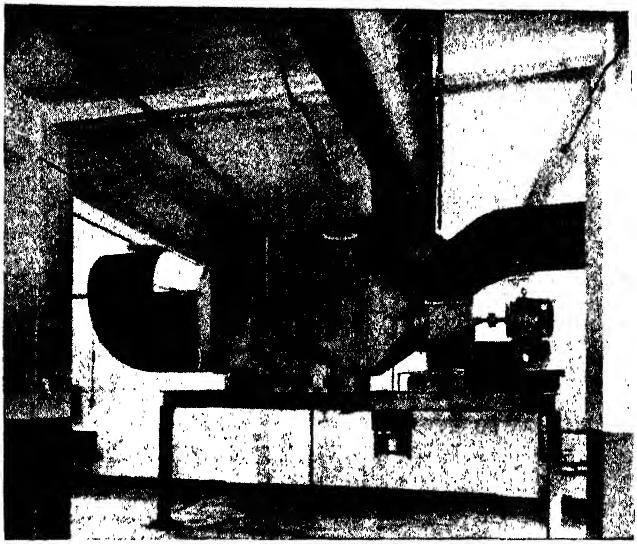


FIG. 29.—" Cyclone " Air Conditioning Plant for ventilating and cooling a chocolate-coating room.

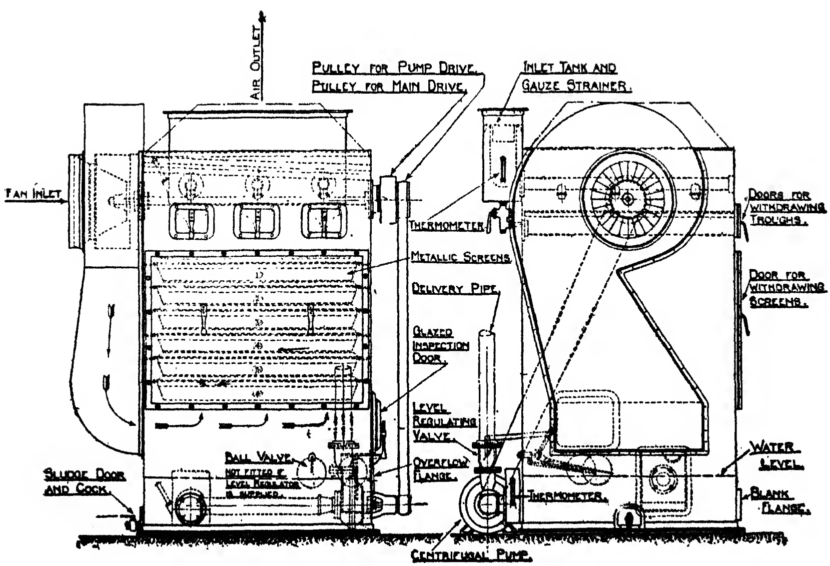



FIG. 30.—Heenan " Cooler."

The object of this machine is to bring air and water into very intimate contact so that the water evaporates and thus cools and humidifies the air. On the other hand, as in the air washer type of plant, if cold enough water is used, dehumidification will occur. The plant is a steel casing containing the cooling surfaces which consist of beds of phosphor bronze "wool." Air is blown upwards through the machine while water is filtered and distributed over the cooling surface, through which it falls. For the recirculation of the liquid a pump is provided. A large purifying action is claimed for this plant. The outlet of the cooler is connected to distributing duct-work in the usual way. This type of plant is not amenable to automatic control.

# CHAPTER VII.

## AUTOMATIC HUMIDITY CONTROLS.

THE full advantage of any system of humidification or dehumidification can only be obtained when automatic control is used. Hand control is generally unreliable, erratic and costly and should be avoided as far as possible. Modern humidity controls are very simple and reliable and save their cost not only by eliminating the labour involved in hand control but also by cutting off the plant to which they are applied when it is not needed. In cases where a humidity must be maintained within close limits, it becomes essential to control by some automatic method. It is sometimes necessary for instance to store textile materials at very high humidities in order to maintain their moisture content. If these relative humidities are exceeded by only a few per cent. there is a great risk of the growth of mildew. With automatic control such a risk can be entirely eliminated.

A humidity control or hygrostat has many features in common with a hygrometer in that change of humidity must bring about movement of some part of the instrument. Combined controls and hygrometers are in fact often made. There is a danger in this practice since any failure of or damage to the sensitive element may cause the recording part of the instrument to show perfect control, when actually the humidity is varying. It is therefore theoretically possible to use any humidity measuring instrument as a control so long as its indicating mechanism can be used to operate a regulating device.

Two methods of control are in general use. The one most frequently used depends on the change of length of hairs, textile threads, goldbeater's skin, animal membranes or similar substances. The other, which is generally more expensive, is based on the wet and dry bulb thermometer. Both types of instrument will be discussed later, but two other methods, which are of interest but have not yet been developed on a commercial scale, must be mentioned first.

The first of these makes use of the dew point. A glass plate is cooled to a definite temperature and the presence of dew on this plate is detected by a photoelectric cell. The current through the cell is amplified and by means of a valve and relay it can be made to carry out any desired operation. ("*Heating, Piping and Air Conditioning,*" 1931, **3**, 306.) Attempts have also been made to use the change in the surface resistivity of a glass or quartz surface when dew is deposited but no commercial instrument, developed on these lines, has found wide application. The second method is that depending on the change in weight of a hygroscopic substance, such as a textile material or paper, with relative humidity. Owing to the great sensitivity of a modern balance this method can give very close control over short periods. The great troubles however are due to the settling of dust on the hygroscopic substance and the disturbing effects of draughts. It is very difficult to overcome these defects without protecting the sensitive element to such an extent that its response to changing humidity is greatly impaired. Use might, however, be made of an enclosure of thin cellophane or some similar substance which is permeable to water vapour, but not to air or dust (Schweitzer, *Naturwissenschaften,* 1933, **21,** 784.)

Returning now to control methods in general use, it is rather a surprising fact that hair, membranes and similar substances have found such a place in control work when they are not reliable for humidity measurement. It is found, however, that after an initial "settling down" period of a few hours, they make very good controls so long as the humidity only varies over a small range. If they are exposed to a low humidity, the control point will be lowered by a few per cent., but will generally return after a few days to its normal value. The behaviour of hairs and similar substances when the humidity varies considerably is therefore not so reliable, but is usually quite good enough for commercial purposes. Such a case occurs when control is only effected during the day and there are large changes in humidity and temperature at night or over weekends. In all cases it is necessary to check controls at intervals against a good hygrometer and this is specially important in cases of intermittent action. The period between such checks depends on the accuracy required but it is advised that it be done weekly in commercial installations, preferably on Monday mornings if the plant has been shut down over the weekends.

While the wet and dry bulb thermometer provides the best available type of hygrometer for ordinary use, especially when ventilation is employed, it is a more difficult matter to apply the same principle to control instruments. A different thermal system must be used for control devices and this cannot have the same precision as the thermometers of an Assmann or "Sling" psychrometer. There is, moreover, considerable friction to be overcome in some instruments, making it necessary for the controlling thermometers to do an appreciable amount of work, which again tends to reduce accuracy. This view has been confirmed by a well known manufacturer of such instruments.

Furthermore, with all types of wet and dry bulb controls, it is essential that the wick and bulb covering be changed as soon as they show the slightest sign of becoming dirty, and that the supply of water for the irrigation of the bulb be well maintained. The necessity for this attention and the risks of poor control if it is neglected are probably two of the best reasons why the hair and membrane types of control are more popular. Even they should have the sensitive element cleaned with a small, soft brush at intervals.

Wet and dry bulb thermostats have sometimes been used to operate humidifying and heating systems independently by attempting to keep the wet and dry bulb temperatures constant. If the control were perfect this would give a definite relative humidity, but it is difficult to obtain sufficient accuracy. If the difference between the two values is in error by only 1° F. the humidity would be 5 per cent. from its correct value at normal room temperature. By working on bulb difference as the criterion for humidity control moderately accurate results can be obtained even with only an approximate control of the dry bulb temperature. Ingenious instruments are on the market which control at any desired relative humidity independently of the temperature. These will be described later.

The next question to be considered in relation to automatic control is the means by which the small change in length of hairs or a membrane or the change in readings of thermometers can be translated into such operations as the opening and closing of dampers, water or steam valves or into the stopping and starting of a humidifying or dehumidifying system. For this function, use has been made of electrical and fluid pressure devices, which must now be considered in detail.

It must be remembered in the following descriptions that humidifying systems are far more common than those for dehumidifying. Consequently if some control systems are described as applying to humidifiers, it should be understood that they could easily be adapted for use with dehumidifying plants. Instruments which are intended mainly for testing rooms, control both wetting and drying devices. With such, either side can be omitted if not required.

Compressed air at pressures from 10-25 lbs. per sq. inch is the most frequent medium for the control of plant. The usual method of operation will be readily understood from the diagram (Fig. 31). The air is supplied at A and passes through an adjustable needle valve B to the pipe line C, leading to the valves or dampers. On the downstream side of the needle valve is a leak-valve D, consisting usually of an orifice covered by a pad which is opened and closed by some mechanical movement produced by the sensitive element. The needle valve B is so set that, when the leak D is open, the pressure in C is very small. When, however, the leak-valve is closed, the pressure in C is equal to that in

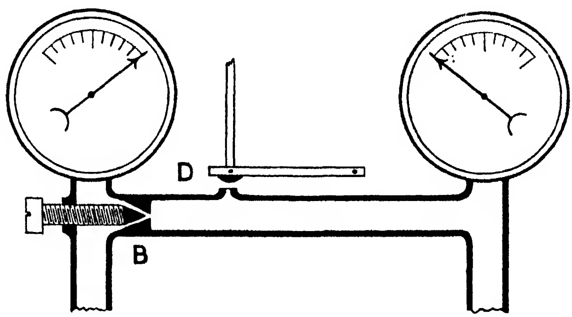



FIG. 31.—Diagram showing Principle of Compressed Air Controls.

A, and this pressure is used for operating the required apparatus. The pressures in A and C are usually indicated by two pressure gauges. The amount of movement necessary to open or close the jet may be only of the order of thousandths of an inch, and owing to the small area of the orifice, the force required is exceedingly small. Sometimes the change in pressure, due to the opening and closing of the control orifice, is made to operate a small diaphragm which opens and closes a larger orifice, thus acting as a relay giving more power in the apparatus controlled.

High humidity may open or close the orifice and the air pressure which acts on the diaphragm-operated valves or dampers may cause them to open or shut according to the arrangement of the apparatus. Thus several different combinations are possible, especially when a relay is used. In choosing one for any particular case care should be taken to see that, if there is a failure in the supply of compressed air or a leakage in the pipe line, all valves and dampers will return to a safe position.

The compressed air is usually provided by a small compressor driven either from shafting or by a separate electric motor. The air is stored in a reservoir at a fairly high pressure and is brought to the control through a reducing valve and water and oil trap.

It is sometimes possible with compressed air to arrange for "floating action" instead of "on and off" control. For this, the sensitive element must grade the air pressure and the valves or dampers be of such a type that their opening varies with the pressure. Up to the present, no application of this method to humidity control work is known, but the effect sometimes occurs accidentally in "on and off" controls. It probably represents the ideal method of control if it can be arranged in a simple and thoroughly reliable manner.

Liquid pressure is also used in control work and can readily be applied to humidity regulation. The usual liquid is, of course, water, but where there is a danger of freezing, oil may be substituted. The water, after passing through a flow restricting device, escapes under constant pressure from a jet, which, as with air plants, can be stopped by a mechanical movement actuated by the sensitive element.

When the orifice is stopped there is an increase of pressure behind it which can be used for operating any valve or similar appliance. The advantage of these controls is that no compressor is required (though, when oil is used, a pump has to be provided to return this to the supply tank, which is high enough to give a suitable head) and thus a considerable saving in cost is effected.

Electrical methods of control also have the advantage that no compressor is needed. Electric power is now available almost universally from alternating current mains. Any desired voltage can be obtained readily by a transformer and with modern rectifiers, such as the Westinghouse copper oxide type, it is very easy to obtain a suitable direct current supply for control instruments if necessary. Thus the power needed is secured without difficulty. A control usually involves contacts which tend to be a source of trouble. With the minute amount of mechanical power available in a control, the establishment of a good electrical contact is apt to be a little uncertain due to dirt, grease or dust on the surfaces. There is also the question of intermittent contact on making or breaking the circuit due to the very slow changes in humidity. Arcing or sparking at the contact points can be reduced by connecting a condenser across the gap, if the supply is direct current. A small rectifier similarly connected is very efficient in damping out these undesired effects. Various ingenious means have been used to overcome these troubles at contacts and these will be noted when individual controls are described.

One of the commonest methods of controlling humidity plant is by the opening and closing of valves and dampers. Electrical apparatus for this purpose calls for careful design. Solenoids may be used on D.C. circuits, but if the supply is A.C. a rectifier must be used on all but the smallest units. The rectifier is usually of the Westinghouse type. Another method of obtaining a considerable force electrically is by the use of an apparatus such as the British Thomson-Houston "thrustor." This consists essentially of a motor-driven centrifugal oil pump which creates the oil pressure necessary to move a piston. When the motor stops, the piston is returned to its normal position by a spring. This device can operate valves or damper systems. There have recently been placed on the market valves which are operated by a small electric motor through gearing, with switches provided so that the motor stops at the full open or full closed position according to the position of the control switch. A further type employs a bellows containing a volatile liquid which is heated by a current switched on by the control, the deflection of the bellows due to the vapour pressure operating the valve. When the current is cut off the vapour pressure falls and the valve is returned by a spring.

When the humidifier or dehumidifier can be arranged to be motor-driven or if the water can be supplied by a motor-driven pump, electrical control becomes easy through the use of suitable relays. Mercury tube relays have been found to be suitable and convenient for this purpose. A combination of the electric and liquid pressure systems has also been used, involving a "hydro-electric relay." This is similar to the liquid pressure controls described, but the mechanical movement is provided by an armature actuated by a solenoid connected to an electrical type of control.

As has been already noted, some types of humidifiers have a hygroscopic control incorporated in their construction. It is claimed that such an arrangement allows for variations due to local causes and would certainly be very convenient in certain cases. On the other hand one instrument controlling a whole room or part of a very large building has the advantages of simplicity and ease of adjustment, while local variations should be allowed for in the layout of the plant.

It is now desirable to consider in detail individual makes which are in general use in this country.

**"Arca" Regulators.**—"Arca" humidity regulators are of the liquid pressure type and generally employ water at a pressure of at least 15 lbs. per sq. inch as the medium of control, although oil or compressed air may also be used. Two forms are available, one depending on the extension and contraction of cotton threads (Fig. 32), and the other on wet and dry bulb thermometers.

In the first type the change in length of the threads is communicated to a pivoted lever, one end of which covers a water jet about $\frac{3}{16}$ inch in diameter. Water is supplied to the jet passing first through a throttling device and then through a diaphragm chamber. A very small movement of the lever towards or away from the jet causes a considerable rise or fall of the pressure of the water between the needle and the jet. These changes of pressure, acting on a spring-loaded diaphragm, cause corresponding movements of a small regulating valve. For most humidity work this valve is sufficiently large, but if the load is very great, the diaphragm can operate a pilot valve controlling a hydraulic cylinder.

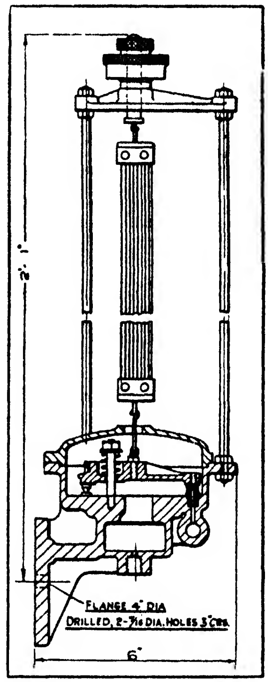


Fig. 32.—"Arca" Humidity Control (Cotton Thread Type).

In the second type, the thermometers consist of tubes exposed to the air and containing a non-expanding steel rod connected to them at their outer end. The expansion of the tubes with increase of temperature is thus communicated to two pivoted levers. The first of these levers is controlled by the dry bulb alone and a device similar to that described above controls the heating system. The other lever, actuated by the wet bulb, carries a water jet which works up against a pad on the dry bulb lever. This jet is therefore suppressed when the bulb difference becomes too small and the pressure so produced is made to regulate the humidifying or dehumidifying apparatus by means of a diaphragm. Thus dry bulb temperature and bulb difference are controlled.

All steam valves used in connection with "Arca" controls are of the single-seated, ported type, and the larger sizes are balanced. The essential feature is that the steam has to pass through the ports before crossing the seat and therefore the inevitable cutting action occurs at the ports and not at the seat. The steam-tightness of the valve is therefore preserved.

**Baldwin Control.**—The operating element of the Baldwin humidity control apparatus is a differential mercury-in-steel thermometer, one bulb having a wet covering. This indicator shows bulb difference directly and, being provided with a contact on the pointer, can actuate a solenoid-operated valve through a relay. Thus the supply of water or steam to the humidifiers is controlled solely by the bulb difference. For many purposes this gives accurate enough control, provided that there are not too great variations in temperature.

The solenoid-operated valve is interesting. The solenoid has merely to open a small pilot valve which causes the steam or water pressure to open the main valve.

**Brecknell, Munro & Rogers Control.**—This control is of the hair-electric type and employs a unique method of multiplication of the work done by the hair in changing in length with the humidity. The end of the bunch of hairs is connected to the escapement of a clockwork mechanism in such a way that, if the element becomes longer or shorter, when it passes the control point the clockwork escapement wheel moves on one tooth and in so doing rocks a lever carrying a large mercury switch. This is intended to switch on the motor-driven humidifier made by this firm or to control the steam supply to Sharman type humidifiers through a solenoid-operated valve. It can of course be used for other purposes.

**Cambridge Controls.**—Two controls have been developed by the Cambridge Instrument Co., Ltd. in collaboration with the Wool Industries Research Association. They are both of the hair type and use electrical transmission. As they were primarily designed for controlling the humidity in testing rooms, where arrangements are provided for both humidification and de-humidification, these instruments control both the "wetting" and "drying" arrangements. Either of these functions can of course be omitted when not necessary.

In the first of these (Apthorpe and Hedges, *Journ. Sci. Instr.*, 1927, **4**, 480) an ingenious method has been adopted to overcome contact troubles.

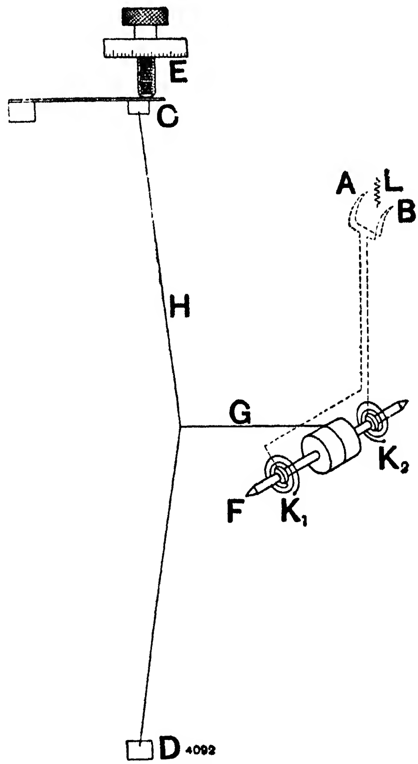


FIG. 33.—Cambridge and W.I.R.A. Humidity Control.

The general arrangement of the instrument is shown in Fig. 33. To the midpoint of the specially selected and grease-free hair (H) 40 cm. in length is attached a thin metal strip G, which passes round a cylinder fixed to the spindle F. This spindle also carries a pointer. The change of length of the hair with the variations in the humidity of the surrounding air results in corresponding movements of the pointer. Torsional control of the spindle is effected by means of two spiral springs K1, K2, which are insulated from the spindle. These springs also serve as connections between a differential copper-constantan thermocouple A, B, mounted at the extreme end of the pointer, and a sensitive moving coil relay. Mounted immediately behind the junctions of the thermocouple is a small electrically heated coil L, which is maintained at a dull red heat.

When the pointer is at the set point of control, both junctions are equidistant from the heater, and the moving coil relay is in its zero position. If the air becomes drier, the hair will shorten, causing the pointer to move so that the junction B is close to the heater. The moving coil relay will then be deflected, thus energising a larger relay which controls the supply of moist air. When the air becomes too moist, the hair will lengthen causing junction A to be influenced by the heater, thus energising another relay which controls the supply of dry air. If the instrument is controlling only a humidifier or dehumidifier, one of the larger relay systems is, of course, omitted. The adjustment of the control is effected by turning the screw E until the pointer is in the centre position when the humidity has attained the required value.

The instrument might be criticised as needing rather a delicate and complicated relay system, especially where, for instance, a hydro-electric relay has to be added to provide large enough forces for opening valves. A second and simpler model (Apthorpe and Marsh, *Journ. Sci. Instr.*, 1931, **8**, 152) has therefore been built which employs platinum contacts instead of the heater and thermocouple device. A blade is attached to the cylinder and this moves between two contact screws. These complete the circuits of the two large relays directly. This instrument, can, however, only be worked when supported on a vibration-free suspension, consisting for instance of three light spiral springs as shown in Fig. 34. Under these conditions the control has given excellent service and very accurate control. The points have to be cleaned periodically by rubbing their contact surfaces with a piece of stiff paper which is not too smooth.

It should be noted that the Cambridge goldbeater's skin humidity recorder previously described could very easily be converted into a control by substituting a suitable relay for the recorder.

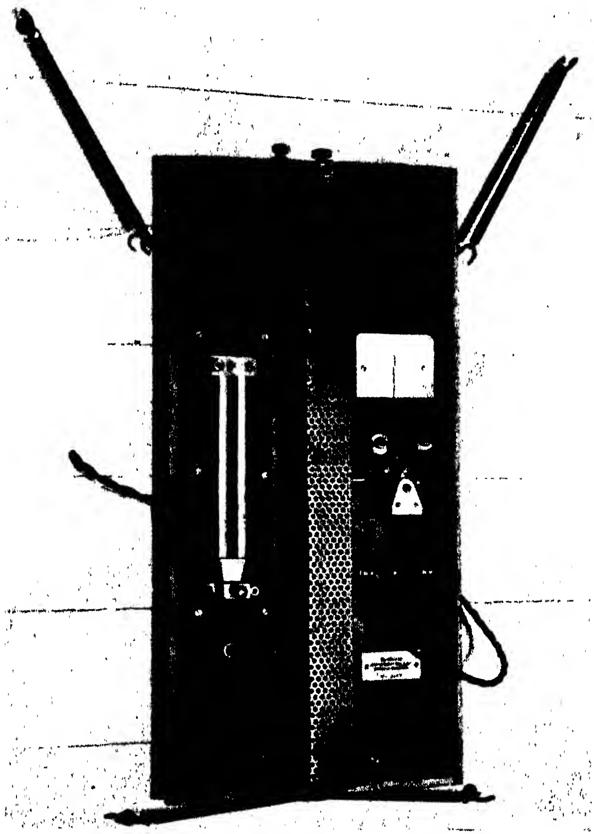


FIG. 34.—Cambridge and W.I.R.A. Simplified Humidity Control.

**Drayton Regulators.**—The Drayton "MS" Differential Humidity Regulator is of the ventilated wet and dry bulb type, using vapour pressure thermometers. It is made in forms suitable for controlling humidifying and dehumidifying systems by the compressed air method, and may be self-contained or of the transmitting type. By a very ingenious arrangement, control is effected at a constant humidity even when the temperature is varying. It makes use of the fact that, with a ventilated wet bulb hygrometer, there is an approximately linear relation between the wet and dry bulb temperatures for a given humidity. In other words, for a fixed humidity and varying temperature, the *changes* of the wet and dry bulb temperatures have a

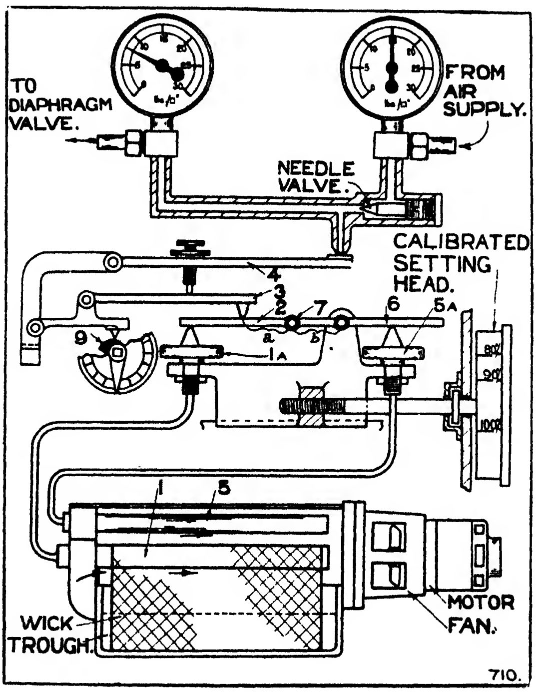



Fig. 35.—Drayton "MS" Humidity Control.

constant ratio which depends on the value of the humidity. (It happens that, for ordinary temperatures and humidities, the ratio of the wet to the dry bulb temperature on the Fahrenheit scale is roughly constant for a fixed humidity.)

The application of this principle to the construction of the instrument is as follows. The vapour pressure of the liquid in the thermometer bulbs causes diaphragms 1A and 5A in Fig. 35 to be distended to an extent proportional to the temperature. Thus considering lever 2, the end carrying the bearing 7 is lowered by an amount depending on the change in the dry bulb temperature, while the other end is raised by an amount depending on the change in the wet bulb temperature. If the humidity remains constant, these changes will always be proportional to one another and there will thus be a position on the bar which does not rise or fall when the temperature changes. Another lever 3 is, therefore, made to bear on lever 2 at some point which is varied according to the desired humidity by the calibrated setting head. Lever 3 operates still another lever 4 which controls the air leak in the compressed air system in the usual way. The cam 9 is provided to set the regulator for the correct wet bulb temperature for any dry bulb temperature. When once set, the correct bulb difference is maintained at all temperatures.

This firm also makes humidity recorder-regulators which also have wet and dry bulbs and compressed air actuation of the controlling mechanism. The wet bulb can be either of the wick-covered type provided with an electric fan for the circulation of air over it, or of the non-aspirated porous tube type. Wet and dry bulb temperatures are shown on the chart and separate controls can be effected by each bulb. These instruments can be provided with a "cycle" device. This consists of a celluloid cam, driven by the clockwork which drives the chart, which alters the control point of either or both of the thermometers in a predetermined manner. These regulators can now be fitted with a "dead beat, dead set" regulator mechanism which prevents "hunting" and maintains a definite setting of the control point. Space does not allow a description of this device to be included here.

Another form of control ("HDP") by the same makers is operated by two helical bimetallic coils, joined in the centre and working in opposition in such a way that a spindle indicates the difference in temperature between the coils.

One coil is covered by a wick dipping in a water trough and thus responds to variation in the wet bulb temperature. The trough is arranged with a water supply. The spindle carries an arm acting on an air valve which can be moved to give various settings. This air valve, by means of a diaphragm, controls the main air-leak in the usual way for compressed air systems. If desired this instrument may be obtained for electric instead of compressed air operation. When a specially accurate control is required, a fan is provided to draw air over the coils, thus giving more rapid response and a more accurate wet bulb temperature.

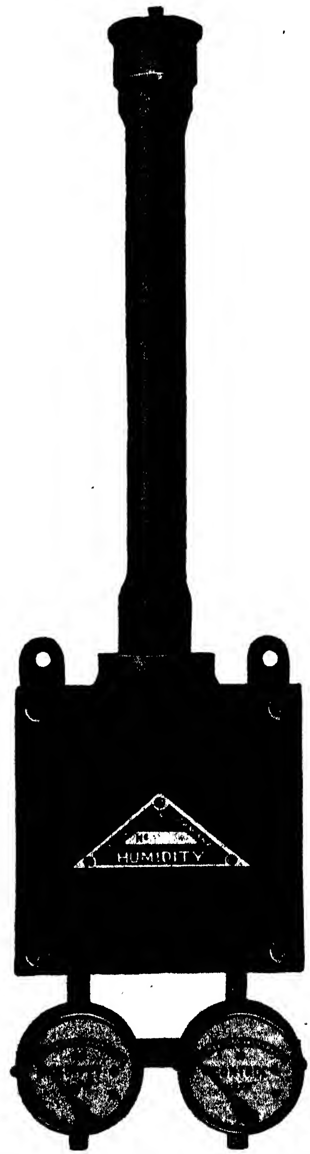



FIG. 36.—Negretti and Zambra Humidity Control.

A hair-operated electric humidostat, with a calibration setting device, is also produced by this firm.

A system of control not previously considered is made by them specially for air conditioning plants. This is designed to prevent deposition of moisture from conditioned air on cold surfaces in rooms during the heating up period and also to prevent cold air being blown in if the room overheats. Two thermostats in the room are used for this purpose in conjunction with double-topped diaphragm valves, and exercise primary control in such a way as to give the effects mentioned. Different arrangements are used according to the type of plant in use.

**Foxboro Controls.**—The Foxboro Company in America make two types of humidity controls, both being combined with a recording mechanism and using compressed air as the transmitting medium. One employs an animal membrane as the sensitive element, while the other is of the wet and dry bulb type which regulates both humidity and temperature. In both instruments the primary air-leak valve controls a diaphragm which in turn operates a larger leak valve. With such a device, it is possible to get a sensitive control with considerable power.

**Negretti and Zambra Controls.**—The hygroscopic control manufactured by this firm is shown in Fig. 36. It is actuated by goldbeater's skin strips connected directly to an air-leak valve, the instrument being of the compressed air type. The air-leak valve (Fig. 37) is not of the usual pattern involving a fine jet closed by a pad, but of the balanced type with conical hard brass seatings. These are self-centering and thus obviate the need for guides, which would introduce friction and the possibility of sticking. The distance between the cones is adjusted by a screw thread when the instrument is assembled. A second feature of the instrument worthy of note is that the goldbeater's skin is enclosed in a polished chromium-plated tube to protect it from the effects of heat radiated by neighbouring hot bodies. To give the necessary exposure to the air, a stream is induced to flow through this tube by a small air-leak in the body of the instrument.

FIG. 37.—Negretti and Zambra Air-leak Valve.

The latest type of control to be introduced is composed of two mercury-in-steel temperature controllers of the compressed air type (Fig. 38). The point worthy of notice is the method of irrigation of the wet bulb D which is often a difficult matter where evaporation is very rapid. A supply of steam is brought to the apparatus by 30 or 40 feet of copper tube A so that the steam is condensed on reaching the apparatus. The water is finally cooled to air temperature by the coil G shown below the wet bulb. The

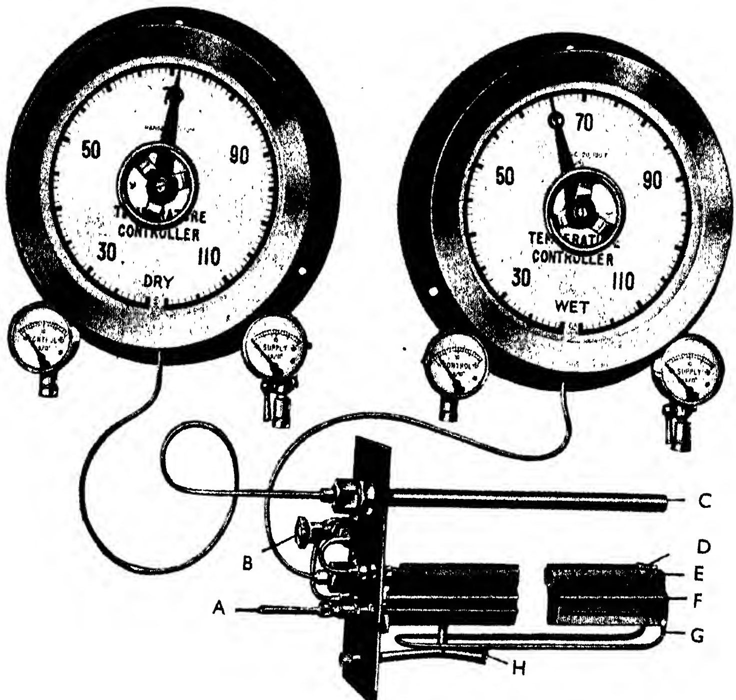



FIG. 38.—Negretti and Zambra Wet and Dry Bulb Humidity Control.

amount supplied can be regulated by a needle valve B, whilst any excess can be drained away. By this means a constant supply of pure water is assured.

A hair hygrometer fitted with electric contacts, made by this firm, may also be used as a control if provided with suitable relays. The types mentioned previously are, however, to be preferred.

**"Park Spray" Psychrostat.**—One instrument of American origin deserves notice as it does not involve hairs or membranes or even a wet wick. This is the "Park Spray" Psychrostat. Air is drawn up one vertical tube over the dry bulb which consists of expansible metal bellows. It then passes down another vertical tube over the wet bulb. At the top of this tube is a water atomiser which serves to keep the bulb wet and to induce the flow of air. The two bulbs are connected by levers to a slide valve device controlling a compressed air system. This lever system is so made that control is effected at the same relative humidity at all temperatures. The interest of this instrument is that it is of all-metal construction and should thus maintain its setting better than instruments involving wicks, hairs or membranes.

**"Services" Control.**—This control was designed specially to meet the need for an accurate instrument which could be constructed at a low cost. Standard products were therefore used as far as possible for its components, the others being of simple construction easily within the scope of any workshop.

Fig. 39 shows the complete control which consists of two parts—the hair control and the relay board. The hairs are pulled to one side by means of a spring blade, carrying contact points, which moves when the hairs extend or contract. When the movement from the zero position is sufficient, one of the relay circuits is closed, thus switching on the humidifying or drying apparatus as required.

When this simple arrangement was first tried, there was much "hammering" of the relays due to the vibration of the spring arm and to sparking at the contact points. To overcome this, Stevenson (*Journ. Sci. Instr.*, 1930, **7**, 293) suggested that when a relay operated it should stay on for a definite period. He obtained this period by means of a "thermic flasher." This worked well, but the thermic flasher needs delicate adjustment and, where A.C. is available, has been superseded by a rotary switch driven by a Warren synchronous motor (Marsh, *Journ. Sci. Instr.*, 1932, **9**, 153.) With this arrangement, once a

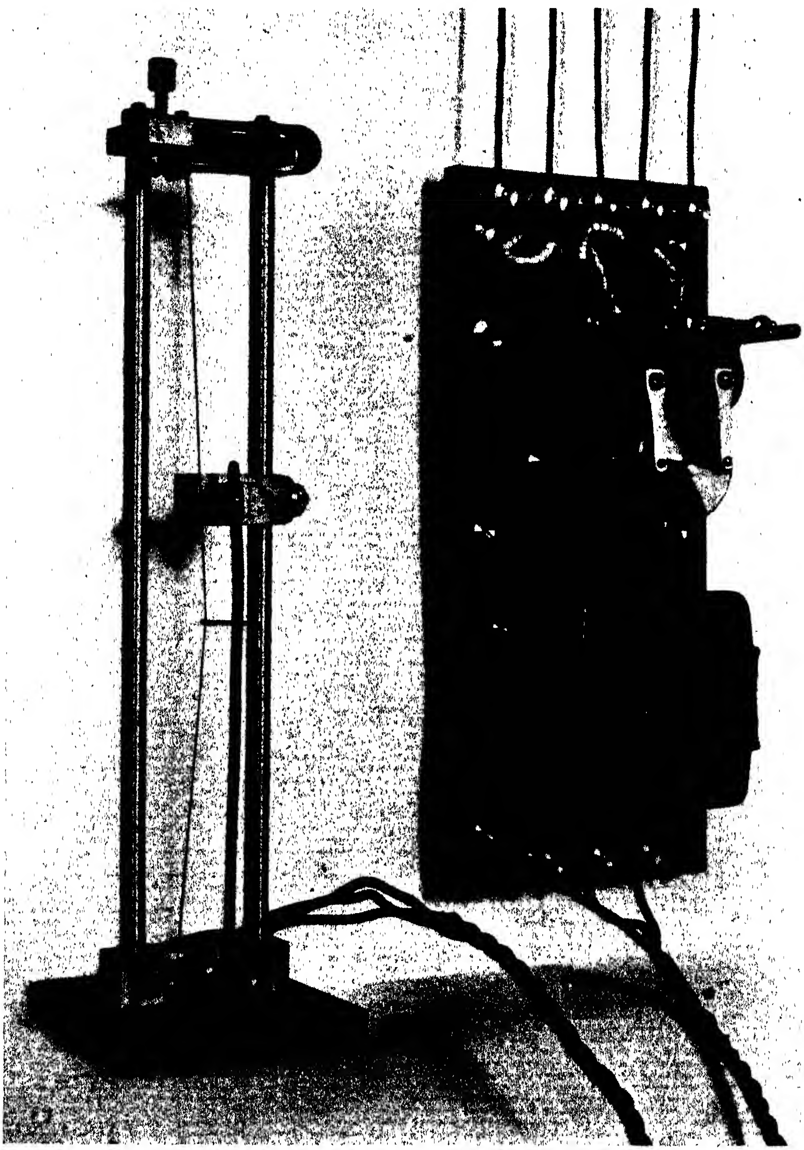


Fig. 39.—" Services " Humidity Control.

relay is energised it is compelled to remain "on" until the end of a 30 second period. Then, if the hair contacts have separated, it will fall to "off," but otherwise it will keep "on" to the end of that period in which the hair contacts open. In this way all hammering has been eliminated.

The original object of this control was to effect the switching on or off of two fan motors of a simple humidity control outfit for small testing rooms which will be described later. It has, however, been also applied to large humidifiers, in which case it either operates a magnetic valve or stops and starts an electrically driven pump as required.

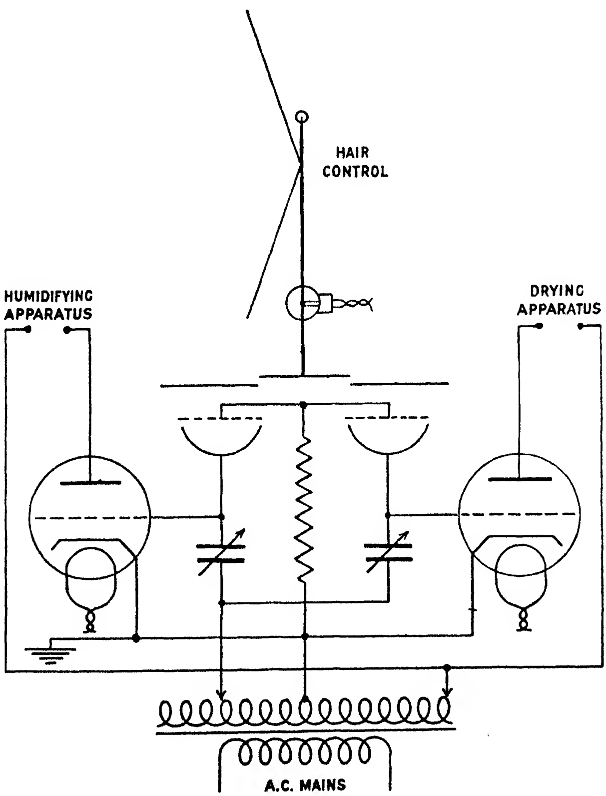



FIG. 40.—Wiring Diagram of Humidity Control using Thyratrons or Gas-filled Relays.

A further development of the plant has been designed recently by the author to give " floating action " instead of " on and off " control (Marsh, *Journ. Sci. Instr.*, 1932, **9,** 153 ; Barker and Marsh, " *Engineering*," 1932, **134,** 493). This makes use of thermionic valves containing mercury vapour, usually called " thyratrons " or " gas-filled relays." The valves are able to pass large anode currents compared with ordinary vacuum valves, and if operated on alternating current, this anode current, which incidentally is rectified, can be controlled by changing the phase of the grid with respect to that of the cathode (Hull, *Gen. Elec. Rev.*, 1929, **32,** 390). The phase-shift can be produced by varying the resistance in a resistance-capacity circuit, for instance by changing the illumination of a photo-cell. Use is made of this property in the control under consideration. Any change in the length of a bundle of hairs due to humidity variation, causes the movement of a shutter which allows light to fall on one of two photo-cells, the change of light depending on the magnitude of the change of length. The two fans are controlled by the photo-cells by means of the circuit shown in Fig. 40 and it will thus be clear that it is possible to vary the fan speed according to the need at the moment. In this way, almost ideal control is obtained, which is far better than could be effected by the " on and off " methods.

**Short and Mason Hygrostat.**—In the " Universal " hygrostat made by this firm (Fig. 41) the sensitive element is a length of specially treated film. It is claimed for this film that it is sensitive to changes of relative humidity, but unaffected by temperature changes, and that it maintains its calibration. Compressed air or electricity can be used and the instrument may be direct or reverse acting. The necessary relays are included in the instrument. Instruments are available either for wall or duct mounting. A humidity indicator is fitted, but this is operated from an entirely separate sensitive element. The sensitivity of the instrument can be changed, the sensitivity being the change in air pressure produced for a given change in humidity.

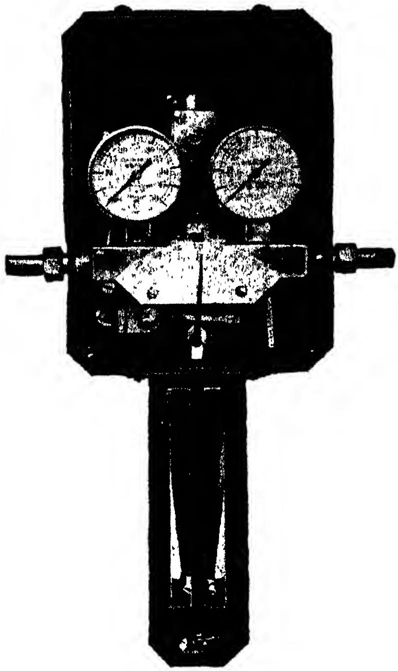


FIG. 41.—Short and Mason "Universal" Hygrostat.

**Siemens Control.**—This control (Fig. 42) is based on the Siemens humidity meter already described. The pointer S carries a small stem which moves over two adjustable contacts (I and II). These contacts are carried on arms mounted concentrically with the coil system M of the indicator, and may be moved to any part of the scale by two knobs. The upper halves of the contacts are spring strips so arranged that the contacts normally are open. Above the pointer is a "chopper bar" F similar to that used in thread recorders. This is pulled down at regular intervals by an electromagnet, A. If the stem on the pointer is over one of the contacts, the upper spring will be depressed and a circuit completed. This, through a relay, can be made to carry out any desired controlling operation. When the contacts are at their closest position, the stem can just pass between them but any deviation from this point causes one or other of the contacts to be depressed. If neither of these contacts is depressed, the chopper bar descends further than usual and closes a third contact (III) which may be made to indicate that correct conditions obtain. This contact may also be used to increase the

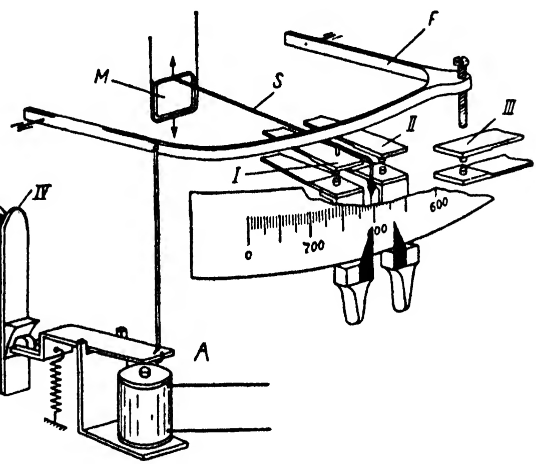



FIG. 42.—Diagram of Siemens Humidity Control.

sensitivity of the instrument by putting it in parallel with one of the other contacts.

The timing of the electromagnet is effected by a synchronous motor and cams for A.C. circuits, or by a bimetallic switch on D.C. circuits. One control of this type can be made by means of an automatic six-way switch to regulate up to six plants under certain conditions. A "programme transmitter" may also be used with the Siemens instrument to vary the control point in any desired manner. By means of a cam, driven by clockwork or by a synchronous motor, a resistance is varied, thus "falsifying" the control point according to any pre-arranged plan.

Humidifier and air conditioning engineers generally use controls made by firms specialising in instrument work. Two, however, make their own controls, which may be noted briefly.

**Andrew Control.**—The "Aero" automatic control is of the membrane type with compressed air transmission. The membrane is enclosed in a casing through which a flow of air is induced.

**"Aerozon" Control.**—This is also of the strip type using compressed air. The strip is enclosed in a vertical tube with an induced circulation of air.

## CHAPTER VIII.

## THERMOSTATS.

It will not be out of place to consider briefly the main principles of the design of the simpler types of thermostats. They are useful in all humidity control schemes, as good control can only be obtained when the temperature is reasonably constant. Furthermore, in many air conditioning plants, there is no humidity control instrument in the usual sense of this term, but control is effected by the dew point and room thermostats. In all cases of such plants, the dew point thermostat has a very important place whatever other control instruments may be used. Thermostats for use only in liquids and for temperatures outside those occurring in normal atmospheres, will naturally be omitted. For a full account of all types of thermostats, reference should be made to books by R. Griffiths and by Behar, recently published on this subject (see Bibliography).

Fluid pressure and electrical systems converting the small movements of thermostats into the operation of valves, etc. are used as with humidity controls. In fact, some of the humidity controls have been developed from thermostats by the replacement of a temperature sensitive element by a hygroscopic one. It is therefore only necessary to consider the means by which temperature changes are converted into a mechanical movement for the operation of a leak valve or electric contacts.

The mercury type of thermometer is very little used. If it is employed, the general method is to seal a wire into the stem of the thermometer at the desired value and another wire at some other convenient position. Electric contact is thus established when a certain maximum temperature is reached and, by means of a suitable relay, the heating is cut off. This instrument suffers from two obvious defects—the lack of adjustment of the control point and the risk of contamination of the mercury surface.

Both of these defects have been overcome in a thermostat made by Messrs. Baily, Grundy & Barrett, Ltd. A small glass capsule containing a short piece of iron is fitted into the top of the thermostat tube and to it is attached a length of platinum wire, passing through and making contact with a fixed platinum spiral connected to an external terminal, and thence down the stem towards the mercury column. The capsule can be moved up and down in the tube by means of a permanent magnet, and hence contact can be made at any desired temperature. In order to prevent fouling of the mercury, a thermionic valve is used between the thermostat and the contactor to be operated, thus reducing the current through the thermostat to a few microamperes. Increased sensitivity could be obtained by using a Beckmann type thermometer. A rough setting of the control point could then be obtained by transference of mercury to the top chamber.

For laboratory work a toluene thermostat is very often employed, arranged either to complete electric circuits or to cut off a gas supply. For great sensitivity the bulb is made to have a large surface. These instruments are so well known that they need not be described further.

A very robust sensitive element is made by enclosing an inner rod in, say, a brass tube. These are connected at one end and the relative movement of the other due to differential expansion is used to operate any desired mechanism.

In temperature control work, however, a bimetallic strip gives very good sensitivity, and has a small heat capacity. The movements of this strip can be made to open and close air or water leaks or to make and break electric contacts.

It is now usual to mount a small piece of iron on the end of the bimetallic strip and provide a small magnet in the neighbourhood of this iron. These are disposed in such a way that as the contacts are closing, the magnet causes the final movement to be performed very rapidly. Similarly, on separating, the points remain together until sufficient force has been built up on the strip to open them quickly. A thermostat of this nature is able to deal with relatively large currents at mains voltage for A.C. supply.

If, however, very large currents are employed, or if the supply is direct current, some form of relay is necessary. The objection to the magnet device is that it produces a "differential" between the temperatures of switching on and switching off. In most applications this is not a serious disadvantage as it saves wear and tear of the instrument, but it is not allowable in accurate control work unless the range is very small.

For accurate work a bimetallic contact without any magnetic device is used. It has, however, to be protected from vibration, and even then the hammering of the relay is not entirely eliminated. One of these is illustrated in Fig. 34 on the left-hand side of the humidity control.

A form of control in commercial use in recent years consists simply of a vapour pressure thermometer bulb connected to a diaphragm or bellows-operated valve which is inserted in a steam or hot water heating system. In consequence of the work which the vapour has to perform in operating the valve, such a control cannot be very precise, but is usually sufficiently so for industrial purposes. Further, owing to the fact that the valve will probably be slightly open for long periods, steam is liable to cut the seating of the valve.

For limited ranges a "capsule" thermostat is often used especially for controlling the temperature in incubators, ovens and rooms. The capsule is essentially a small flexible metal box containing a suitable liquid. The vapour pressure of the liquid causes the box to distend, thus operating contacts or gas valves.

An excellent temperature control for industrial purposes involves mercury-in-steel thermometer bulbs. The range covered by these instruments is large. The Bourdon tube operates a lever regulating an air-leak or tilting a mercury-tube switch. For air thermostats a type of bulb must be used having as large as possible a surface for its volume to give the necessary sensitivity. Electrical temperature indicators of the resistance or thermoelectric type can also be converted into controls by the addition of suitable contacts or similar device.

# CHAPTER IX.

## HUMIDITY CONTROL IN TESTING ROOMS AND LABORATORIES.

PHYSICAL measurements and tests of the attributes of many materials are affected by the humidity of the air, and in such cases some form of humidity control is necessary in the testing room. The need arises more especially in the case of hygroscopic materials such as textiles, paper and many foodstuffs. The physical properties of these substances change to a great extent when the humidity varies and hence, to make measurements of any value, or results reproducible, they must be carried out under known humidity conditions.

Methods have been suggested to obviate the necessity for controlling the humidity of a whole room. One expedient often used in industry is to provide a standard sample with which the sample under test may be compared. This obviously has its limitations and is not reliable unless precautions are taken to ensure that both samples are in exactly the same hygroscopic condition.

Another method is to use a humidity chest which usually consists of a large box with a fan giving air circulation. In the base of the box is a tray containing a saturated salt solution. This has a definite vapour pressure and therefore, if the air is in equilibrium with this solution at a constant temperature, it will have a definite relative humidity, whose value will depend on the particular salt used. Tables and curves are given in the "*International Critical Tables*" (Vol. I., p. 67). Common salt (NaCl) has the very useful property that its solubility changes very little with temperature and therefore over a fairly wide range of temperatures the humidity it gives is approximately constant (about 73-75 per cent. R.H.). Sulphuric acid and glycerine solutions have also been used but, when these absorb or lose water, their strength is changed and therefore the humidity is not constant. (Tables relating to sulphuric acid are given by Wilson, *J. Ind. Eng. Chem.*, 1921, **13**, 326).

Such a method of controlling humidity is satisfactory when it can be arranged that the samples under measurement can be left in the controlled space until equilibrium is reached and then all the measurements carried out without removing them. It has been used for very accurate control work (Marsh and Earp, *Trans. Faraday Soc.*, 1933, **29**, 173), in conjunction with fine temperature control. This latter is obtained by means of a water-jacketed metal box, the water being thermostatically controlled. Where, however, it is necessary to remove the samples for measurement, the accuracy is greatly decreased, and unless the measurements can be carried out in a few seconds this method is relatively useless. Several methods of producing a definite humidity, variable at will, in small closed spaces, are described in " The Measurement of Humidity in Closed Spaces " (*D.S.I.R. Food Investigation Special Report No.* 8 (Revised Edition, 1933)).

The use of controlled rooms for the testing of textiles has now become general practice. A Carrier plant was installed at the Manchester Testing House and Laboratory in 1913, and is still in constant use. As this type of plant has already been described, there is no need to explain its working here.

The air conditioning type of plant has also been used in controlled rooms constructed more recently. In the London School of Hygiene and Tropical Medicine, the installation is of the Carrier type and is provided with a refrigerator enabling a wide range of humidities and temperatures to be obtained. A similar plant by Hall & Kay, Ltd., at the Building Research Station, Garston, Herts., has been modified to give a very exact control in several cement testing rooms.

For most purposes, however, a small room can be used which may be humidified by blowing air over wet pumice, coke or even over a tray of water. Solid calcium chloride is used for drying the air.

One of these rooms which has given excellent service is that at the laboratories of the Wool Industries Research Association, Leeds. This room, which will now be described in detail, measures $19\frac{3}{4}$ feet × $12\frac{3}{4}$ feet × $7\frac{3}{4}$ feet and therefore has an approximate volume of 1,950 cu. ft. It is situated in a cellar, which obviates the need for a costly refrigerating plant. The walls are inside ones and thus not in contact with the earth. Air is circulated internally by means of a centrifugal fan driven directly by a $\frac{1}{2}$-H.P. motor, being withdrawn at the end of the room by a duct near the floor and returned near the other end as high as possible. After leaving the fan, the air passes up a heating "tower" which is a brick chamber 4 feet square by 5 feet high, in which is a heater comprised of seven 250 watt radiator lamps controlled by a Baily, Grundy and Barrett mercury thermostat and thermionic relay. From the heating tower the air may pass either through the wetting or the drying tower or return directly to the room as required. The route is controlled by two electro-magnetically operated mushroom valves on the drying and wetting towers respectively. These valves are controlled by a simplified Cambridge hair control, already described, through relays. The wetting tower is filled with pumice over which flows a stream of water which can be preheated if necessary by an electric heater. The drying tower is fitted with racks carrying lumps of solid calcium chloride and both towers are about 4 ft. square and 5 ft. high. The controls are all operated on 6 volts A.C., which is supplied from a small transformer. The maximum variations in this room during the course of a week are less than 1 per cent. in relative humidity and 0·5° F. in temperature as indicated on hair and bimetallic recorders respectively.

A room of similar general design has been built at the Bradford Conditioning House. Arrangements were made to draw up cool air from the cellars when desirable and to circulate it between the double walls of the room. Control is effected by a large piece of flannel suspended from a balance. As already mentioned, this method gives sensitive regulation but is liable to change of the control point due to the deposition of dust on the flannel.

Some years ago the need arose for an inexpensive plant which could be placed in any suitable room involving only a minimum of structural alterations. The "Services" humidity control already described, and the plant now under consideration, were developed by the Wool Industries Research Association for this purpose. The wetting and drying arrangements consist of two towers each having a fan at the top, which can be switched on or off by the automatic control, one tower containing wet pumice or coke and the other calcium chloride. This design does not give circulation of air when the humidity is correct, but this is not found to be a serious disadvantage. It could, of course, be easily overcome by fitting a circulating fan in the room.

The two towers are built in one unit, which stands in a metal tray (Fig. 43). This completely obviates all risk of leakages or overflow. The tray is provided with a 2 inch diameter drain pipe arranged for facility in cleaning. The towers are lined with sheet lead or roofing felt to render them waterproof.

The drying tower (the right-hand one) is made without any projections on the inside so that the trays, shown on the right of the diagram, may be put in from the top. Calcium chloride is bought in 2 cwt. drums and is broken into lumps of approximately 6 inch cubes as far as possible.

The smaller lumps produced are used on the lower trays, while the larger lumps are placed on the upper ones. As they are used they fall through the wide spaces in these trays and thus replenish the lower ones. Recharging may therefore generally be carried out by placing some new

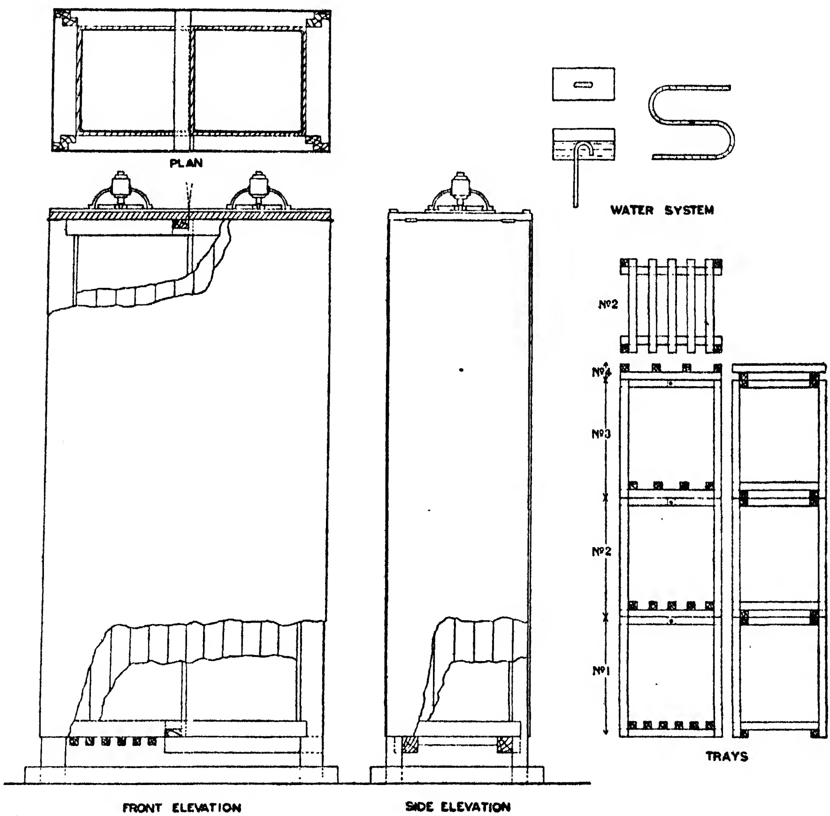



FIG. 43.—Testing Room Humidity Outfit. Scale ½ inch to 1 foot.

large pieces on trays 3 and 4, but at intervals trays 1 and 2 should be charged as well. Dr. B. P. Ridge has suggested to the author recently that any parts of a plant which come in contact with calcium chloride should be painted with a cream consisting of 4 parts cement and 1 to 2 parts of calcined magnesia mixed with a solution of calcium chloride. This sets in a few hours, forming a hard, resistant coating.

There are no trays in the wetting tower (left side). It is completely filled to within about 9 inches distance from the fan with pumice in lumps, each having a volume of between 3 and 5 cu. ins. If pumice is too expensive, foundry coke may be used. Either filling should be well washed before being put into the tower. The water is best sprayed from an S-shaped perforated tube. Instead of a slow steady flow, a large intermittent one can be provided by means of an automatic syphon tank, such as is shown in Fig. 43. This arrangement makes distribution very much easier. If very high humidities are required, or if the water supply is cold, a small electric heater is fitted to this tank to warm the water before it enters the tower. The water temperature should always be well above the dew point of the room at the desired humidity.

A room fitted up with this type of control outfit at Nottingham University College (Textile Department) has been described in detail elsewhere (Edwards, *Journ. Text. Inst.*, 1932, **23**, T274.) Several outfits have been installed by Government departments, research organisations and mills. The room used by the British Silk Research Association, which somewhat resembles those just mentioned, has been described recently by Lonsdale ("*Engineering*," 1935, **139**, 321).

A few particulars of the features which make a room suitable for conversion to a controlled humidity room may now be enumerated, so that, if a choice of rooms is possible, the most suitable may be chosen.

It is preferable that the room should have the minimum amount of outside wall, but if there is outside wall, it should be thick. Any room with walls whose outer surfaces are below the ground should be avoided. A cellar might, however, be used provided that it is entirely surrounded by other rooms. A plaster or good wood ceiling is essential and a concrete or similar floor is better than wood. There should be only one door and the minimum amount of window area in the room. The walls and ceiling of the room should be in good repair. They should be painted, preferably with an enamel paint, to prevent absorption of water by the plaster. Windows and ventilators should be permanently fastened or stopped up so that no outside air can find its way directly into the room. The door should fit tightly all round and it is an advantage if double doors can be arranged to form a small air-lock. If additional ventilation is found to be necessary, a single ventilator which can be closed if required should be fitted so that it opens into the room near the inlet of the wetting tower. It is preferable that the ventilator should draw its air from another room and not direct from the open air. The room must have an electric power supply day and night, a water supply and a drain. The drain is best connected to the sewers. Electric lighting is desirable.

Thermostatically-controlled heating is essential in any room to be controlled. For this purpose electric heating is by far the simplest and not expensive in installation and running costs. Economy in the latter can be effected by employing a radiator connected to the water heating system to take the main load and using the controlled electric heating to make up the difference. The radiator must then, of course, be hand-controlled, and so regulated that it does not overheat the room at any time when the electric heating is off. There are several reliable commercial thermostatic switches on the market, but one with the smallest possible range between switching on and switching off should be obtained. Indicator lamps showing when the heaters are functioning are a convenience. Care should be exercised to see that the heaters are more concentrated on cold walls and near doors and windows which are likely to cause cool regions in the room. It is often useful to split the heaters into two parts consisting of two-thirds and one-third of the total load respectively, each part being as well distributed about the room as possible. The two parts are controlled by separate switches, so that one-third, two-thirds or the whole of the heating can be called upon as required, according to the weather. If the heating is too rapid in warm weather, a small lag in the thermostat will allow very large variations in the room temperature. The best condition for getting close control with any thermostat is when the rate of increase of temperature with the heating on is equal to the rate of cooling with it off.

The equipment of any controlled room should include a good hygrometer and a recording thermo-hygrograph. This latter instrument is extremely useful as it is possible with experience to trace the cause of any failure of the plant by the records produced.

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"*The Aerologist*" (U.S.A.).

# APPENDIX I.

## Application of the Factory and Workshop Acts to Artificially Humidified Buildings.

BEFORE embarking on any humidification scheme it is necessary to consider whether the conditions produced will contravene the Factory and Workshop Acts.

The following information, which has been kindly supplied by H.M. Inspector of Factories, Leeds, is intended to serve as a guide to the position generally. In most cases it would, however, be a wise proceeding to consult the Inspector of Factories of the district before the scheme is put in hand to ensure that there are no special regulations applying in that particular industry or process. It is necessary to point out that for purposes of legal discussion the actual wording of the Acts must be used. References to the various sections are therefore given throughout.

### I.—Industries Other than Textile.

The *Factory and Workshop Act,* 1901, *Section* 6, says that "adequate measures must be taken for securing and maintaining a reasonable temperature" for the comfort of the workpeople. The term "reasonable temperature" is taken to include humidity if both tend to be high. In general if the wet bulb temperature is above 75° F., objections are liable to be raised by the Inspector of Factories. Special circumstances and abnormal weather conditions would of course receive consideration in determining if a temperature is "reasonable."

### II.—Textile Industries.

Special regulations apply to the textile industries. It is impossible here to give full details for all the textile industries, but the following is a résumé of the requirements of the Factory Acts for the woollen and worsted industries. It may be taken that the regulations for the other textile industries are very similar.

"By Section 96 of the Factory and Workshop Act, 1901, extending Sections 90 to 95 of that Act, the following provisions apply in every room, shed or workshop or part of any wool or worsted textile factory in which atmospheric humidity is artificially produced by steaming or other mechanical appliances.

"**TECHNICAL.**

"**Ventilation.**—Means of ventilation must be provided and maintained to supply during working hours not less than 600 cubic feet of fresh air per hour for each person employed (S.R.O. No. 79 of 1902).

"**Permissible Humidity.**—The amount of moisture in the atmosphere must not at any time be in excess of such amount as is represented by the number of grains of moisture per cubic foot of air shown in the Humidity Table (Forms 315, 316) for the temperature existing in the room, etc. at that time (Copy of Forms 315 and 316 appended).

"The fact that one of the wet bulb thermometers in the factory gives a higher reading than the figure shown in column III of the Humidity Table opposite the temperature reading in column II, is evidence that the moisture exceeds the prescribed limit (Sec. 90).

"**Hygrometric Records.**—There must be provided, maintained and kept in correct working order two sets of standardised wet and dry bulb thermometers. One set is to be fixed in the centre and one at the side, as agreed with the factory inspector, so as to be plainly visible to the workers. The occupier or manager or person for the time being in charge must read the thermometers twice daily during working hours, viz. between 10 a.m. and 11 a.m. and between 3 p.m. and 4 p.m., and he must there and then enter the readings of each thermometer on the official Record of Humidity (Form 318).

"The Humidity Records for the current month must be kept hung up near to each set of thermometers. At the end of each month the Records, duly filled in, must be sent to H.M. Chief Inspector of Factories, Home Office, London, S.W. 1, and copies must be kept at the factory for reference.

"Each form is *primâ facie* evidence of the humidity of the atmosphere and temperature in the factory in which the form was hung up (Sec. 92).

"**Hygrometers.**—The construction and maintenance of hygrometers should be to the standard laid down for cotton cloth factories by Order of the Secretary of State in 1929 under the Cotton Cloth Factories Regulations.*

"**Excessive Warming.**—The temperature shall not at any time be raised by any artificial means above 70° F. except in so far as may be necessary in the process of humidification. Gas lighting is not to be taken as contravening this restriction (Sec. 90).

"**Humidity Tables.**—The Humidity Table (Form 316) for factories in which the spinning of merino, cashmere or wool by the "French" or "dry" process is carried on is that prescribed by Order of the Secretary of State dated 24th December, 1898 (S.R.O. 1114 of 1898) (Sec. 96).

"**Purity of Water, Heat Insulation, etc.**—There are no special requirements at present as to purity of water used for humidification, nor to size of pipes and extent or amount of non-conducting covering materials, nor to provision of cloakrooms, etc.

"**ADMINISTRATIVE.**

"**Special Abstracts of Acts.**—An Abstract of the special provisions of the Factory Acts relating to certain Humid Textile Factories must be kept affixed in the factory in such manner that it can be easily read (Form 314).

"**Posting up of Humidity Tables.**—A copy of the appropriate Humidity Table must be kept hanging up in a frame and properly glazed, in a conspicuous position near to each set of thermometers (Sec. 92).

"**Inspection.**—Quarterly inspection and examination to be made by factory inspectors.

"**Contravention Notices.**—In case of any contravention of above provisions as to Humidification the factory inspector must give notice in writing specifying details and can only take proceedings in cases of continuance thereafter or repetition within 24 months (Sec. 95).

"**Notices of Commencement and Cessation.**—At or before the time of commencing to use artificial humidity the occupier of every factory must send notice thereof in writing to H.M. Chief Inspector of Factories, Home Office, London, S.W. 1 (Form 61).

"The above requirements remain in force until written notice of cessation of the use of artificial humidity has been similarly sent (Sec. 93)."

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* See p. 19.

*Copy of Form 315.*

## FACTORY AND WORKSHOP ACTS, 1901 to 1920.

### Maximum Limits of Humidity of Atmosphere at Given Temperatures Permitted by the Act.

| Grains of Vapour per cu. ft. of Air. | Readings of Thermometers. | | Per cent. of Humidity (100=Satn.) | Grains of Vapour per cu. ft. of Air. | Readings of Thermometers. | | Per cent. of Humidity (100=Satn.) | Grains of Vapour per cu. ft. of Air. | Readings of Thermometers. | | Per cent. of Humidity (100=Satn.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry Bulb. | Wet Bulb. | | | Dry Bulb. | Wet Bulb. | | | Dry Bulb. | Wet Bulb. | |
| 1·9 | 35 | 33 | 80 | 4·5 | 57 | 55 | 87 | 8·25 | 79 | 74·5 | 77·5 |
| 2·0 | 36 | 34 | 82 | 4·7 | 58 | 56 | 87 | 8·55 | 80 | 75·5 | 77·5 |
| 2·1 | 37 | 35 | 83 | 4·9 | 59 | 57 | 88 | 8·6 | 81 | 76 | 76 |
| 2·2 | 38 | 36 | 83 | 5·1 | 60 | 58 | 88 | 8·65 | 82 | 76·5 | 74 |
| 2·3 | 39 | 37 | 84 | 5·2 | 61 | 59 | 88 | 8·85 | 83 | 77·5 | 74 |
| 2·4 | 40 | 38 | 84 | 5·4 | 62 | 60 | 88 | 8·9 | 84 | 78 | 72 |
| 2·5 | 41 | 39 | 84 | 5·6 | 63 | 61 | 88 | 9·2 | 85 | 79 | 72 |
| 2·6 | 42 | 40 | 85 | 5·8 | 64 | 62 | 88 | 9·5 | 86 | 80 | 72 |
| 2·7 | 43 | 41 | 84 | 6·0 | 65 | 63 | 88 | 9·55 | 87 | 80·5 | 71 |
| 2·8 | 44 | 42 | 84 | 6·2 | 66 | 64 | 88 | 9·9 | 88 | 81·5 | 71 |
| 2·9 | 45 | 43 | 85 | 6·4 | 67 | 65 | 88 | 10·25 | 89 | 82·5 | 71 |
| 3·1 | 46 | 44 | 86 | 6·6 | 68 | 66 | 88 | 10·3 | 90 | 83 | 69 |
| 3·2 | 47 | 45 | 86 | 6·9 | 69 | 67 | 88 | 10·35 | 91 | 83·5 | 68 |
| 3·3 | 48 | 46 | 86 | 7·1 | 70 | 68 | 88 | 10·7 | 92 | 84·5 | 68 |
| 3·4 | 49 | 47 | 86 | 7·1 | 71 | 68·5 | 85·5 | 11·0 | 93 | 85·5 | 68 |
| 3·5 | 50 | 48 | 86 | 7·1 | 72 | 69 | 84 | 11·1 | 94 | 86 | 66 |
| 3·6 | 51 | 49 | 86 | 7·4 | 73 | 70 | 84 | 11·5 | 95 | 87 | 66 |
| 3·8 | 52 | 50 | 86 | 7·4 | 74 | 70·5 | 81·5 | 11·8 | 96 | 88 | 66 |
| 3·9 | 53 | 51 | 86 | 7·65 | 75 | 71·5 | 81·5 | 11·9 | 97 | 88·5 | 65·5 |
| 4·1 | 54 | 52 | 86 | 7·7 | 76 | 72 | 79 | 12·0 | 98 | 89 | 64 |
| 4·2 | 55 | 53 | 87 | 8·0 | 77 | 73 | 79 | 12·3 | 99 | 90 | 64 |
| 4·4 | 56 | 54 | 87 | 8·0 | 78 | 73·5 | 77 | 12·7 | 100 | 91 | 64 |

*Copy of Form 316.*

## FACTORY AND WORKSHOP ACT, 1901.

### Humidity Table.

*Applicable to the Spinning of Merino, Cashmere or Wool, by the French or Dry Process.*

**Maximum Limits of Humidity of Atmosphere at Given Temperatures Permitted by the Act.**

| Grains of Vapour per Cubic Foot of Air. | Readings of Thermometers, in Degrees Fahrenheit. Dry Bulb. | Readings of Thermometers, in Degrees Fahrenheit. Wet Bulb. | Percentage of Humidity (Saturation = 100). |
|---|---|---|---|
| Figures are exactly the same as on Form 315 herewith from Temperatures of 35° F. to 70° F., thereafter the following figures are to be read. | | | |
| 7·1 | 70 | 68 | 88 |
| 7·3 | 71 | 69 | 88 |
| 7·6 | 72 | 70 | 89 |
| 7·8 | 73 | 71 | 89 |
| 8·1 | 74 | 72 | 89 |
| 8·4 | 75 | 73 | 89 |
| 8·6 | 76 | 74 | 89 |
| 8·9 | 77 | 75 | 89 |
| 9·2 | 78 | 76 | 89 |
| 9·5 | 79 | 77 | 90 |
| 9·8 | 80 | 78 | 90 |
| 10·1 | 81 | 79 | 90 |
| 10·5 | 82 | 80 | 90 |
| 10·8 | 83 | 81 | 90 |
| 11·1 | 84 | 82 | 90 |
| 11·5 | 85 | 83 | 90 |
| 11·8 | 86 | 84 | 90 |
| 12·2 | 87 | 85 | 90 |
| 12·6 | 88 | 86 | 90 |
| 13·0 | 89 | 87 | 90 |
| 13·4 | 90 | 88 | 90 |
| 13·8 | 91 | 89 | 90 |
| 14·2 | 92 | 90 | 90 |
| 14·7 | 93 | 91 | 90 |
| 15·1 | 94 | 92 | 90 |
| 15·5 | 95 | 93 | 91 |
| 16·0 | 96 | 94 | 90 |
| 16·5 | 97 | 95 | 90 |
| 17·0 | 98 | 96 | 90 |
| 17·5 | 99 | 97 | 91 |
| 18·0 | 100 | 98 | 90 |

# APPENDIX II.

## List of Manufacturers.

**Plant.**

"A.C.C."—Air Conditioning Corporation (Jeffreys), Ltd., Barron's Place, Waterloo Road, London, S.E. 1.

"Aerograph"—The "Aerograph" Co., Ltd., Lower Sydenham, London, S.E. 26.

"Aerozon"—"Aerozon" Air Conditioning Co., 43 Bloomsbury Square, London, W.C. 1.

Andrew—The Andrew Machine Construction Co., Ltd., Oliver Street, Stockport.

Angus—Baynes & Co., 99 St. Paul's Road, London, N. 1.

"Aquair"—Clark & Vigilant Sprinklers, Ltd., Atkinson Street, Deansgate, Manchester.

Bahnson—The Bahnson Co., British Agents: Mellor, Bromley & Co., Ltd., "Minotaur" Works, Leicester.

Brecknell, Munro and Rogers—Brecknell, Munro & Rogers (1928), Ltd., Pennywell Road, Bristol, 2.

"British"—Brightside Foundry and Engineering Co., Ltd., 15 Chicheley Street, London, S.E. 1.

Carrier—Carrier Engineering Co., Ltd., 24 Buckingham Gate, London, S.W. 1.

"Champion"—James Howarth, Ltd., Victoria Works, Farnworth, Nr. Bolton.

Chapman—Chapman Engineering Co., 74 Corporation Street, Manchester.

"Cyclone"—Matthews & Yates, Ltd., Swinton, Manchester.

Gorford—Gorford's Heating and Conditioning Co., 25 Victoria Street, London, S.W. 1.

Hall & Kay—Hall & Kay, Ltd., Stockport Road, Ashton-under-Lyne.

Heenan—Heenan & Froude, Ltd., Worcester Engineering Works, Worcester.

" INTERNATIONAL "—Smethurst Industries, Ltd., 37 Deansgate Arcade, Manchester, 3.

" LOW-ZONE "—Hall & Kay, Ltd., Stockport Road, Ashton-under-Lyne.

MUSGRAVE—Musgrave & Co., Ltd., Sardinia House, Kingsway, London, W.C. 2.

OGDEN—Ogden Engineering Co., Ltd., 2 Blue Boar Court, Market Place, Manchester.

" PARK SPRAY "—Parks-Cramer Co., British Agents: Cook & Co. (Manchester), Ltd., 18 Exchange Street, Manchester.

SHARMAN—Brecknell, Munro & Rogers (1928), Ltd., Pennywell Road, Bristol, 2.

SILICA GEL—Silica Gel, Ltd., Bush House, Aldwych, London, W.C. 2.

" SIROCCO "—Davidson & Co., Ltd., " Sirocco " Engineering Works, Belfast.

" STANDARD "—Standard & Pochin (Engineers), Ltd., Evington Valley Road, Leicester.

STURTEVANT—Sturtevant Engineering Co., Ltd., 147 Queen Victoria Street, London, E.C. 4.

SUTCLIFFE—Sutcliffe Ventilating and Drying Co., Ltd., Cathedral Gates, Manchester.

" TEXTILE "—" Textile " Air Systems, Victoria Works, Whitefield, Manchester.

" TWONE "—White's Engineering Co. (Pendleton), Ltd., Church Street, Manchester, 6.

UNIT AIR CONDITIONER—Air Conditioning Corporation (Jeffreys), Ltd., Barron's Place, Waterloo Road, London, S.E. 1.

" VENTI-HUMID "—White's Engineering Co. (Pendleton), Ltd., Church Street, Manchester, 6.

" VORTEX "—Mather & Platt, Ltd., Park Works, Manchester.

**Instruments for the Measurement and Control of Humidity and Temperature.**

A.E.G.-MUIRHEAD " RANAREX "—A.E.G. Electric Co., Ltd., 131 Victoria Street, London, S.W. 1.

" AERO "—Andrew Machine Construction Co., Ltd., Oliver Street, Stockport.

" AEROZON "—" Aerozon " Air Conditioning Co., 43 Bloomsbury Square, London, W.C. 1.

"Arca"—British "Arca" Regulators, Ltd., Windsor House, Victoria Street, London, S.W. 1.

Baily, Grundy & Barrett—Baily, Grundy & Barrett, Ltd., 2 St. Mary's Passage, Cambridge.

Baldwin—James Baldwin & Co., Ltd., Devonshire Brass Works, Keighley, Yorks.

Brecknell, Munro and Rogers—Brecknell, Munro & Rogers (1928), Ltd., Pennywell Road, Bristol, 2.

"Cambridge"—Cambridge Instrument Co., Ltd., 45 Grosvenor Place, London, S.W. 1.

Casartelli—V. Casartelli & Sons, Ltd., Garratt Street, Oldham Road, Manchester, 10.

"Drayton"—Drayton Regulator and Instrument Co., Ltd., West Drayton, Middlesex.

Fagelston—Griffin & Tatlock, Ltd., Kemble Street, London, W.C. 2.

"Foxboro"—Foxboro Co., British Agents: Foxboro-Yoxall, Ltd., Morden Road, Merton, London, S.W. 19.

Katathermometer—J. J. Hicks, 8-10 Hatton Garden, London, E.C. 1.

Negretti & Zambra—Negretti & Zambra, 38 Holborn Viaduct, London, E.C. 1.

"Park Spray"—Parks-Cramer Co., British Agents: Cook & Co. (Manchester), Ltd., 18 Exchange Street, Manchester.

Rendall—C. H. Casella & Co., Ltd., Regent House, Fitzroy Square, London, W. 1.

"Services" { Kelvin, Bottomley & Baird, Ltd., 18 Cambridge Street, Glasgow, C. 2.
Reynolds & Branson, Ltd., 13 Briggate, Leeds, 1. }

Siemens—Elliott Bros. (London), Ltd., "Century" Works, Lewisham, London, S.E. 13.

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