VENTILATION AND HUMIDITY

IN TEXTILE MILLS AND FACTORIES

CECIL H. LANDER

VENTILATION AND HUMIDITY IN TEXTILE MILLS AND FACTORIES

VENTILATION AND HUMIDITY

IN TEXTILE MILLS AND FACTORIES

BY

CECIL H. LANDER

M.Sc., A.M.I.C.E., A.M.I.M.E.

Lecturer in Civil Engineering in the University of Manchester

WITH DIAGRAMS

LONGMANS, GREEN, AND CO.

39 PATERNOSTER ROW, LONDON

NEW YORK, BOMBAY, AND CALCUTTA

1914

PREFACE

During the past few years attention has been directed to the conditions prevailing in textile mills and factories, where, owing to the requirements of manufacture, high temperatures and large percentage humidities co-exist. Agitation on the part of the Lancashire weavers led to the intervention of the Home Office, and the subsequent modification of the Factory Acts, which now require that if the wet-bulb temperature in a weaving shed reaches a certain specified maximum, all artificial humidification shall be cut off. The importance of the subject to all interested in the textile trades made it desirable that an account of the general questions of ventilation and humidification, considered mainly from the point of view of abating these high temperatures, should be available, and it is with such an object in view that the Author submits this small book to his readers.

It is hoped that the Work may also prove useful to Managers and Owners of Textile Mills situated in tropical countries. Paradoxical though it may appear, factories are comparatively speaking more easily cooled in a hot, dry climate than in a cool, humid one such as that of Lancashire or Ireland. Powerful ventilating systems may be used, and owing to the great difference existing between the dry- and wet-bulb readings the cooling effects of water humidification are considerably greater.

The Author wishes to acknowledge his indebtedness to H.M. Stationery Department for their consent to the reproduction of certain tables and diagrams, and to several manufacturing firms who have supplied him with valuable data and lent blocks for illustrations. Thanks are due to his colleague, Miss Margaret White, M.Sc., of the Meteorological Department, for kindly criticism and for assistance in seeing the work through the Press.

Finally, he takes this opportunity of expressing his gratitude to Professor J. E. Petavel, F.R.S., a member of the Departmental Committee, for much valuable advice.

C. H. L.

THE UNIVERSITY,
MANCHESTER.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

VENTILATION AND HUMIDITY IN TEXTILE MILLS AND FACTORIES

CHAPTER I

Introductory—Ventilation—Temperature, Humidity, and Purity of the Air—Special Conditions required in Textile Industries—Temperature—Vapour Pressures—Latent Heat—Measurement of Humidity—Absolute and Relative Humidity—Wet and Dry Bulb Hygrometers—Recording Hygrometers—Factory and Workshops Acts Regulations for Hygrometers—Sizing—Functions of the Ingredients of Size—Percentage Humidity used for Various Classes of Goods—Good and Bad Weaving Days—Humidification by Direct Injection of Steam—Physiological Effects of High Humidity.

The objects of ventilation are to provide an atmosphere at reasonable temperature, containing a minimum amount of products of respiration and combustion, and it is essential that the fresh air should be distributed over the building where required without causing draughts.

Until a comparatively recent date the provision of an adequate system of ventilation received little consideration whilst a building was being designed; on the rare occasions when the completed structure proved to be well ventilated this was a matter of chance. The great improvement during recent years in the atmosphere of mills and factories can be traced almost entirely to the regulations made from time to time by the various Factory Acts. Even in cases where efficient ventilation has not been compulsory, the provisions of the law have, by demonstrating the possibility of designing efficient plant, and by providing a market for such plant, led to its almost universal adoption.

Even at the present day there is little special provision made for ventilating private houses in this country, the necessity for domestic ventilation being less urgent in a climate where the temperature range is moderate than in such countries as America, where most complete and elaborate plants are often provided for residential buildings. They comprise not only fans and heating coils, but refrigerators, humidifiers, and air filters.

Public halls and theatres or other large rooms can be suitably ventilated by air mechanically blown in at scattered places, and left to escape as best it can. Its distribution over the building can be to some extent controlled by the provision of outlet openings, the positions of which are determined from careful estimates of the disturbances which will be brought about by convection currents, the general direction of which can often be prophesied with considerable accuracy.[1] In addition to the plenum fans a number of exhaust fans are occasionally provided, and the amounts of air dealt with by the two sets of fans are adjusted in such a manner that there is a slight excess of pressure in the building. The latter system is often adopted in large workshops and factories. The exhaust system, in which air is sucked out of the room by fans, and which therefore produces a slight diminution of pressure, is sometimes installed, but is less suitable. Air flows into the room through the numerous openings which must exist in the walls and roof, and some may therefore be induced from sources which are injurious or dangerous to health. In weaving sheds during hot weather it is necessary to have the ventilating air as cool as possible. With the exhaust system considerable volumes of air may be drawn in through interstices in the neighbourhood of the valley gutters, and which through contact with the hot slates of the roof in sunny weather may often greatly exceed the normal shade temperature. During cold weather air flowing into the room from such haphazard sources will be felt as an unpleasant draught by any worker upon whom it impinges. Operatives in the textile trades, being accustomed to spend most of their lives in a warm, damp atmosphere,

[1] For a full exposition of the theory of ventilation and air currents, as far as it has been developed up to the present time, the reader is referred to the book entitled "Air Currents and the Laws of Ventilation," by W. N. Shaw, Sc.D., F.R.S.

are peculiarly susceptible to draughts, and it is therefore absolutely necessary to adopt a system of ventilation which shall make it impossible for cold currents of air to blow directly upon any person engaged in the building. The chilling effect of a draught is produced by the combined action of the velocity, temperature, and dryness of the current. In places where draughts are persistent improvement can often be effected by the provision of a radiator, which by warming the air neutralizes the excessive chilling effect.

The room may be warmed in one of two ways, either by heating the fresh air before it enters the building, or alternatively by provision of radiators, heating pipes, etc., in the room itself. The latter is the most convenient method where the exhaust system is installed, although by the provision of a large inlet opening containing heating coils, it is possible to warm most of the inlet air before it enters the factory.

The source from which ventilating air is drawn is of great importance. It has already been pointed out that the temperature of air lying in the roof valleys is liable to be considerably greater than the ordinary shade temperature during hot weather. If then it is convenient to take air from the top of the building, as is often done in single-storey sheds, the inlet ducts should be arranged to have their openings at a height of about six feet above the ridges of the roof. These ducts form a convenient receptacle for heating coils to warm the inlet air during cold weather.

It is often necessary in large towns to filter the incoming air, and this can best be effected by the use of moistened fabrics, cotton wool, loofahs, or coke, inserted in the air ducts between the fan and the room to be ventilated. The necessity for this becomes very apparent in mills spinning high-class yarns of cotton or flax where any staining of the product causes a serious depreciation in value. Fine yarns are peculiarly liable to this staining owing to the greater length of time that they remain on the frame. This problem has been solved very completely, and it is now possible to produce perfectly clean white yarns in large towns during periods of heavy black fog.

In designing a ventilating plant three factors present themselves: temperature, humidity, and purity, the last being estimated by the amount of carbonic acid present, for although recent medical research has shown that the absolute amount of CO_2 is comparatively unimportant since CO_2 is an inert gas, yet it forms the only practical means at our command for estimating the amount of micro-organisms present in cases where it is derived from animal exhalations. The Cotton Cloth Factories Act passed in 1889 stipulated a minimum of 600 cubic feet of fresh air for each person employed. In 1898 a Statutory Order of the Secretary of State under powers conferred by the Cotton Cloth Factories Act, 1897, required that the carbonic acid in humid sheds should not exceed nine volumes in ten thousand; this was taken to be complied with if the amount of carbonic acid did not exceed that in the outside air by more than five volumes per ten thousand. To maintain this standard of purity some 2000 cubic feet of fresh air must be supplied hourly for each operative present, which in an average weaving shed amounts roughly to one complete change of air per hour. The regulation was on the whole obeyed satisfactorily, the nine volume standard being only exceeded under circumstances brought about by temporary and accidental causes. In the case of non-humid sheds, however, no standard of ventilation existed until the Act of 1911, and as a consequence the air in these sheds, as measured by the carbonic acid test, was often exceedingly impure. It has also been asserted that the percentage humidity in these sheds, owing to the moisture given off in the breath and exhalations from the bodies of the operatives, is often as great as that in humid factories. Statistics collected by H.M. Inspectors of Factories during 1906 and 1907 appeared to show that in many dry sheds improved ventilation was desirable although, generally speaking, the results were fairly satisfactory. On the other hand, the percentage humidity was considerably lower than that in humid sheds, an average of 68 per cent. being rarely exceeded.

Since the nine volume standard was introduced in 1897, modern scientific research combined with the experience of workers in humid atmospheres has clearly proved that high wet-bulb temperatures have a serious effect upon persons exposed to their influence, and that it is quite as important to secure reasonable wet-bulb temperatures as it is to insist upon high standards of ventilation. Large volumes of air passed into the factory compel the introduction of large quantities of artificial humidity if the percentage degree of saturation is to be maintained. The bulk of weavers in Lancashire are opposed to the introduction of humidity in any form. We are therefore dealing with two conflicting factors, so must be content with a compromise. On this account the rather stringent regulation of nine volumes per ten thousand has been relaxed to twelve volumes in ten thousand or eight volumes in ten thousand in excess of the outside air, whichever is the greater, in humid sheds, and a standard of fifteen volumes in ten thousand, or eleven volumes in ten thousand in excess of the outside air, whichever is the greater, has been introduced for dry sheds. That these standards are not unduly lax will be seen by comparison with those recommended for other trades. In the Mines Regulation Act of the Colony of Victoria the maximum allowed is twenty-five volumes, whilst in the second report of the Royal Commission on Mines the standard recommended is one hundred and twenty-five volumes in ten thousand, this large amount being justified in mines since much of the CO_2 is due to causes other than the presence of human beings and animals, and is therefore without harmful significance. During the winter months, when gas, etc., is used for illumination during the early morning hours, tests of CO_2 contents in the air, when taken with a view to legal proceedings, are postponed until after the dinner interval.

There is little difficulty in dealing with any or all of the three factors—temperature, humidity and purity—provided that none of them are extremes, where, however an extreme condition is required, ventilation becomes expensive and in many cases difficult.

A typical instance of an extreme case arising mainly from requirements of temperature occurs in the case of rooms containing dust extractors of large capacity. The extractor itself forms a powerful exhaust ventilating system, often capable of completely changing the air of the room once per minute. An attempt is made to warm the incoming air by the installation of radiators in inlet openings, but a great quantity of air enters the room through openings other than these, and therefore it is often difficult in rooms of this class to maintain an equable temperature during cold spells.

An example where exceptionally high purity is required occurs in most coal mines, where the problem is to dilute any fire damp which may be present to a degree well below the lower limit of inflammability and thus prevent any possibility of its ignition. As regards the ventilating volume, this depends upon the character of the seams worked (*i.e.* whether they give off gas freely or not) and upon the average daily output. We meet with ventilating plants capable of passing as much as three-quarters of a million cubic feet per minute through the mine, although this is about the maximum in this country, and has probably not been exceeded elsewhere. A quarter of a million cubic feet per minute is a fairly average volume for modern collieries in Lancashire and Yorkshire.

The best idea of the magnitude of such a volume would be obtained by converting the volume to a statement of tons of air per minute, for which purpose a cubic foot of air may be taken as weighing 0·075 lb. This works out to about 20 tons of air per minute, or 28,800 tons per day of 24 hours, a weight many times as great as the coal raised in the same period of time. One would probably require such a volume for a colliery producing from 3000 to 4000 tons of coal per day. Comparison shows that such a plant as would be used to ventilate an average weaving shed (say, 600,000 cubic feet) with air changed once per hour would need to be only one sixtieth the size.

In the textile industries the dampness of the atmosphere in which manufacturing processes are carried on is of primary importance. That this was recognised by the early spinners and weavers is shown by the fact that hand looms, etc., were often installed in a damp portion of the worker's cottage, the earth floor was watered if necessary and wet cloths hung round or near to the warp beam. On the introduction of the spinning frame and the power loom and the consequent grouping of many machines under one roof the textile industry tended to rapid growth in districts where the natural amount of atmospheric humidity was great. The localisation of cotton spinning and weaving in Lancashire and that of flax spinning and linen weaving in the north of Ireland is partially accounted for by the moist climate of those districts.

The practice of infusing artificial humidity into the atmosphere of a textile mill or factory was probably first introduced in America, where the dry conditions obtaining rendered the working of yarns very difficult. From there it found its way to this country and became common here about 1872, being introduced to facilitate the weaving of heavily sized calicoes for the Indian market.

If a yarn of any material be exposed to air of given humidity it will either absorb or yield up moisture until an equilibrium is established between the moisture in the fibre and that in the surrounding air. The amount of moisture in the fibre is influenced also by the dry-bulb temperature but to a much less degree. Thus, at a temperature of 75° F., Schloesing[1]

[1] Th. Schloesing Fils: "Hygroscopic Properties of Textile Materials." *Textile World Record*, Boston, November, 1908.

gives the following figures for the relation between the relative humidity of the air and the moisture in one hundred parts of dry material when this equilibrium is established.

TABLE I.

MOISTURE CONTAINED IN VARIOUS YARNS AFTER THEY HAVE BEEN EXPOSED FOR SOME TIME IN AIR CONTAINING DIFFERENT PERCENTAGES OF HUMIDITY.

Relative humidity of the air.	Moisture for 100 parts of dry material.		
	American cotton	Raw Cevennes silk.	Wool.
% 10	2·5	3·3	7·0
40	5·0	8·0	12·0
60	7·0	10·0	14·5
80	10·0	14·5	18·6
90	14·5	18·6	23·5

The above figures for the amount of moisture would be reduced very slightly for dry-bulb temperatures higher than 75°, and increased very slightly for dry-bulb temperatures lower than 75°. The presence of deliquescents in a sized yarn would of course lead to an increase in the moisture absorbed.

The strength of yarn is dependent to some extent upon the moisture contained in the fibre, and therefore it is desirable to work the material in an atmosphere whose humidity is sufficient to ensure maximum strength. Experiments have been carried out from time to time on the strength of yarn before and after drying and the following tables refer to reliable tests of cotton yarn and cloth :—

TABLE II.[1]

STRENGTH OF COTTON YARN CONTAINING VARYING PERCENTAGES OF MOISTURE.

Original weight of yarn – grains.	Condition.	Percentage of moisture.	Breaking strain, lbs.
33·21	Unaltered	8·93	64·0
33·33	Moistened	17·39	69·2
38·85	Dried	2·89	39·9

A standard of moisture of 8½ per cent. in cotton is recognized by the Manchester Chamber of Commerce, and it will be seen that a large increase above this amount in the weight of moisture carried does not increase the strength very greatly, but that drying of the yarn below the standard produces a great decrease in strength. The effect is even more noticeable in flax yarns, which being of a harder and more brittle nature are toughened and rendered more elastic by the addition of moisture almost up to the maximum amount which the fibre can absorb. High-class cotton yarns and coarse linen yarns have a large breaking strength and therefore can be woven in a much drier atmosphere than can the lower qualities, there being more margin for weakening due to drying.

The above results are also confirmed by tests carried out on cloth, Table III. giving the average

[1] Wm. Thomson: "The Sizing of Cotton Goods."

strength of wool, cotton and flax as determined in experiments carried out by Mr. F. W. Barwick at the Manchester Chamber of Commerce Testing House.

TABLE III.[1]

SHOWING THE VARIATION IN THE STRENGTH OF VARIOUS MATERIALS CAUSED BY EXPOSURE TO ATMOSPHERES OF DIFFERING HUMIDITIES.

Relative humidity of the air.	Wool (serge).	Cotton (drill).	Flax (canvas).
%	Average strength lb.	Average strength lb.	Average strength lb.
44	186	521	599
44	182	523	613
47	181	538	637
56	180	527	652
56	175	542	654
57	173	545	650
59	174	541	650
60	175	531	639
62	175	550	669
65	169	552	681
66	173	563	687
68	173	551	661
70	159	571	702
71	173	568	712
72	169	555	682
72	168	569	688
75	168	582	710
77	165	581	710
82	167	591	728
82	160	592	729

During the spinning of cotton a second reason is evident whereby a dry atmosphere is conducive to defective production; the roving becomes electrified by the friction generated in passing over parts of the

[1] "The Handbook of the Manchester Chamber of Commerce Testing House."

machine, fibres are caused to stand out by their mutual repulsion and thus escape being spun into the yarn. The product is loose and rough, the yarn tending to become oozy and it is then weaker in tension than a properly spun compact yarn. A relative humidity of from 50 per cent. to 54 per cent. is recommended as being high enough for cotton-spinning rooms, and from 55 to 65 per cent. as being suitable for combing and preparing rooms. Electrification is a source of great trouble in weaving sheds; the passage of the shuttle across the loom and the friction of the reed against the warp causing the loose fibres on the surface of the yarn to stand out to such an extent as to offer resistance to the moving portions of the mechanism; breakages of the yarn are more frequent and the cloth is depreciated in value, the work of running the loom is greatly increased, and the wages of the weaver suffer in consequence. A change in the humidity tends to cause an alteration in the width of the cloth, which comes out of the loom broader and with the grain of the cloth altered if the percentage moisture falls to any great extent. This would be corrected by putting greater weights upon the beam, thus loading the warp and tending again to more breakage. Goods sized very heavily for weight require a moist atmosphere in order to keep the size soft and obviate its being beaten out of the cloth. It is sometimes stated that fewer accidents from flying shuttles occur in the humid sheds, and this appears to be somewhat confirmed by statistics. A flying shuttle is often started by broken ends, and any diminution in these will lessen the chances of accident, although of course breakages of yarn are not always at the root of the evil. Goods which require the greatest percentage of humidity in weaving are the fine linens and cambrics, which are best worked in an atmosphere containing about 88 per cent. of moisture. For percentages lower than this breakages increase, even when the load on the warp is allowed to remain the same, and a point is eventually reached where it becomes almost impossible to keep the loom running at all.

In the woollen trade a high percentage of humidity is used in mills working on the French or dry process. All wool contains a high percentage of moisture, in fact the standards allowed by Chambers of Commerce in towns interested in this industry vary from 18 to 20 per cent. moisture in the wool by weight as against 9 to 11 per cent. allowed for cotton. The spinning of wool by the old process is effected by the addition of small quantities of olive oil, and where this is done artificial humidity is not usually required. The French or dry process of spinning is carried out without oil upon self-acting mules in much the same way as is that of mule-spun cotton yarn, and it is in this branch of the wool trade that artificial humidification becomes necessary.

Before passing on to the consideration of humidity as it affects manufacturing processes it is convenient to consider briefly that branch of physical science which immediately bears upon the subject. The simple laws governing the evaporation and condensation of water are often indifferently understood by persons using humidifiers, and in fact some want of knowledge of the subject has in the past been displayed even amongst the makers of such apparatus.

It is necessary to obtain a clear conception of what is meant by the quantity of heat in a body in contradistinction to the temperature of that body. Temperature may be defined as a condition that determines which of two bodies when placed in contact will part with heat to the other—thus a hot body, or in other words, one which is at a high temperature will lose heat to a cold body or to one of low temperature, this transfer of heat will continue until both bodies are at the same temperature. The quantity of heat contained in a body will depend upon the mass or quantity of matter contained in the body and also upon its temperature: thus we might have three pieces of iron, say, weighing one, two, and six pounds respectively, their temperatures may be such that neither of them would lose heat if placed in contact with either of the others, but the piece weighing two pounds would contain twice the amount of heat which is contained by the one-pound piece, and in the same way the six-pound mass of iron would contain six times that amount of heat.

A useful analogy can be obtained by considering two cisterns of water connected by a pipe, the water level being different in the two vessels. Water will flow from the higher vessel through the pipe to the lower vessel. The difference in level of the two cisterns corresponds to the temperature difference between two bodies in thermal communication, but we cannot deduce from this alone the amount of water actually present in either of the two vessels.

Temperature is usually measured by its effect upon the volume of certain substances which expand with an increase, and contract with a decrease in temperature. A thermometer depends for its action upon the expansion and contraction of the mercury or other liquid contained within the bulb and tube. The graduation is an arbitrary one obtained by noting the height of the liquid in the tube at freezing point and also its height at boiling point under a pressure of 14·7 lbs. per square inch. The difference in these heights is then divided into 180 equal parts or degrees in the Fahrenheit thermometer, and into 100 equal parts in the Centigrade thermometer. Freezing point corresponds to a temperature of 32° on the Fahrenheit scale and to zero on the Centigrade scale, so that the boiling points will be denoted by 212° and 100° respectively.

The amount of heat contained in a body has been shown to depend upon the mass of the body in addition to the temperature of the substance: it also varies with the material, thus less heat is required to raise the temperature of 1 lb. of iron through one degree than is required to raise that of 1 lb. of water through one degree. Hence, in finding the amount of heat contained in any body it is necessary to know (1) its weight, (2) its temperature, (3) the capacity of unit mass for heat as compared with that of unit mass of some standard substance. The standard substance taken is pure water, and a unit of heat is defined as the quantity of heat required to raise unit mass of water through one degree. If lbs. and degrees F. are taken, the unit is termed the British Thermal Unit or B.T.U. If grammes and degrees Centigrade are taken, the unit is termed the small Calorie.

As a simple example, then, it will require $5 \times 12 = 60$ B.T.U. to raise the temperature of 5 lbs. of water through 12° F.

The ratio of the amount of heat necessary to raise a given weight of any substance through one degree to that required to raise an equal weight of water through one degree is termed the specific heat of that material, thus the specific heat of iron is equal to 0·114, which means that to raise a given mass of iron through one degree requires only about one-ninth that required to raise the same mass of water through one degree. In order, then, to find the amount of heat necessary to raise a given weight of any material through any given temperature interval, we multiply together the weight in lbs., the rise in temperature, and the specific heat of the substance.

The following table gives approximate values of the specific heat of a few typical substances :—

TABLE IV.

Substance.	Specific heat.
Glass	0·2
Iron	0·114
Copper	0·095
Lead	0·031
Mercury	0·033
Air (at constant pressure)	0·237
Water	1·00

Water has a higher specific heat than any other known substance, and this fact has an important bearing upon the climate of places near the coast. Owing to the high specific heat and to the ease with which heat is distributed through water by convection and other currents, the sea is not warmed to anything like the same extent as the land by the rays of the sun; it is therefore cooler than the land in summer, and warmer in winter, thus tending to equalize any large variations in the temperature of the air passing over it.

The comparatively small ranges of temperature between summer and winter experienced in our islands as compared with the ranges experienced in many other countries of the same latitude can be attributed in some measure to this cause.

It is well known that water exists in three different states according to the temperature and the pressure to which it is subjected, *i.e.* ice, water, and steam, the change from ice to water taking place at a temperature of 32° F. (the freezing-point). Change of state from water or ice to vapour occurs at all temperatures until the atmosphere lying immediately above the water or ice surface contains the maximum amount of vapour which it can carry at its particular temperature.

Consider a closed vessel completely exhausted of air into which it is possible to introduce a small quantity of liquid. On entering the vessel evaporation will take place very rapidly until the space unoccupied by the liquid is completely filled with vapour. When steady conditions are reached, which will occur almost immediately, the vapour will be exerting a definite pressure which depends upon the common temperature of itself and the liquid.

The space is said to be saturated with vapour at the given temperature, and the pressure per unit area which it exerts is termed the vapour pressure of the liquid at that temperature. Had the space above the water contained air, evaporation would have proceeded much more slowly, but the final result would have been the same, an identical quantity of liquid would have been evaporated, and the vapour pressure corresponding to the common temperature would have been added to the initial pressure of the air, which would then be said to be saturated at that temperature. Vapour pressures of water have been very carefully determined and are tabulated in Steam or Hygrometrical tables.[1]

[1] "Hygrometrical Tables," Glaisher. "Steam Tables," Marks and Davies.

It is important to note that as the temperature increases the vapour pressure also increases, and consequently a greater weight of vapour is required to saturate a given volume at high temperatures than is required to saturate the same volume at low temperatures.

Now consider the evaporation of water in air under a given barometric pressure which remains constant; the action will continue until the air above the surface is completely saturated, when if p_v represents the vapour pressure at the temperature, and p_a represents the air pressure, we shall have $p_v + p_a = P$, where P is the constant barometric pressure. If we raise the temperature of the water, p_v will also rise, and therefore p_a must decrease. When $p_v = P$, the temperature corresponding to p_v will be the boiling point at that pressure, and ebullition or boiling will occur, the water being vaporized very rapidly both at the surface and below the surface. The boiling-point at any pressure then is the temperature at which the vapour pressure becomes equal to the external pressure.

If water at a certain temperature is in contact with air at a lower temperature, evaporation will take place even when the air is already saturated at its own temperature. The layer of air immediately in contact with the water surface is warmed by direct conduction, and its percentage humidity temporarily reduced; evaporation then takes place, and the humidity of this thin layer of air is raised. It now tends to flow upwards owing to the lightening caused by its increase in temperature and the increase in amount of water vapour carried, which is lighter than air at the same temperature. As soon as this air has left the water surface it loses heat to the surrounding atmosphere and eventually its temperature falls below the dew-point corresponding to the weight of water vapour carried. Some of this vapour is then condensed and becomes visible.

Total Heat of Water. Latent Heat.—Let us now consider the amount of heat required to raise the temperature of unit weight of water to the boiling-point corresponding to the pressure exerted upon it and to evaporate it under constant pressure

Let t_1 = initial temperature of water

t_2 = temperature of water which has a vapour pressure $= p$

p = constant pressure under which evaporation is to occur.

If we now proceed to apply heat to the water the temperature will rise until it corresponds to the temperature of water which has a vapour pressure $= p$, *i.e.* t_2.

The amount of heat put in is termed the sensible heat of the water, and will be equal to the weight of water multiplied by the temperature rise, *i.e.* if h = sensible heat, w = weight of water, then $h = w(t_2 - t_1)$.

If now we continue to apply heat, the temperature of the water will cease to rise, but evaporation will take place, and this will continue until all the water has been evaporated, when an additional amount of heat will have been absorbed. This quantity of heat which is necessary to change the state from the liquid to the saturated vapour is called the latent heat, since it has apparently disappeared or become latent. In other words, this amount of heat has been added without changing the temperature. The quantity of heat which is rendered latent is dependent upon the temperature, and is constant at any given temperature, its value at atmospheric pressure, *i.e.* at temperature of 212° F., is about 966 B.T.U. per lb. of water evaporated.

The total heat then contained in 1 lb. of saturated vapour at temperature t_2 is equal to $t_2 - 32 + L_2$, if we arbitrarily consider freezing point to be our initial or datum temperature at which the body contains zero heat.

If we reverse the process, *i.e.* condense a quantity of saturated vapour, an amount of heat exactly equal to the latent heat will be given up, and will be absorbed by surrounding bodies, whose temperature is thereby raised. Evaporation of moisture in a factory will therefore have a cooling effect, since heat is rendered latent, whilst condensation will have a warming effect, since heat previously latent is given up to the contents of the room.

Cooling of the human body is partially effected by the evaporation of perspiration ; exertion, or exposure to a high temperature causing the flow of perspiration to be more rapid. In a dry atmosphere it is soon absorbed, heat being rendered latent, thus preventing rise of bodily temperature.

In a very moist atmosphere the evaporation is checked, and the damp, uncomfortable feeling experienced during atmospheric conditions of high humidity is attributable to this cause. In very dry atmospheres the moisture of the human body is absorbed too rapidly, causing drying of the skin and general discomfort.

If additional heat be applied to saturated vapour its temperature will rise and the vapour will behave more like a perfect gas, the rise in temperature being accompanied by a rise in pressure if the volume be maintained constant, or by an increase in volume if the pressure be maintained constant. The relation which exists between pressure, volume, and temperature, is approximately expressed by the formula $pv = R\tau$

where p = pressure,

v = volume,

τ = absolute temp., *i.e.* temp. Fahr. + 461 degs.

In this state the vapour is said to be superheated, and the formula for the total heat then becomes

$$H = t_2 - 32 + L_2 + 0{\cdot}48(t_s - t_2)$$

the figure 0·48 representing the specific heat of superheated steam at constant pressure, t_s being the temperature to which the steam is superheated, and t_2 being as before the temperature of evaporation.

The vapour contained in a volume of air at given dry and wet-bulb temperatures exists in this superheated state, the temperature of evaporation being that of the dew-point.

The total heat, both latent and sensible, contained in a cubic foot of moistened air can be obtained by multiplying the weight of vapour present in lbs. by the total heat per lb. as found by the above formula, and adding to this the heat contained in each cubic foot of dry air at the given dry-bulb temperature. This latter will be given with sufficient accuracy for most purposes by taking the weight of dry air as 0·075 lb. per cubic foot, and its specific heat as 0·24 B.T.U. per lb.

Measurement of Humidity.—The wetness or dryness of air depends upon two factors, firstly, the absolute amount of water vapour present in unit volume of air, and, secondly, the temperature of the air. A cubic foot of air at any given temperature can absorb only a certain definite amount of vapour; when the air actually holds this quantity it is said to be in a state of saturation. If the amount of moisture present exceeds this amount the excess can only exist as water, which is either precipitated or suspended in the air in the form of finely divided drops.

If the air does not contain a sufficient quantity of vapour for saturation its degree of wetness is measured by the ratio of the quantity actually present to that quantity which would be present if the air were in the saturated state. This ratio is termed the relative humidity, and if converted to a percentage is known as the percentage humidity.

The absolute amount of water vapour necessary to saturate a given volume of air increases with the temperature of the air, and from this it follows that if we heat air containing water vapour the relative humidity falls; on the other hand, if we abstract heat from air containing water vapour the relative humidity rises until at some definite temperature the air becomes fully saturated; this temperature is called

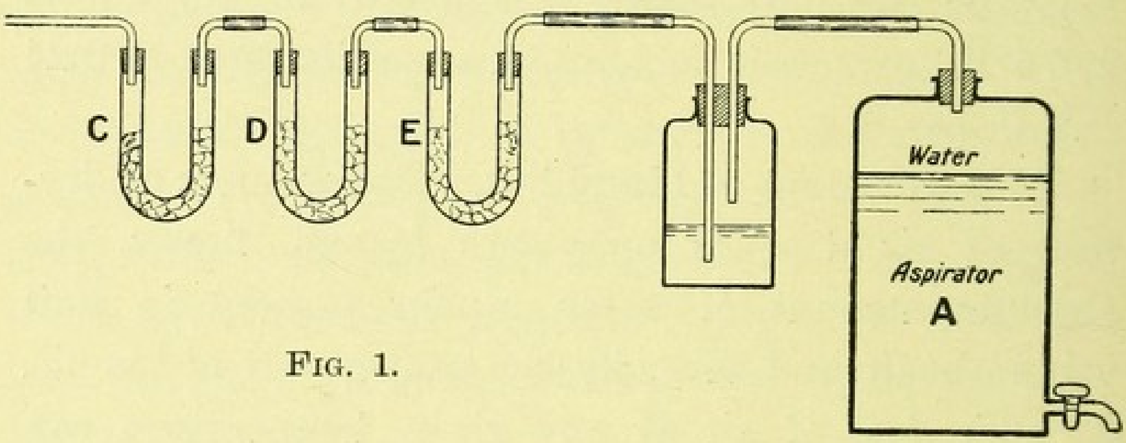


Fig. 1.

the dew-point, since if the temperature be lowered still further vapour must be condensed and will usually be deposited in the form of dew.

The absolute amount of vapour present, or as it is sometimes called the "absolute humidity," can be measured by slowly drawing a definite quantity of air over some strongly hygroscopic substance. In the apparatus shown in Fig. 1 air is passed through **U**-tubes C, D, E, etc., which contain pumice stone soaked with sulphuric acid. These tubes are carefully weighed on a chemical balance before and after the experiment. The volume of air which has passed through the apparatus can be measured from the amount of water which is drawn from the aspirator A, and the difference in the total weight of the **U**-tubes gives the weight of water vapour which was present in the given volume of air.

The relative humidity can best be estimated by the use of wet and dry bulb thermometers, the difference in whose readings measures the cooling effect of the evaporation going on, this cooling effect being greater when evaporation is rapid. A piece of fine muslin is wrapped round the bulb of the thermometer and is kept moist by a wick which dips into a small vessel of water. This, the wet-bulb thermometer, falls by an amount which is dependent upon the relative humidity of the surrounding air and to a slight extent upon the magnitude of air currents impinging upon the bulb. The dry-bulb thermometer measures directly the temperature of the surrounding atmosphere. The indications given by wet and dry bulb thermometers are interpreted by the use of tables of humidity, an extract from which is given in Table V. Thus it will be seen that if the dry and wet bulbs give readings of 72° and 66° respectively, then the relative humidity will be 69 per cent., and 5·9 grains of water vapour will be present in each cubic foot of air. It follows that if the air is saturated there will be no evaporation from the wet bulb and the readings will be identical on both bulbs; the relative humidity will then be 100 per cent.

A frequent cause of error in the estimation of humidity in a room is that of partial drying up of the moisture round the wet bulb, which may be due to shortage of water in the reservoir or to a strangling of the wick by its being tied too tightly. Whenever readings are taken the state of the muslin should be ascertained in order to obviate errors due to these causes.

Sir Henry Cuningham, K.C.B., suggests that the following precautions should be taken in observing the wet and dry bulb hygrometer.

1st. The instrument should be screened from the observer. The human body emits both heat and moisture and while the amount of the former radiated is sufficient to raise the dry-bulb thermometer one or two degrees in a few minutes, the latter by raising the humidity in the immediate neighbourhood may increase the wet-bulb reading also.

For these reasons it is advisable on approaching the instrument to read off the temperatures indicated without delay.

2nd. The instrument should not be hung on a cold, outside wall where, owing to the proximity of the cold masonry, the temperature will be lower and the relative humidity higher than in the shed.

TABLE V.

EXTRACT FROM GLAISHER'S TABLES.

Reading of thermometer. Dry.	Reading of thermometer. Wet.	Temperature of the dew-point	Elastic force of the vapour.	Vapour in a cub. ft. of air.	Degree of humidity (satn. = 100).	Weight of a cub. ft. of air. Bar. reading 29 inches.
71	71	71·0	0·759	8·3	100	502·9
	70	69·2	0·714	7·8	94	503·2
	69	67·5	0·672	7·3	88	·4
	68	65·7	0·633	6·9	83	·7
	67	64·0	0·596	6·5	78	·9
	66	62·2	0·560	6·1	73	504·2
	65	60·4	0·526	5·7	69	·4
	64	58·7	0·494	5·4	65	·6
	63	56·9	0·464	5·1	61	·7
	62	55·2	0·436	4·7	57	·9
	61	53·4	0·409	4·4	53	505·1
	60	51·6	0·383	4·2	50	·3
72	72	72·0	0·785	8·5	100	501·8
	71	70·2	0·739	8·0	94	502·1
	70	68·5	0·696	7·6	89	·4
	69	66·7	0·655	7·1	84	·6
	68	65·0	0·617	6·7	79	·9
	67	63·2	0·581	6·3	74	503·1
	66	61·5	0·547	5·9	69	·4
	65	59·7	0·514	5·6	65	·6
	64	58·0	0·483	5·3	61	·8
	63	56·2	0·454	5·0	57	·9
	62	54·5	0·426	4·7	54	504·1
	61	52·7	0·399	4·4	51	·3
	60	51·0	0·374	4·1	48	·5
73	73	73·0	0·812	8·8	100	500·7
	72	71·3	0·766	8·3	94	501·0
	71	69·5	0·722	7·8	89	·3
	70	67·8	0·680	7·4	84	·5
	69	66·0	0·641	7·0	79	·8
	68	64·3	0·604	6·6	74	502·0
	67	62·6	0·568	6·2	70	·3
	66	60·8	0·534	5·8	66	·5
	65	59·1	0·502	5·4	62	·7
	64	57·3	0·472	5·1	58	·9
	63	55·6	0·443	4·8	54	503·1
	62	53·9	0·416	4·5	51	·2
	61	52·1	0·390	4·2	48	·4
	60	50·4	0·366	4·0	45	·5

The effect of draughts upon the bulbs has been investigated by Jelinck, who produced large differences in the readings by allowing a strong wind to play upon the wet bulb.

Again, it is of importance that pure water should be used, and in a room where manufacturing processes are being carried out frequent changes of muslin and wick are necessary.

Hygrometers depending for their action upon the hygroscopic elongation and contraction of certain fibres are exceedingly useful in detecting rapid changes of humidity. They can be calibrated to give directly the percentage humidity, but used in this way they must be checked at frequent intervals. In the experiments of the Home Office Humidity Committee recording hygrometers were used, the variations in length of a small bundle of hair actuating the pencil arm. These records were useful in tracing out the manner in which humidity varied over short time intervals, but for absolute measurements of percentage humidity direct readings of wet and dry bulb thermometers were relied upon.

Hair hygrometers have been found useful by managers of certain weaving factories where variations of humidity are undesirable, the automatic record being exceptionally valuable in detecting differences from a constant percentage. In some cases abroad hair hygrometers, which indicate the percentage humidity upon a dial, are used. Where these have

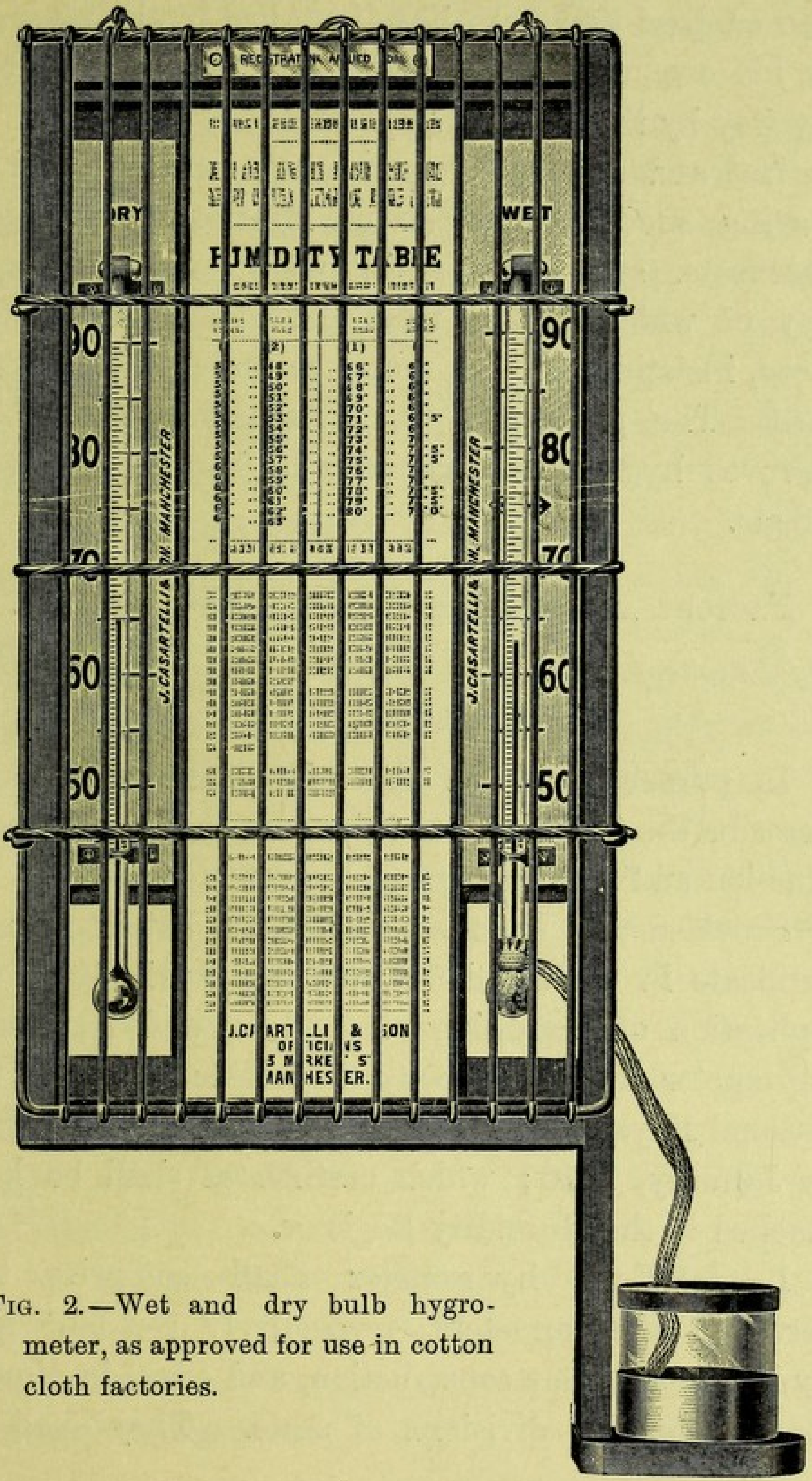


FIG. 2.—Wet and dry bulb hygrometer, as approved for use in cotton cloth factories.

been adopted they have been installed by the manager for his own convenience, and are not recognized in any way by the Factory Department.

Wet and dry bulb hygrometers formerly used in weaving sheds were often of inferior construction, inaccurate, and badly maintained. Regulations, a copy of which is appended, have now been introduced, insisting upon a much better class of instrument. The plate, Fig. 2, illustrates one of these approved hygrometers as made by Messrs. Casartelli & Sons.

Factory and Workshops Acts, 1901 to 1911.

Regulations for Cotton Cloth Factories.—Hygrometers Order.

In pursuance of the above Regulations I hereby prescribe the following conditions as regards the construction and maintenance of hygrometers:—

Provided that the Inspector of the district may by certificate in writing defer until 1st April, 1914, the application of Conditions 2 (*a*, *b*, *c*) and 3 to any hygrometer furnished with a certificate from the National Physical Laboratory of date not earlier than 1st January, 1910; which certificates shall be kept attached to the Humidity Register.

1.—(*a*) Each hygrometer shall comprise two mercurial thermometers, respectively wet-bulb and dry-bulb, of similar construction, and equal in dimensions, scale, and divisions of scale. They shall be mounted on a frame, with a suitable reservoir containing water.

(*b*) The wet-bulb shall be closely covered with a single layer of muslin, kept wet by means of a wick attached to it and dipping into the water in the reservoir. The muslin covering and the wick shall be suitable for the purpose, clean, and free from size or grease.

2. With regard to each thermometer as above, whether wet-bulb or dry-bulb:—

(*a*) The bulb shall be spherical, and not less than two-fifths nor more than three-fifths of an inch in diameter.

(*b*) The bore of the stem shall be such that the position of the top of the mercury column shall be readily distinguishable at a distance of four feet.

(*c*) The scale from 45° to 85° shall extend over not less than 5 inches, beginning not less than 1½ inches from the top of the bulb. Each degree and half-degree, between 45° and 85°, shall be clearly marked on the stem by means of horizontal lines, which shall be shorter for half-degrees than for whole degrees, and shall be readily distinguishable at a distance of two feet.

(*d*) The markings as above shall be accurate; that is to say, at no temperature between 45° and 85° shall the indicated reading be in error by more than two-tenths of a degree.

(*e*) A distinctive number shall be indelibly marked upon the thermometer.

(*f*) A dated certificate of examination of the thermometer, and of its compliance with Condition 2, specifying its distinctive number as above, from the National Physical Laboratory or other authority approved by the Chief Inspector of Factories, shall be kept attached to the Humidity Register. If an Inspector gives notice in writing that a thermometer is not accurate, it shall not after one month from the date of such notice be deemed to be accurate unless and until it has been re-examined as above, and a fresh certificate obtained, which certificate shall be kept attached to the Humidity Register.

(*g*) The construction shall be such that the thermometer may be exposed without injury to a temperature of 110°.

3. Each hygrometer shall be so mounted that—

(*a*) No part of the wet-bulb shall be within 3½ inches from the dry-bulb or within 3 inches from the surface of the water in the reservoir, and the water reservoir shall be below it, on the side of it away from the dry-bulb.

(*b*) The bulb of each thermometer shall be freely exposed on all sides to the air of the room.

(*c*) The corresponding points of the two thermometers shall be on the same level.

There shall be marked on the frame of each hygrometer, in such manner as to be readily distinguishable at a distance of six feet,

(*d*) The words "Wet" and "Dry," respectively over (or near to) the wet-bulb and dry-bulb thermometers: and

(*e*) The temperatures of 50°, 60°, 70°, 80°, and 90°, by horizontal lines and figures; and

(*f*) The temperatures of 45°, 55°, 65°, 75°, and 85°, by horizontal lines, shorter than those marked in pursuance of Regulation 3 (*e*); except that for the wet-bulb thermometer the temperature of 75° shall be conspicuously marked by an arrow or similar distinctive device.

4. Each hygrometer shall be maintained at all times during the period of employment in efficient working order, so as to give accurate indications; and in particular,

(*a*) The wick and the muslin covering of the wet-bulb shall be renewed once a week.

(*b*) The reservoir shall be filled with distilled water or pure rain water, which shall be completely renewed once a day.

(*c*) No water shall be placed in the reservoir, or applied directly to the wick or covering, during the period of employment.

5. No hygrometer shall be affixed to a wall, pillar or other surface, unless protected therefrom by wood or other non-conducting material at least half an inch

in thickness and distant at least one inch from the bulb of each thermometer.

R. McKenna,
One of His Majesty's Principal
Secretaries of State.

Home Office, Whitehall,
18th March, 1912.

Sizing.—The humidity required for the successful manipulation of cotton yarns in the weaving sheds is intimately connected with the question of sizing, and it is therefore desirable at this stage to discuss shortly the reasons for the application of size, and also the materials used for different classes of goods. The primary object of sizing is to increase the strength of the thread and to fix all projecting fibres upon its surface, but it is often applied with the object of obtaining increase in bulk and weight and to obtain improved appearance. Some classes of customers, *e.g.* the Hindoo coolie, judge a cloth by the feel and never wash it. This market is catered for by very heavy sizing.

Mixings of size are classed by the percentage ratio of weight of size to that of the yarn, *e.g.* a yarn sized 50 per cent. is one in which every 100 lbs. of pure yarn carries 50 lbs. of size, making a total of 150 lbs.

All single-twist warp yarns in cotton are sized, the minimum of about 5 per cent. being used when weaving qualities only are desired, and the cloth afterwards is to be bleached and dyed or finished. In linen weaving sizing is used for weaving purposes only, the minimum quantity necessary for this being applied.

The ingredients used in different size mixings may be classed as follows :—

1. Adhesives.
2. Softeners.
3. Weighting materials.
4. Antiseptics.
5. Deliquescents.

The function of adhesives is to strengthen the yarn and to carry other ingredients. Flours and starches of various materials such as sago, rice, wheat, and potatoes are used, together with gum tragazol from the "locust bean" and dextrine.

Softeners are used to render the yarn pliable and to counteract the somewhat brittle nature of the other ingredients; they include glycerine, soft soap, wax, tallow, greases and oils.

Of weighting substances, china clay is much used for grey yarns on account of its mixing well with other ingredients and its great density. French chalk and sulphate of baryta are also used to a great extent.

Antiseptics have for their object the prevention of mildew, which is particularly liable to attack cloth or yarns containing flour and tallow, and often results in seriously weakening the fabric. Zinc chloride has been found to be the most efficient substance for preventing these growths, and a sufficient quantity, *i.e.* from 3 to 4 per cent., is usually incorporated in the mixing.

Deliquescents, such as magnesium chloride and calcium chloride, are used for the purpose of attracting moisture to the yarn. It has been suggested that by making greater use of them, the necessity for high humidities during manufacture might be obviated; it is, however, undesirable to use large quantities of deliquescent materials, since mildew is particularly liable to attack materials sized in that way. In the opinion of many of the witnesses who gave evidence before the Departmental Committee on Humidity, it may be possible in the future to produce a size which will obviate the need for artificial humidification, but this can only be brought about by experimental work carried out by manufacturers.

Percentage Humidity used for Various Classes of Goods.—The amount of humidity necessary under various conditions is a subject upon which a great difference of opinion exists. It is undoubtedly greater for the successful weaving of poor cotton yarns and low-priced goods. Heavily sized yarns also require fairly high humidities for their successful manipulation, and finally it is in the linen trade that we find the greatest percentage humidity used especially where fine plain linens and cambrics are manufactured. The only class of cotton goods where artificial humidification appears to be entirely dispensed with are coloured fabrics, and even here it is claimed that the risk of colours running is the bar to its adoption, and that the actual weaving of the cloth would be much improved were it possible to humidify the room. Linen damasks and coarse linens require only low percentage of dampness and are often woven in dry sheds.

Of the whole number of the sheds in which cotton weaving is carried on about 61 per cent. are worked without the use of artificial humidity.

In general the better classes of cotton goods are manufactured in dry sheds, although sometimes the same classes are manufactured in humid sheds. In the latter, however, yarn of slightly inferior quality is used, and it might appear that if better material were used in these factories artificial humidification would become unnecessary. It should be pointed out, however, that the supply of high-class yarn is to some extent limited, and that if a number of factories commenced to use this better-class material, the demand would exceed the supply and prices would rise to an extent which would preclude profitable manufacturing. The demand for material at a low price would continue, and would be supplied by other countries.

Table VI. refers to observations taken in a number of cotton sheds using different percentages of size, viz. light sizing (5 to 25 per cent.), medium sizing (25 to 70 per cent.), and heavy sizing (70 to 200 per cent.). The percentage humidity is given at the times when readings are taken for the official Factory

Department returns, and it appears that the relative humidity actually used was slightly greater in sheds where lightly sized goods were made than in other sheds of the cotton industry. This, of course, is opposed to the recognised fact that high humidity is required more for the heavily sized work, and seems to indicate that a greater percentage than that absolutely necessary has been sometimes infused into the light-sizing factories.

TABLE VI.

6—7 a.m.			10—11 a.m.			3—4 p.m.		
Light.	Medium.	Heavy.	Light.	Medium.	Heavy.	Light.	Medium.	Heavy.
79	75	76	76	72	73	74	70	71

It is generally agreed that a temperature in the neighbourhood of 70° is the most suitable for cotton weaving, with an average humidity of 76 per cent. for the materials woven in humid sheds, and 65 to 70 per cent. for goods dealt with in humid factories.

In the Irish linen trade a much higher degree of humidity is necessary than that required for weaving cotton. This is provided for by the scale allowed, in which the bulb readings must always differ by more than 2° F., corresponding to a maximum humidity of 87 per cent. at low temperatures to 90 per cent. at the high temperatures. In factories weaving fine cambrics it is usual to find the bulbs practically always showing the maximum degree of dampness, which is so great that it would detrimentally affect cotton goods if woven in the same shed, and therefore it is usual to weave linen only in sheds dealing with the finest and most expensive cambrics.

Certain factories in Belfast and neighbourhood manufacture medium and coarse linens and also coarse cottons and unions consisting of cotton warps and linen weft, in the same room. Where this is done the shed manager usually works with about three degrees difference between wet and dry bulbs instead of the minimum difference of two degrees required by the Factory Department. A notable difference between the cotton and linen trade is that high humidity is required for the cheap cotton goods (which are for the most part exported), whereas high degrees of moisture are required for the most expensive of the plain linens.

Apparatus for humidifying is often installed in cotton card rooms, spinning rooms, etc., but a high percentage humidity is rarely required, the apparatus being only used on exceptionally dry days.

Occasionally installations are found in winding rooms, but this only occurs where the room is liable to become excessively dry owing to the proximity of boilers or flues.

In the wet spinning process, as applied to flax, the roves are drawn through a trough of hot water before passing on to the flyers. The temperature of the water used varies according to the class of yarn, the draft and the lea, being about 135° F. for leas of 140, to 180° for leas of 20 or 30.

In rooms where this process is carried on, both humidity and temperature may become excessive, owing to the escape of steam through the lids and radiation of heat from the outside surfaces of the troughs. In order to render the escape of steam as small as possible, the lids are arranged with lips dipping into the water and forming a water seal, thus confining evaporation to a comparatively small surface at the front and back of the trough. Exhaust apparatus is occasionally used to draw off any escaping steam, and it is found that in rooms so equipped the percentage humidity and the temperature are less than in mills where these points have not received attention. Operatives often object to this exhaust apparatus on the ground that it hinders them in their work, but when properly designed no difficulty should be experienced.

Another fruitful cause of high humidity in wet spinning mills is the large amount of spray thrown off by the flyers. This falls slowly to the ground, large quantities of moisture are evaporated on the way, and the floors are often thoroughly wet. Splash guards are sometimes installed, which divert the spray to a properly designed drain, so keeping it out of the atmosphere.

Good and Bad Weaving Days.—It is a well-known fact that on certain days weaving is more difficult than on others, and this difficulty is generally associated with a dry, east wind. On such occasions weaving is difficult even with the bulbs in the factory showing a percentage humidity which would be considered ample on an average day. Definite data on this subject are very difficult to obtain, for unless the conditions are extremely bad or good there does not often exist a consensus of opinion by the operatives concerned.

Several explanations have been offered, but the one which commends itself to the writer is that on days of high dry winds the moisture is liable to be localised, and perhaps to drift about the shed owing to leakage from walls and roof allowing an inlet to the dry air; thus, although the thermometers show a good percentage of moisture, since they are usually in the most favourable position in the shed, a number of looms may be working under adverse conditions. This explanation seems to be confirmed to some extent by the fact that whilst a worker in one portion of the shed will affirm that it is a very bad day for weaving, another operative, some little distance away, will hold the opinion that the day is neither good nor bad. If a weaving shed is protected from dry winds by high buildings it is generally considered that the shed will be less susceptible to differences in the outside conditions, and it is owing to this fact that where a weaving factory is associated with a spinning mill it is usual to arrange the building plans in such a manner that the shed is protected from the east winds, which in this country are usually associated with low outside humidity. In planning a mill abroad attention should be paid to this point, and, if possible, protection arranged on the side of the driest winds.

The simplest method of obtaining a moist atmosphere is by the direct injection of steam; pipes being run round the shed, the steam issuing from fine nozzles in these pipes. The amount of steam entering the shed can be regulated by a main throttle valve, and its distribution altered by cocks on the nozzle themselves.

Until the attention of the Home Office was directed to this matter, the system was undoubtedly the cause of much unnecessary suffering on the part of the operatives in humid factories. Great lengths of pipe, badly insulated, were introduced into the shed, and a large quantity of unnecessary heat was given off by radiation. The system, however, has advantages from the manufacturing point of view, inasmuch as the humidity can be raised with great rapidity.

The percentage humidity allowed has been the subject of legislation on several occasions. Under the Cotton Cloth Factories Act, 1889, it was permissible to have any temperature in the sheds, provided that the relative humidity, as measured by wet and dry bulb thermometers, did not exceed a certain prescribed scale, a copy of which was hung in the factory alongside the thermometers. Readings of these thermometers were taken three times a day, at specified hours, in the cotton sheds, and twice a day in the linen factories. At the end of each month copies of the records were sent to the Factory Department, copies being also kept in the mill for reference.

This Act has now been amended by the Cotton Cloth Factories Act, 1911, which retains the bulk of the schedule of humidity but does not allow a temperature less than 50° F. dry-bulb during working hours, except during the first half hour from the commencement of work, and prohibits the introduction of artificial humidity when the wet-bulb exceeds 75° F.

The method of recording readings of wet and dry bulb hygrometers in cotton cloth factories has also been modified by the Act of 1911. Observations are now taken jointly, by representatives of the occupier and of the operatives employed, three times during the working day, viz. between 7 a.m. and 8 a.m., between 11 a.m. and 12 noon, and, except on Saturdays, between 4 p.m. and 5 p.m. These readings are entered in a register kept in the factory, and only those observations which record contraventions of the humidity regulations are forwarded, on a prescribed form, to the inspector of the district. At the end of each week a declaration in the register is signed by both parties that the requirements have been complied with.

The humidity allowed by the various schedules in force varies in different industries, *e.g.* in the Irish linen trade a difference of not less than 2° F. has to be maintained between the bulbs; in the cotton trade the difference required is greater at the higher temperatures.

Attention was directed to the steaming question by an agitation amongst the Lancashire weavers during 1906, which culminated in a ballot being taken, in which 68,000 out of a possible 72,500 voted in favour of total abolition of steaming, threatening to strike if their demands were not acceded to. Conciliation was brought about by the appointment of a Departmental Committee of the Home Office to consider the whole question. After taking an immense amount of evidence both for and against steaming, the need for more exact data led the Committee to undertake full scale experiments on the entire subject. The results and conclusions are discussed in the second report of the Committee, which was presented to Parliament in January, 1911, and on the basis of which the Act was passed in August, 1911, empowering the Secretary of State to draw up regulations embodying the recommendations of the Departmental Committee.

Physiological Effects of High Humidity.—The operatives in humid weaving sheds make complaint of two causes of physical discomfort; firstly, "that on account of their clothes being damped by the steaming of the sheds, they are rendered peculiarly susceptible to the contraction of coughs, colds, lung diseases, and rheumatism ; and, secondly, that the effect of working in a hot, moist atmosphere leaves a feeling of exhaustion at the end of the day, and is permanently conducive to an indifferent state of health." It must however, not be supposed that the garments of the operatives are liable to absorb moisture to the same degree as the yarn, for hygroscopic ingredients, such as $CaCl_2$ and $MgCl_2$ are introduced into the size of the latter for the specific purpose of increasing its absorptive power. Should, however, clothing be hung on cold walls or columns without any protecting material to prevent direct contact, it would become wetted by the water condensed on the cold surface. Recent legislation, which should remove in great measure the complaint of the operatives, compels the provision of outside cloakrooms, or alternatively of cupboards or pegs insulated from the walls by boarding or other means, inside the factory, where the operatives may keep their outdoor clothes.

The organs of the human body, in performing their functions, are continuously generating heat, and it is necessary that this heat be carried away from the skin, otherwise a rise of bodily temperature ensues. The heat generated varies in accordance with the amount of work performed, hard manual labour being accompanied by the generation of large quantities of heat, a less amount being given off when light occupations only are engaged in. The removal of surplus heat from the human body is effected partly by direct conduction and convection and partly by evaporation of perspiration, the former being proportional to the temperature difference between any exposed parts of the body and the external air, the latter being proportional to the amount of perspiration and the dryness of the atmosphere. In a hot dry atmosphere evaporation is rapid, and the increased absorption of heat thereby is responsible for most of the cooling effect, the amount dissipated by conduction and convection being small. In a hot, humid atmosphere evaporation is checked, large quantities of heat cannot be abstracted from the body, and it therefore becomes difficult to engage in hard manual labour. If the clothing be reduced so that a greater surface is exposed to cooling influences, more work can be done and less discomfort experienced. In this way it is obvious that with air saturated at a temperature of 98·4°, the normal body temperature of a healthy human being, no heat could possibly be given off, there being no margin for evaporation and no thermal difference. Any heat generated by the internal organs would of necessity go to raise the bodily temperature. The above hypothesis of air saturated at 98·4°, of course, represents an extreme condition; in point of fact, wet-bulb temperatures much below this limit are sufficient to cause serious danger of heat stroke.

Inquiries into the physiological effects of high humidity and temperature were made by the Departmental Committee, data being obtained from experts in other trades, and also from medical research carried out on the operatives of the weaving industry. The general conclusions arrived at were that the bodily discomfort or danger to health depends on the wet-bulb temperature only, that it begins to be felt at or about 75° wet-bulb, and becomes more serious as the wet-bulb temperature rises, until at about 90° wet-bulb there is grave danger of collapse.

The discomfort or danger varies with the individual, and it is possible to become in some degree inured to wet-bulb temperatures slightly higher than those mentioned.

Doctors Pembrey and Collis, in their report to the Departmental Committee, say:—"Weavers appear to be small in stature, spare in build, thin in the face, pale in complexion, and to have a wearied look. Many of them complain that their appetites are poor and require tempting, and that they suffer from indigestion. These conditions cannot be explained otherwise than by the prolonged exposure to the effects of the warm moist atmosphere in which weavers work, for they are not seen in outdoor labourers or in workers in other industries in Lancashire."

CHAPTER II

Three Principles of Humidification—Advantages and Disadvantages—Commercial Humidifiers—Carrier—Drosophore—Hall and Kay—Hart—Howorth—Ingersoll Rand Company's Turbo Humidifier—Jacobine—Kestner—Mather and Platt's Vortex—Matthews and Yates' Cyclone—Parson's—Pye's—Pal's—Local Humidification—British Humidifier Company—Hargreave's Warp Moistener—Heenan and Froude's—Special Devices—Hart's Humidifying Back Rest—Underground Ducts.

In general ventilation and humidification may be carried out in three distinct ways.

(1) By injection of steam into the shed or into the incoming air of a plenum ventilating system.

(2) By passing the whole of the ventilating air over surfaces kept moist by means of cold or warm water.

(3) By "atomizing" water and using this to supersaturate either the incoming air of a plenum ventilating system, or by injecting the "atomized" water directly into the shed.

Each system has its advantages and disadvantages, thus in the first method the humidity can be raised with great rapidity, but no cooling effect can be secured since the water is already evaporated before entering the factory, and in addition some heat is introduced, which will be slightly less in quantity than the sensible heat of the steam used.

In the second system slight cooling effects may be obtained, but the humidity, although under control, cannot usually be raised with the rapidity possible when steam jets are installed. The cooling effect depends very largely upon the ventilating volume and upon the height of the outside wet bulb in relation to the height of the wet and dry bulbs in the factory. Thus, suppose we have a system of this description installed in a shed where the maximum percentage humidity allowed by the Factory Department is required for the successful weaving of the class of goods manufactured, and imagine that the readings in the shed at a certain time are 74° dry, 70½° wet. This corresponds to a percentage humidity of 81½, and 7·4 grains of vapour will be carried by each cubic foot of air. Let the outside readings be 60° dry, 55° wet. By passing the whole of the ventilating air over water surfaces, it will be possible to saturate it and to cool it down to a temperature approximately corresponding to its initial wet-bulb temperature, a temperature slightly lower than this being obtained if the water is very cold. If then this air be blown into the shed at 55° saturated, it will have a cooling effect corresponding to the volume per minute and to the difference between shed temperature, *i.e.* 70° and its own temperature 55°. Each cubic foot of air, however, although saturated at

55° F., will contain only 4·1 grains of water vapour, and the net result will be that the shed will dry rapidly. By heating the water we can send air into the factory saturated at any temperature, and it will be necessary to adjust matters so that each cubic foot of ingoing air contains approximately the same amount of water vapour as is contained by each cubic foot of air already in the shed. In the example this will be 68° F., which contains when saturated at that temperature 7·5 grains of water vapour. It will be seen then that we have now only 6° F. difference between shed temperature and ventilating air temperature, and unless the volume of the latter is very great the temperature of the factory will continue to rise.

Again, even though the inlet air contains the same amount of water vapour as the shed air and the ventilating volume is sufficiently great to counteract the rise of the dry-bulb temperature the wet-bulb will have a tendency to fall owing to the absorption of moisture by the warps which is constantly going on as a fresh surface of yarn is exposed in the unwinding. This absorption is very noticeable in a linen factory, where the humidity almost invariably falls considerably during meal hours even when all ventilation openings are closed. In order, then, to obtain the percentage humidity required, it would probably be found necessary to send the ventilating air into the factory at a temperature of about 70° F. dry, 70° F. wet, and our margin of temperature difference available for cooling is still further reduced. The method is most efficient when the shed temperature is high, owing to the wider difference required between the bulbs, but its application is more suitable to spinning mills, where large percentages of moisture are not necessary.

Considered from the point of view solely of obtaining a cool atmosphere in summer, the third method presents many advantages, since the fine drops of water evaporate in the shed and absorb much heat, which is rendered latent; the atmosphere of the factory is thus cooled very appreciably. It is of great importance, however, that the water on leaving the duct opening or the humidifying machine should be pulverized as finely as possible. This may be judged to some extent by holding a felt hat or a piece of woollen cloth in the supersaturated air for a few seconds. On removing the cloth it should not appear moist, but if the finger be drawn over its surface a wet track will be apparent During winter the water used for humidifying may be heated in order that it may neutralize in some measure the cooling effect; the main heating of the factory being effected by means of radiating pipes. At first sight it might appear that this method would entail increased cost for warming during cold weather, but it should be pointed out that since each cubic foot of humidified air in the shed contains a definite amount of sensible heat and of latent heat, it cannot make any difference whether the latent heat is given to the vapour before entering the shed, as it would be in an ordinary steaming system, or after it has entered the shed, as would occur in the method under consideration.

Combinations of one or more of the above methods present some advantages; if, *e.g.*, the incoming air be passed through mats saturated with cold water, or led over a sufficient area of water surface as is done in some of the humidifiers on the market, the air may be cooled down and at the same time its percentage humidity raised to an amount corresponding almost to complete saturation; but as has already been pointed out the absolute amount of water vapour present is insufficient to maintain the humidity required in the factory. If now the air be supersaturated by the injection of a small quantity of steam, a mixture can be obtained which will be comparatively cool and yet will maintain the percentage humidity when introduced into the factory. If atomized water be used for supersaturation the cooling effect obtainable will be much greater.

The detailed methods by which the makers produce an efficient machine are interesting and ingenious, and an attempt will now be made to describe some of the more important humidifiers upon the market. Since the publication of the report of the Departmental Committee greater attention has been paid to the question of conditioning by water atomizers, and several manufacturers have modified their apparatus so as to enable it to be run either wholly by steam or water or by a combination of both. Where figures are given for the apparatus necessary for a certain size of shed, it must be recognized that these are very approximate. Much depends upon the design of the room, its situation and the class of goods manufactured. When installing a new humidifying system the owner or manager is usually in a position to know which of the three principles is most likely to serve his particular purpose, after which the detailed design is best left to an independent expert or to one of the makers of a machine working on the principle selected, who can usually be relied upon to supply an apparatus suitable to the local conditions.

The "Carrier" Air Washer and Humidifier.—A typical humidifier, working on the plenum system, is that known as the Carrier humidifier, where the humidity is controlled automatically and where, therefore, constant conditions can be approximated to with very fair accuracy.

The washing and humidifying chamber is built of sheet metal strongly braced with angle irons at the corners. Installed in this chamber are a number of water sprays working at a pressure of about twenty-five pounds per square inch. On entering the nozzle water is led tangentially to a circular chamber and so acquires a rapid vortex motion. The outlet is situated at the centre of the vortex chamber, and is about $\frac{3}{32}$ in. in diameter. On leaving the jet the water is whirling rapidly, which greatly assists in ensuring efficient atomization. Air is drawn through the washing chamber by means of a fan, and on leaving the chamber passes over a number of galvanized eliminator plates, so dispersed as to intercept any free moisture. A second series of sprays is installed, the discharge from which flows down the eliminators, so washing all solid particles into the sump at the bottom of

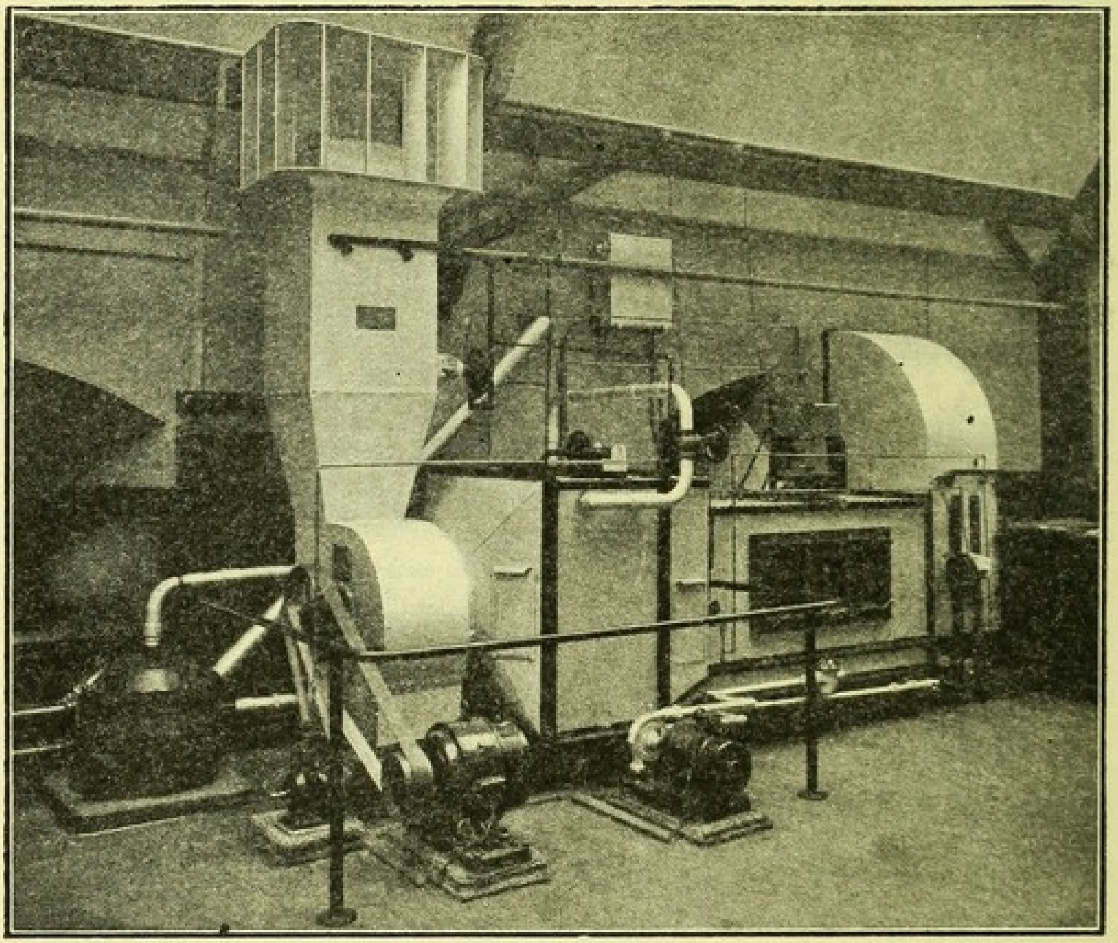


Fig. 3.—The Carrier Humidifier plant installed in the testing house of the Manchester Chamber of Commerce.

the humidifier. A small pump recirculates the water after filtering. The spray water can be heated by means of steam injected into the pump suction pipe. Before entering the room the air passes through a heating chamber. The apparatus is supplied by the makers with automatic control capable of maintaining either relative or absolute humidities constant. In an installation supplied to the Manchester Chamber of Commerce Testing House, Fig. 3, this consists of two thermostats, one situated at the outlet end of the apparatus and therefore being exposed to the saturated air, the other being exposed to the room temperature. The former is therefore governed by the dew-point temperature, the latter by the dry-bulb temperature. If the latter tends to rise, the expanding member of the thermostat opens a small air valve and so allows compressed air to pass along piping to a small air motor, which actuates a damper, allowing a greater portion of the humidified air to pass into the room without going through the air heaters. If the temperature to which the other thermostat is exposed tends to rise, compressed air is admitted to a diaphragm-controlled valve situated in the main which supplies steam to heat the spraying water. This valve checks the flow of steam and so reduces the temperature of the saturated air leaving the apparatus. Other examples which have been installed are controlled in a similar manner by hygrostats situated in the mill or factory.

The "Drosophore" Humidifier.—Appliances for humidifying the air of the room or shed are distributed at even intervals and close to the roof or ceiling. Ventilation is carried out by means of separate fans drawing air from the outside, these being assisted by several specially constructed ventilating "Drosophores," also drawing air from the exterior.

The Drosophore machine consists of a sheet metal cylinder (Fig. 4), which contains a water atomizing

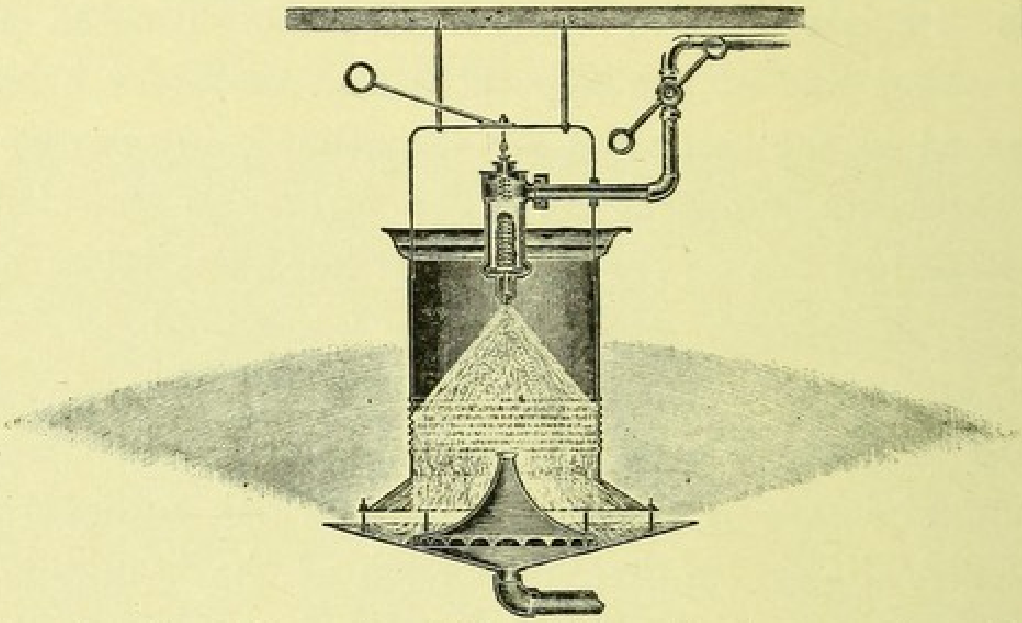


FIG. 4.—The "Drosophore" Humidifier, showing spray in action.

device. Water is supplied under pressure through galvanized iron piping; excess water being led from a sump in the lower portion of the apparatus by means of a second pipe. The action of the water jet induces a strong current of air through the cylinder, which by passing through the spray is humidified and supersaturated by finely divided particles of water. This is distributed to the shed through a circular opening above the water sump. For ventilating purposes the upper portion of the cylinder can be connected to the outside atmosphere by means of a duct, the humidifier then drawing air directly from the outside of the room or shed.

A water pressure of about 100 lbs. per square inch is required for the atomizing jet, and this is supplied under ordinary circumstances by means of a small force pump. The return water from the humidifier, which consists of those drops of water which are intercepted by the sides and bottom of the cylinder, is passed through a filter and into the pump suction tank, a ball valve connected to a clean water supply furnishing water to replace that absorbed by the shed atmosphere.

A very ingenious form of water jet is used in connection with the apparatus, it being possible to clean the filters and jets, and also to flush out the water pipes from the floor level and so avoid risk of accident through approaching the moving shafting, etc., by means of ladders. When working, water passes from the inside to the outside of the gauze filter, finally being pulverized by ejection through the orifice, which is partly closed by a needle valve.

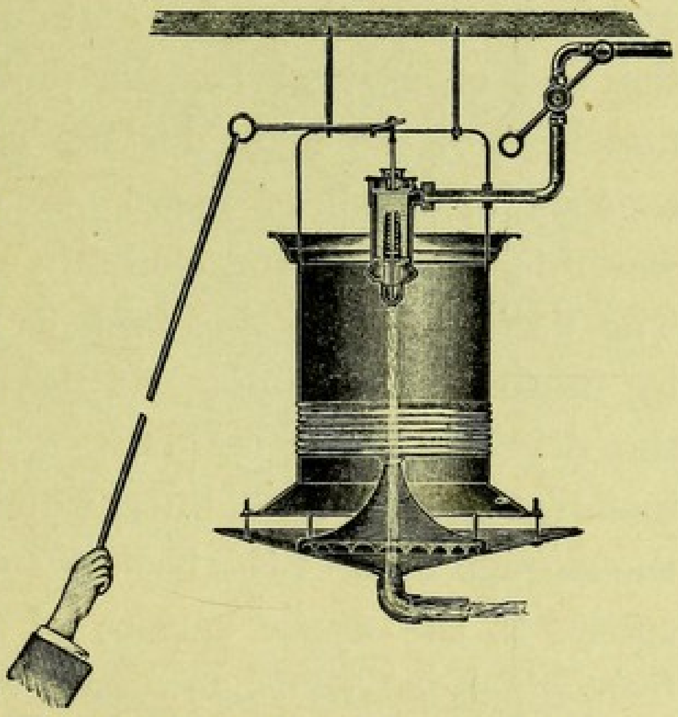


FIG. 5.—The "Drosophore" Humidifier, showing working of cleansing and flushing device.

When it is desired to flush out the apparatus, the lever is pulled by chain or other connection from the floor. The gauze cylinder is raised until the plate at its upper end is pressed firmly against the top cap. At the same time a valve is opened in the bottom plate of the filter, and the water can now flow only from the outside to the inside of the gauze. The lifting of the second valve raises a needle situated in the spraying orifice and so allows a strong flush of water to pass through the device (Fig. 5).

Hall and Kay's Apparatus.—In this system air is saturated by being passed over a large water surface, and is delivered through metal ducts to distributors at the end of vertical branch pipes connected to the underside of the main ducts. The humidifier proper consists of a sheet metal box (Fig. 6) to which water is admitted and stored in a tank at the bottom. The water level in this tank is maintained constant by means of an automatic float valve connected to the drinking-water mains. A belt-driven pump is installed in the humidifier, which draws water from the storage tank at the bottom and delivers it through sprays to the upper surface of an air filtering box, from which it trickles down and returns to the storage tank. Steam pipes are arranged in the humidifier for the purpose of warming the water and so enabling a greater weight of vapour to be delivered to the main ducts for distribution in the mill or shed. The fresh air is supplied by means of a fan, which draws or blows air through the moistened filtering material to saturate it at the required temperature. Valves are arranged so that it is possible to obtain the whole of the air either from the outside atmosphere or from the room to be humidified, or partially from both. The machine is easily controlled, and has given

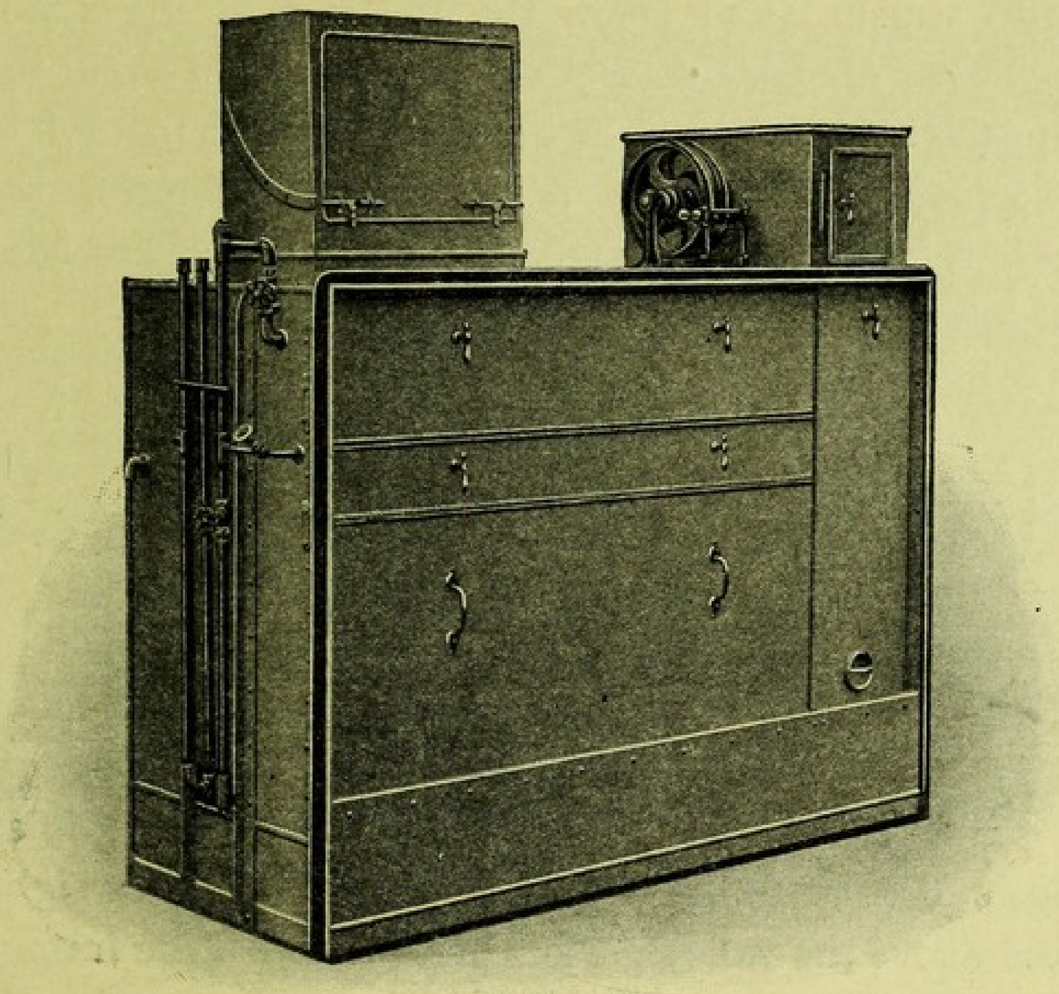


FIG. 6.—Outside view of Humidifier as installed in combing, pre - paring, spinning, and weaving rooms. Hall & Kay, Ltd.

satisfaction to a large number of users both at home and abroad.

For humidifying and ventilating yarn conditioning cellars Messrs. Hall and Kay use a different form of apparatus. This consists of an open trough containing water, which can be heated by steam pipes running from end to end of the trough below the water surface. A fresh-air pipe also runs along the trough, having vertical branches which deflect the ventilating air over the water, thus conditioning it with vapour at or below the pressure of the atmosphere. A constant level of water is preserved in the apparatus by an automatic float valve connected to the water main. Fig. 7 is a drawing showing the patent humidifying trough, several of which are used at intervals over the cellar.

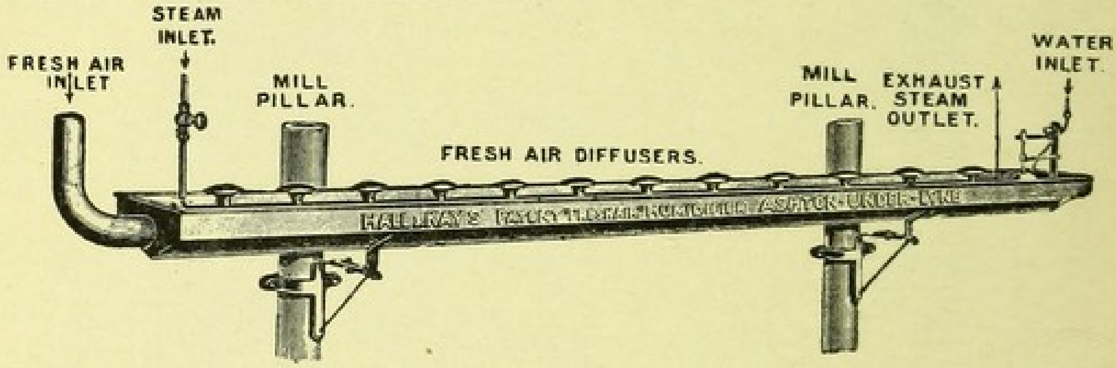


Fig. 7.—Humidifying trough as used in yarn conditioning cellars. Hall & Kay, Ltd.

Hart's Humidifier.—In this apparatus the inlet ducts B (Fig. 8) draw air fron a level of six or eight feet above the valley gutters of the roof. The framework D is surrounded by the cocoanut matting E, which is kept constantly moist by contact with the water trickling from the trough C. A section of the lower end of the apparatus, which is situated within the shed, is given in Fig. 9, and a photograph of the interior of a weaving factory, showing the external form of the humidifier, in Fig. 10. The fan A (Fig. 9) projects air through the perforations in the drum C and also through the curved outlet tubes D, the stream being thus broken up very efficiently and obviating any chance of draughts impinging upon the worker. The air is humidified with steam at atmospheric pressure by means of the ring humidifier

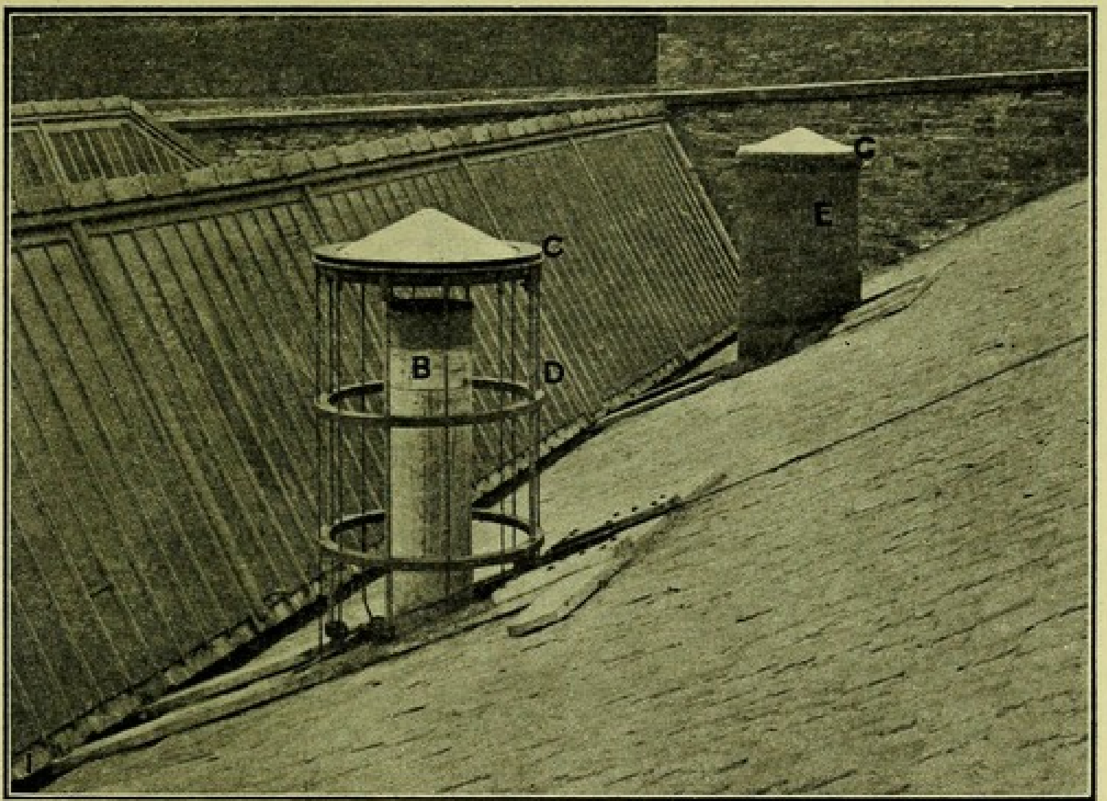


FIG. 8.—Inlets to Hart's Humidifier (old type).
B, Inlet duct; C, Trough supplied with water; D, Timber framing to carry filter mat; E, Filter mat moistened by water trickling down from water trough.

E. The inlet duct is fitted with a heating coil for use during cold weather. Several of these machines are placed at suitable intervals in the shed, the number of looms allowed to each humidifier varying from 120 to 150, according to conditions, such as the number of operatives present in the shed, the size of the looms, etc. When used in spinning, combing, card rooms, etc., horizonal air ducts of sheet iron lead the air from inlets in the side of the room to the apparatus. It is sometimes desirable to clothe these ducts with some insulating material in order to obviate

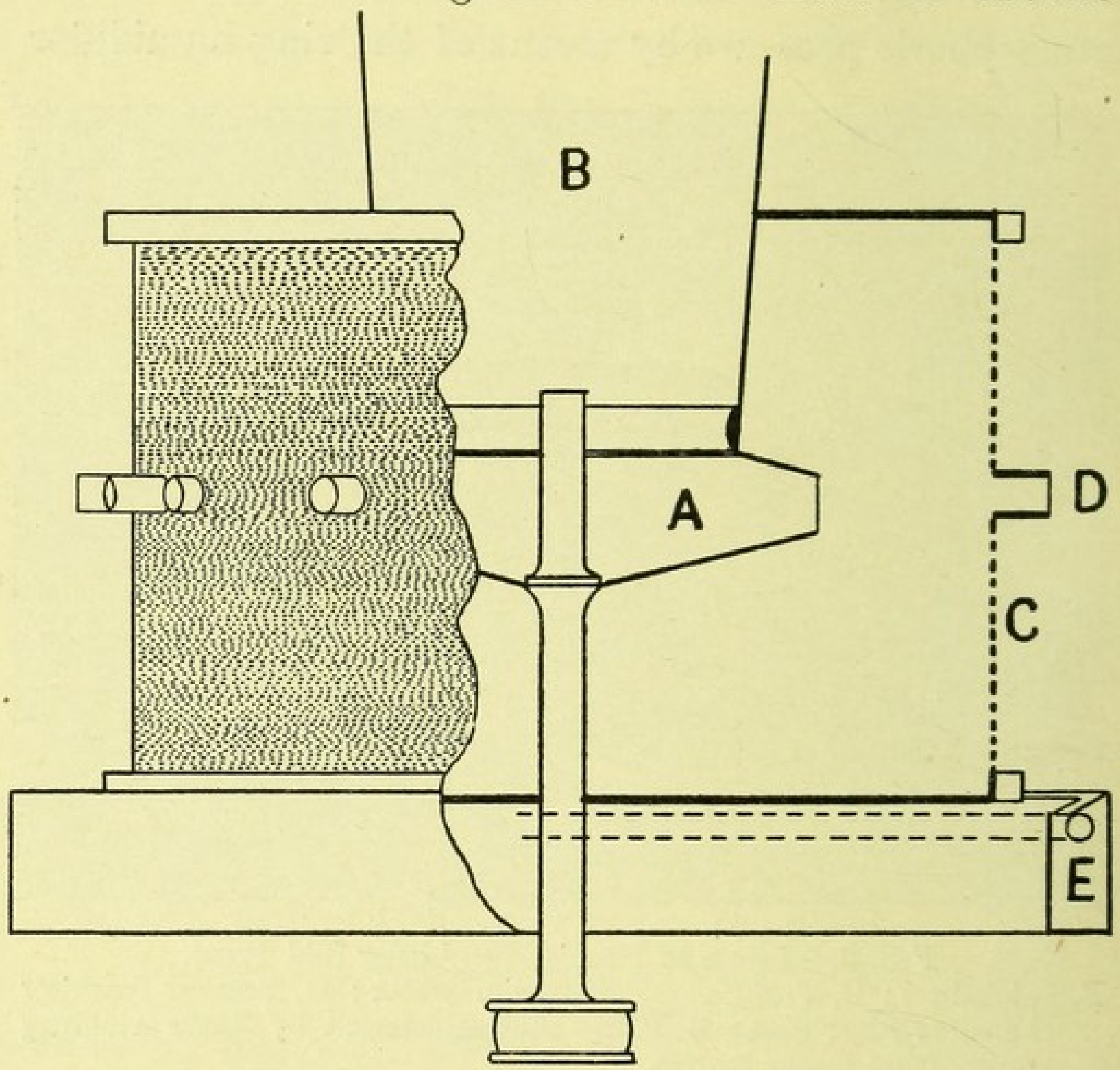


FIG. 9.—Section of Hart's Humidifier.
A, Fan wheel; B, Inlet duct containing steam coil; C, Perforated sheet metal drum; D, Outlet tubes, slightly curved in plan; E, Humidifying trough.

condensation and consequent dripping during cold weather.

Mr. Hart has recently invented and placed upon the market a very ingenious apparatus for washing, cooling, and humidifying air. It can also be used for

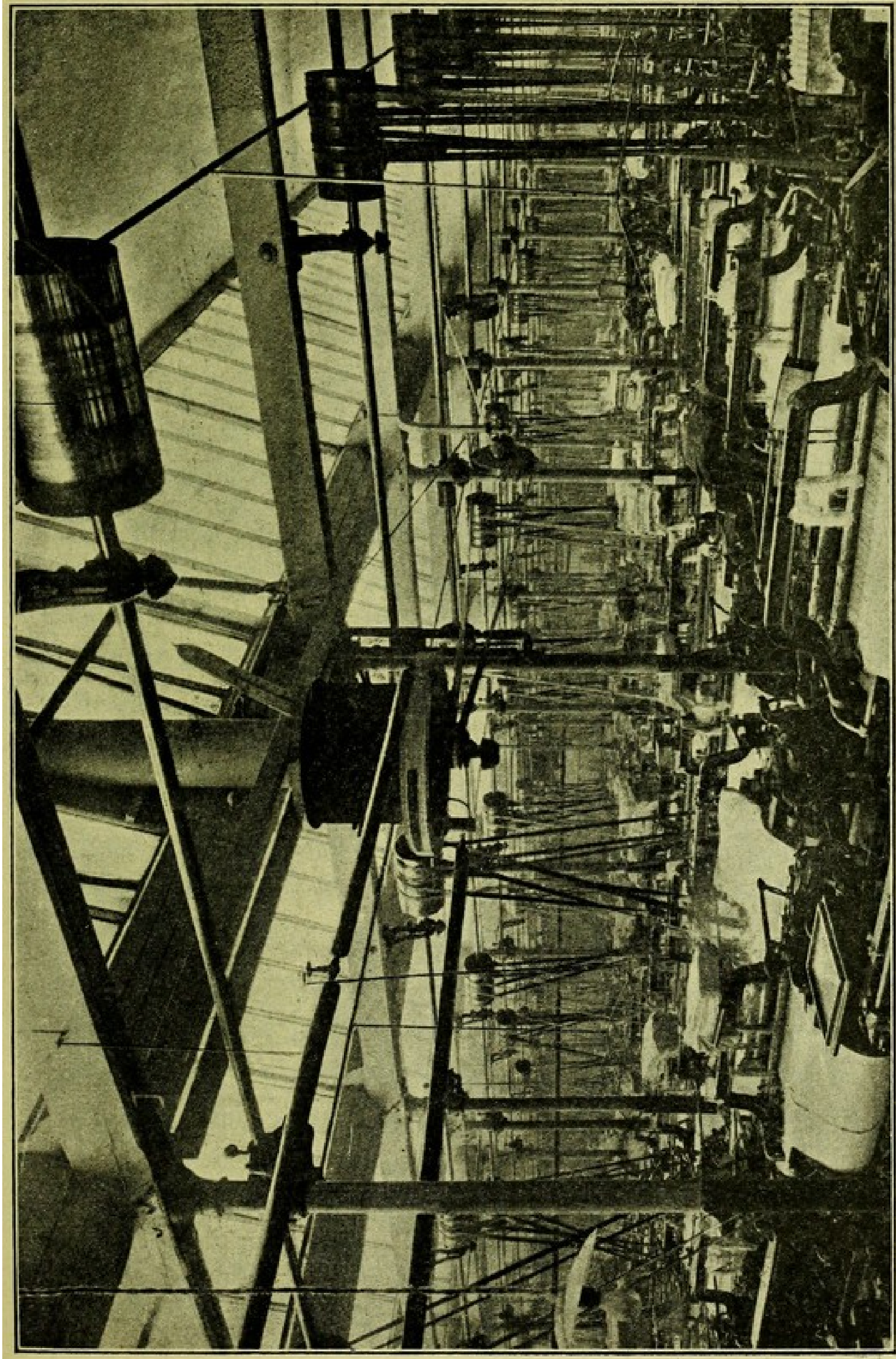


Fig. 10.—Hart's Humidifier as installed in weaving shed.

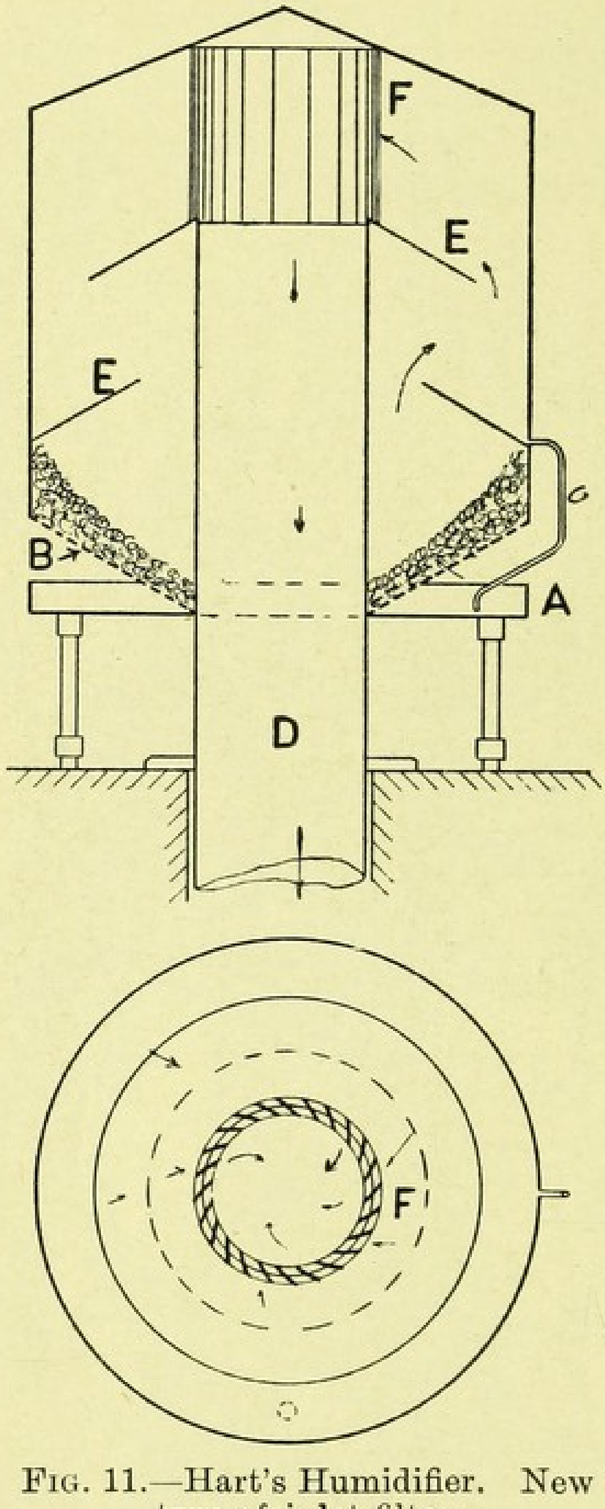


FIG. 11.—Hart's Humidifier. New type of inlet filter.
A, Water trough; B, Tinned sheet copper, punched, as shown in Fig. 13; D, Outlet from washer, and inlet duct to humidifier; E, Separator plates; F, Guide vanes; G, Drain pipe from separator plates.

numerous other purposes where it is desired to obtain an intimate interaction between a liquid and a gas.

As installed in connection with textile mills and factories, it replaces the mat filter previously described. It can also be arranged to draw air from the room, wash, cool, and humididify it, and recirculate it again to the mill. A section of the apparatus is given in Figs. 11 and 12, in which A is a trough containing water, the sloping sides B of Fig. 11 being formed from a piece of tinned sheet copper (Fig. 13), punched in such a manner as to form openings through which air can pass in a direction approximately at thirty degrees to the surface of the plate.

The vertical portion C of Fig. 12 is bent from a piece of sheet copper (Fig. 14), in which the holes are so formed as to direct the air upwards at the same time. The duct D in both figures is connected with either a fan or one of the ordinary type of Hart's humidifier.

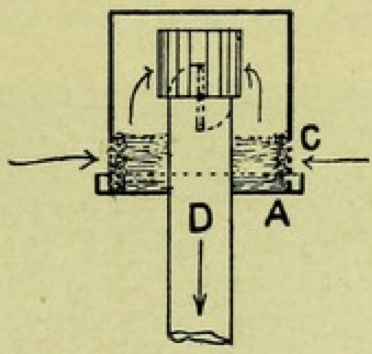


Fig. 12.—Hart's Humidifier. Alternative type of inlet filter for use where space is limited.
A, Water trough; B, Tinned sheet copper punched as shown in Fig. 14; D, Outlet from washer and inlet to humidifier.

On starting the fan air flows into the chamber through the approximately tangential holes in B and C and forms a vortex inside the drum. Water in the trough rises, owing to centrifugal force in Fig. 11, and owing to the upward direction of the air jets in Fig. 12, and flows over the perforated copper portion in the form of foam, the stream varying according to requirements from one to seven inches thick and extending to a height slightly above the top of the perforated cage. The whole of the inlet air must then pass through this ring of revolving foam in a spiral direction, thus passing through one or more feet of foam, and, as the fresh air is subdivided in passing through the cage, intimate interaction is secured. In addition to the pull of the fan the centrifugal motion of the water tends to separate out the air and so little extra back pressure is thrown upon the blower.

In a machine tested by the author this back pressure did not exceed 0·25 inch of water, and so was practically negligible. In another form of the apparatus the perforated cage is surrounded by a volute casing and the air forced in. The washing water

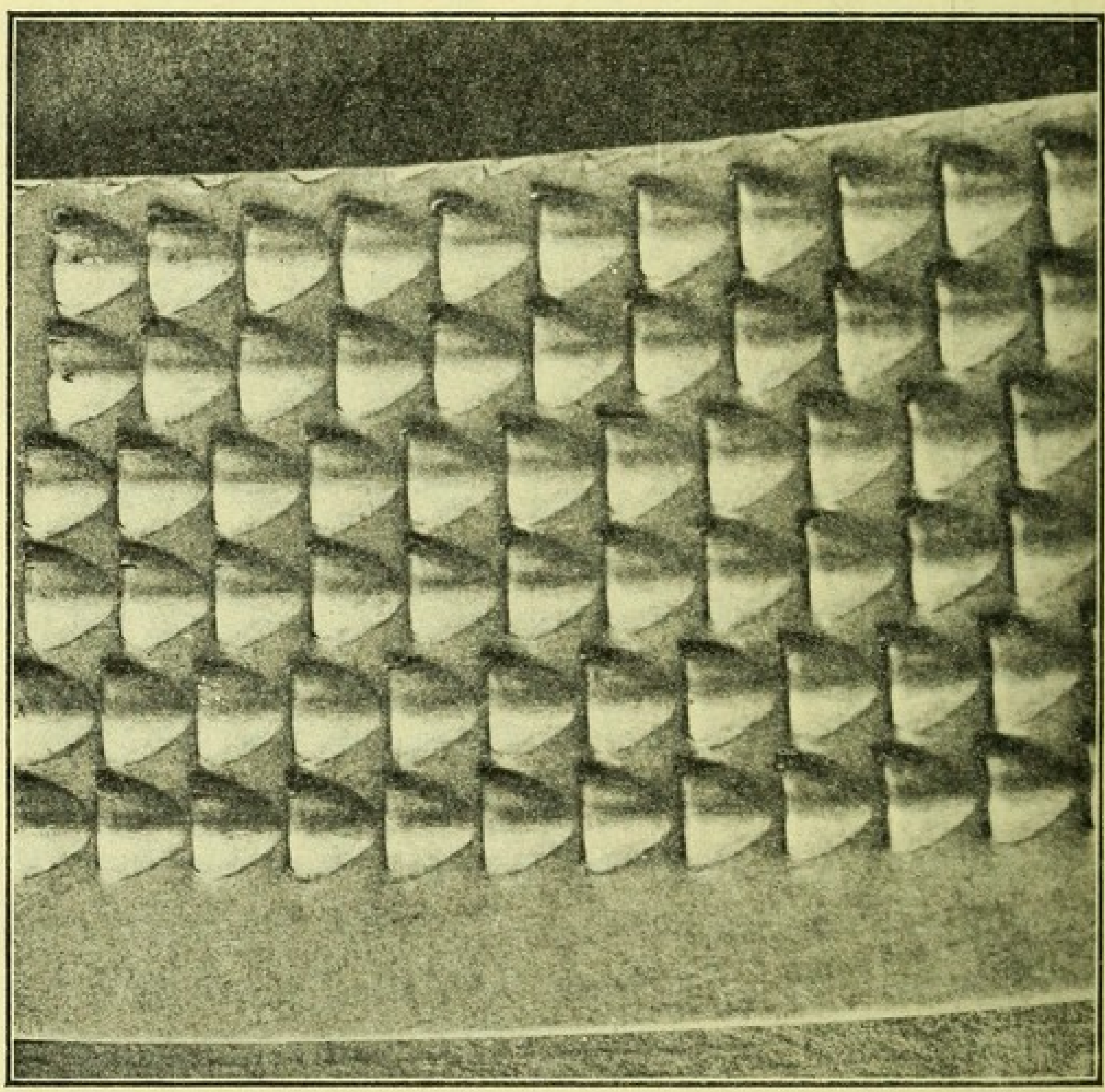


FIG. 13.—Hart's Humidifier. Sheet copper plate punched to form air ports in a direction approximately at 30° to the surface of the plate.

may, if necessary, be warmed by a steam coil to ensure the apparatus against danger of freezing during the winter and also to enable the amount of vapour carried into the air of the factory to be adjusted to suit the hygrometric conditions maintaining. Clean feed water is used in such quantities as will slightly exceed the amount evaporated and so result in a quantity of overflow sufficient to maintain the washing water at a reasonable standard of cleanliness. When the

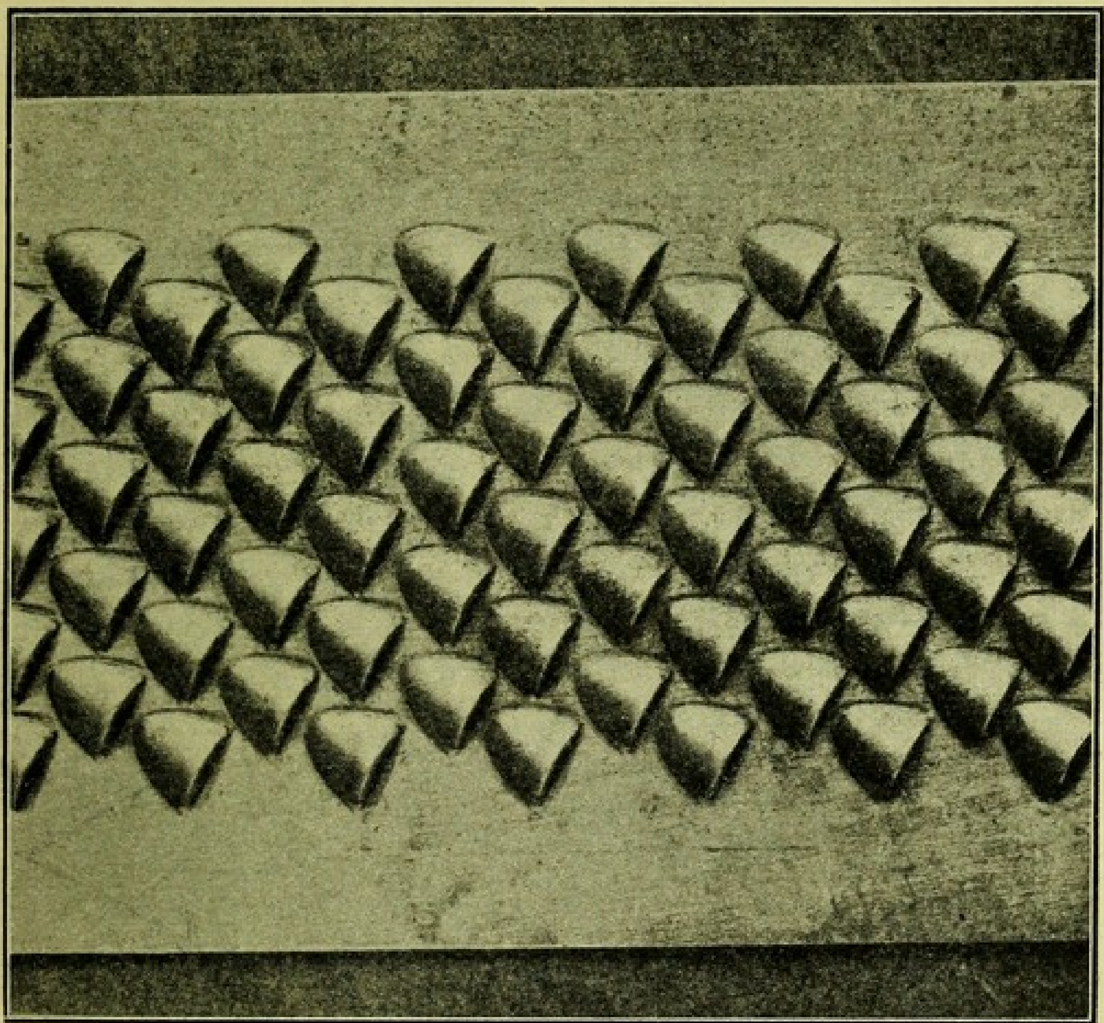


Fig. 14.—Hart's Humidifier. Sheet copper plate punched to form air ports in a direction approximately at 30° to the surface of the plate, and at an angle to direct the steam upwards.

engine is stopped during meal hours or at the end of the day the foam drops to the bottom of the trough and overflows, automatically cleansing the apparatus.

Howorth's Apparatus.—This is a typical system in which humidified air is distributed over the shed by means of large sheet-iron ducts suspended from

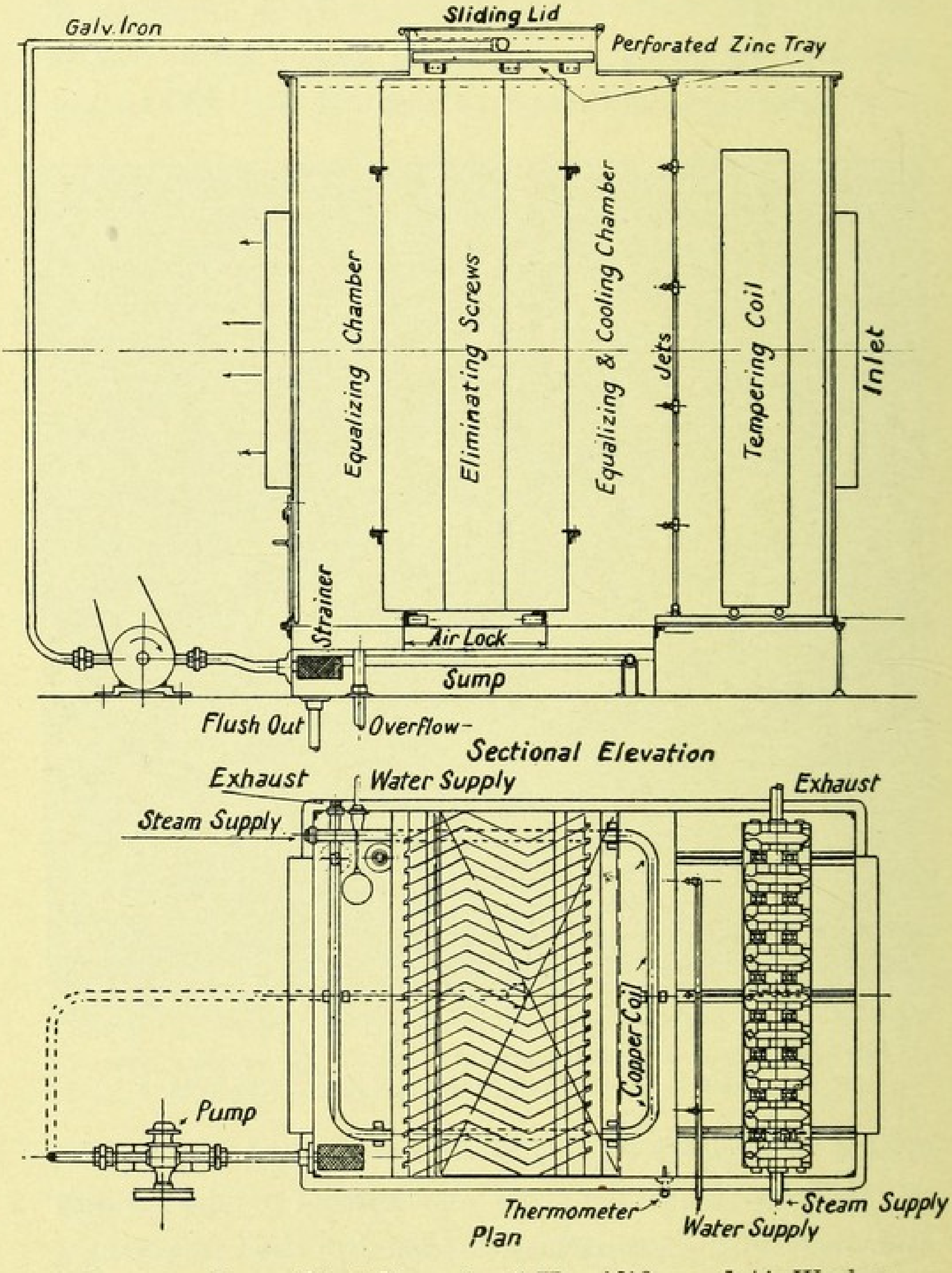


FIG. 15.—Howorth's "Champion" Humidifier and Air Washer.

the roof. The body of the conditioning apparatus consists of a galvanized sheet-iron box having an inlet opening (Fig. 15). On entering the humidifier the air passes through a steam-heated radiator and into the washing and cooling chamber, in which several water

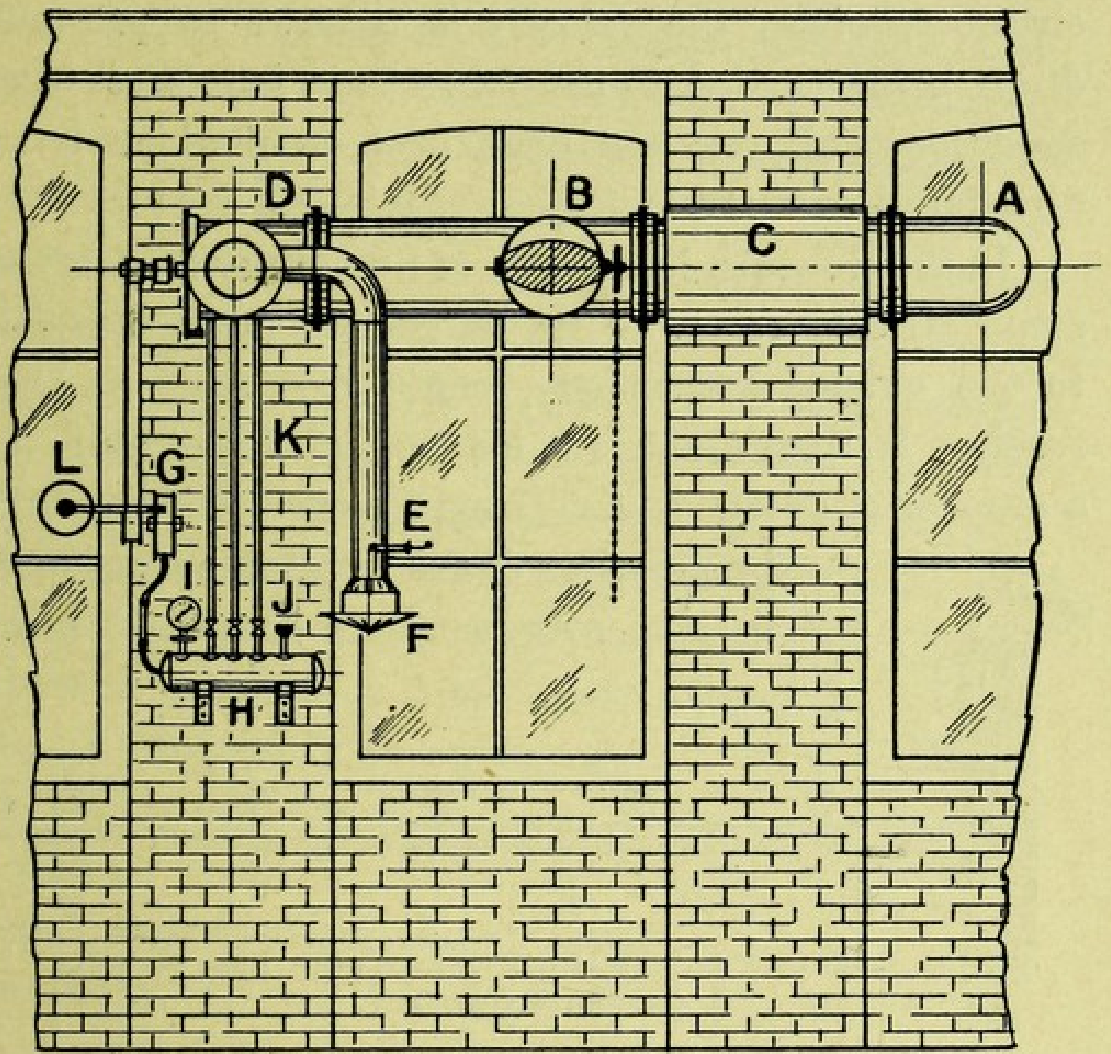


FIG. 16.—Howorth's Humidifier (1913 type).
A, Fresh-air inlet; B, Recirculating inlet; C, Air filter; D, Fan; E, Regulating damper; F, Distributor; G, Air compressor; H, Compressed air receiver; I, Pressure gauge; J, Relief valve; K, Supply pipe to jets; L, Air filter for compressor.

pulverizers are at work. The water to these sprays is supplied by a small force-pump, and can be heated to any required degree by means of a steam coil in the supply tank. The air next passes through the eliminator screens which contain a number of angle plates kept constantly wet, and so disposed as to compel the air to follow a sinuous course. On leaving the eliminator screens it passes through the equalizing chamber, where the velocity is reduced to prevent drops being carried to the fan. This fan forces the conditioned air into the main duct, from which it is distributed over the factory as required.

In the Howorth latest type of humidifier (Fig. 16) a small air compressor G has its suction side connected to the outside atmosphere, and forces air into the receiver H, from which it is led through the pipes K to a number of patent jets. These " mist nozzles " work on the principle of the injector, a stream of air passing over a nozzle connected to a fresh-water tank. The action of the jet is to create a dense cloud or fog of minutely divided drops of water. The main supply of air is drawn through the inlet A by means of the fan D, passing on its way to the fan over an air heater contained within the box C. The humidified air is then distributed over the factory by means of the ducts and the distributors F (Fig. 17). Regulation

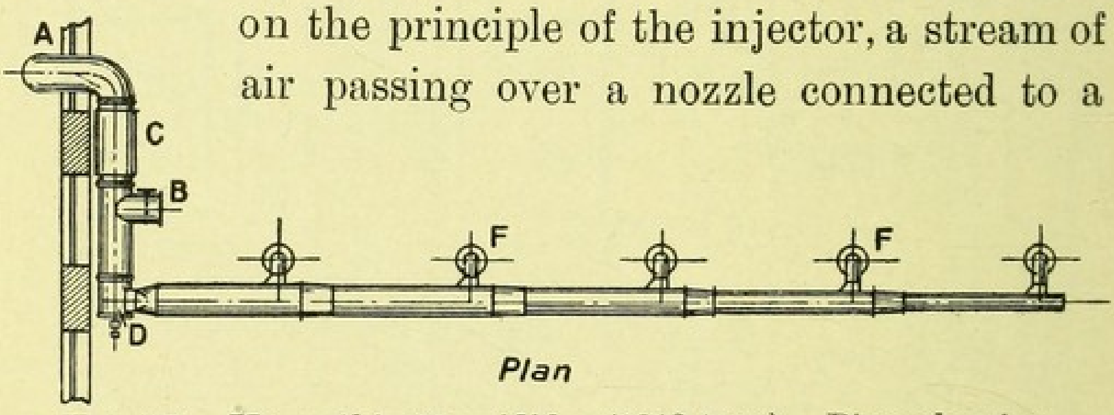


FIG. 17.—Howorth's Humidifier (1913 type). Plan showing distributing ducts.

of humidity is effected by means of valves upon the air pipes K. The pressure used is low, only about 5 lbs. per square inch being required to effect a very complete atomization of the water supply. In winter the water for humidification can be warmed by means of a copper coil fitted in the water cistern, and if necessary air can be drawn, by means of the damper B, from the shed and recirculated. Conditioned air is forced into the factory at a height of about 7 feet above the floor line. In spinning rooms, etc , outlet ventilators (Fig. 18), which can be closed off if necessary, are inserted in the walls of the window recesses at a height of about 12 inches above the floor, thus affording a degree of elasticity in the distribution which is lacking in certain other systems. When the plant is installed in spinning rooms the incoming air is passed through a filter cloth formed by folding a special material in zig-zag form. The edges are then doubly sewn so as to form pockets, the number of pockets depending upon the volume of air to be treated, and to some extent upon the district. The great advantage of this method of filtering is that the amount of surface presented is very large, the air velocity low, and the resistance offered to the fan correspondingly small.

In the case of conditioning cellars and mixing rooms no fan is used, the energy of the jets being great enough to induce a current sufficient for the comparatively small volume of ventilation required.

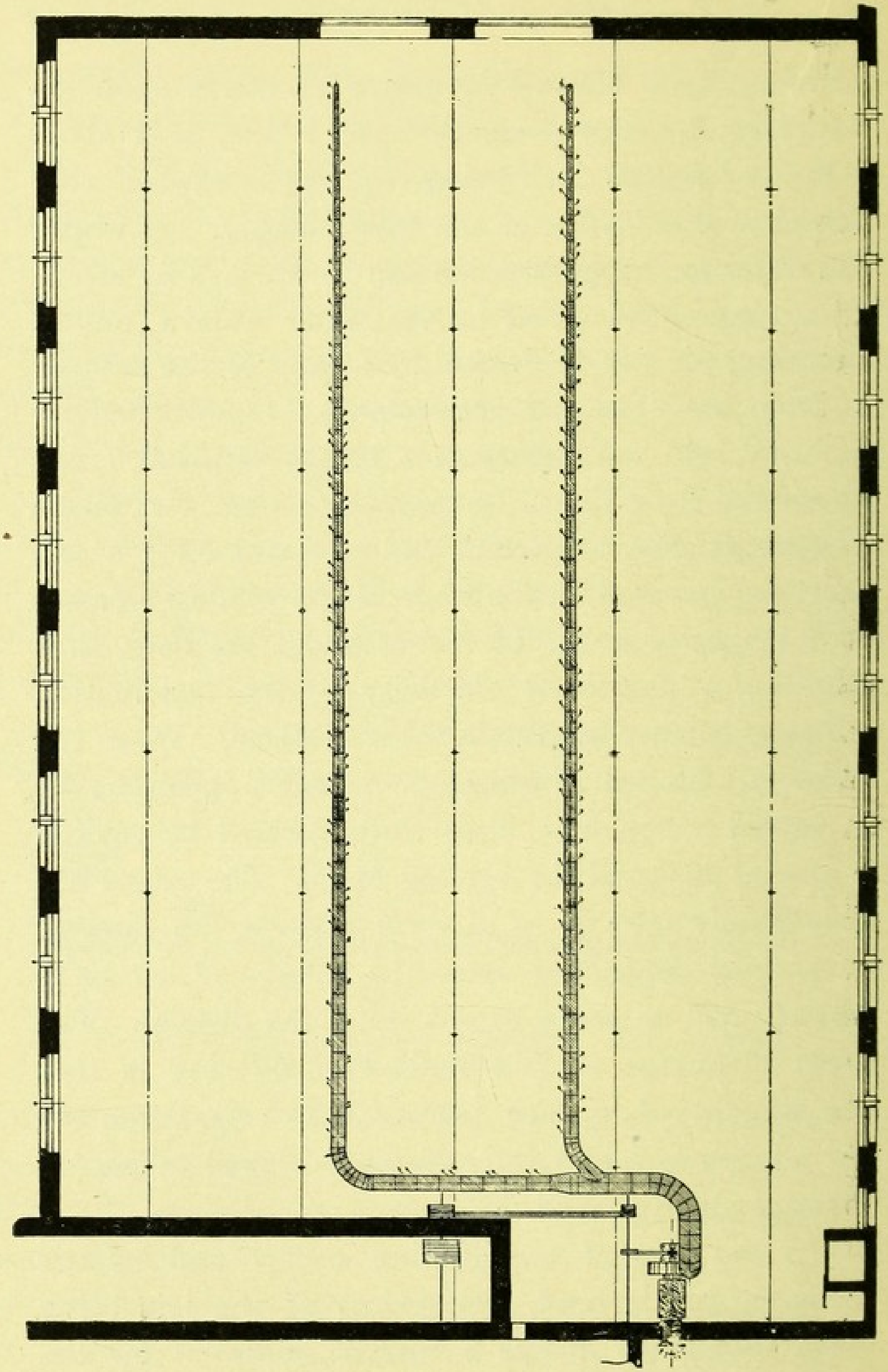


Fig. 18.—Howorth's Humidifier. Plan showing distributing ducts and air outlets in the window recesses of a spinning room.

The Ingersoll-Rand Coy.'s Turbo Humidifier.— This apparatus, which is giving complete satisfaction to a number of users, is an example of a water humidification system run separately from the shed ventilating plant. The air which it injects into the factory carries water in an exceedingly finely divided state. Again, no moving parts are incorporated in the nozzles, and if any clogging up of the orifices or stoppage of either the air or water supply occurs, the jet simply ceases to work and any damage by water overflowing on machinery, yarns or cloth is obviated. The distributing nozzle, which will humidify and cool from 6000 to 20,000 cubic feet of room space, is shown in section by Fig. 19.

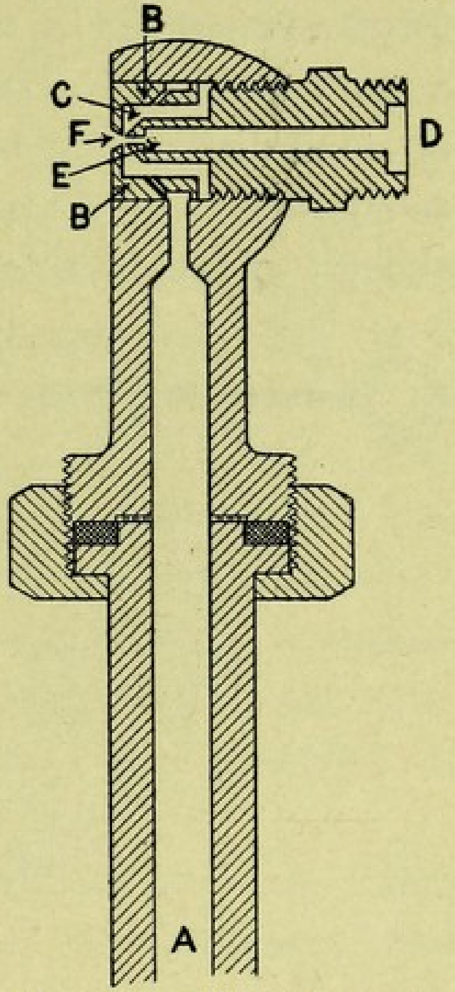


FIG. 19. — The Ingersoll-Rand Company's Turbo Humidifier. Section of Spray Nozzle.

A, Compressed air inlet; B, Bronze bush; C, Vortex chamber; D, Water inlet; E, Water jet; F, Combining jet.

The inlet D is connected to a water main, which is run dead level across the shed, whilst the inlet A is supplied with compressed air at pressures of 30 lbs. or 65 lbs. per square inch, according to the requirements set by local conditions. The compressed air passes through tangential ports in the bush

BB, and so sets up a vortex in the chamber C. The vacuum induced at the centre of the vortex draws water through the jet E, and the action of the vortex motion of the water and air finely pulverizes the former, when it is delivered to the shed through a fine opening F. The air and water pipes, which are of small diameter and galvanized, are run side by side as shown in Fig. 20, and the water main, which is set about two inches below the centre line of the jet, is

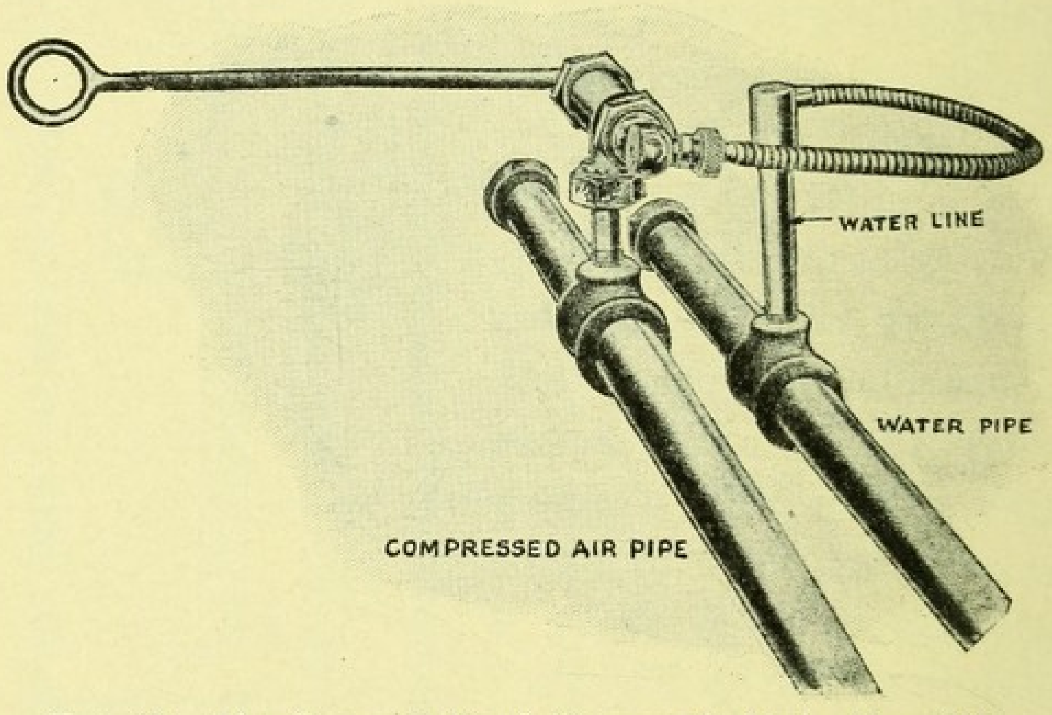


Fig. 20.—The Ingersoll-Rand Company's Turbo Humidifier. Arrangement of air and water connections.

connected with an overflow pipe which prevents water flowing through the nozzles when the air supply is shut off. The water supply is derived from a ball-tap controlled tank equipped with overflow, draw-off pipe, and filters, a second gauze strainer being installed in the jet itself. The amount of moisture can be controlled by a main valve set in the air pipe and also by separate cocks on each nozzle. All parts are made interchangeable and it is a small matter to take down and clean any jet which may become choked without in any way interfering with the general humidification of the factory. However, owing to the fact that drinking water is used, and that the filtering arrangements are very complete, cleaning, although a very simple matter, is rarely required. It is well known that if air at high pressure be allowed to expand through an orifice its temperature will fall very rapidly; indeed, this property is made use of in machines for liquifying air and other gases. The expansion, then, of the compressed air through the distributing nozzles will have a small additional cooling effect, the total cooling effect due to water evaporation and expansion of the air being about 5 per cent. greater than that due to the latent heat absorbed in the vaporization of the atomized water.

Jacobine System.—This apparatus has been installed in several factories on the Continent, but has not yet been used to any great extent in the British Isles. Humidification is effected solely by means of water pulverizers, and the action of the jet is made to force air into the shed and so replace any mechanical fans. The general arrangement is shown in Fig. 21, A and B being inlet openings which can draw air either from the outside atmosphere or from the interior of the shed.

The ejector atomizers are shown at E; they are supplied with high-pressure water by the force-pump D. At a point in the ducts beyond the jet a separating chamber is arranged which catches all large drops of water and returns it to the feed tank by pipes F. This water is efficiently filtered and again pumped through the atomizers. A ball-tap G connected to the drinking-water main preserves the level in the feed tank, thus replacing water which has been

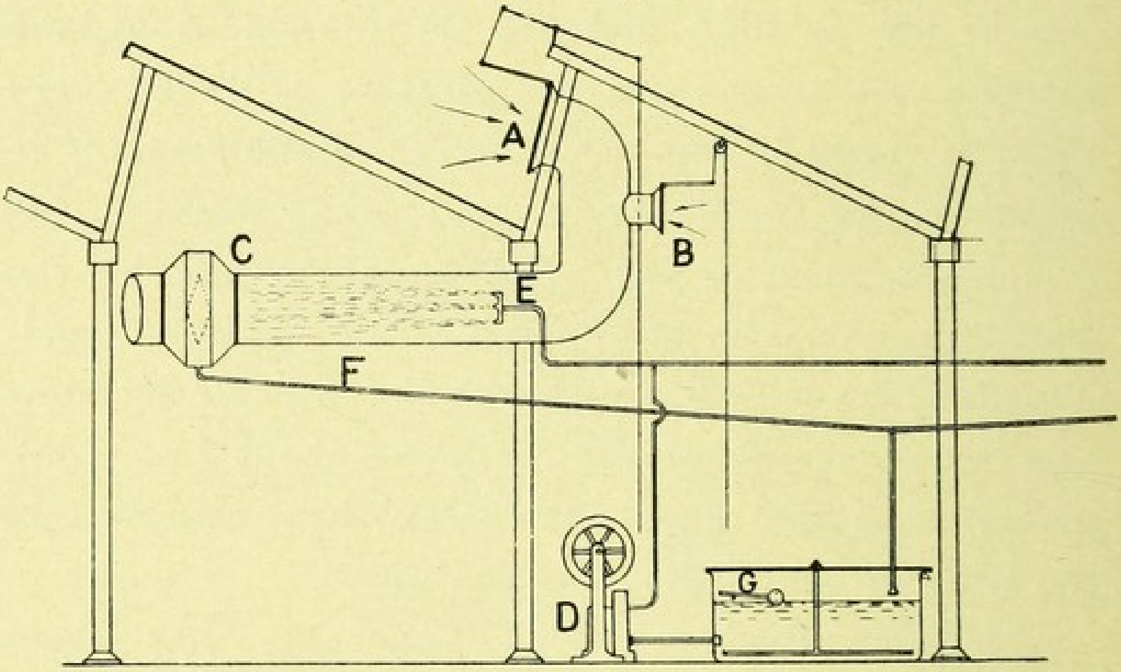


FIG. 21.—"Jacobine" Humidifier.
A, External air inlet; B, Recirculating air inlet; C, Separating chamber; D, Force pump; E, Spray nozzles; F, Return water pipe; G, Ball tap.

used for humidification. Continental users of the apparatus state that it is quite reliable in action, and that there is no difficulty in maintaining reasonably high degrees of humidity.

Kestner's System.—In the original humidifier, as made by Messrs. Paul Kestner, air is drawn through the inlet duct by means of a fan F, Fig. 22. Dampers are so arranged that it is possible either to take air from the outside of the factory or to recirculate that already inside the shed. Conditioning can be carried out wholly by steam or by a mixture of steam and finely divided water. The steam or hot-water inlet is shown at A, the cold-water pipe being immediately above the steam inlet.

Water is sprayed by a rose to the rapidly revolving

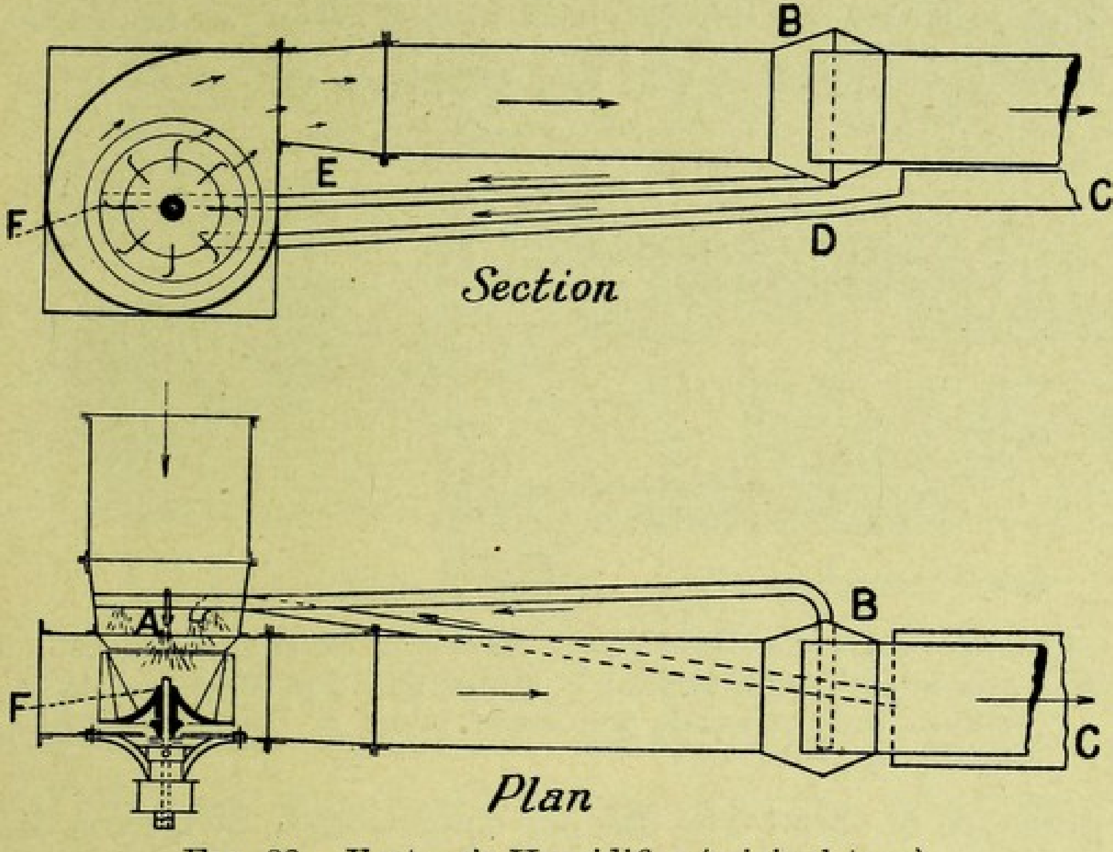


FIG. 22.—Kestner's Humidifier (original type).
A, Steam and water nozzles; B, Intercepting chamber; C, Trough to collect water from main ducts; D, Return pipe from trough; E, Return pipe from intercepting chamber.

fan wheel, which breaks it up into a finely divided spray and so mixes the air and water together as to obtain thorough saturation. Large drops of water carried over into the ducts are collected in the chamber B, and returned to the fan wheel. The trough has for its object the interception of water which would otherwise precipitate in the factory, this water being returned to the fan by the drain pipe D.

In the humidifiers installed at the present time the assistance of mechanical fans is dispensed with, and spray nozzles (Fig. 23) substituted, which, in addition to humidifying, will displace a large volume of air. The jets are placed one behind the other, so that the effect is cumulative, and are supplied with water at a

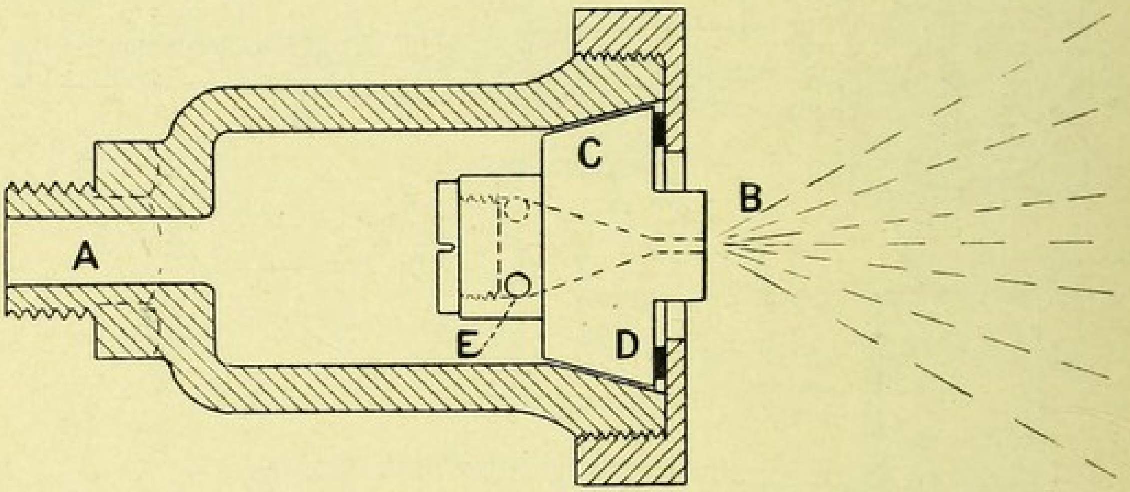


FIG. 23.—Kestner's Humidifier. Section of water spray nozzle. A, Water inlet; B, Jet orifice; C, Coned plug; D, Machined joint between body of nozzle and coned plug; E, Inlet passages to coned plug.

pressure of about 170 lbs. per square inch, by means of a pump. The air travels at a high velocity in the jet chamber, but its speed is reduced very considerably before being discharged into the room in order that any large drops of water may be separated out and returned to the pump suction tank. The makers claim that for each horse-power per hour used in driving the pump a volume of 280,000 cubic feet of air can be discharged into the factory or spinning room.

A general view of the complete apparatus is given in Fig. 24.

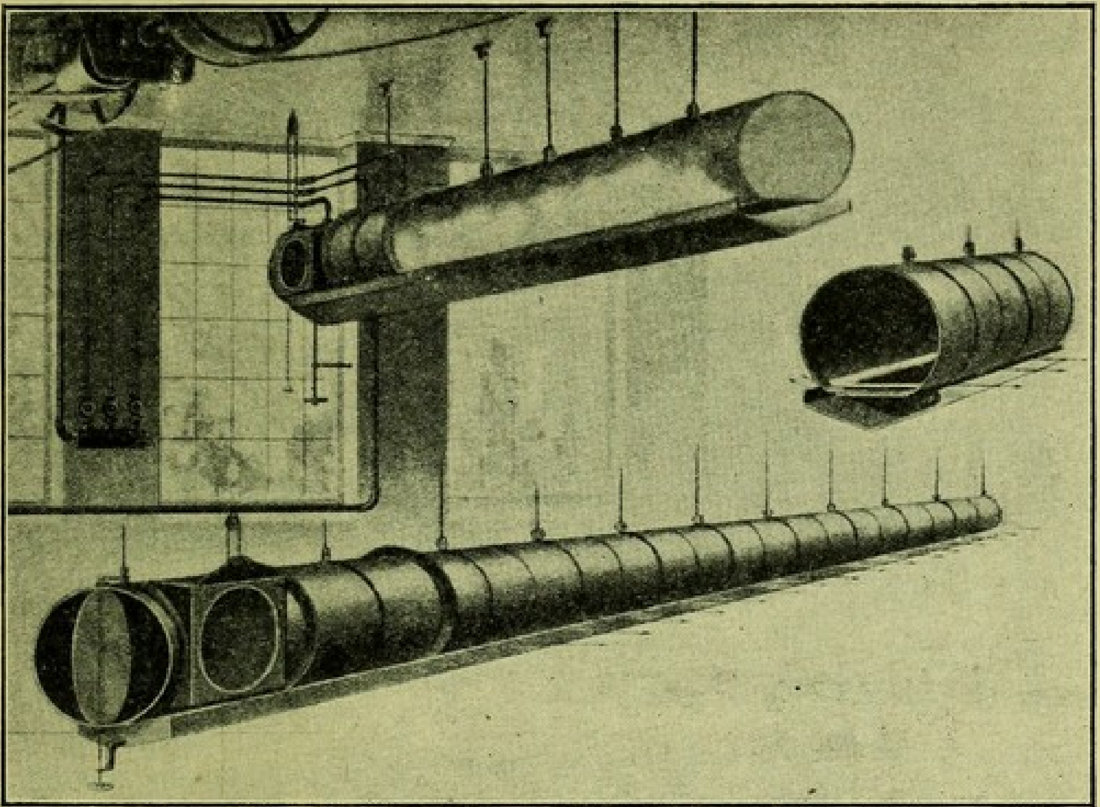
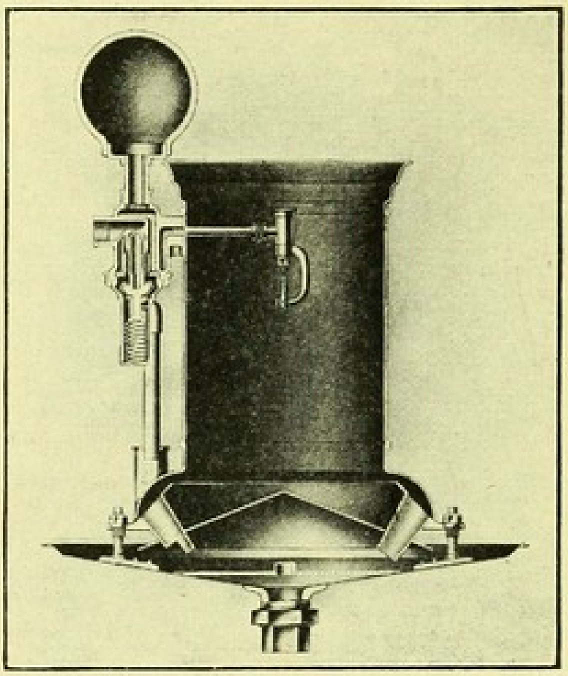


Fig. 24.—Kestner Humidifier. Distributing ducts and controlling apparatus.

Mather and Platt's "Vortex" System.—This apparatus is typical of the method of humidification by water only, introduced directly into the shed itself. Fig. 25 gives a section of the spraying apparatus, which consists of a cylindrical sheet-zinc body, in the upper portion of which is placed a jet. Water at a pressure of about 140 lbs. per square inch issues from the nozzle, impinges upon the flat end of a nickle steel pin, and is split up into a hollow cone of fine spray, which extends to the side of the cylinder. This hollow cone, moving at a high velocity, creates a partial vacuum in the upper portion of the humidifier, and thus induces a strong current of air through the cylinders. This, passing through the spray, is cleansed from dust and fibre and escapes through a horizontal opening in the lower part of the apparatus, carrying with it a mist of finely divided particles of water. This is soon evaporated in the shed, and thus maintains the required humidity. The inlet end of the apparatus may be arranged to draw air from the outside and assist the ventilating system. The main part of the water cone, consisting of finely divided particles of water which are collected on the side of the cylindrical casing of the humidifier, flows back to the feed tank.



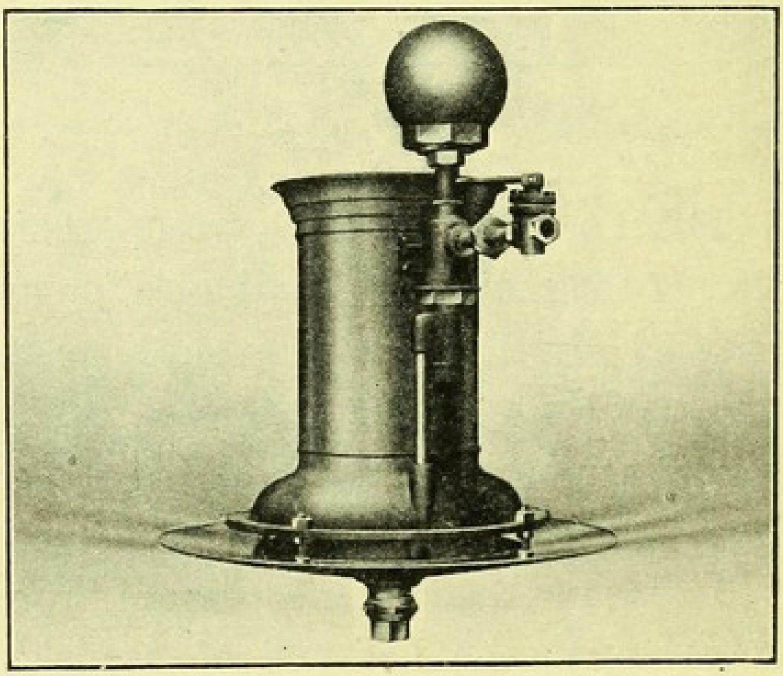


FIG. 25.—Mather and Platt's "Vortex" Humidifier.

In apparatus for water humidification it is very essential that the machine should not commence to work before the supply water has reached the correct pressure, otherwise the particles of water carried into the shed may be too large for quick evaporation, in which case water will settle either on the floor or the looms. In order to obviate this and also to prevent clogging of the jet by dust or fibre which may have been picked up beyond the main filter, an automatic valve shown in section in Fig. 26, is installed in the type under consideration. On starting the apparatus the water pressure in pipe A rises until it is sufficient to force open the spring-loaded valve B, the lower portion of which also acts as a valve and will now be held tight against the coned face E. Pressure water then passes through the ports C and D and the gauze filter G to the spraying nozzle. A small volume of water will also pass into the air vessel

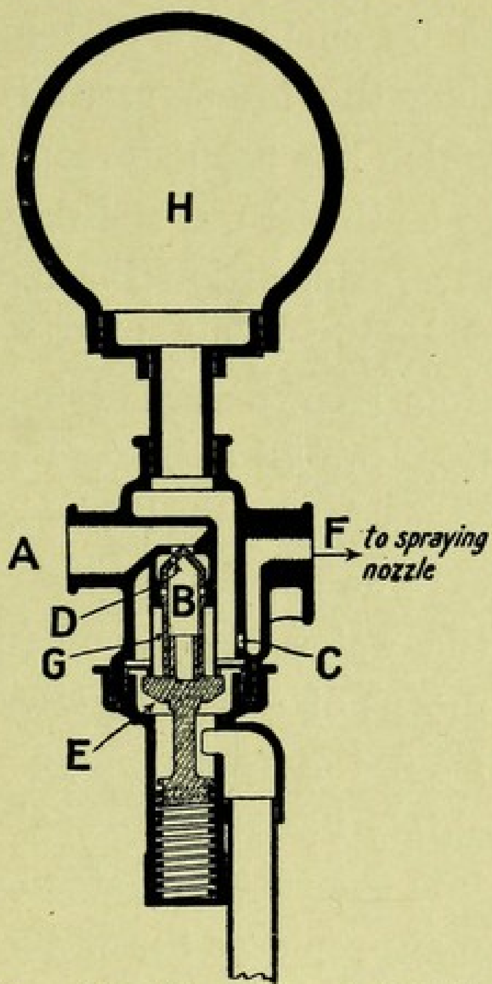


Fig. 26.—Mather and Platt's "Vortex" System. Self-cleansing valve as fitted to each Humidifier.

A, Water supply pipe; B, Spring loaded valve; C and D, Ports for passage of water; E, Coned face at lower end of valve; F, Connection to spraying nozzle: G, Gauze filter; H, Air vessel.

H, compressing the air to about 140 lbs. per square inch. When the humidifier is turned off the pressure in the supply pipes falls, allowing the upper valve to be smartly closed by the spring. At the same time the lower valve is opened, allowing the water which has been stored under pressure in the air vessel to be thrust out and make its escape by passing in the reverse direction through the filter and down to the waste pipe. The filter is thus efficiently cleansed every time the humidifier is put out of action. The valves have proved to be very reliable, it being usual for them to work long periods without any attention whatever.

The supply arrangements are shown in Fig. 27, the water being pumped from the suction tank by means of a belt or steam-driven force-pump. Water from the return pipe from the humidifiers passes slowly upwards through the coke filter and overflows into the suction water tank. A ball-tap on the town's main replaces the water carried away for humidifying purposes. The floor space allowed to each machine varies according to the manufacturing processes going on in the room where installed, and also upon the climatic conditions. In Lancashire about 800 square feet are allowed to each humidifier in ring spinning mills, whilst as much as 2000 square feet are allowed in carding and preparing rooms. For ordinary weaving sheds an allowance of 1000 square feet of floor space per humidifier will usually give satisfactory results. The amount of water used depends upon

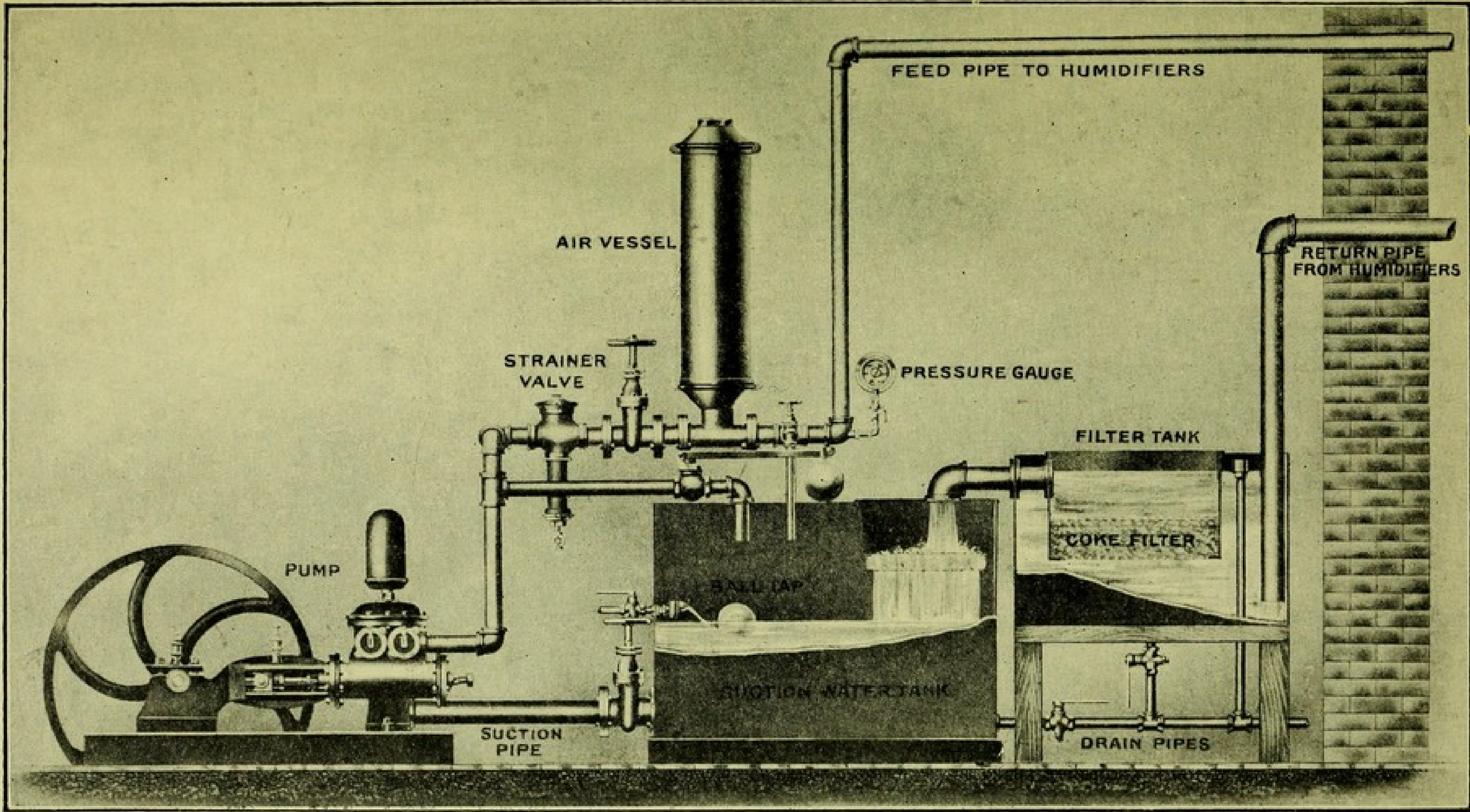


FIG. 27.—Mather and Platt's "Vortex" System. General arrangement of pump, suction tank, filters, etc.

the temperature and the relative humidity of the shed air, taken in conjunction with the ventilating volume and the hygrometrical conditions of the outside atmosphere. Under normal conditions about one and a half gallons of water will be atomized and dispersed per hour, whilst with exceptionally dry outside weather conditions coupled with high internal temperatures, as much as two and a half gallons would possibly be required. Figs. 28 and 29 are photographs of a weaving shed and a winding room in which the apparatus is installed. The "Vortex" machine has proved of value for practically all the processes that raw cotton passes through until it leaves the weaving shed as cloth in the grey state.

Matthews and Yates' "Cyclone" System forms an interesting example of a humidifying plant distributing the conditioned air by means of ducts. Each unit of the apparatus consists of a large inlet pipe projecting through the roof to a height sufficient to ensure drawing in a supply of cool air. This inlet tube contains a spiral steam heating coil so arranged as to ensure that the air shall come into intimate contact with the hot surface of the metal. At this point the air enters a cooling chamber consisting of a large rectangular tank fitted with a patented spraying device. The fan is fixed with its suction side connected to the cooling chamber, and with its delivery tube opening into the top of the main duct. Air blown out by the fan splits into two

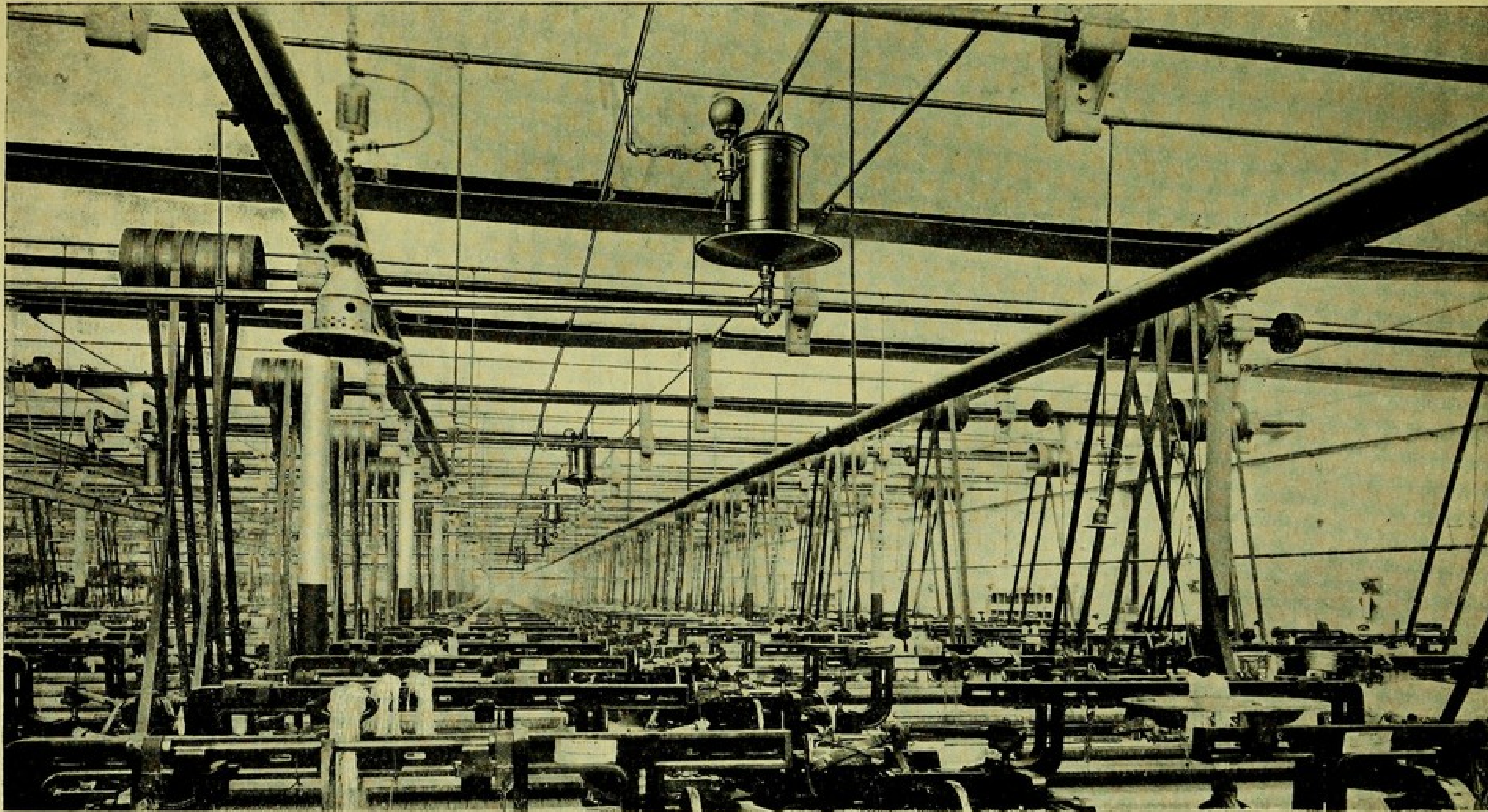


FIG. 28.—Mather and Platt's "Vortex" System. Humidifier installed in weaving shed.

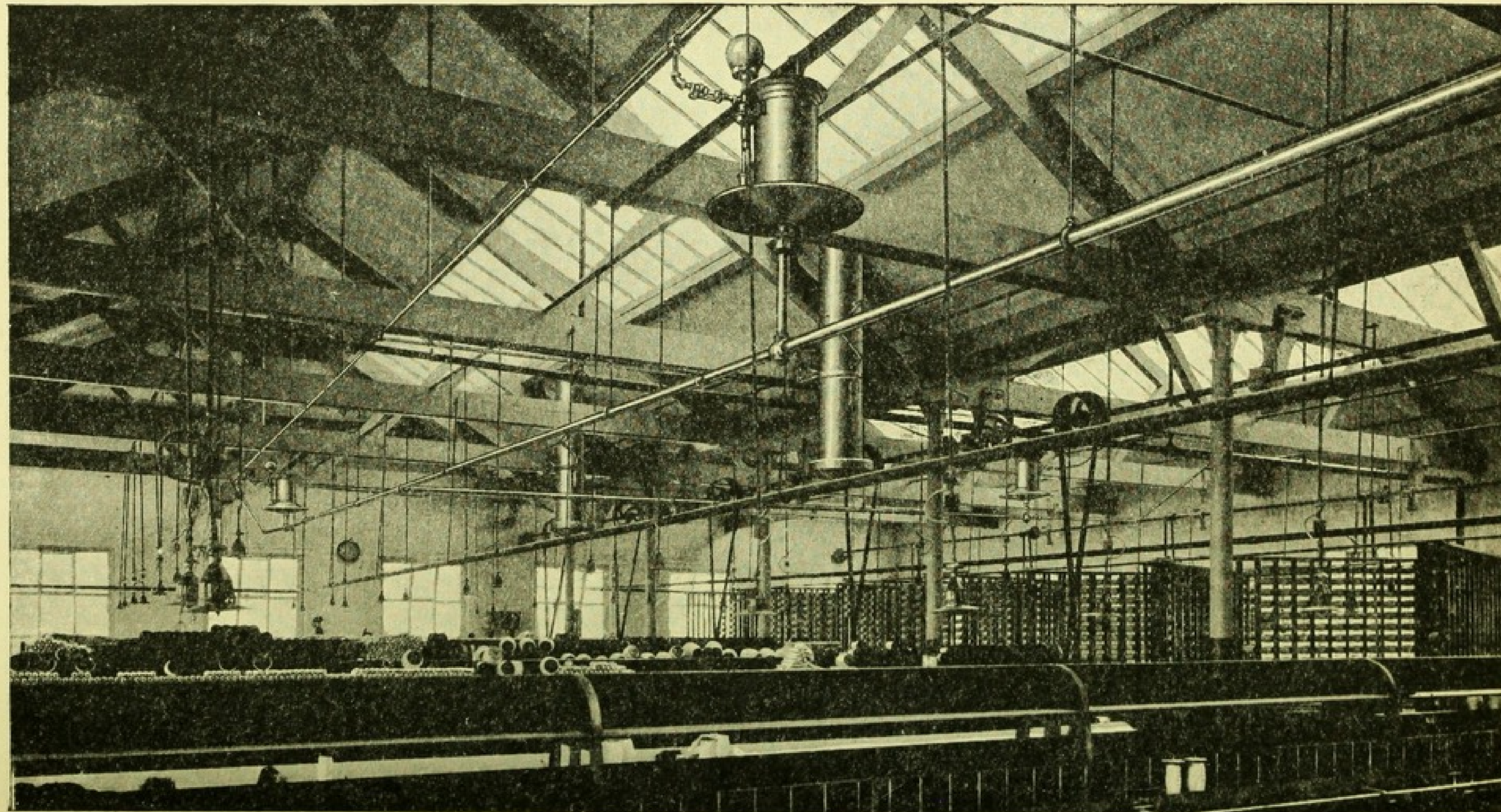


FIG. 29.—Mather and Platt's "Vortex" System. Humidifier installed in winding room.

streams, which flow along both branches of the main duct and out through openings in the sides.

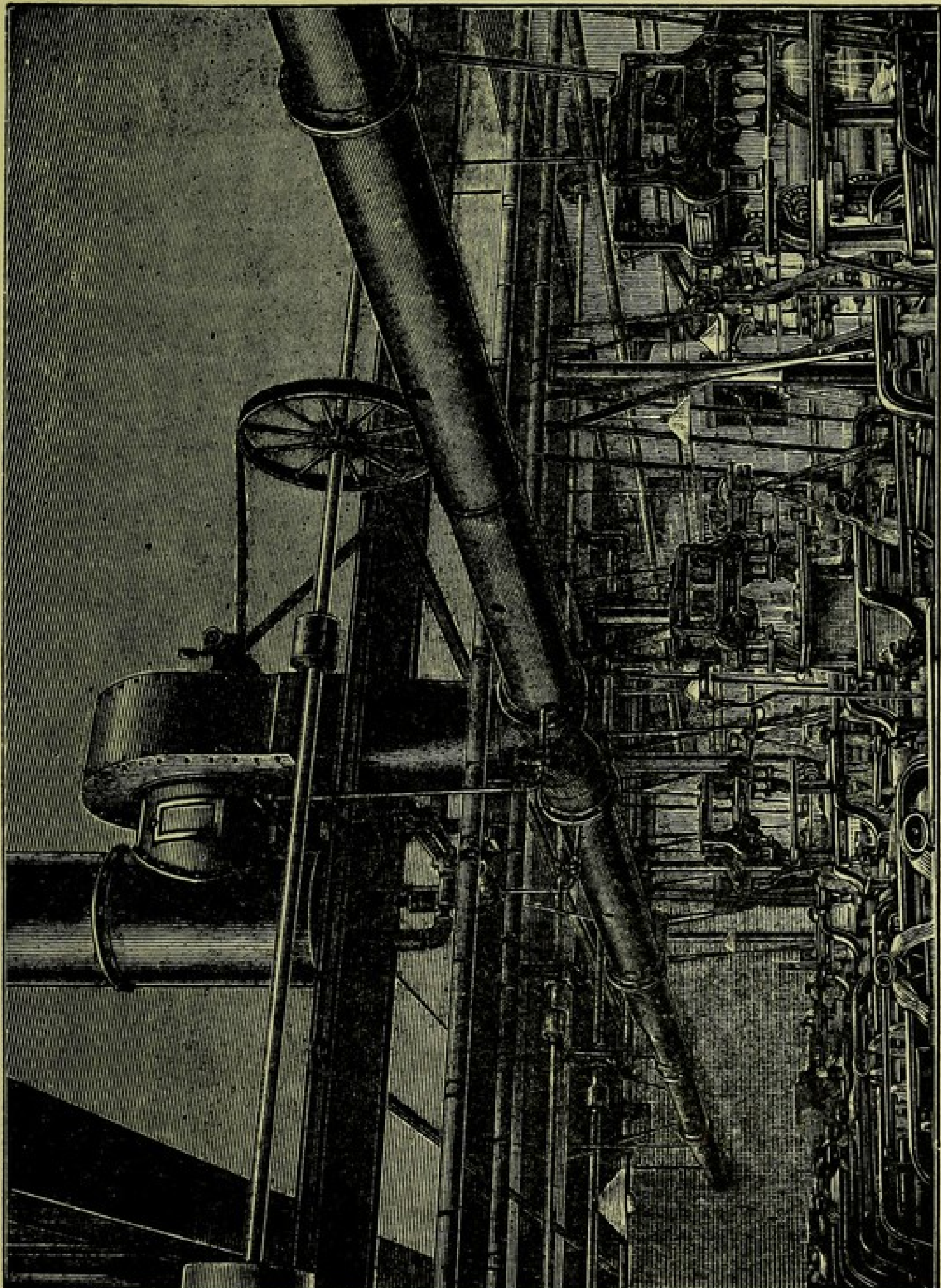


Fig. 30.—Messrs. Matthews and Yates' "Cyclone" Humidifier installed in weaving shed.

Humidification is effected by two steam nozzles fitted inside the distributing pipe immediately below the fan, one facing each way and each being under separate control. Water-sprays are also installed close to the steam jets so that water humidification may be adopted either wholly or in part during the hottest weather. The ducts are of sheet zinc, and are therefore very

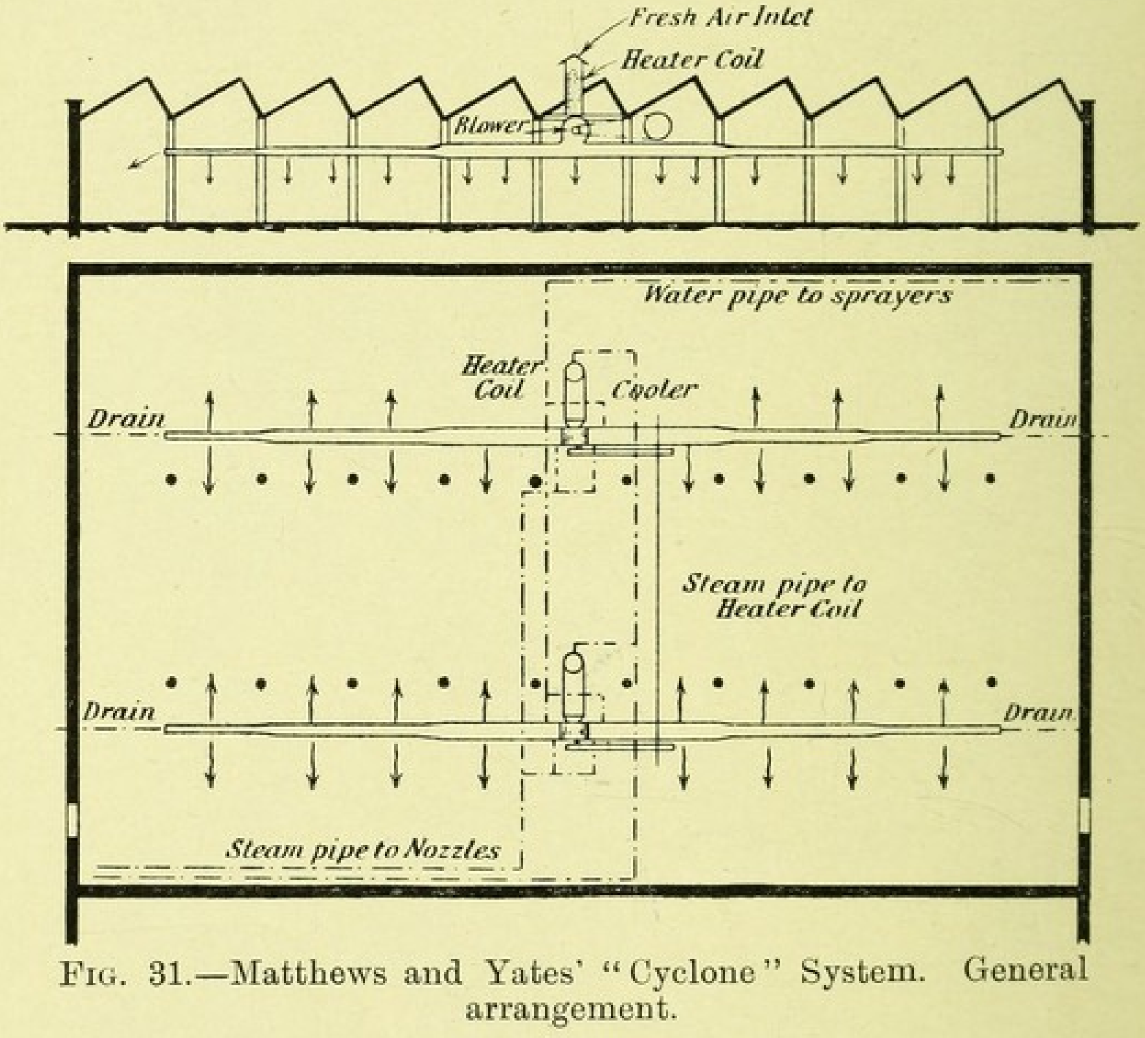


FIG. 31.—Matthews and Yates' "Cyclone" System. General arrangement.

durable. They are carried by light hangers from the roof principals. The fan and inlet coil are usually mounted upon a light platform carried by the girders which support the roof. Sliding doors are provided at intervals along the top of the ducts, etc., so that little trouble is experienced in cleaning out the apparatus at frequent intervals. Fig. 30 is a photograph of the humidifier as installed in a weaving shed. When applied to spinning, preparing, and other rooms, the air is brought from a window instead of being drawn

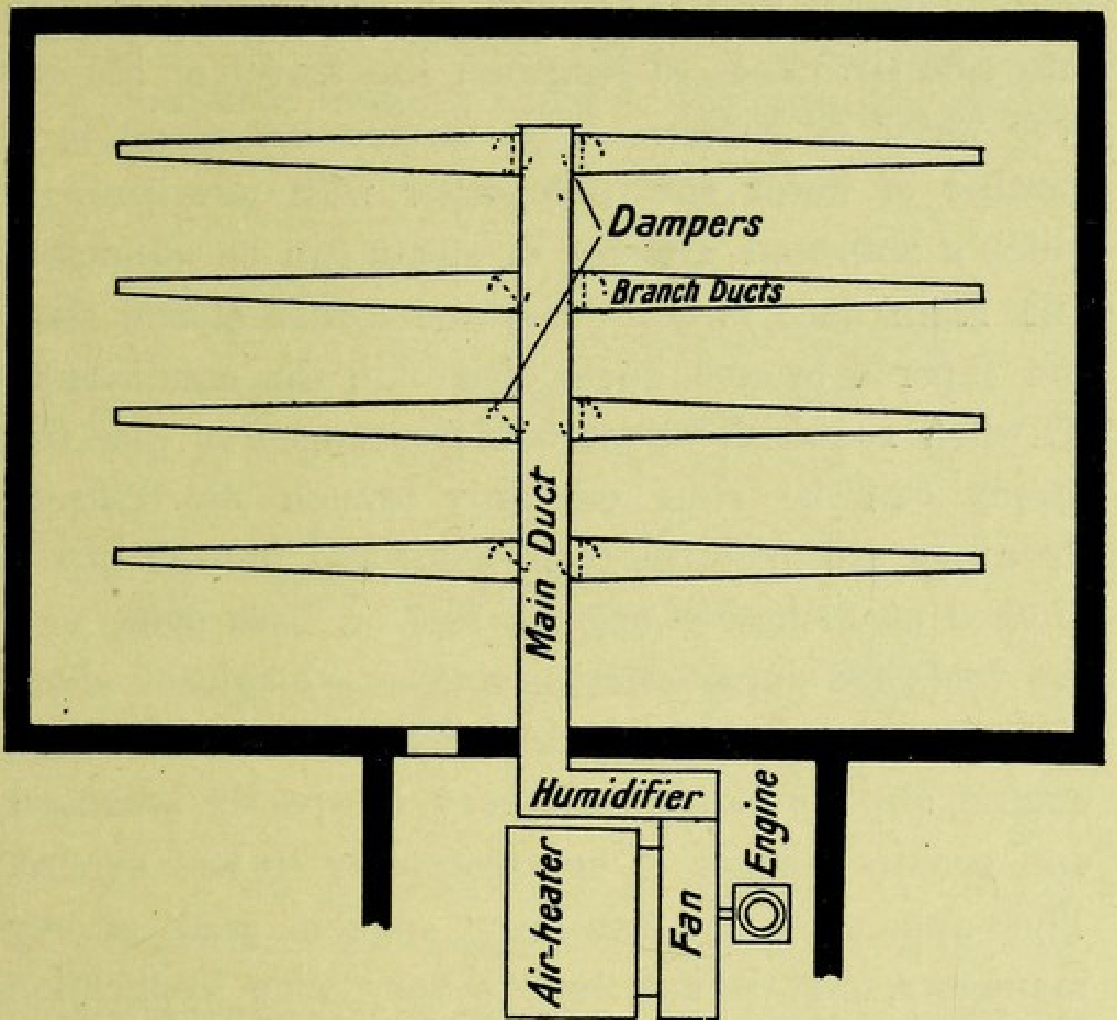


FIG. 32.—Parsons' Humidifier. Diagram of general arrangement of apparatus in weaving shed.

through the roof. Fig. 31 shows a portion of a weaving factory in plan and section in which two complete cyclone plants are installed.

Parsons' System.—This apparatus, a general arrangement of which is shown in Fig. 32, is an example of a duct system in which the humidifier proper, together with the fan and small engine for driving the same, are usually installed in a separate room outside the factory. The suction side of the fan is connected up to draw air over a tubular heater. It then passes into the mixing box, which is divided into compartments to lengthen the travel of the air over water or steam. This mixing box contains a number of water sprays together with jets through which a sufficient amount of steam can be admitted. The main duct is led down the centre of the shed and tapered branch ducts distribute the conditioned air when required, valves being arranged so that the supply can be shut off any branch as desired. Openings are made in both main and branch pipes, pitched at distances of four feet on both sides, and the ducts are slung from the roof at a height of about eight feet above the floor level The heater, fan, engine, and humidifier are very compactly arranged and occupy a space of approximately 10 feet square. The apparatus is generally spoken well of by managers, and it has had a very wide application in factories of the Lancashire and Yorkshire district.

Pye's "Unique" Humidifier.—This interesting apparatus is installed in a number of mills and factories, but since the death of the patentee in 1906 the business has been discontinued. It consisted of a circular mixing chamber lined with porous material, two doors being arranged for inspection and cleaning purposes. The inlet contained a fan or blower together with a steam heating coil, if required. Two injectors were installed in the mixing chamber, one of which was connected up to the water main and discharged a finely divided spray. The second injector, shown in section in Fig. 33, discharged into the centre of three conical rings B. A current of air was therefore induced through the annular orifices,

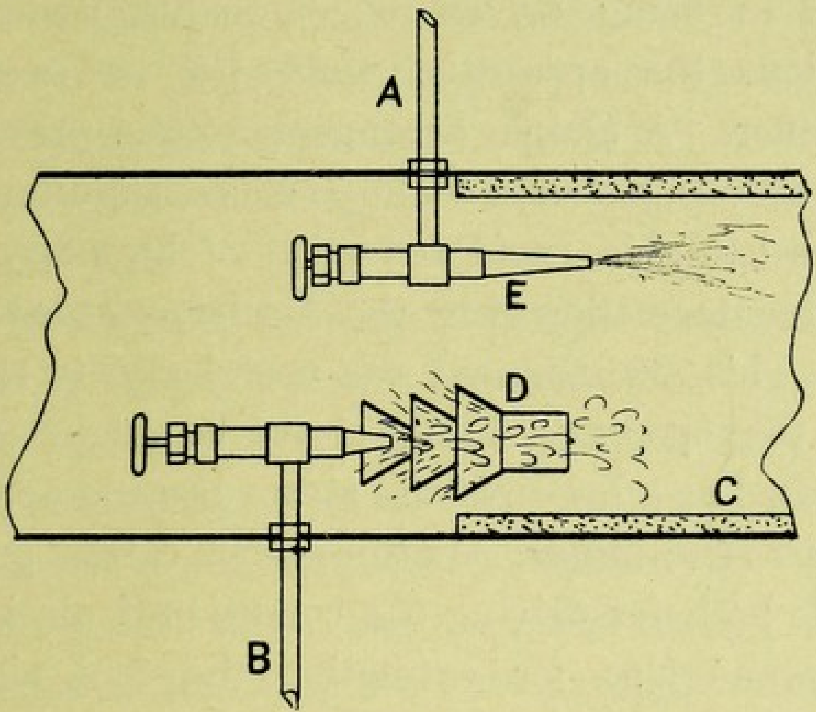


FIG. 33.—Pye's "Unique" Humidifier.

A, Water inlet; B, Steam inlet; C, Porous lining six feet long; D, Steam and air ejector cones; E, Water spray nozzle fixed over steam ejector but slightly in front, so that the steam has to pass through the water.

thus tending to the rapid diffusion of vapour in the ventilating air. The distribution of air inside the factory was effected by means of ducts provided with openings which could be partially or wholly closed by sliding valves. The apparatus could be arranged to recirculate a portion of the air if desirable, which is frequently the case during a cold winter night. No fouling of the atmosphere is going on since the operatives are not present in the factory, and the most economical means of maintaining temperature is to recirculate, passing the air over the steam coils. The blowers of Pye's apparatus could be reversed, so that air could be ejected from the shed instead of being driven in; of course, under these conditions the apparatus could not be used as a humidifier. A simple arrangement was provided by which all air apertures could be closed simultaneously, thus assisting in rapid reduction of humidity should the percentage allowed by the Act be exceeded at any time. This arrangement was useful also in spinning mills, the openings being closed at night and the pipes used as a low-pressure steam heating apparatus.

Pal's Humidifier.—In this system careful provision is made both for driving the conditioned air into the factory and also for extracting the foul air. Air, drawn from a sheltered place at the outside of the building, is first washed and filtered by passage through a revolving screen and a fine spray of water. It next passes through coils, which can be heated by exhaust steam in the winter or cooled by ice water during hot weather, and is then delivered to main ducts running along the shed near to the roof. At intervals along this main duct steam turbine-driven fans are situated, which drive the air into branch ducts, the volume being under control. If additional moistening or heating is required the exhaust from these turbines is injected into the branch ducts.

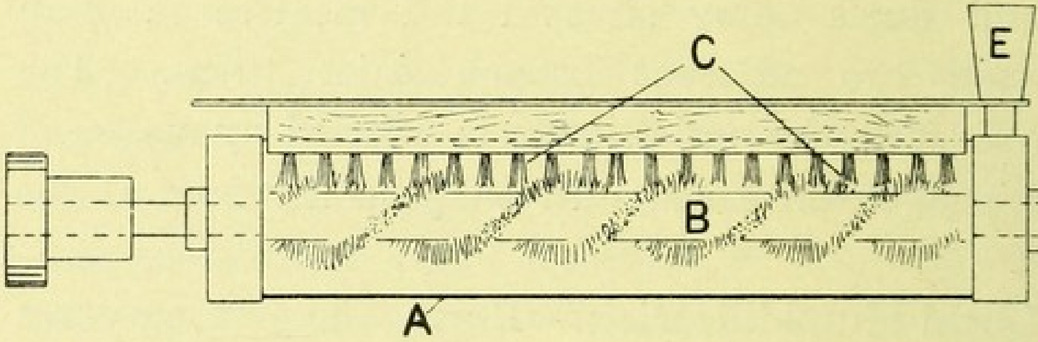
Outlet for vitiated air is provided for by underground ducts communicating with the factory by means of gratings in the floor. The gratings are so arranged that short circuiting of air from the inlet ducts is reduced to a minimum, the lines of underground ducts being situated intermediate in plan between two adjacent branch inlet tubes. The exhaust from the outlet ducts is effected by means of additional steam turbine-driven propeller fans at the ends.

Local Humidification.—During the past few years several systems of local humidification have been introduced, the principle being to confine the moisture to the atmosphere surrounding the warp yarn, since it is at this point where it is required, its existence over the whole shed being a disadvantage hitherto considered inherent to the weaving of fine linen and heavily sized cotton yarns.

Other advantages of this method are that with some of the systems the moisture can be adjusted to the requirements of each particular warp, since it often happens that the yarn on one loom may be soft, whilst that on its immediate neighbour may be dry and hard. Where two classes of fibre such as cotton and linen are woven in the same shed its advantages are even more apparent.

Local humidification may possibly offer a solution of the steaming difficulty in the future, but at the present time the method has not been adopted on any large scale.

British Humidifier Company.—This machine has been designed for the direct application of moisture to the warp yarn during the process of weaving cotton, linen, and wool; it can also be used to distribute oil



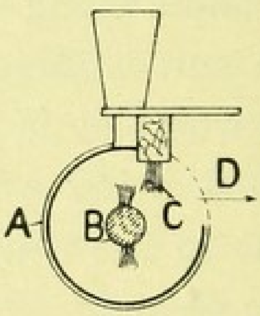


Fig. 34.—The British Humidifier Company's Warp Moistener.

A, Brass distributing tube containing water; B, Revolving spiral brush; C, Stationary brush; D, Gauze screen; E, Water inlet funnel.

upon shoddy in willowing machines, and upon woollen slivers as they pass through the gill boxes. The apparatus consists of a brass tube A (Fig. 34) slightly longer than the width of the warp beam. Inside the tube is a spiral brush B, which revolves at a slow speed, being actuated by toothed gearing and pawls from the crank shaft of the loom. The tube also contains a stationary brush C, the bristles of which bear down on those of the revolving brush. As the latter revolves particles of water are flicked off and pass through an opening in the side of the brass tube, the opening being covered by a fine gauze screen. The water supply is provided by a small depth of water at the bottom of the tube, this being replenished by hand about twice per day, overflows being provided

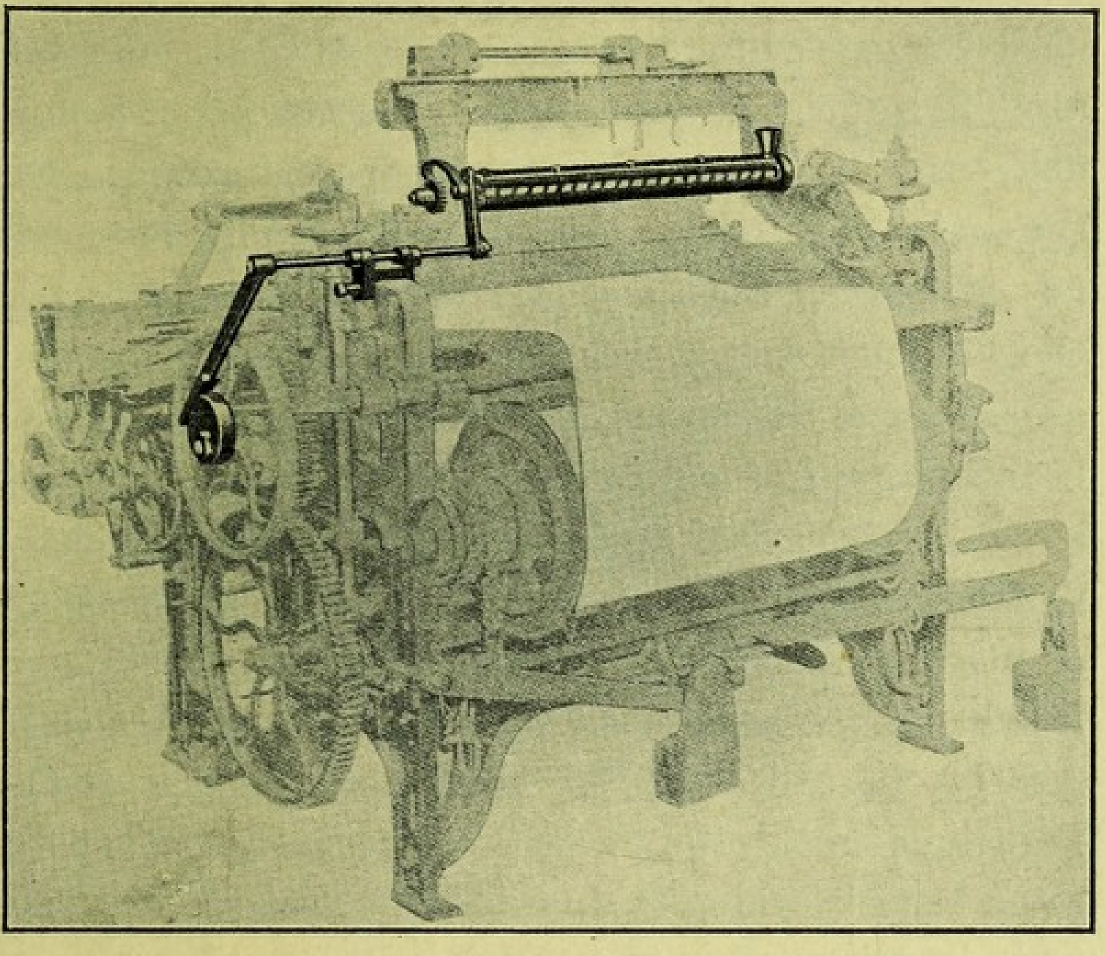


Fig. 35.—The British Humidifier Company's Warp Moistener fitted to loom.

so as to obviate any spilling of water about the warp yarn. The volume of spray delivered can be adjusted by altering the bearing pressure exerted between the two brushes, this being effected by adjusting screws,

H

causing the stationary brush to advance or to recede as required. The machine can be attached to almost any loom, and is supplied by the makers complete with cam and driving gear, brackets, water feed, and overflow pipes, etc. Fig. 35 illustrates the method of driving and attachment to the loom.

Hargreave's Patent Warp Moistener and Humidifier.—The complete installation for a weaving shed consists of an air compressor, with air chamber and filter of size proportionate to the number of looms, delivering air to a main supply pipe extending down the centre of the shed. From this main pipe branches are laid along the alleys between each row of looms, the branches being either overhead or underground according to the circumstances of each case. These branches are in turn connected to the warp moisteners by drop pipes half an inch in diameter. The warp moistener extends along the warp threads, and consists of a slotted tube containing filtered water, and connected at the end to an induction tube and nozzle. Air passing through the contracted portion of the induction tube draws water through the nozzle, at the same time breaking it up into a fine mist-like spray. This is delivered uniformly along the whole width of the warp. A regulating device consisting of a pivoted damper can be set to control the amount delivered, from zero to a maximum, the amount of opening being indicated by a pointer moving over a scale.

Any moisture not emitted through the slotted tube is filtered and returned to the water chamber to be again recirculated. All the air is filtered before entering the main pipes, the filtering chambers being fitted with an arrangement for heating the incoming air in winter and cooling it in summer. The system has the merit of flexibility; being adjustable between wide limits it will no doubt be most valuable in preventing a shed from reaching high wet-bulb temperatures, since the cooling effect of any water not absorbed by the warp will by its evaporation tend to lower the temperature of the factory.

Heenan and Froudes' Local Humidifier.—In this apparatus, which was originally intended for general humidification, the air is passed over a large surface of water, which can be warmed if necessary. It is then conducted through pipes A (Fig. 36) to T-shaped headers B, from which it is blown directly on to the warp yarns. These headers are connected to the main ducts by flexible tubes, so that they can be slung out of the way when putting on fresh beams. The cross-sectional areas of the ducts are so proportioned as to supply a constant volume of humidified air to each loom. The humidifier proper has also been largely used for cooling gas-engine jacket water, condensing water, etc. It consists of a number of concentric cylinders A (Fig. 37), mounted upon a skeleton frame carried by a shaft B. The lower ends of these cylinders are immersed in a tank of water which contains a steam heating coil. Air is blown

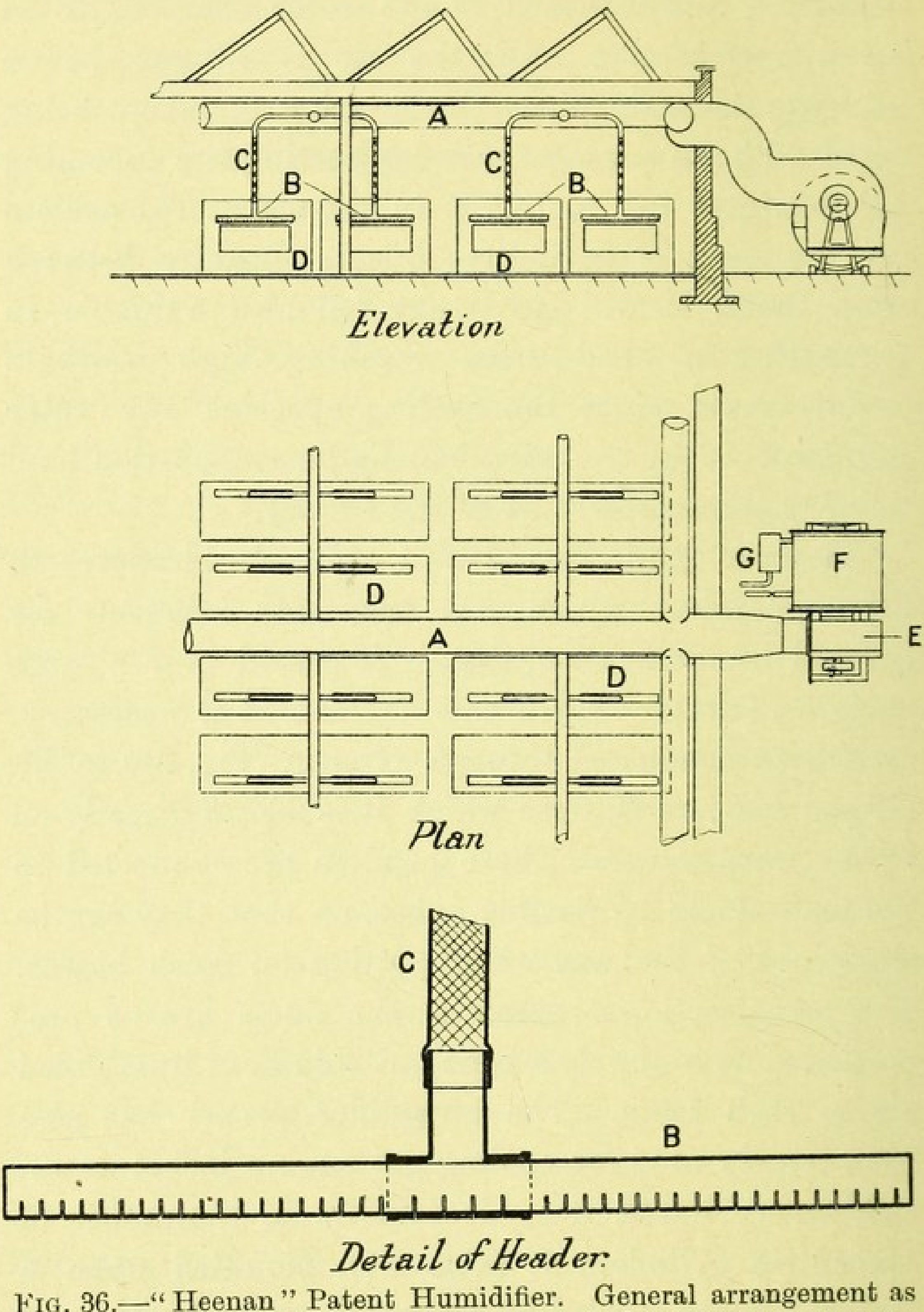


Fig. 36.—"Heenan" Patent Humidifier. General arrangement as applied to a weaving shed.

A, Main duct; B, T-shaped distributor; C, Flexible pipe D, Loom; E, Fan; F, Humidifier, see Fig. 37; G, Ball-controlled supply tank.

through the upper portions of the concentric cylinders, which slowly rotate, and are thus maintained in a moist condition. If cold water is used the air on leaving the machine is saturated, and has a temperature at or about its initial wet-bulb temperature, and by heating the water it can be saturated at higher

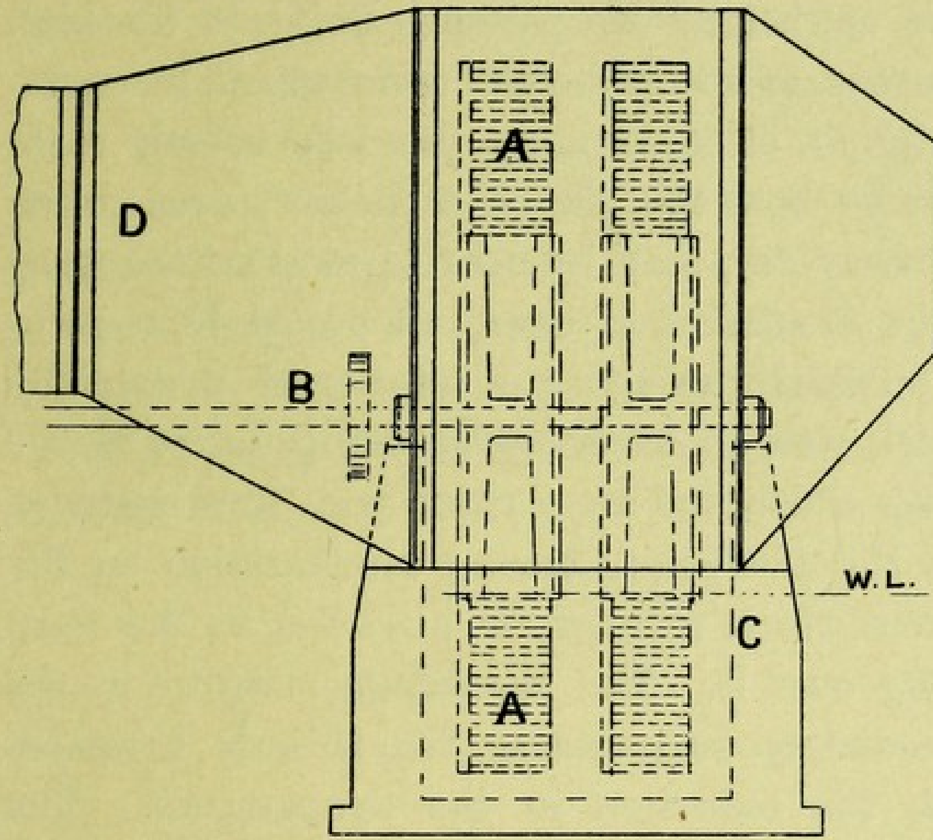


FIG. 37.—" Heenan " Humidifier.
A, Concentric sheet-metal cylinders; B, Shaft revolving slowly; C, Water tank containing steam coil; D, Inlet for unconditioned air; E, Outlet for conditioned air.

temperatures. If the level of the water is altered so that some of the inner cylinders are not immersed the air can be conditioned to practically any combination of dry- and wet-bulb temperatures desired. This is governed by a ball valve so designed that its working height can easily be adjusted. The machine is thus very flexible, and should do much to solve the problem of high wet-bulb temperatures in weaving factories.

Hart's Patent Cooling and Humidifying Back Rest.—This interesting apparatus, whilst effecting its purpose most efficiently, has not been placed upon the market by the patentee owing to the high cost inherent to the principle upon which it works. A description of it is none the less useful, since it illustrates how the air of a factory, even when comparatively dry, may be used to moisten the warp threads in an efficient manner. A cooled brine solution is pumped through the interior of a specially made back rest, so lowering the temperature of the metal over which the warp yarns pass to a point at or below the dew point, causing condensation on the roller, from which moisture is absorbed by the warp in passing over it. The percentage moisture of the air immediately surrounding the threads increases owing to the reduction in the temperature. The warp yarn then is passing through an atmosphere of high humidity and its moisture is maintained. On leaving the back rest the yarn commences to dry, but is woven into the cloth before sufficient time has elapsed for this to become serious. The only bar to the adoption of such a system on a large scale is the exceedingly high cost of providing and running a refrigerating plant.

Underground Ducts.—In several factories in Great

Britain and abroad the distributing ducts have been arranged under the floor of the factory, humidification being effected either by steam or by atomized water. In some cases a grid has been provided under each warp beam, the method then becoming one of partial local humidification. The system has advantages, since it has been found possible to run the main shed with a greater difference in the bulb readings than would otherwise be necessary for the class of goods woven. It has also the advantage of occupying none of the space above the looms whilst forming an efficient duct system. Its one drawback appears to be that the ducts, unless made excessively large and therefore being very expensive to build, are difficult to keep clean.

CHAPTER III

TEMPERATURE CONDITIONS IN TEXTILE FACTORIES AND MILLS

Temperature Conditions in Textile Factories and Mills—Sources of Heat in Weaving Sheds—Shed Constants—Quality of Lagging on Steam Ducts—Whitewashing Slates and Windows—Methods of Cooling—Tests for Efficiency of Lagging—Electrical Method of Checking the Test—Recommendation of the Departmental Committee.

The dry-bulb temperature of rooms where textile manufacturing processes are carried on varies between wide limits, both during any one day and also from day to day.

Certain characteristics of the temperature variation curve are, however, always present. Considering, firstly, a weaving shed run under either dry or humid conditions, the temperature invariably has its minimum value at the commencement of the working day. When the machinery is started, a rapid rise occurs and is maintained until work ceases for the breakfast interval. The temperature then falls, as shown in Figs. 38 and 39, until the looms, etc., are again started. A rise then continues during the whole of the morning, the rate of which is less than that during the first period of the working day. A

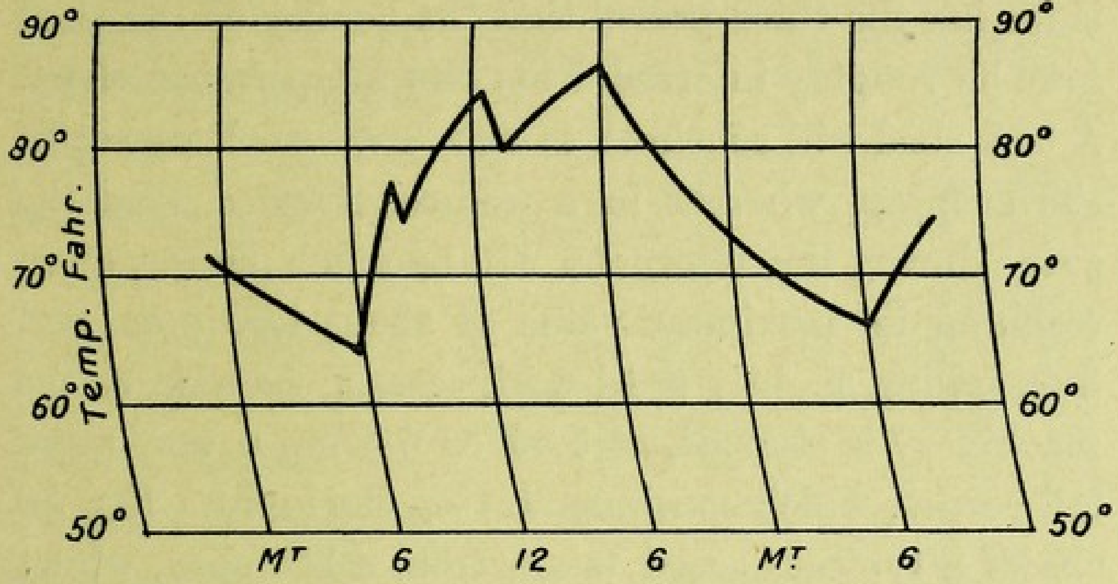


FIG. 38.—Temperature Record taken in a Hot Weaving Shed. The temperature rises rapidly whilst work is in progress, and falls during meal intervals. The maximum is reached at the end of the working day.

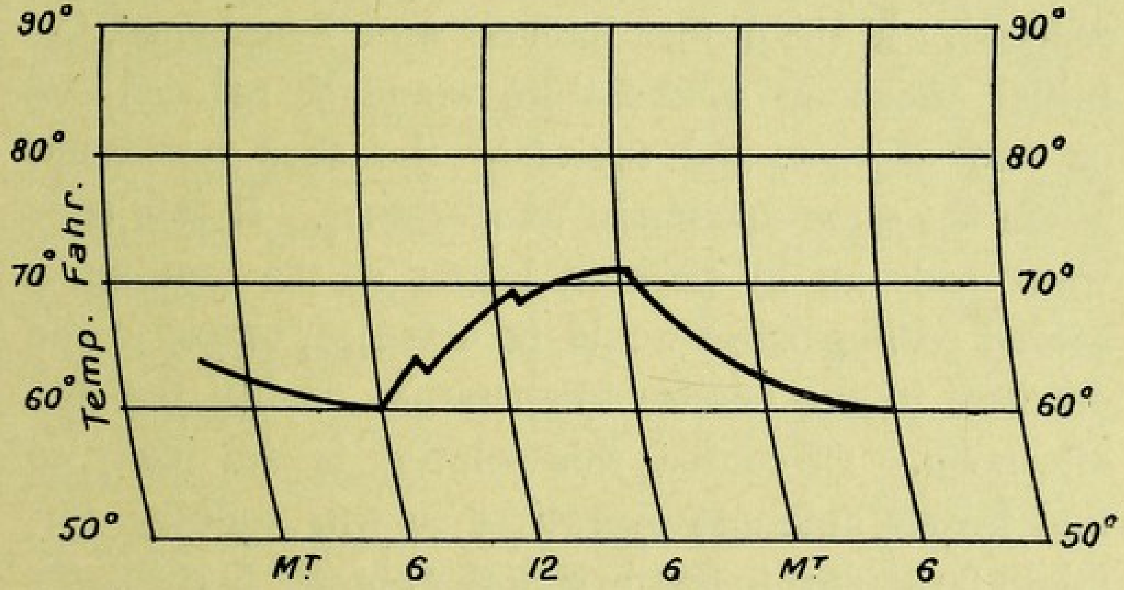


FIG. 39.—Temperature Record taken in a Cool Weaving Shed. The temperature rises more slowly, and reaches a lower maximum earlier in the afternoon.

second fall in temperature occurs during the dinner hour, after which the rise is continuous during the afternoon, the rate being again less than that experienced during the second or morning period. It is during the third period that the quality of the shed may be roughly inferred from one temperature chart. A bad shed will continue to rise until work ceases in the evening, whereas in a well-constructed shed the curve during the afternoon will be much flatter, often reaching its maximum value at about 4.30 p.m., and then falling slightly until work ceases. As soon as the machinery is stopped, at 5.30 or 6 p.m., a very rapid fall occurs, which continues during the night. Fig. 38 shows a typical record taken from a hot shed, whilst Fig. 39 is taken from a cool one.

The above characteristics immediately suggest a method whereby the maximum temperature might be reduced. If the dinner interval were lengthened, the initial afternoon temperature would be reduced one or two degrees, and therefore the shed would not attain the same maximum temperature. If this time were made up by working longer in the evening, a second cooling effect would be obtained, owing to the decrease in the outside temperature during the late afternoon. Of course, this solution is not likely to find favour amongst operatives in this country, but might be applied to textile factories abroad, particularly those in the tropics.

In spinning mills the conditions are much more regular, although the temperatures are usually higher. Fig. 40 is a typical record taken from a mill using the wet process. It will be seen that the minimum temperature occurs at about 4.30 to 5 a.m., and is immediately followed by a sharp rise. This rise is due to the watchman or other person turning on steam to the spinning troughs. When work commences a fall is noted, although the actual heat generated or introduced is greater by the heat of the operatives and the machinery heat. The fall is caused by the starting of the ventilating system, the capacity of which, unlike that in the weaving shed, is of sufficient size to cool the room down appreciably. The

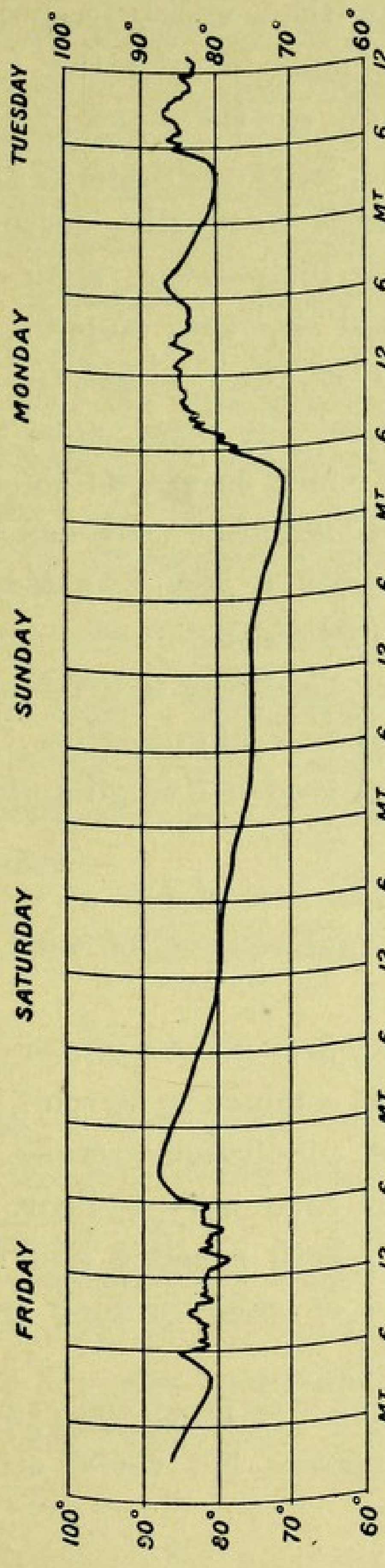


FIG. 40.—Temperature Record taken in a Wet Spinning Mill. The minimum temperature is reached at about 4.30 a.m., when a rise occurs owing to the steam being turned on in the troughs. A fall takes place when work, and consequently the ventilating system, is started. The temperature then varies irregularly during the day, and again rises when work ceases, owing to the stoppage of ventilation. The rise continues until troughs and room reach steady conditions at about 8 p.m., when a steady fall continues during the night.

temperature then varies irregularly during the day, it being difficult to infer the meal hours from any characteristic of the curve. On stopping work in the evening, however, a sharp rise again occurs, the rate of which gradually decreases until at about 8.0 p.m. the temperature again falls. This rise can be explained by the stopping of the ventilating system. Hot water remaining in the troughs continues to heat the room until a steady temperature is reached, which occurs, as we have seen, about two and a half hours after work has ceased.

The sources of heat in a textile mill or a weaving shed are as follows :—

1° Power necessary to drive machinery.

2° Bodily heat of operatives.

3° Steam used in "conditioning" air, or in heating troughs.

4° Radiant heat of sun.

5° External sources of heat, *e.g.* adjacent boiler houses.

Heat may flow out of a mill or shed by several routes.

1° Direct conduction to roof.

2° Direct conduction to walls.

3° Direct conduction to floor.

4° Heat, both sensible and latent, carried in air flowing out of shed through interstices or through exhaust fans.

The problem is much too complicated to admit of direct calculation, but useful estimates of the law of variation of maximum temperature may be obtained in the case of a weaving shed; thus, neglecting conduction through walls and also heat carried away by escaping air, we may consider the shed as lying between two planes at different temperatures. The plane corresponding to the subsoil will have a temperature which is sensibly constant from day to day. The other plane, *i.e.* the roof, will then be at a temperature which for the purpose of this estimate may be considered as the mean temperature during any one day. If, then, t_m represents this mean temperature and θ represents that of the subsoil, the shed will tend to a mean temperature of $\frac{t_m + \theta}{2}$ when work is not in progress. The increase in temperature above this during working hours is caused by the machinery heat, etc., and will be sensibly constant from day to day.

The max. temperature will be given by $C + \frac{t_m + \theta}{2}$

or $t_{max.} = a + \frac{t_m}{2}$.

The constant a will be characteristic of the shed, *i.e.* in a good shed it will have a low value, whilst in the case of a hot shed "a" will be greater. Values of these constants for certain sheds have been determined and found to be about 50 for an average shed and 55 for a hot shed. The mean temperature outside, *i.e.* t_m, was taken as the average height of the outside thermograph record between 6 p.m. and 6 p.m., but a sufficiently good approximation may be obtained from the mean between the outside maximum and minimum.

On a sunny day the temperature will rise above that given by the formula by an amount which depends upon the season and on the number of hours of bright sunshine. During the summer months the expression then becomes $t_{max} = a + \frac{t_m}{2} + ch$.

h = no. of hours of bright sunshine.

c = about 0·4.

Thus on a day of continuous bright sunshine, say from 4 a.m. to 6 p.m., *i.e.* 14 hours, the maximum temperature in the shed will be increased by 5° or 6° F., owing to solar radiation alone. On such a day the mean outside temperature would be higher than on a day of no sun, so that a second increase in temperature would be introduced owing to the higher air temperature. On a day when the outside mean temperature is great the maximum temperature attained in the factory will naturally be larger than on days when the outside mean temperature is small. The difference, however, between the inside maximum and outside mean is smaller on days of high mean outside temperatures; in other words, the inside maximum increases with, but at a slower rate than, the mean outside temperature. The reader must be warned against attaching too much importance to the above formula, although it proved of great value in tracing the effect of experimental alterations to sheds during the investigations of the Departmental Committee.

In estimating the effect of an experimental plant intended to cool a shed, it will obviously be useless to compare the difference between the inside maximum and outside mean temperature taken on days with and without the plant running, unless the outside temperature on the days compared happens to be the same. If we compare the difference between the inside maximum and half the outside mean temperatures, or in other words, find the value of the shed constant "*a*" on days with the cooling plant in action and compare it with that found on days when the plant is not working, we are, within reasonable limits, independent of weather conditions, and the difference between the two values of "*a*" will be a direct measure in degrees of the value of the apparatus as a cooling agent.

A better method of investigation is to select two sheds close together, and as far as possible similarly situated. If records be taken over a considerable period in the two sheds, it will be found that the difference between the daily maxima will be sensibly constant, *i.e.* one shed will always attain a temperature perhaps one or two degrees above the other. The experimental alteration is then carried out on one of the sheds and records again taken in both for a sufficiently long period. If the experiment be a successful one the temperature of the shed will be reduced and a measure of its effect can be obtained by comparing the differences between maxima in the two sheds before and after the alteration.

Considering now the sources of heat. The power necessary to drive the whole of the machinery within the shed will appear as heat, since energy goes in as work and none reappears in the potential form. Each horse-power will introduce 2540 B.T.U. per hour, and it can be shown during cloudy weather that about two-thirds of the total heat generated in the shed is due to this cause. The bodily heat given off by the operatives will account for about one-sixth of the total, and, provided the pipes are well covered, the steam-jetting system will only account for one-sixth. If the quality of the lagging is poor, or if it has seriously deteriorated, the heat introduced from this source may be three times as great, or in other words, may amount to three-eighths of the total heat generated in the factory.

An example showing the effects of the four sources of heat and the cooling effect of one change of air per hour is given in Fig. 41. Since the total amounts of heat introduced or abstracted are directly proportional to the number of looms in the factory, the diagrams are drawn for each set of four machines, and it is assumed that the four looms are tended by two operatives. A length of 18 inches of steam pipe covered with lagging of average quality has been allowed to each loom, and the cubic capacity of the shed per loom has been taken as 800 cubic feet. The heat given off by the operatives cannot be exactly calculated, since, as has been shown

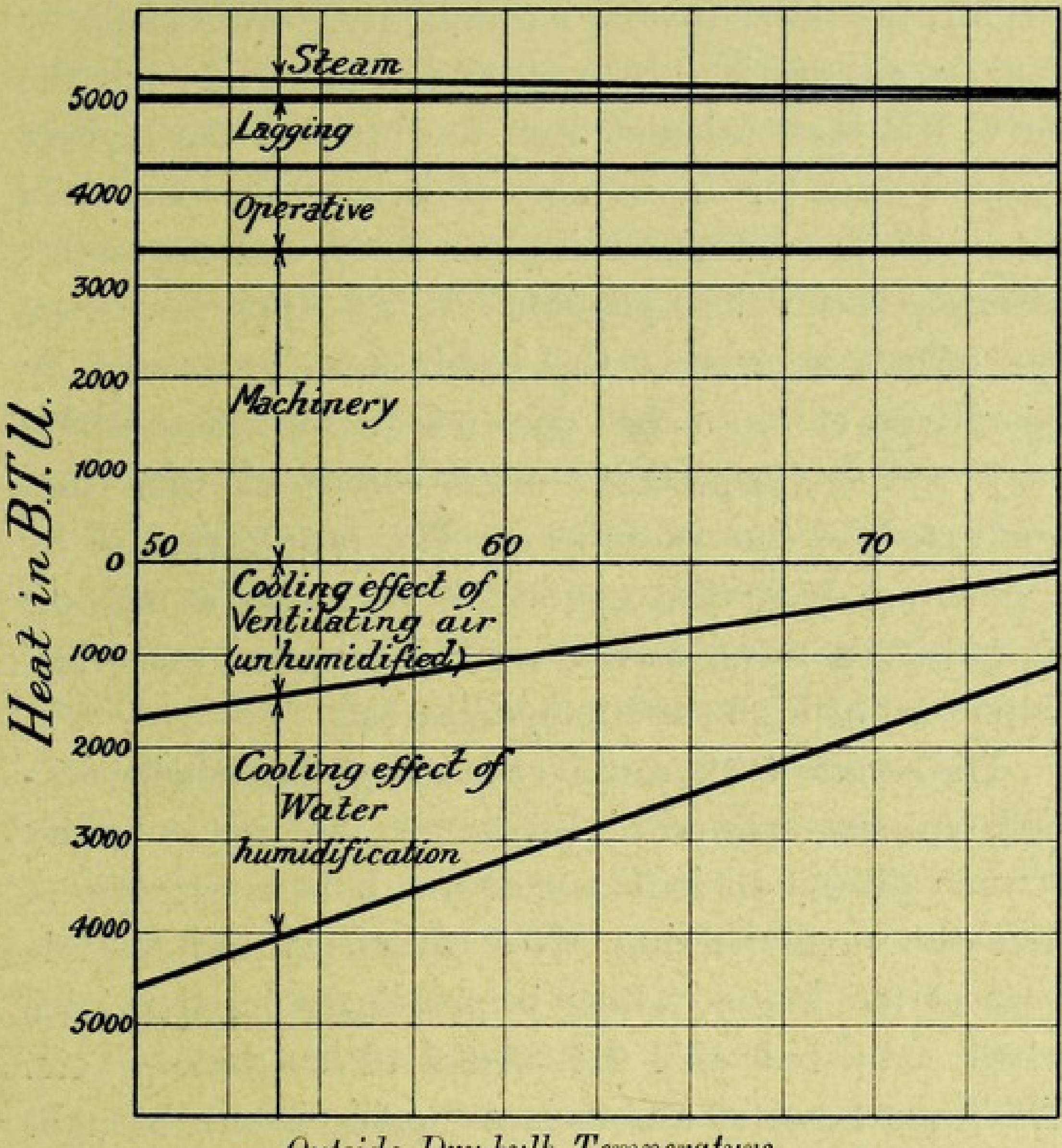


FIG. 41.—Curves showing approximately the heat introduced into a shed per hour for each set of four looms on a cloudy day, also the cooling effect of ventilating air unhumidified. The additional cooling effect of humidification by water atomization is also clearly shown. The rate of ventilation has been taken as one complete change of air per hour, and it is assumed that by some external means the temperature of the shed is maintained constant at 77° dry, 73° wet. The percentage humidity outside has been taken as 66 per cent.

in Chapter I., the bodily heat is dissipated partly by direct conduction, etc., and partly by evaporation, the former going to raise the temperature of the surrounding air, the latter raising its humidity. Data given by various authorities are somewhat conflicting, but the curve has been calculated on the basis of the highest figure quoted for the number of British thermal units given off per human being per hour, and no underestimate is therefore possible. This is important since the curves show that the bodily heat generated by operatives, etc. in a shed does not amount to anything very serious, especially when compared with that generated by the machinery. The heat given off by conduction from the operatives decreases as the air temperature rises, and therefore becomes even less important at high shed temperatures.

The results are plotted on a base showing outside dry-bulb temperatures, and it is assumed that the humidity of the external air is 66 per cent. It is interesting to note the small heating effect caused by the sensible heat of the steam, which is practically inappreciable when compared with the effects of machinery, etc. The importance of an efficient lagging is also brought out by the curves, and it will be seen that, considered from the shed temperature point of view, the heat radiated from the external surface is the chief disadvantage attending humidifiers which require the introduction of steam pipes into the shed itself. The large part played by ventilation in preventing the rise of temperature is also apparent from the diagram, although this falls off as the outside mean temperature approaches the temperature of the shed. Again, if the ventilating air be humidified by cold, atomized water, the cooling effect will be sufficient to neutralize the machinery heat when the external temperature is in the neighbourhood of 60° F., and even under high mean temperature conditions the ventilating air humidified by atomized water will still be able to counteract about two-thirds of the heat due to the horse-power absorbed. If the external air be drier than that taken for the example the heat due to sensible heat of the steam will be slightly increased, owing to a greater weight of vapour being required for humidification, but the net heating effect will still be small. On the other hand the cooling effect of atomized water will be greater. If the shed temperature is higher than that taken in the example, the percentage humidity remaining the same, the heating effect from the steam and the radiation from the lagging will be very slightly reduced, but the cooling effect of the ventilating air will be increased. The cooling effect of the water atomization will also be increased, since a greater weight of moisture will be required in order to maintain the relative humidity in the shed, and so more heat will be rendered latent in the factory. The combined effects of the sources of heating and cooling are shown in Fig. 42, the upper line giving the amount of heat which must be extracted through walls and roof in order to maintain the temperature in the shed at 77° dry, 73° wet, when steam is used for humidification, the lower line showing the amount when water atomization is adopted.

The effect of solar radiation has been investigated and found to increase the total rise of temperature during the day by 27 per cent. to 50 per cent. when the roofs are efficiently whitewashed. This effect

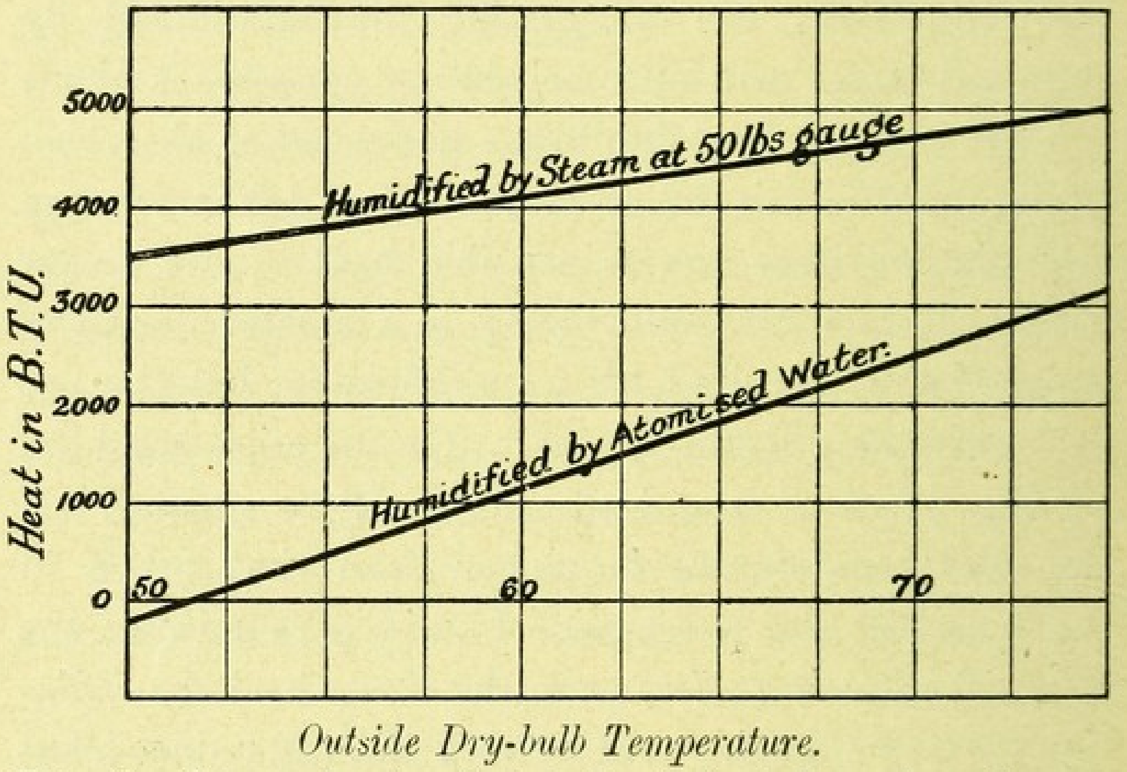


FIG. 42.—Curves showing heat to be abstracted per hour from a shed for each set of four looms if the factory be maintained at a constant temperature of 77° dry, 73° wet, when the shade temperature has values ranging from 50° to 75° Fahr., the percentage humidity outside being 66 per cent.

would be greater if the slates were left unwhitewashed. It is important that the glass of northern-light windows should also be whitewashed during the summer, and it is preferable to execute this on the inside of the window. A considerable quantity of radiant heat can penetrate to the shed through a clear-glass window, being reflected from the white slates to the ceiling and then down into the shed. It is now required by the Factory Act that all windows should be whitewashed, except when it can be shown to the satisfaction of the Inspector that the shelter afforded by other buildings prevents direct rays penetrating at any time during the day. The period during which this is compulsory extends from the 31st day of May to the 15th day of September in each year. Exemption from whitewashing slates is allowed only if the shed is efficiently sprayed with water, except during rain, whenever the dry-bulb temperature in the shed reaches 70° F.

Methods of Cooling.—Experiments were made by the Departmental Committee with a view to determine to what extent the maximum temperature of a weaving-shed in summer might be reduced without reducing the percentage humidity and so detrimentally affecting the quality of the work turned out. It is obvious that this object might be attained in two ways—

(1) By decreasing the rate of generation of heat;

(2) By increasing the rate of abstraction of heat.

With the type of loom at present in use a reduction of machinery heat can only be effected by reducing the number of looms, or in other words, by an increase in the shed volume per loom.

The number of operatives present in the shed depends upon the class of loom used and also upon the goods woven. In Lancashire it is usual for a weaver to tend either four or six looms. In Ireland the maximum number of looms per operative is usually two. Automatic looms, such as the Northrop, are not usually installed in the damp sheds; they require a fairly high quality of yarn and artificial humidity is not usually required. In sheds, however, where Northrop looms are installed, one operative can look after more machines, the maximum being about twenty-four. However, the number of persons present in a factory is comparatively unimportant; as we have seen, only about one-sixth of the total heat is attributable to their presence, and any attempt to reduce machinery heat by increase in capacity per loom will at the same time decrease the animal heat by a proportional amount.

No shed should be planned in such a manner that it is liable to receive heat from boilers or flues. This point, however, has not always had the attention it deserves, as there exist a number of sheds where the excessive temperatures reached on hot days in the summer can be attributed to some extent to the existence of a boiler flue built directly adjoining one wall of the shed. In some cases the main flue actually passes under the floor of the shed to a chimney on the far side.

With regard to the amount of heat radiated from the steam pipes, it was felt that some improvement could be effected by insisting upon a good class of pipe covering, and an investigation was undertaken with a view to determine the best covering available, and also to establish a standard efficiency to which all laggings used in weaving sheds should in the future conform. Manufacturers of covering material were invited, by advertisement, to co-operate in the work, and the result was that the qualities of pipe-clothing materials covering practically the whole range in commercial use were determined.

Each maker was asked to cover two seven-foot lengths of one-inch diameter piping, the pipes being supplied by the Committee. One sample was to be of four inches external diameter, the other to be of any thickness deemed suitable by the manufacturers, this latter to be accompanied by a price for 1000 feet lin. covered at makers' works, including ten right-angled bends.

A standard outside diameter of four inches was fixed in order that direct comparison of the various materials might be obtained; but although in general it is cheaper to install a thin high-class covering, the second sample was allowed since efficiency can in some measure be obtained by a greater thickness of an indifferent covering.

A diameter of one inch was selected for the test-pipe, since this size is generally in use in weaving factories; in fact, the modification of the Factory Act recommended by the Committee, and since adopted, is that no humidifying steam pipe shall exceed one inch internal diameter.

The method of carrying out the test had to be specially devised in order to suit this size of pipe, since the inlet connections and other radiating surfaces in the ordinary steam condensing method would form a very large proportion of the total radiating surface, and would thus involve large corrections. It was decided to use the pipe itself as the collecting vessel. Steam was led in from a separator by a fine copper tube. This copper tube was carefully lagged, and a correction determined for the amount of heat radiated therefrom.

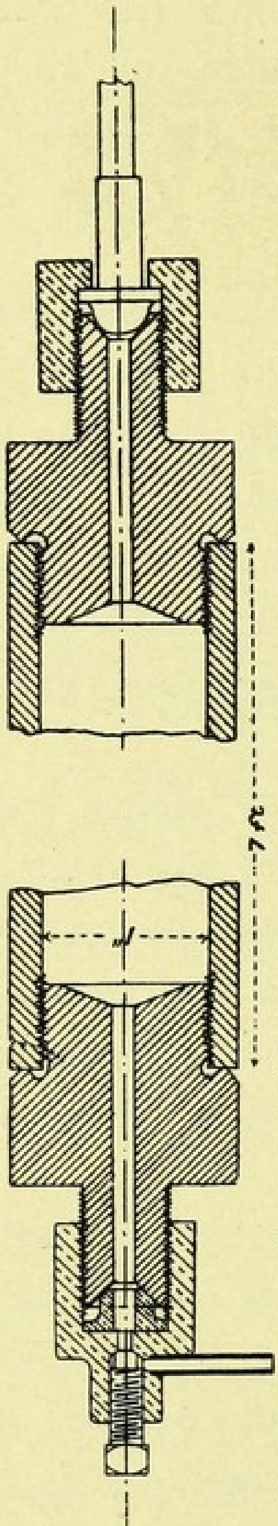


FIG. 43.—Test Pipes used for Steam-pipe Covering experiments. (Condensation method.)

The manner of conducting the test was as follows: Steam was allowed to blow gently through the pipe (Fig. 43) for some hours, in order to obtain a steady temperature in the lagging. At a definite time the pipe was carefully drained and the outlet valve shut off. Steam then condensed in the pipe (the amount condensed being, of course, proportional to the amount of heat given off by the lagging and inlet connections). At the end of a definite period steam was shut off from the pipe by crushing the copper inlet tube in two places. This pipe was then severed between the two closures in order to eliminate inaccuracies by leakage from or to the separator. The test pipe was then allowed to cool, after which the water collected was carefully measured. The method proved very reliable, the wastage of copper tube being justified since it obviated the use of three valves.

The correction for heat lost by the ends and by the inlet tubing was determined by testing a pipe six inches long with the same end fittings and covered with a standard lagging.

If s is the area of the external surface of the pipe, and a, b, are constants, the heat loss from pipes of any length, with the same fittings irrespective of length, can be represented by the following :—

$$H = as + b$$

b will then be the end correction, and from two tests of different lengths of pipe simultaneous equations can be determined which will afford solutions for both a and b.

In experimental work of this character it is always desirable if possible to check the accuracy of any results by an entirely independent method. This was done in the pipe covering testing by the use of the apparatus shown in Fig. 44. A one-inch steam pipe A was closed at the ends by the steel plugs B and C. An inner tube D of thin steel passed through the plug B, a steam-tight joint being obtained by brazing. At the other end of the test pipe the plug C was fitted with a gland and stuffing-box, making a tight joint against the steel tube D. A long coiled resistance of manganin wire was then inserted in the inner tube, being insulated from the metal by a thin tube of glass. An opening in the plug B was closed by a small screw valve, and a copper tube was connected to a sensitive pressure gauge. The manner of conducting the test was as follows: A small amount of water was introduced into the pipe by the valve B.

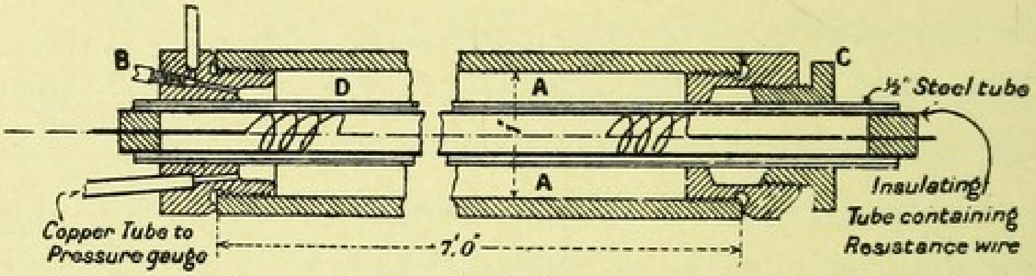


FIG. 44.—Test Apparatus used in Steam-pipe Covering experiments. (Electrical method.)

A, One-inch diameter steam-pipe; B, Steel plug brazed to tube P; D, Thin steel tube containing insulating tube and resistance wire; C, Plug with stuffing box and gland.

An electric current was allowed to flow through the resistance wire, so heating it and generating steam in the pipe A. The valve B was allowed to remain open until all air had been blown out. This valve was then shut and the current adjusted so as to obtain a steady pressure of steam in the steam space. This was maintained for some hours in order to ensure steady temperature conditions in the lagging. The only readings required were the current, the electric motive force, and the steam pressure when steady. From the two former the heat loss was calculated, and from the latter the temperature of the pipe was deduced, being that corresponding to the pressure of saturated steam. As before, the corrections for end effects, etc., were obtained by testing identical coverings applied to two lengths of pipe, these lengths being 7 feet and 6 inches respectively. The two methods of test gave results which showed a very good agreement. It was found that the total loss of heat per square foot of external metal surface of the covered pipe was proportional to the difference between the temperature of the steam and that of the surrounding air. Further experimental work[1] shows that the heat loss from a bare pipe per square foot at any given temperature difference is very great for surfaces of small diameter such as wires, and at first decreases rapidly as the diameter increases. For diameters of 4 inches and over the heat loss per square foot at any given temperature difference is practically constant. Table VII. gives the total heat loss from metal surfaces of various diameters for different temperature differences, whilst Table VIII. gives heat loss from pipes one inch diameter covered with commercial lagging.

TABLE VII.

GIVING VALUES OF THE HEAT LOSS FROM METAL SURFACES, SUCH AS BARE STEAM PIPES OF VARIOUS DIAMETERS, UNDER DIFFERENT TEMPERATURE CONDITIONS, THE TEMPERATURE OF THE AIR BEING 60° F.

Exter. dia. of radiator ins.	Heat loss per hour in B.T.U. per sq. ft. per deg. Fahr. temperature difference.			
	At atmos. press. 212° F. (Temp.diff.152.)	Steam at 100 lbs. 338° F. (Temp.diff.278).	Steam at 200 lbs. 388° F. (Temp.diff.328).	Superheated steam at 500° F. (Temp.diff.440).
0·20	3·94	5·40	5·75	6·00
0·50	3·35	4·26	4·50	4·88
1·00	2·92	3·72	3·93	4·30
2·00	2·59	3·37	3·58	3·92
3·00	2·50	3·30	3·48	3·80
5·00	2·36	3·18	3·35	3·70
12·00	2·35	3·14	3·32	3·66

[1] Lander and Petavel, "Heat Loss from Metal Surfaces," Brit. Assoc., Sect. G, 1912.

TABLE VIII.

Giving Values of the Heat Loss from One Inch Diameter Metal Surfaces covered with Various Materials, the Temperature of the Air being 60° F.

Material.	Thickness of covering.	Weight per foot run.	Heat loss per hour in B.T.U. per deg. Fahr. per sq. foot of external surface of pipe.	Percentage efficiency at 100 lbs. press.
	inches.	lbs.		
Sectional cork . . .	1·75	1·4	0·407	88
Slag wool	1·3	2·6	0·461	87
Silk waste	1·3	2·1	0·461	87
Slag wool and air space	1·3	2·8	0·504	86
Silk waste and air space	1·3	2·3	0·504	86
Sectional cork and air space	1·3	1·1	0·504	86
Hair felt with layer of asbestos next pipe . .	1·3	2·7	0·547	84
Slag wool fabric . . .	1·3	2·5	0·561	84
Slag wool covered with woollen felt . . .	1·3	2·1	0·561	84
Sectional magnesia . .	1·5	—	0·583	83
Cellular asbestos . . .	1·3	2·0	0·612	83
Hair felt	0·5	—	0·673	80
Diatomite	1·4	2·2	0·716	79
Magnesia plastic . . .	1·2	2·0	0·789	77
Mica plastic	1·4	2·6	0·900	75
Magnesia rope . . .	0·7	0·8	1·27	64
Asbestos rope	0·7	1·9	1·98	44

At 100 lbs. steam pressure the experiments proved that in a one-inch pipe an efficiency of 88 per cent. could be obtained by such materials as cork, slag wool applied in sheet iron cases, and silk waste, whilst an efficiency of 80 per cent. was possible with various high-class coverings consisting of woollen felt, hair felt, sectional magnesia, cellular asbestos, etc. The efficiency is equal to $\frac{H_B - H_C}{H_B} \times 100$.

where H_B = heat lost by the bare pipe,

H_C = heat lost by the covered pipe,

and it will thus be seen that with an efficiency of 88 per cent., seven-eighths of the heat which would have been given off by the bare pipe is prevented from escaping. With an efficiency of 80 per cent. four-fifths of the heat is saved, this, of course, being accompanied by a corresponding saving in the amount of steam used. Efficiencies as low as 44 per cent. were shown by some laggings, amongst which were a number of nondescript plastic compositions and asbestos rope.

From these data the Committee recommended that "on and after the first day of June, 1912, the pipes used for the introduction of steam for humidifying purposes be covered with non-conducting material, kept in good repair, in such a manner that the amount of steam condensed in the covered pipe shall not exceed one-fifth of the amount of steam condensed in the bare pipe under the same conditions, and that the occupier of every shed in which such pipes are installed be furnished by the manufacturers of the covering with a certificate to the effect that a sample of the covering has been tested by some authority to be approved by the Chief Inspector of Factories, and has been found to conform to the above standard; that all hangers supporting the pipes be separated from the bare pipes by an efficient insulator not less than half an inch thick, that all uncovered jets project not more than four and a half inches beyond the outer surface of the covering, and that the steam pressure be as low as practicable and not greater than 70 pounds per square inch."

Three authorities have been appointed for Great Britain, viz., the National Physical Laboratory, the Whitworth Engineering Laboratory of the Manchester University, and Edinburgh University Engineering Laboratory.

All the manufacturers who had supplied coverings which by the original tests were proved to have an efficiency of 80 per cent. and over were granted certificates for lagging conforming to the sample tested. Many of the makers who failed by a small margin have, by improvements in quality or slight increases in thickness, now obtained the required certificate for certain of their coverings.

The introduction of this standard of efficiency for coverings installed in weaving sheds has undoubtedly reacted in favour of a general adoption of better laggings throughout the textile trade, as it is becoming usual for managers to insist upon an approved covering for all purposes, it being better economy to pay a slightly higher price for boiler coverings, etc., and so save in the coal bill. Hitherto, mill owners have had no guarantee that any given material would do all that its maker claimed for it, unless they submitted it to tests at their own expense.

Regarding coverings in good condition already installed in mills the strict letter of the regulation makes it incumbent upon the owner to prove that his

COPY OF
No.______

The University of Manchester.

WHITWORTH ENGINEERING LABORATORY.

STEAM PIPE COVERING TESTS.

For Messrs. ....

DISTINCTIVE MARK OR NUMBER OF COVERING	MAKER'S DESCRIPTION OF NATURE OF COVERING MATERIAL	MEAN THICKNESS OF COVERING	WATER CONDENSED PER SQUARE FOOT OF EXTERNAL SURFACE OF BARE PIPE PER HOUR	WATER CONDENSED PER SQUARE FOOT OF EXTERNAL SURFACE OF COVERED PIPE PER HOUR	PERCENTAGE EFFICIENCY

IN ACCORDANCE WITH THESE TESTS, THE COVERING WHEN APPLIED TO A ONE INCH PIPE IN A LAYER OF NOT LESS THAN   INCHES THICK CONFORMS TO THE STANDARD REQUIRED BY REGULATION 6 (c) OF THE REGULATIONS DATED DECEMBER 21ST, 1911, MADE BY THE SECRETARY OF STATE UNDER THE FACTORY AND WORKSHOP (COTTON CLOTH FACTORIES) ACT, 1911 (1-2 GEO. 5, C. 21), AS TO HUMIDITY AND VENTILATION IN COTTON CLOTH FACTORIES

Certificate of Efficiency of Steam Pipe Covering.

covering complies with the requirements. In cases where doubt has arisen upon this point tests have been made upon a seven-foot length of pipe cut out of the steam range of the shed. This is fitted with plugged ends and tested in the usual manner. If it conforms to the standard a certificate is granted for the particular shed in which it is installed, but the certificate is provisional, inasmuch as the shed manager must be responsible to the Factory Inspector, and must satisfy him that the sample length is fairly representative of the whole range.

CHAPTER IV

Method of Cooling by Abstraction of Heat—Roof Sprays—Ventilation during Night and Non-working Periods—Water Humidification—Fans—Powerful Ventilating Systems—Water Humidification by Atomizers in the Shed.

Cooling by Abstraction of Heat.—Although the most satisfactory method of obtaining lower maximum temperatures during the summer months is to prevent heat from entering the shed, much can be done to abstract heat from the room after its generation. Several methods have been suggested, the most important being the following :

Cooling the roof by sprays of water.

Ventilation during the night and non-working periods.

Exceedingly powerful ventilating systems blowing in saturated or supersaturated air.

Humidification by evaporation of water inside the shed.

Pipes circulating brine cooled by means of a refrigerator.

The last method does not appear to be commercially possible, the high initial cost required for such an apparatus being a charge which would prove too great under most circumstances, since its use under average conditions would be confined to short periods during the summer months.

The capital cost of an ammonia refrigerating machine and pipes circulating brine, sufficiently large to cool a shed of 500,000 cubic feet capacity through 15° F., would be about £1500, and about 50 H.P. would be required to run the plant. Assuming such a shed to contain 600 looms and the power absorbed per loom to be $\frac{1}{3}$ H.P., it will be seen that the power required for the refrigerating machine would be about one quarter of that necessary to run the factory itself. Again, skilled attendance would be necessary while the plant was working.

Roof Sprays.—A shed may be cooled by spraying water on the roof, the object being to obtain a reduction of temperature of the slates, not so much by the direct cooling action of the water as by that brought about by its rapid evaporation.

In several mills in the Lancashire district apparatus was already installed for this purpose, but the method had proved expensive, owing to the immense amount of water used. It was recognized that for roof spraying to be efficient and cheap the roof must be kept constantly moist, and that a minimum amount of water should run to waste. Revolving sprays, such as are used for watering lawns, were tried, but did not give a good covering power, a great quantity of water being thrown down close to the spray, and consequently streaming away to the gutters. Improved jets of various types were designed and tested, and a type finally evolved, which, with a nozzle $\frac{1}{32}$ in. in diameter, could keep a circle of sixty feet diameter constantly moist. These sprays were turned in gunmetal, and worked upon the principle of Barker's mill, or a reaction wheel, the water thereby furnishing the motive power. The water was thrown from the extremity of an arm 15 inches long, and was directed upwards at an angle of about 45°, the direction in plan of the jet being roughly 30° to the centre line of the arm. Under a pressure of 60 lbs. per square inch, it was found that these sprays had their greatest covering power when making about 100 revolutions per minute, and the speed was kept down to this by light metal wind vanes. The revolving bearings of the jet took the form of a truncated cone, grooves being turned at intervals in order to reduce leakage of water between the surfaces to the minimum necessary for lubrication. The angles of the cone were proportioned in such a manner that the upward pressure of the water was slightly greater than the total weight of the revolving parts. When not working the heads settled down on to the machined cone, forming a joint which was comparatively impervious to the weather, and so corrosion was very slight. When working, very little friction occurred between the bearing surfaces, and therefore the wear was reduced to a negligible quantity. In order to secure the best results such revolving jets must be carefully proportioned to the available head of water, but when this is done the saving is very great as compared with most of the crude systems of roof moistening by

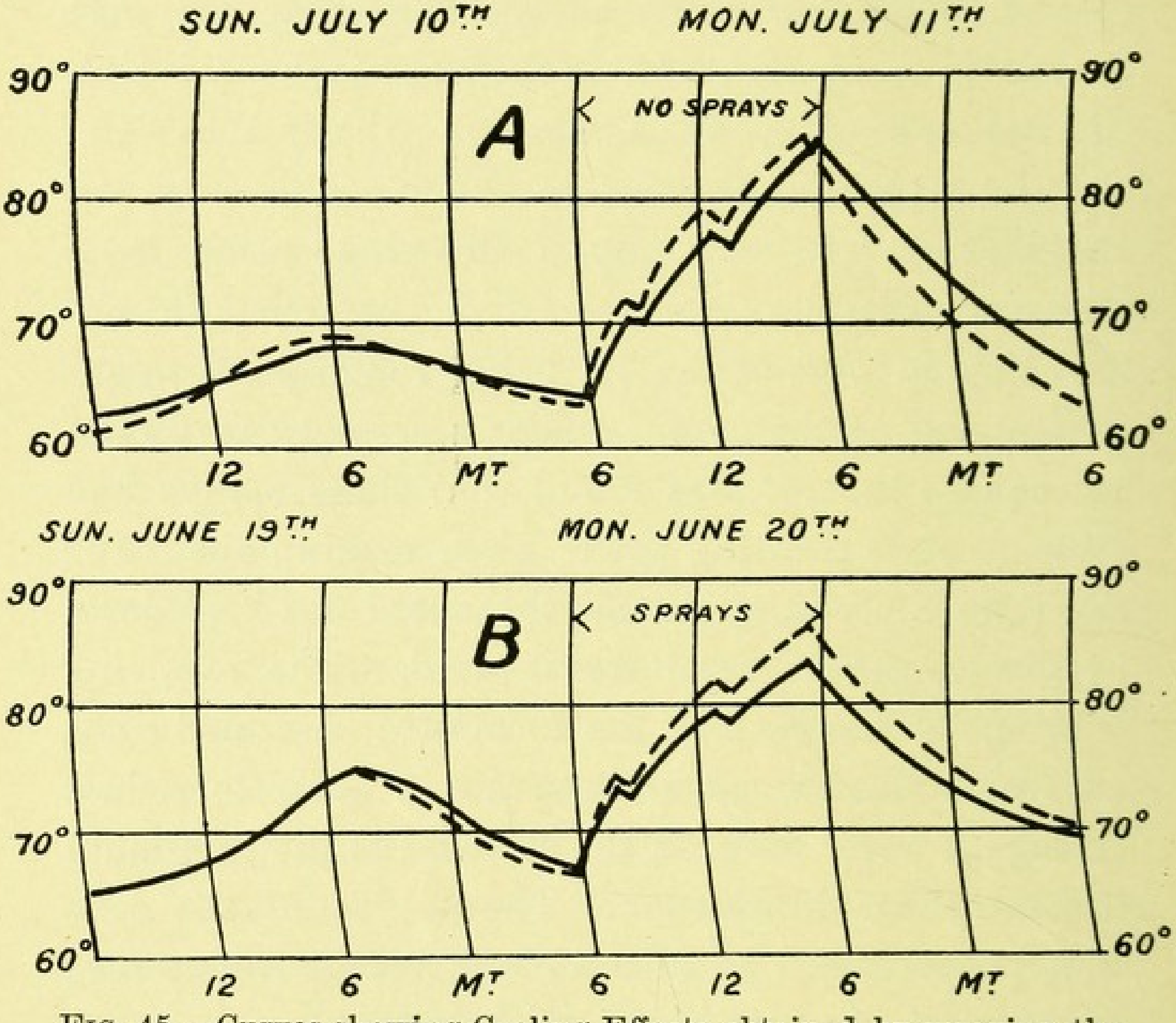


FIG. 45.—Curves showing Cooling Effects obtained by spraying the roofs with water (*also opposite*).

A gives a comparison between two adjacent sheds under ordinary conditions; B gives a comparison between the same two adjacent sheds when one of them is sprayed with water. The thick line in both cases refers to the shed fitted with the experimental spraying plant. The diagrams C and D refer to similar experiments carried out on another pair of sheds.

means of stationary jets laid at intervals along the ridges. The amount of water used worked out roughly at one to one and a half gallons per loom per hour, in a shed of average size, say 300 to 500 looms. The experiments on the cooling effect were made by choosing sets of two adjacent sheds, one being equipped with sufficient roof sprays, the other

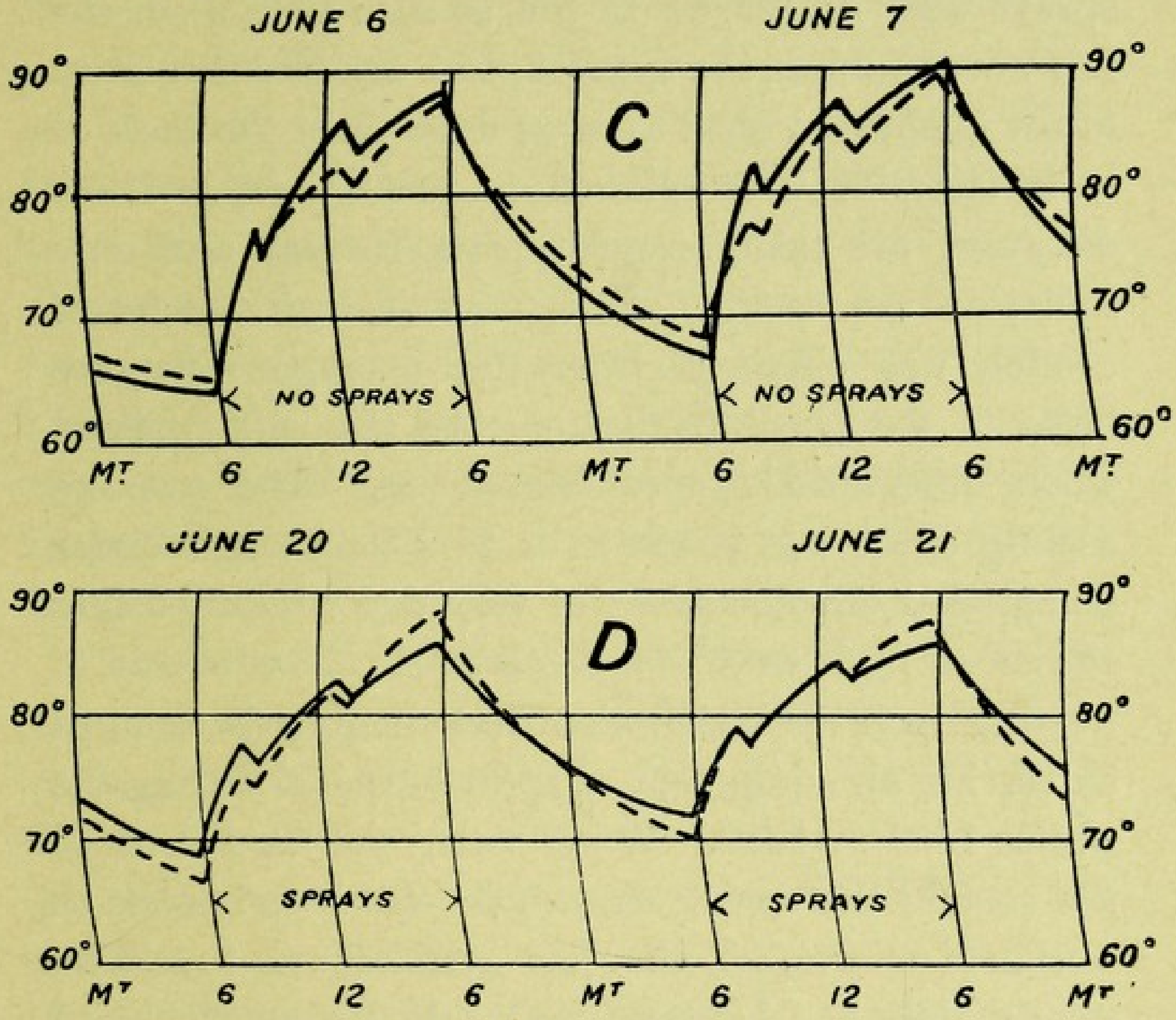


FIG. 45 (*see opposite*).

being used for comparison purposes only. The sheds were kept under observation for some considerable time, the sprays being run during alternate weeks. From an analysis of the temperature records taken during the periods when the sprays were not in use the relative properties of the two sheds could be obtained, and these were compared with those taken in both sheds during the time when sprays were running. The effect of the sprays is shown in Fig. 45, the thick line being a record taken in the shed where sprays were installed. It will be seen that when the jets were running, the sprayed shed was cooler relative to the unsprayed shed than on days when the roofs of both factories were allowed to remain dry. These diagrams are taken from typical records and only illustrate the cooling effect. The actual amount of cooling was obtained from the average difference between the shed maxima during the whole period when observations were carried on. The average cooling effect was about 2° or 3° F., although under exceptional circumstances of very dry winds, cooling effects as high as 6° were observed. The effects of weather upon the installation were roughly determined by leaving an equipment of sprays exposed during the winter 1909 to 1910. When water was turned on to the roof in the spring the whole was found to be in working order, and the jets commenced revolving immediately. Of course it would be advisable to take off the heads during the winter in any large town.

Ventilation during Night and Non-working Periods.—Temperature records taken in a spinning mill or weaving factory during non-working periods, *e.g.* week-ends or stoppages for holidays, show that the room does not cool completely during one night. Unless outside circumstances interfere, it will be noticed that the minimum temperature reached during successive nights decreases, and a period of about three days in weaving sheds and longer in spinning mills is required before the rooms reach steady temperature conditions. Fig. 40 is a diagram from a wet spinning mill taken during a week-end stoppage. The mill was not working on the Saturday morning, and thus two clear days elapsed before spinning was resumed. It will be seen that the minimum temperature was reached on Sunday night, and it is probable that had the mill been stopped for a longer period the room would have cooled still further. The variations during the days of Saturday and Sunday are, of course, due to the greater external temperatures.

The effect of a low minimum temperature during a night upon the maximum temperature observed during the following day is that the maximum is lower. This effect is very noticeable, inasmuch as the maximum temperatures reached, even during hot weather, on a Monday afternoon, average less than those observed during the afternoon on other days of the week. It would appear that if this minimum temperature could be artificially lowered beneficial effects would accrue. One method whereby the lowering of the minimum can be effected is by leaving doors and windows open during the night, or by running the fan continuously. Tests were made in this direction, but the effect proved to be small in all sheds where experiments were carried out. In addition to reducing the temperature, the absolute amount of moisture present was also reduced, and this led to the necessity for heavy steaming when work was resumed in the morning. This method might be more valuable if the capacity of the fans were much greater. In order to obtain a low temperature on starting in sunny weather, it has been found beneficial in some cases where water atomizing humidifiers are installed to start the jets about half an hour before work commences in the morning, and for this reason makers of that type of apparatus now arrange that the pumps can be driven independently of the line shafting.

Water Humidification of the Air at the Fans.—Humidification by water only is always advantageous from the point of view of cooling. Experiments bearing on this were carried out upon the plant ventilating the main building of the Manchester University. All the air was drawn through wet matting, and it was found that the air was cooled almost to the extent of the difference between the wet- and dry-bulb temperature. In this country this usually amounts to 4° or 5°, and on exceptionally hot dry days may be 10°. In the central provinces of India, where several cotton factories have recently been erected, differences of 25° to 35° between the wet and dry-bulbs are frequently recorded during the dry periods. During one month of the year 1909, the average difference was 30°. With a good apparatus the full effect of this large difference may be obtained, and provided the ventilating volume is sufficiently great, much more may be done to cool a shed in these countries than is possible in Great Britain.

This system of water humidification was applied to a medium-sized shed weaving plain goods. Air was drawn through a wet mat of about 70 square feet surface at the rate of 340,000 cubic feet per hour. The relative humidity in the fan chamber was always above 95, and the temperature reduced to within one degree of the outside wet bulb. This, of course, does not imply that the humidity in the shed could be maintained by this means alone. On entering the shed the temperature of the air is raised, and the relative humidity, since each cubic foot of air still contains the same weight of moisture, is reduced; *e.g.* consider air at 60° F. dry-bulb, and 90 per cent. humidity, the amount of moisture contained in each cubic foot is equal to 5·2 grains. If this air is now heated, as it would be on passing into the shed, to a temperature of 75°, then the 5·2 grains of water is only sufficient to give it a relative humidity of 55 per cent. This method, however, is of value during excessively hot weather, since it is then that the difference between shed temperature and outside temperature is a minimum.

In view of the fact that it is difficult to reach anything like the percentage of humidity allowed by the Act in humid factories by the use of wet matting alone, a dry shed is now allowed to pass the ventilating air through wet cloths, provided that no ducts are placed in the shed, that the air is drawn directly from the outside atmosphere, and that the method is only used when the dry-bulb temperature in the shed reaches 70° F. and over.

The experimental apparatus installed for water humidification was afterwards modified by the addition of several "atomizers" placed in the fan chamber. The air in the duct beyond the jets was by this means supersaturated, and finely divided spray was carried into the atmosphere of the shed. Even under these improved conditions the required moisture could not be maintained, and it was found necessary to inject an additional amount of steam directly into the duct. The results of this test may be summed up by saying that wet matting and sprays at the inlet will considerably improve the temperature conditions obtaining in the shed, but that, unless the ducts are very short, it is difficult, if not impossible, to maintain humidities approaching those allowed by the Cotton Cloth Factories Schedule. Greater difficulties again will attend the application of the system to sheds weaving fine and medium linens on account of the greater amount of moisture required.

The same principle is made use of in Little's Cooler and Humidifier. The apparatus consists of a number of concentric cylinders of sheet metal, the lower parts

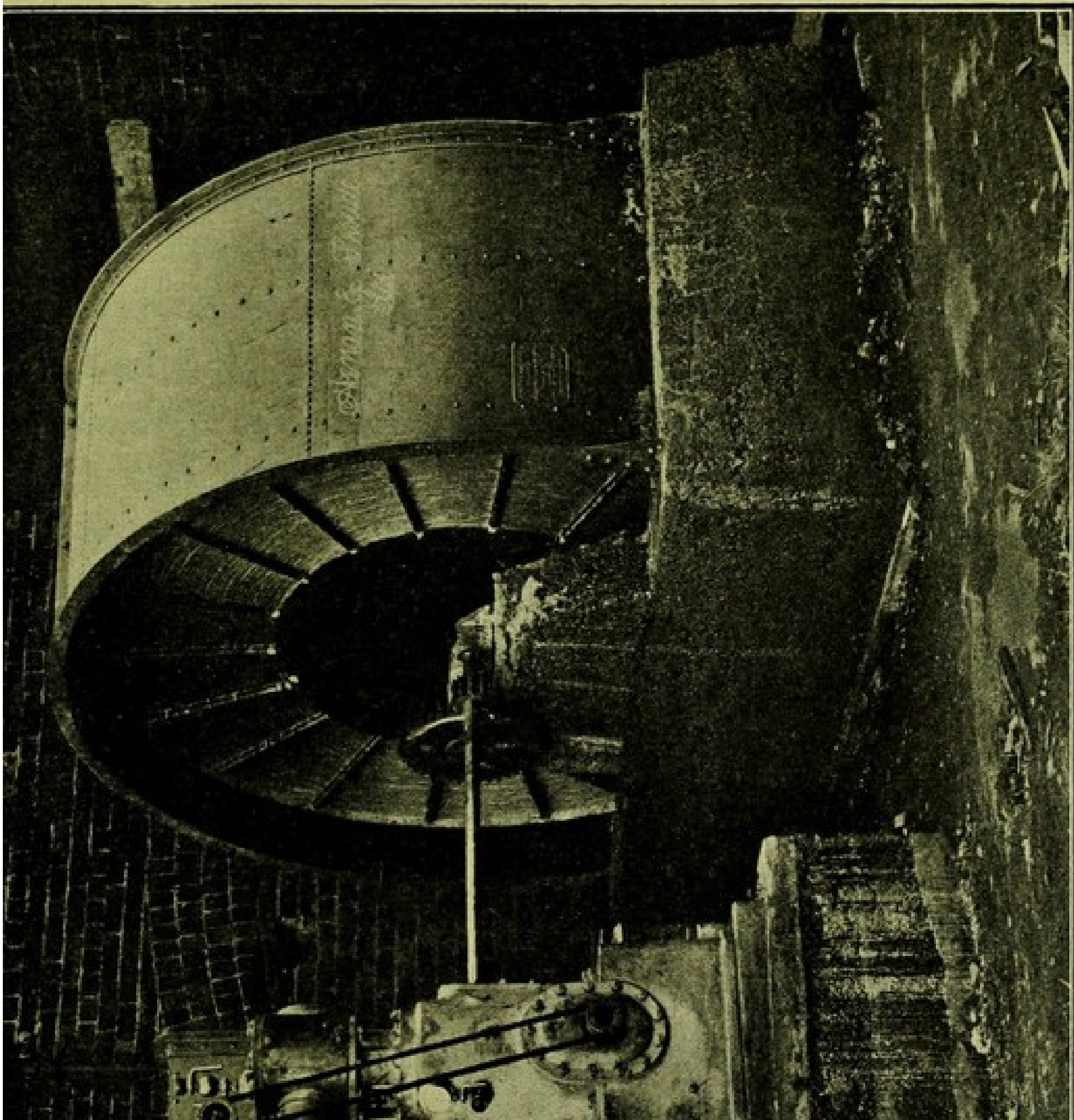


Fig. 46.—Photograph during erection of experimental Plant for Water Humidification installed at a Blackburn shed.

of which are kept immersed in water. Air is blown through the upper portion of the cylinders, which are slowly rotated. The air is thus passed over a very large surface kept constantly moist, and is therefore cooled down to about its initial wet-bulb temperature, and at the same time saturated. The photograph (Fig. 46) was taken during the erection of a large experimental plant of this nature installed at a Blackburn shed. The humidifier wheel was 9 feet in diameter, and provided a total surface of 9,000 square feet, the effective evaporative surface being 6,700 square feet. A small vertical engine of 15 horse-power was used to drive a 4 feet 6 inch fan and a small compressor. Water pulverizers, working on the principle of the common scent spray, were inserted at intervals along the main ducts of the shed, the air blast producing a mist of finely-divided drops of water. The permanent apparatus in use in the shed was of that type in which live steam is mixed with the ventilating air before it is blown into the factory, the distribution of the conditioned air being effected by means of main and branch ducts. This humidifier was run on alternate days during the period occupied by the experiments, and on the remaining days the conditioning was performed by the experimental plant. On an average the results showed a lower maximum temperature of about 1·3° in favour of the Little apparatus, although on warm, dry days differences as great as 5° were obtained.

This experimental plant was of very large size for the shed in which it was installed, but the distributing ducts being those connected with the permanent plant were probably rather small for the large quantities of air dealt with (about three changes per hour). The small effect produced illustrates the difficulty experienced in cooling buildings where manufacturing processes are carried out requiring high humidity.

The makers of the Little apparatus have now modified their system by introducing the cooled humidified air through flexible pipes connected to nozzles through which the humidified air is blown directly on to the warp itself. This was described in detail in Chapter II.

Powerful Ventilating Systems.—Increase in the amount of air driven into a factory will tend to reduce the temperature, this effect being much more marked with an efficient humidifier in use. It has been pointed out above that when saturated air enters a shed it is usually warmed, and therefore the percentage humidity falls. If the air is in greater quantity, its temperature will be raised by a smaller amount, and this amount could be reduced as much as we pleased by sending in sufficient air. Commercial considerations, *e.g.* the huge ventilating plant required and the difficulty of distributing the air, preclude any extreme application of this method, but examples exist in the tropics where by using about ten times the amount of air customary in this country it has been possible to obtain temperatures in the shed only four or five degrees above the outside temperature during the rainy periods. For example, the inside temperature of one factory varied from 86° when the outside temperature was 80° F., to 93° when the outside temperature was 92°, during the monsoon. In the dry period the temperature reached in the shed was actually lower than the outside temperature, and the mean temperature in the shed was less than during the rainy season; thus, in this factory the temperature varied from 78° when the outside temperature was 78°, to 92° when the outside temperature was about 104°. This latter is due to the fact that the air is sent in supersaturated, and at the temperature of the outside wet-bulb, which is lower during the dry period, and the quantity of air is sufficient to overpower the heating effect of the factory upon it.

Humidification by Water "Atomizers" in the Shed itself.—Considered from the point of view solely of cooling, the most successful method is that associated with the "atomization" and evaporation of water at a number of isolated points within the shed itself.

In determining the cooling effect of atomized water as compared with steam used for humidification, it is not desirable to institute direct comparisons between two sheds fitted, one with an installation of water pulverizers, the other with steam-jetting apparatus. Difficulty would be experienced in determining the effect of the humidification system apart from the effect of slight differences in the shed construction, such as variations in absolute size, in capacity per horse-power, or in any of the other factors which work together in producing a cool or a hot shed. The alternative method of investigation is to install duplicate apparatus in one shed, and either compare the maxima attained with each plant running on days of similar outside weather conditions, or to compare the maxima in the experimental shed with those experienced in a companion shed near by into which no modifications are introduced. It is difficult to select for comparison days on which the outside weather conditions are identical, but provided sufficient observations can be obtained, any advantage given to one system on a certain day will be counterbalanced by a disadvantage on some other day on an average. To obtain definite information upon this point, two sheds were each fitted with duplicate apparatus consisting of a range of well-covered pipes for the direct injection of steam and an installation of "Vortex" humidifiers drawing their air supply from the interior of the factory. The main ventilation system in each case was independent of the humidifying apparatus, thus confining any advantages observed during the use of either system to that obtained solely from the different principles used in moistening the atmosphere. The two systems were used during alternate weeks, and were compared by selecting days of similar outside mean temperatures. Table IX taken from the experimental report of the Committee, shows in a striking manner the great advantages to be obtained from water atomizers in the shed itself so far as temperature only is concerned. The results show an average difference of 6·7° F. obtained in a shed of eighty looms, and a difference of 4·3° F. obtained in a larger shed of 330 looms, both weaving plain goods. The covering of the steam piping in the small shed was of better quality than that in the larger shed, which may account in a small measure for the greater reduction of maxima obtained in the latter.

TABLE IX.

COMPARISON OF HUMIDIFICATION BY WATER AND BY STEAM.

Date.	Maximum. temperature in shed.	Mean temperature outside.	*Difference.*
Shed D.	*Atomized water.*		
Sept. 1	71·5	57·0	*14·5*
,, 2	71·5	61·0	*10·5*
,, 5	69·0	55·0	*14·0*
,, 6	70·0	54·5	*15·5*
,, 7	70·0	58·0	*12·0*
,, 14	68·5	54·5	*14·0*
,, 15	67·5	55·5	*12·0*
,, 16	68·5	55·5	*13·0*
,, 19	67·5	56·0	*11·5*
,, 20	65·5	49·5	*16·0*
Mean . .	68·9	55·6	*13·3*

Date.	Maximum temperature in shed.	Mean temperature outside.	*Difference.*
Shed D.	*Steam.*		
Sept. 6	73·0	57·0	*16·0*
,, 9	76·0	56·0	*20·0*
,, 12	74·5	57·5	*17·0*
,, 13	76·0	56·0	*20·0*
,, 21	74·5	47·5	*27·0*
,, 22	76·5	51·0	*25·5*
,, 23	77·0	52·5	*24·5*
,, 26	75·0	60·0	*15·0*
,, 27	78·0	61·0	*17·0*
,, 28	78·0	59·5	*18·5*
,, 29	79·5	63·0	*16·5*
,, 30	78·5	55·5	*23·0*
Mean . .	76·4	56·4	*20·0*

COMPARISON OF HUMIDIFICATION BY WATER AND STEAM.

SHED "M."

Average of differences between daily maximum temperature in shed and mean outside temperature.

1910.	"Atomized water."	Steam.	*Difference.*
May	27·0	30·5	*3·5*
June	18·5	21·0	*2·5*
July	14·0	21·0	*7·0*
Mean . .	19·8	24·1	*4·3*

The above figures are the mean of all the readings taken.

The maximum cooling effects experienced were 8° and 10° respectively. The curves (Fig. 47) are temperature records taken on days when the outside conditions were similar, the upper line referring to steam-jetting humidification, the lower to water atomization. The percentage humidity in a shed where water only is used is much more uniform than in a shed where steaming is adopted. This may be

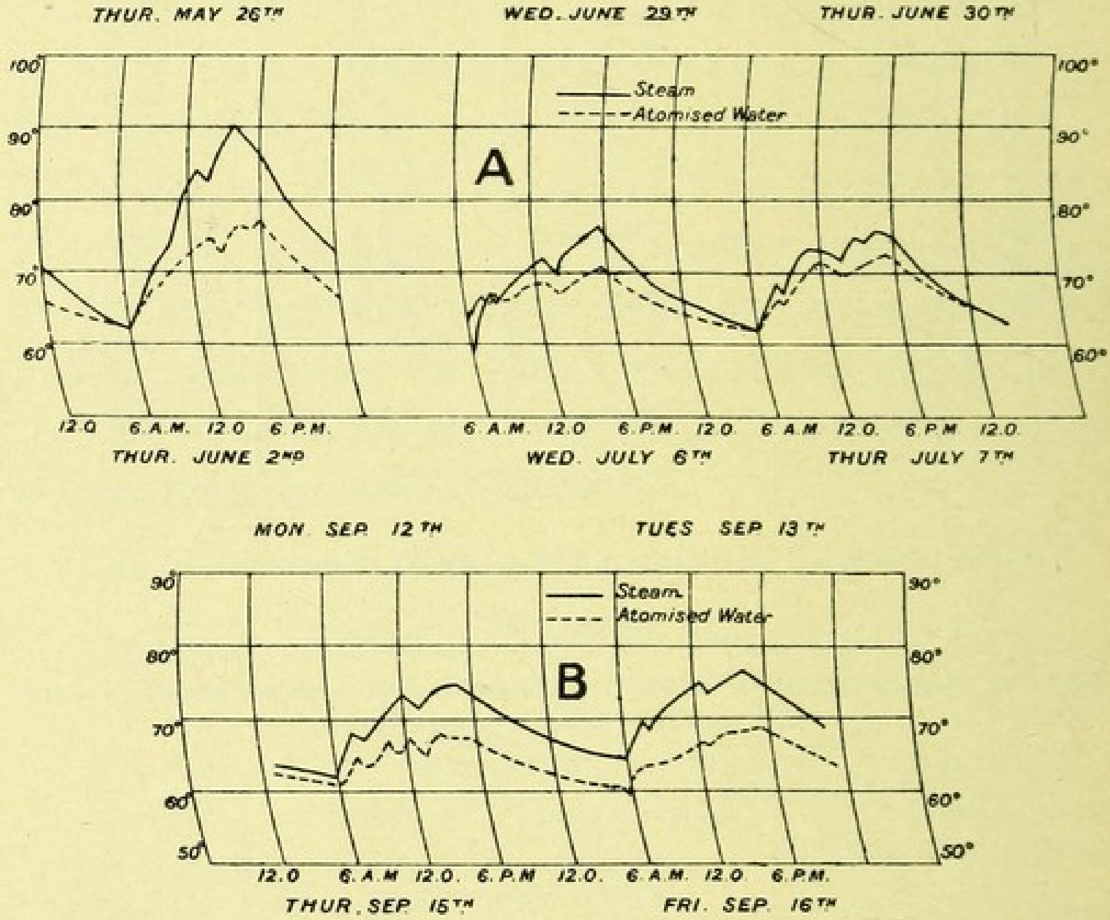


Fig. 47.—Curves showing comparison between Humidification effected by Steam and by Atomized Water.

A refers to a shed fitted with steam jets and an installation of water atomizers. The thick line gives the temperature recorded on certain days when steam was used for conditioning, the dotted line referring to days of similar outside temperature conditions when atomized water only was used; B refers to another shed in which similar tests were carried out.

an advantage, inasmuch as there is less likelihood of the limits defined by the schedule being exceeded, but it is an advantage of the steaming system that the humidity can be raised with great rapidity. Apart from questions of temperature, inquiry seems to indicate that operatives prefer the use of atomized water to the infusion of live steam, although objection is taken to any system of artificial humidification. The appearance of a main blowing off high-pressure steam on a hot summer day is not one likely to have a soothing effect upon a tired worker.

CHAPTER V

The Effect of Design and Construction on Maximum Temperature—Windows—Cubic Capacity per Loom—Position of Main Drives—Large and Small Sheds—Types of Roof—Total Effect of several Small Defects.

The Effect of Design and Construction upon Maximum Temperature Attained.—Although it is a very difficult matter to cool satisfactorily an existing hot shed, a new factory can be constructed which shall rarely, if ever, reach an excessive temperature. The site should be carefully chosen, a moist foundation, such as that afforded by clay subsoils, assisting in maintaining cool conditions in summer, and at the same time, by supplying moisture to the atmosphere, reducing the amount of steam necessary to maintain good weaving conditions. Such a site, whilst undoubtedly presenting advantages during hot weather, is liable to render the factory uncomfortable during the early hours of a winter morning, thus necessitating a slight extra expense for heating. In several new factories, which have proved to be comfortable both in summer and in winter, the clay has been excavated to a depth of some two or three feet and then filled up with a loose material such as clean gravel or broken brick, the floor of the shed being laid directly upon this.

When designing a new weaving shed or spinning mill, it is desirable to incorporate those features which tend to the elimination of large amplitudes in the oscillations of the temperature curve, since factories designed on these lines will neither reach excessive temperatures in the summer nor be uncomfortable during cold weather. It is, however, much more difficult to cool such a factory by external means should it reach high temperatures through the neglect of some important detail.

In small weaving sheds advantage in this direction may be gained by arranging the floor levels below the surrounding ground; in fact, in some cases the roof of the factory has been at this level, the shed then being entirely underground. The walls of such a shed are shielded from direct solar radiation, and since the temperature of the subsoil at small depths is much below the mean atmospheric temperature during hot weather, heat will flow from the shed to the earth. This effect becomes of less importance to a large factory, since the wall area per loom decreases with the absolute size. Two adjoining sheds, both identical in other respects and both protected on the east, showed a constant difference of 2° between the maximum temperatures attained on any one day. The warmer shed was built with its floor level slightly above that of the surrounding ground; the other being at a depth of about 14 feet below this level.

The degree of shelter which can be afforded by adjacent buildings is also of importance. As was shown in Chapter I., a high building on the east will protect the factory from the dry east winds, which are usually associated with bad weaving conditions; it also shields a small portion of the shed from direct solar radiation. On the other hand, the presence of buildings adjoining the shed reduces the length of outside wall and thus will prevent to some extent the escape of heat. Again, a spinning mill is often run under high temperature conditions, and the presence of such a mill may act as a slight source of heat.

Windows should face as far as possible due north, since this is the direction from which they receive a minimum amount of direct sunshine. Except by shelter of other objects it is impossible to eliminate the sun's rays. Even with a vertical window facing due north, the sun will shine into the room in summer during the early morning and late afternoon. Vertical windows are inconvenient both from the lighting point of view and also from structural considerations. On this account an angle of 60° to the horizontal has been adopted as a fair compromise, and in future no shed may be erected where the roof lights are inclined to the horizontal by a less amount. In this latitude on midsummer day, the rays of the sun will almost graze the glass at midday and will shine into the shed during the morning and afternoon; the angle at which the rays strike the glass will, however, be very small, and no great quantity of heat will find its way into the shed, especially if the glass is efficiently whitewashed.

A space of about half an inch is usually left between the lower edge of the glass and the bottom frame to allow an outlet for foul air, etc.

The best form of shed both from the weaving point of view and also for the prevention of excessive temperatures is the large one-storey building built directly upon the ground and lighted from the roof. Rooms situated at the top of a high building such as an old spinning mill are occasionally used as weaving sheds, and are usually fairly comfortable. Owing to the exposure the shed is cooled by wind, but the beneficial effect of a cool damp floor is of course lost. Such a room is liable to the effects of dry winds in a very large degree, and therefore the days of bad weaving are more frequent than would otherwise be the case.

The most undesirable position for a weaving shed is upon the lower floors of high buildings. In this case the cooling surface of the room is reduced to the four walls only, and therefore excessive temperatures are bound to occur during hot weather.

A most important point is the amount of space allowed per unit of work dissipated. This may be conveniently measured by the cubic capacity per loom, since the amount of power required by the average loom in humid sheds is about one-third horse-power. In the weaving of plain cotton goods the cubic capacity per loom varies from about 420 cubic feet per loom to 1200 cubic feet per loom; or 1260 cubic feet per H.P. to 3600 cubic feet per H.P. Whilst there is probably no necessity to provide so great a specific capacity as the latter figure, there can be no doubt that the former figure is much too low. The capacity per loom is to some extent governed by legislation, since The Cotton Cloth Factories Act, 1911, provides that the average height of a new shed shall not be less than 14 feet 6 inches. Taking a 40-inch plain loom as occupying a floor space of, say, 7 feet by 4 feet, and allowing a passage of 1 foot on two sides of the loom, the volume of the shed provided works out to 580 cubic feet. Under ordinary circumstances, the provision of a larger volume than this is desirable as tending to a cool factory. Of course the question of capital cost is exceedingly important, and it may show a better return to work for a short period during the summer with low humidity in order to prevent the wet-bulb rising above 75° F., which by the new regulation must not be exceeded. The effect of large shed capacity can be obtained to some extent by an increase in the ventilating volume, which fact is of importance to owners of sheds in which the volume per loom is upon the low side.

It is desirable, if possible, to place all main driving arrangements outside the shed; this applies particularly to bevel gearing driving the countershafts. Considerable work is dissipated in these drives and converted into heat, which if outside the factory can play no part in raising the temperature. It may be objected that the effects of some of the points in design are very small, but the writer wishes to point out that it is only by carefully observing these small details that a shed can be built in which high temperatures will rarely if ever be obtained. The effect upon the shed temperature of small defects in construction are cumulative, and careful observation of known cool sheds will show that attention has been paid to most of these details.

The effect of cubic capacity per H.P. can be observed in Fig. 48, where two sheds are compared; firstly, when all looms are working in both sheds; secondly, when about half the looms in one shed are stopped. The thin line in both figures refers to a factory in which all looms were running continuously, the thick line being a temperature record taken in a shed where, firstly (Fig. 48, A), all looms were kept working, and, secondly (Fig. 48, B), half the looms were stopped. It will be seen that with all looms running in both sheds the maximum temperature in the experimental shed was about 7° greater than in the comparison shed, this difference being reduced to about 2° F. when only half the machines were working in the experimental shed. Since all shafting and belts are running

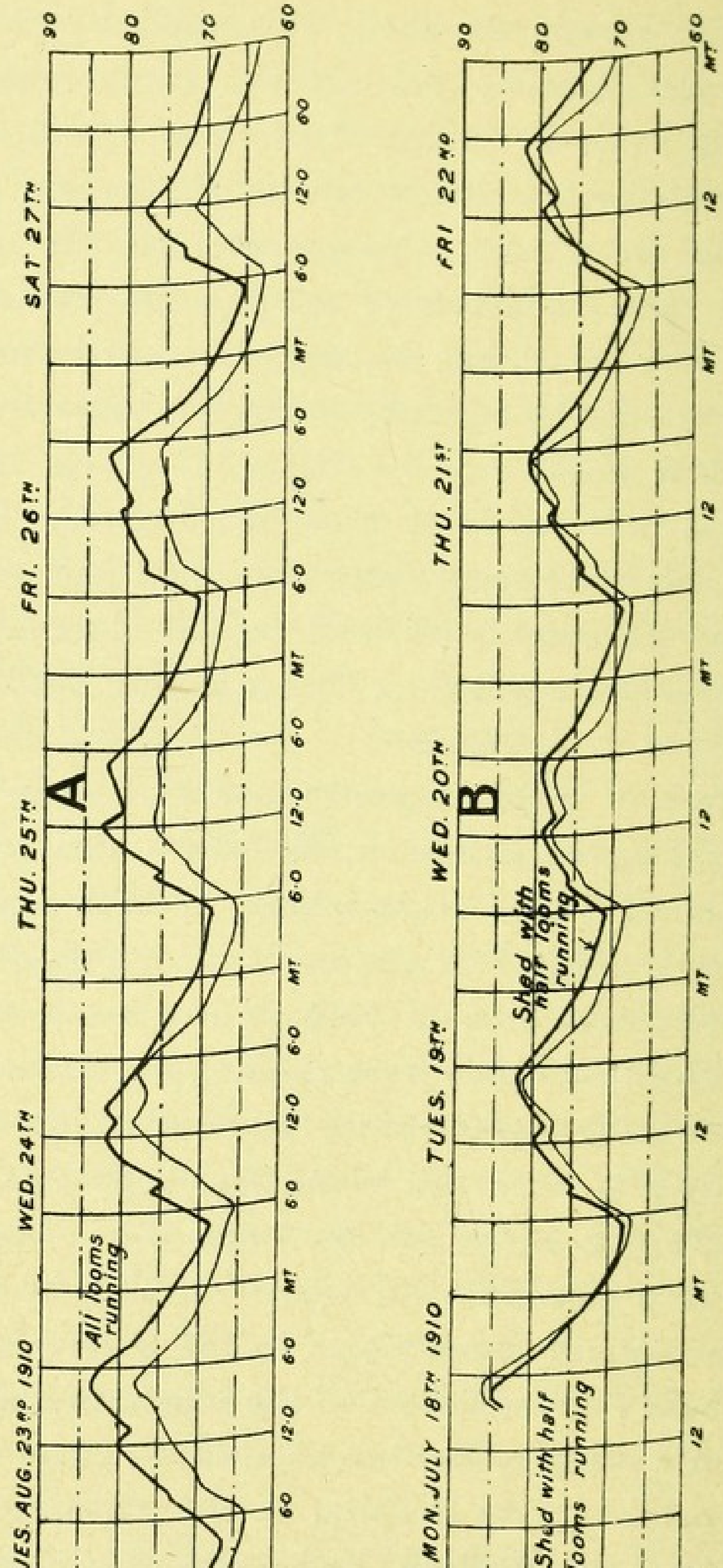


FIG. 48.—Curves showing effect of large Cubic Capacity per loom. A gives a comparison between two sheds in which all looms were running continuously; B gives a comparison between the two sheds when half the looms only were working in one of them.

continuously the reduction in temperature is less than if the cubic capacity per loom were doubled.

Large and Small Sheds.—Although presenting advantages in capital cost and in working, it is not advisable to build sheds of very large sizes, since, other conditions being the same, these sheds are more likely to reach excessive temperatures than are those of more moderate size. In factories the cooling area per loom due to the roof and the floor is dependent purely upon the area occupied by each loom, and, therefore,

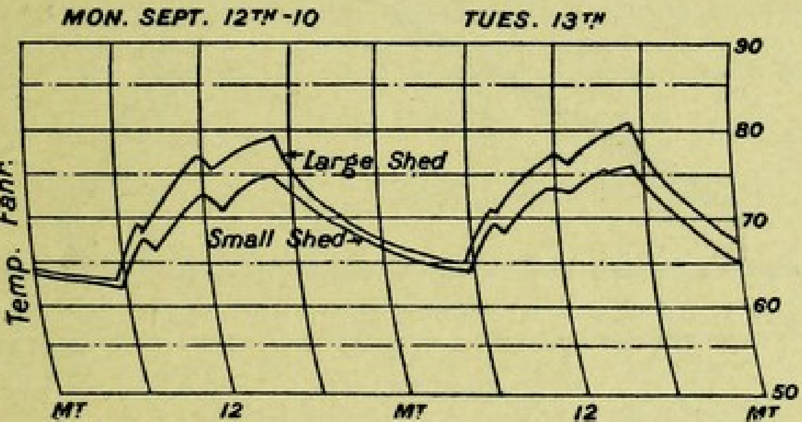


FIG. 49.—Curves giving a comparison between two sheds of similar construction weaving similar goods with equal percentages of humidity. The smaller shed is cooler on account of the greater wall area per loom.

independent of the absolute size of the factory. The ratio of wall area to the number of looms decreases, however, with the size of the shed, and thus a large shed does not part with its heat quite so quickly as does one of smaller dimensions. The effect of this is illustrated in Fig. 49, where two sheds are compared, both of similar type, having the same cubic capacity per loom, working similar goods with the same percentage humidity, the only difference being one of absolute size. The upper line refers to a shed of 400 looms, the lower to one of 100.

The difference in the average maxima of some fifteen exceptionally large and small sheds during the summer of 1910 amounted to about 3° in favour of the small factories, care being taken to select sheds which were as comparable as possible.

Roofs.—Several different types of roof are used

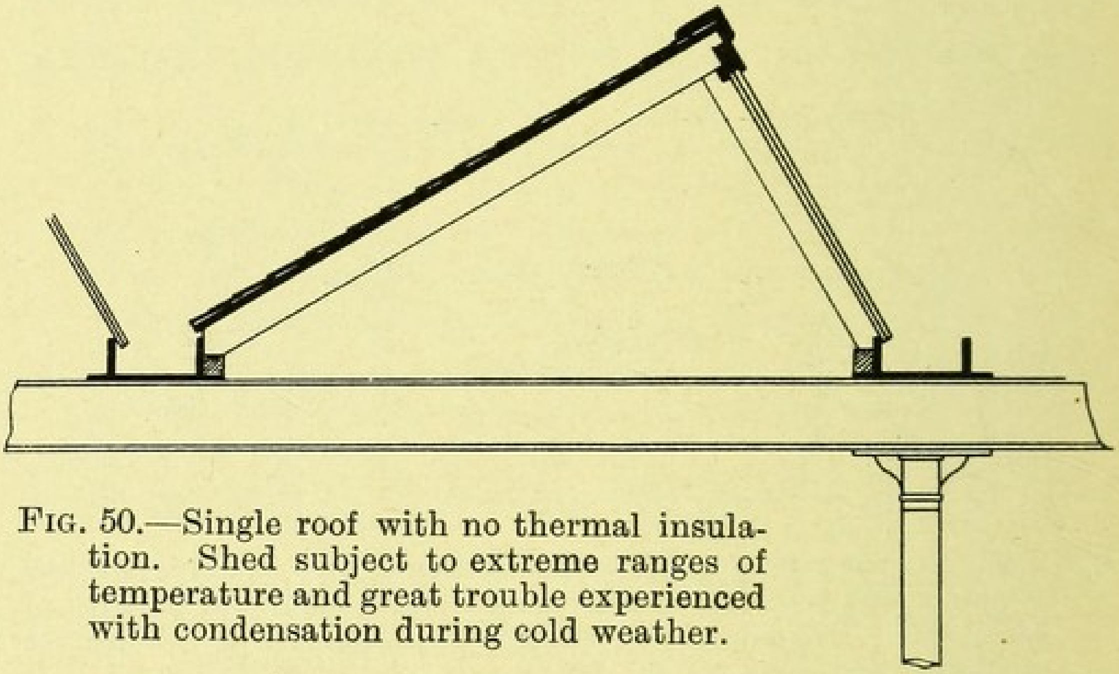


FIG. 50.—Single roof with no thermal insulation. Shed subject to extreme ranges of temperature and great trouble experienced with condensation during cold weather.

for weaving sheds, which, although differing amongst themselves in minor details, may be grouped in classes.

1. The single roof, having no cavity between slates and ceiling.

2. The double roof, having an unventilated cavity.

3. Double roof, with large unventilated cavity and heat insulating material between slates and upper sheeting.

4. Ventilated cavity roofs.

5. Flat roofs, of brick or concrete, often carrying on their upper surfaces a small depth of water.

A single roof, with no attempt at thermal insulation (Fig. 50), consists of principal spars carrying on their upper sides a layer of timbering on which the slates are laid. Such a roof is cheap, and enables the shed to part rapidly with its heat during the night, but heat from the sun passes easily through, and sheds having this type of roof often reach excessive temperatures. This roof is very sensitive to external cold, and much trouble is usually caused by condensation of moisture upon its inner surface, this moisture dripping upon the looms and warp, causing rusting of the metal and damage to the fabrics.

In slightly less degree these objections are shared by the small-cavity roof. The cavity is formed by a plaster ceiling carried by the underside of the main spars. The roof is still a poor insulator, allowing heat to flow readily either to or from the interior of the factory.

In the type having a large unventilated cavity a separate spar may be used to carry the ceiling and render the cavity continuous throughout the length of the factory. This type does not possess any advantages over the small-cavity roof, except such as are contributed by better workmanship, etc. The roof is naturally more expensive, and greater care is taken during erection, inasmuch as the slates are often pointed upon the inner side, so rendering the roof a better heat insulator.

Roofs of the third type have definite insulating properties given to them by the introduction of a layer of one-inch boarding covered with felt laid directly upon the main spar. The inside is often sheeted with tongued and grooved match-boarding. Although sheds of this type cool less completely during the night, they are much less sensitive to solar radiation, and those which have been kept under observation for some time are consistently cooler than the average, other conditions being the same.

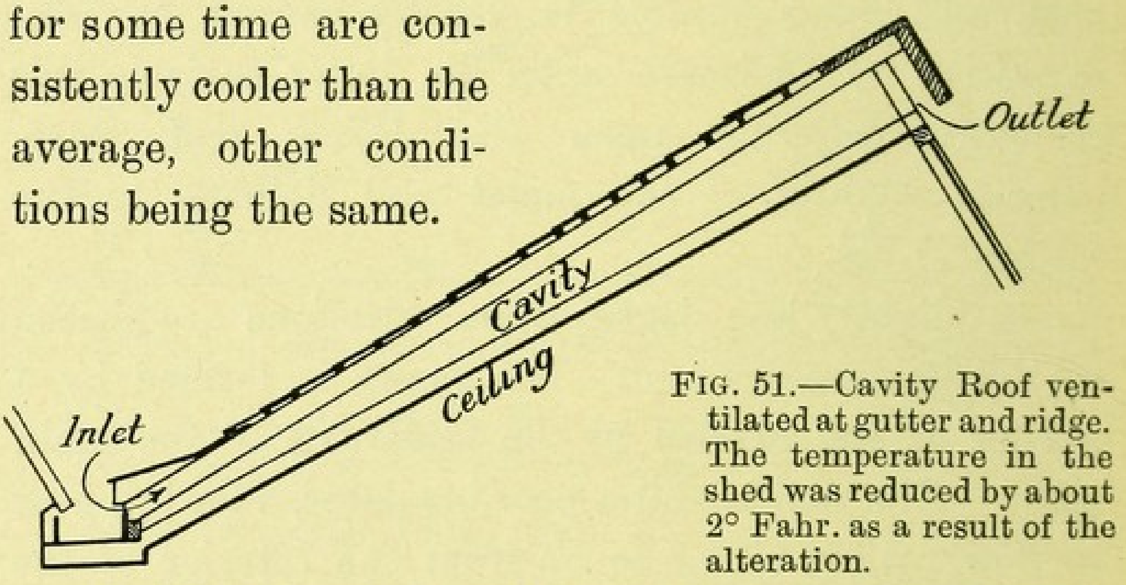


FIG. 51.—Cavity Roof ventilated at gutter and ridge. The temperature in the shed was reduced by about 2° Fahr. as a result of the alteration.

Ventilated cavity roofs have often been suggested as a means of obtaining lower maxima during the summer months. If inlet openings of sufficient size are arranged at the eaves and outlets at or near the ridge, a current of air will be induced through the cavity by the warming effect of the slates. This current of air will have a slight cooling effect on the ceiling, but since it is drawn from the roof valley its initial temperature is often so much above the mean shade temperature that very small temperature differences will occur between cavity and shed. The effect was investigated by altering the existing roof of a medium-sized shed. One hundred and forty ventilators were arranged at the eaves and roof, as shown in Fig. 51. They were spaced twelve feet apart and were about four feet in width. The current of air induced through the cavity by the warming effect of the slates was, however, small. The alteration produced a cooling effect of about 2° F.

In applying this method of cooling to an existing mill or to a new factory, the inlet and outlet ventilators should be arranged to close in winter or during cold weather; if this be not done, the action will continue, the air in the cavity receiving heat from the shed and thus cooling the ceiling. Trouble will then be experienced by excessive condensation upon the inner surface of the roof, and the shed may be rendered unpleasantly cold.

Sheds having flat roofs of brick or concrete, carrying on their upper surfaces a small depth of water, are characteristic in having small temperature variations. The daily oscillation is checked by the large thermal capacity of the roof and the water, and so excessive maxima are experienced less frequently than in those factories in which the ordinary saw-tooth roof is erected. The layer of water also shields the shed from the sun's rays and acts as a cooling agent on account of its evaporation. Lighting is somewhat difficult to arrange, but is usually obtained by skylights projecting above the water surface, as shown in Fig. 52. It is almost impossible to arrange the glass in such a manner that it is not exposed to direct sunlight, but the effect of this is not so serious as it would be in a shed of normal type. The properties of a factory of this type were investigated by records taken during

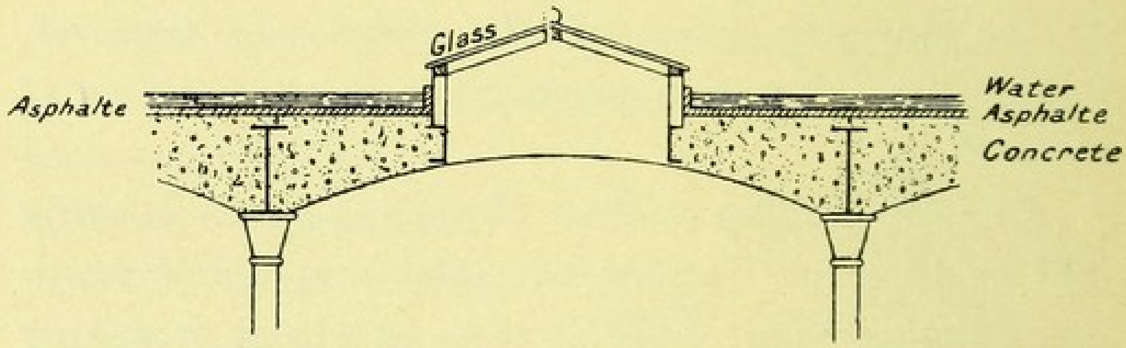


Fig. 52.—Flat Roof of brick or concrete carrying a small depth of water. Sheds having a roof of this type are characterized by the small amplitude of the temperature variations.

a long stoppage on account of bad trade, and a typical chart is reproduced in Fig. 53, A, in which a concrete-roof shed is compared with one having a single roof. The lower line is from an outside thermometer. It will be noticed that the oscillations experienced in the single-roof shed are equal in magnitude to those outside, whilst the curve for the concrete-roof shed has a total variation of only five degrees during the four days referred to. In Fig. 53, B the effect during hot weather is shown, the concrete-roof having slightly greater oscillations of temperature, but their amplitude being much less than those outside or in the single-roof factory.

All timber used in weaving shed roofs should be of good quality, well seasoned by natural means, and

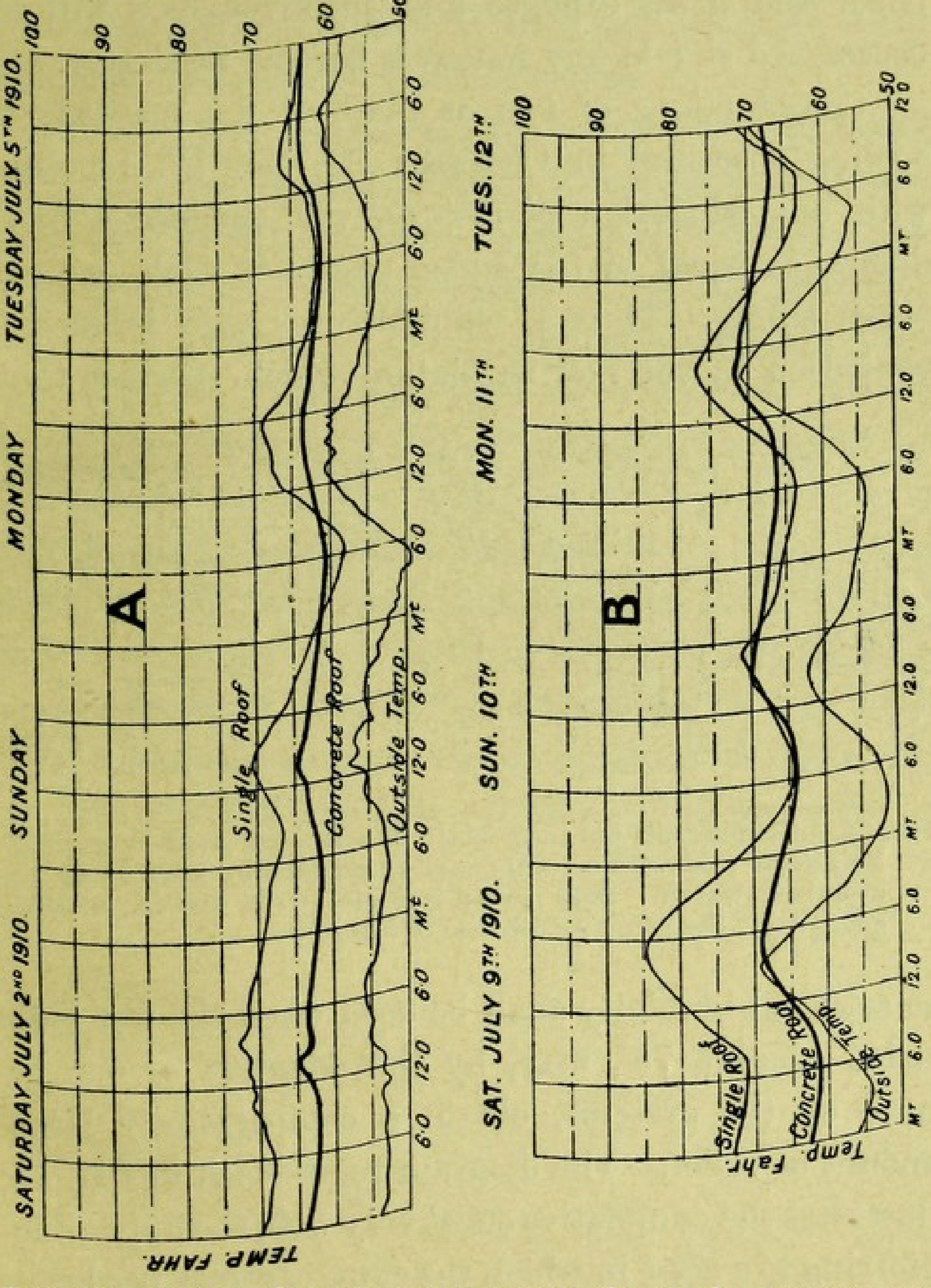


FIG. 53.—Curves showing small amplitude of the temperature variations in a shed having concrete roof as compared with a shed having an ordinary single roof. A refers to a cool period; B refers to a hot period.

painted with high-class materials. Wet rot is particularly liable to attack the wood of a humid weaving shed, and great expense and inconvenience will be occasioned should any renewals become necessary.

Combinations of two or more of the methods of cooling described in Chapters III. and IV., together with a good design of factory, will produce a total difference equal to the added effects of each method taken singly. Thus a manufacturer who is inconvenienced by the new regulation which specifies that

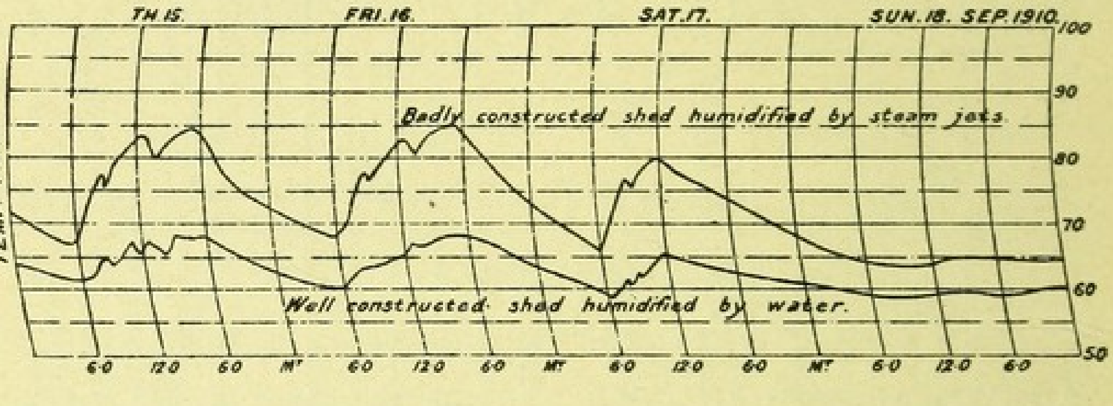


Fig. 54.—Comparison between badly constructed shed humidified by steam jets with a well-constructed factory humidified by atomized water. Both these factories were weaving similar goods with the same percentage of humidity.

no artificial humidity shall be used when the wet bulb inside exceeds 75°, may, by the adoption of one or more of the systems, obtain a comparatively large amount of relief. The diagram reproduced in Fig. 54 illustrates the cumulative effect very well, the upper line referring to a shed in which the cubic capacity per loom was small, the shed badly constructed and humidified by steam jets; the lower line referring to a factory weaving the same class of goods, with similar percentages of size, where, on the other hand, the shed was of good construction, large and airy, and atomized water was used for humidification purposes.

In spinning and preparing rooms the ventilating apparatus may be proportionately much more powerful than that usually installed in weaving factories, since high humidity is not so essential. In flax spinning rooms the mechanical system is augmented by opening windows. The best form of window is one in which the whole of the upper portion is occupied by a centrally hinged fanlight, and so a great area of opening may be provided if necessary. In some of the more modern flax rooms propeller fans are used, and the air is conducted to these by ducts drawing air from a position at or near the centre of the room. Good results have been obtained by apparatus of this type, coupled with the judicious opening of the fanlights.

APPENDIX I

STATUTORY RULES AND ORDERS, 1911
No. 1259.

FACTORY AND WORKSHOP.

Health and Safety.

Regulations, dated December 21, 1911, made by the Secretary of State under the Factory and Workshop (Cotton Cloth Factories) Act, 1911 (1-2 Geo. 5, c. 21) as to Humidity and Ventilation in Cotton Cloth Factories.

In pursuance of section 1 of the Factory and Workshop (Cotton Cloth Factories) Act, 1911, I hereby make the following Regulations, and direct that they shall apply in substitution for sections 90, 91, 92, and 94, and Schedule IV. of the Factory and Workshop Act, 1901, to all factories in which is carried on the weaving of cotton cloth.

These Regulations shall come into force on 1st April, 1912, provided that paragraphs (*c*), (*d*), (*e*) and (*f*) of Regulation 6 shall not come into force until 1st June, 1912.

Provided further that the Chief Inspector of Factories may by certificate in writing suspend the operation of Regulation 1 (*a*) in respect of any *humid shed* for a period not exceeding two years from 1st April, 1912, if satisfied, after an inquiry at which the occupier and persons employed shall be heard, that all reasonably available means to keep down the temperature have been adopted, and that by reason of the circumstances of that *humid shed* it is not at all times practicable, notwithstanding the full use of such means, to prevent without cessation of *artificial humidification*, the wet-bulb reading of the *hygrometer* from exceeding 75 *degrees.* Any such certificate shall be subject to the condition that the arrangements for cooling the shed shall be kept in efficient working order, and used whenever necessary, and in the event of any contravention of this condition the certificate may at any time be revoked by notice in writing from the Chief Inspector of Factories.

Definitions.

For the purposes of these Regulations,—

Humid shed means any room in which the weaving of cotton cloth is carrried on with aid of *artificial humidification.*

Artificial humidification means humidification of the air of a room by any artificial means whatseover, except the use of gas or oil for lighting purposes only. Provided that in a room in which there are no distributing pipes or ducts, the introduction of air directly from the open air outside through mats or cloths moistened with cold water shall not, if adopted solely at times when the temperature of the room is 70 *degrees* or more, be deemed to be *artificial humidification.*

Dry shed means any room, other than a *humid shed*, in which the weaving of cotton cloth is carried on.

Degrees (of temperature) means degrees on the Fahrenheit scale.

Hygrometer means an accurate wet-and-dry-bulb *hygrometer*, conforming to such conditions, as regards construction and maintenance, as the Secretary of State may prescribe by order.

Regulations.

1. There shall be no *artifical humidification* in any *humid shed*—

(*a*) at any time when the wet-bulb reading of the *hygrometer* exceeds 75 *degrees;* or

(*b*) at any time when the wet-bulb reading of the *hygrometer* is higher than that specified in the Schedule of this Order in relation to the dry-bulb reading of the *hygrometer* at that time; or, as regards a dry-bulb reading intermediate between any two dry-bulb readings indicated consecutively in the Schedule, when the dry-bulb reading does not exceed the wet-bulb reading to the extent indicated in relation to the lower of those two dry-bulb readings; or

(*c*) at any time, after the first half-hour of employment in any day, when the dry-bulb reading of the *hygrometer* is below 50 *degrees;* or

(*d*) at any time, within the first half-hour of employment on any day, when the wet-bulb reading of the *hygrometer* is less than 2 *degrees* below the dry-bulb reading.

2. No water which is liable to cause injury to the health of the persons employed, or to yield effluvia, shall be used for *artificial humidification*, and for the purpose of this Regulation any water which absorbs from acid solution of permanganate of potash in four hours at 60 *degrees* more than 0·5 grain of oxygen per gallon of water, shall be

deemed to be liable to cause injury to the health of the persons employed.

3. In each *humid shed* two *hygrometers*, and one additional *hygrometer* for every 500 or part of 500 looms in excess of 700 looms, shall be provided and maintained, in such positions as may be approved by the Inspector of the District.

A copy of the Schedule appended to this Order shall be kept affixed near to each *hygrometer* provided in pursuance of this Regulation.

4. In every *humid shed* the readings of each *hygrometer* provided in pursuance of Regulation 3 shall be observed on every day on which any workers are employed in the shed, jointly by representatives of the occupier and of the persons employed, between 7 and 8 a.m., between 11 a.m. and 12 noon, and (except on Saturday) between 4 and 5 p.m..

The prescribed Humidity Register shall be kept in the factory. If any readings taken as above are such as to indicate contravention of Regulation 1 or Regulation 5, the persons who have taken them shall forthwith enter and sign them in the prescribed Humidity Register, and a copy of each such entry shall also be sent forthwith, in the prescribed form, to the Inspector of the District.

At the end of each week the persons appointed to take the readings shall enter and sign in the prescribed Humidity Register a declaration that during the week the readings have been duly taken by them as required by this Regulation, and that (subject to any exception recorded as above) no readings have been such as to indicate contravention of Regulation 1 or Regulation 5.

The entries in the Humidity Register shall be *primâ facie* evidence of the temperature and humidity of the air of the *humid shed*.

5. In every *dry shed* and in every *humid shed* the arrangements shall be such that (1) during working hours the temperature shall not at any time on that day be below 50 *degrees*, and (2) no person employed shall be exposed to a direct draught from any air inlet, or to any draught at a temperature of less than 50 *degrees*.

Provided that it shall be sufficient compliance with the requirement marked (1) in this Regulation if the heating apparatus be put into operation at the commencement of work, and if the required temperature be maintained after the expiration of half-an-hour from the commencement of work.

In a tenement factory it shall be the duty of the owner to provide and maintain the arrangements required for the purpose of the requirement marked (1) in this Regulation.

6. In a *humid shed* in which steam pipes are used for the introduction of steam for the purpose of *artificial humidification* of the air—

(*a*) the diameter of such pipes shall not exceed two inches; and in the case of pipes hereafter installed the diameter shall not exceed one inch;

(*b*) such pipes shall be as short as is reasonably practicable;

(*c*) such pipes shall be effectively covered with insulating material kept in good repair, in such manner that the amount of steam condensed in the covered pipe shall not exceed one-fifth of the amount of steam condensed in the bare pipe under the same conditions; and there shall be kept attached to the General Register a certificate from the manufacturer of the covering to the effect that a sample of the covering has been tested by an authority approved by the Chief Inspector of Factories and has been found to conform to the above standard;

(*d*) all hangers supporting such pipes shall be separated from the bare pipes by an efficient insulator not less than half-an-inch in thickness;

(*e*) no uncovered jet from such a pipe shall project more than 4½ inches beyond the outer surface of such covering;

(*f*) the steam pressure shall be as low as practicable, and shall not exceed 70 lbs. per square inch;

7. In every *humid shed* hereafter erected—

(*a*) the average height of the shed shall not be less than 14½ feet, nor the height of the valley-gutters from the floor less than 12 feet;

(*b*) the lights shall as far as possible face true North; or if this be impracticable, between North-East and North-North-West;

(*c*) the glass of the lights shall be at an angle of not more than 30 degrees to the vertical, except in the case of flat concrete or brick roofs;

(*d*) the boiler-house and engine-room shall be separated from the shed by an alley-way, not less than 6 feet wide and either open to the outside air or provided with louvre or roof ventilators capable of being opened in summer and of an area equal to one quarter of the floor area of the alley-way;

(*e*) no boiler flue shall pass under the shed, or within 6 feet horizontally from the wall of the shed.

8. In every *humid shed* and in every *dry shed* the whole of the outside of the roof (windows excepted) and the inside surface of the glass of the roof-windows shall be white-washed every year before the 31st May, and the white-wash shall be effectively maintained until the 15th of September.

Provided that the above requirements of this Regulation, so far as regards roof-windows, may be suspended by certificate in writing from the Inspector of the District, if it is shown to his satisfaction that the roof-windows are so placed, or are so shaded by adjacent buildings, that the direct rays of the sun can never impinge upon them at any time during any day; which certificate shall be kept attached to the General Register.

9. In every *humid shed* and in every *dry shed* the arrangements for ventilation shall be such that at no time during working hours shall the proportion of carbon dioxide in the air in any part of the shed exceed the limit specified below for that shed, namely—

for *humid sheds* eight
for *dry sheds* eleven } parts by volume of carbon dioxide per 10,000 parts of air in excess of the proportion in the outside air at the time.

Provided that—

(1) during any period in which it is necessary to use gas or oil for lighting purposes, and

(2) before the end of the dinner-hour on any day in which gas or oil has been so used,

it shall be sufficient compliance with this Regulation if means of ventilation sufficient to secure observance of the above requirement during daylight are maintained in full use and in efficient working order.

10. In every *humid shed* erected after 2nd February, 1898, sufficient and suitable cloak-room or cloak-rooms shall be provided for the use of all persons employed therein, and shall be ventilated and kept at a suitable temperature.

In every *humid shed* and *dry shed* to which the above provision does not apply and in which a suitable and sufficient cloak-room is not provided, suitable and sufficient accommodation within the shed shall be provided for the clothing of all persons employed, within a reasonable distance of the place of employment and consisting of a sufficient number of pegs, not less than one for each person employed and not less than eighteen inches apart, and of a covering of suitable non-conducting material spaced not less than half-an-inch from the wall or pillar and so arranged that no moisture either from above, or from the wall or pillar, can reach the clothing.

R. McKenna,
One of His Majesty's Principal
Secretaries of State.

Home Office,
Whitehall,
21st December, 1911.

Schedule.

Humidity Table, for the purposes of Regulation 1.

Dry-bulb readings.	Wet-bulb readings.	Dry-bulb readings.	Wet-bulb readings.
(1)	(2)	(1)	(2)
50°	48°	66°	64·0°
51°	49°	67°	65·0°
52°	50°	68°	66·0°
53°	51°	69°	67·0°
54°	52°	70°	68·0°
55°	53°	71°	68·5°
56°	54°	72°	69·0°
57°	55°	73°	70·0°
58°	56°	74°	70·5°
59°	57°	75°	71·5°
60°	58°	76°	72·0°
61°	59°	77°	73·0°
62°	60°	78°	73·5°
63°	61°	79°	74·5°
64°	62°	80°	75·0°
65°	63°		

APPENDIX II

Form 317.—*March*, 1912.

FACTORY AND WORKSHOP ACTS, 1901 TO 1911.

RECORD OF HUMIDITY.

For use in Humid Sheds of Cotton Cloth Factories.

Shed

Hygrometer { distinctive mark
position in shed

DATE.	READINGS OF HYGROMETER.						If no humidity, insert "None."
Year Month	Between 7 and 8 a.m.		Between 11 a.m. and 12 noon.		Between 4 and 5 p.m.		
Day	Dry bulb.	Wet bulb.	Dry bulb.	Wet bulb.	Dry bulb.	Wet bulb.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1st 2nd 3rd 4th 5th etc., etc. 29th 30th 31st							

At the beginning of the month the Sundays, whole holidays, and in the shorter months the 31st or other excess days, should be erased, in order to lessen the risk of entries being made under the wrong dates.

APPENDIX III

Form of Register of

HYGROMETER READINGS

Indicating contravention of Regulation 1 or Regulation 5.

HUMID SHED

(designation or number).

Hygrometer readings indicating contravention of Reg. 1 or Reg. 5.							During the week specified in col. 8 we have in pursuance of Reg. 4 duly taken the readings of each Hygrometer. Except as recorded in cols. 1 to 5, no reading has been such as to indicate contravention of Reg. 1 or Reg. 5.	
Date.	Hour.	Hygrometer (distinctive mark).	Readings.		Signatures.	Notice sent to Inspector (date).	Week ended (date).	Signatures.
			Dry bulb.	Wet bulb.				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

APPENDIX IV

Form 80.—*March*, 1912.

FACTORY AND WORKSHOP ACTS, 1901 TO 1911.

REGULATIONS FOR COTTON CLOTH FACTORIES.

Form prescribed by the Secretary of State for

NOTICE OF HYGROMETER READINGS

indicating contravention of Regulation 1 or Regulation 5.

Occupier

Address of Factory

The following notice is sent in pursuance of Regulation 4, paragraph 2.

Humid Shed (designation or number).	Copy of entries in cols. 1 to 5 of the humidity register.				
	Date.	Hour.	Hygrometer (distinctive mark)	Readings.	
				Dry bulb.	Wet bulb.

Signature

of Occupier or Agent

Date

Copies of all entries in cols. 1 to 5 of the Humidity Register must be sent forthwith, on this Form, to the Inspector of the District.

PRINTED BY
WILLIAM CLOWES AND SONS, LIMITED,
LONDON AND BECCLES.