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The Optimum Humidity for Mental Work

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THE OPTIMUM HUMIDITY FOR MENTAL WORK

By WILLIAM H. BURNHAM, Clark University

Most people have only a vague idea of the hygienic significance of humidity in the air of the home or the schoolroom. Much of the recent literature on the subject is likely to leave one with confused or erroneous ideas.

On the one hand are those who apparently have found the key to human happiness and efficiency in an optimum humidity. On the other hand are those who generalizing hastily from the investigations of the New York Commission on Ventilation conclude that apart from unusual conditions the humidity in the air of a schoolroom is of minor importance.

An ardent representative of the former class is Mr. Watt who has discussed at length the relation of humidity to health; and on the basis of his observations in the Graham School in Chicago condemns the dry atmosphere of the ordinary schoolroom and insists in the most emphatic language upon the need of a proper degree of moisture. In a personal letter a few years ago he wrote:

"We have humidified the air in all regular rooms and reduced the temperature to 62 with everyone comfortable and enthusiastic over it. This is the greatest thing in education at this minute. The hot dry air of ordinary schools makes catarrh, pneumonia, tuberculosis, grippe, dyspepsia, general debility, headache and torpor. By injecting steam into the tempered air chamber we lower the danger of colds and make the teachers who formerly were chilly in 70 satisfied with 62. More than satisfied."

Watt apparently would make a lack of humidity responsible in large degree for the moral and mental defects of humanity in general. In his book he has chapters on "American dry rot;" "The steam heated woman;" "Dryness as a cause in falling off in church attendance." Of his own experience in Chicago he says:

"We avoid hundreds of daily headaches, we cure stupidity, we permit clearness of thought, we have cut down the number of cases of office discipline more than 75% since we turned on the steam." (13)

On the other hand the New York Commission (10) from studies of the physiological condition and ability to do intellectual work as gauged by standard psychological tests under varying conditions of humidity, reported no appreciable results. The subjects of this experiment, it is reported, worked naturally and they were no less efficient and showed no poorer control under the excessively dry conditions than under the more favorable conditions. The subjects did not feel uncomfortable, and there seems to have been no real physiological disturbance, because the tests of pulse and temperature gave negative results.

Between these extremes are conflicting reports of many observations of the effects of different conditions of humidity. Obviously it is desirable that further investigations be made. Meanwhile it seems possible to come to closer quarters with the problem and to get a clearer view of the significance of the known facts.

The problems of temperature and of humidity are inseparably connected. Air, using the word as we usually do, always contains a certain amount of moisture. It seldom contains all it can hold. When it does it is said to be saturated. Speaking from a more strictly scientific point of view, Dr. Wilson says:

"The expression, 'capacity of air for moisture' is misleading. A better expression is, capacity of space or vapor for moisture, because the presence of air in space has nothing whatever to do with the capacity of the space for moisture, the only effect of the presence of air being to retard the diffusion of moisture within the space." (*Science*, 1911, p. 152.)

Absolute and relative humidity are distinguished. The absolute humidity is the amount of moisture actually contained in a given space or atmosphere. The relative humidity is the ratio of this actual humidity to the possible humidity at saturation for the given temperature and pressure; and it is reckoned in the percentage which the absolute humidity is of

the total possible humidity. That is, an atmosphere of a given temperature would contain 100 parts of water at the saturation point. We find it does contain 75 parts, then it has a relative humidity of 75%. The warmer the air, the greater the amount of moisture it can hold; hence for a given percentage of relative humidity, the warmer the air the greater is the amount of moisture it contains, or the greater the absolute humidity. Thus the relation of the relative humidity to the temperature is an important one, and absolute humidity as well as relative humidity has hygienic significance.

To understand the hygienic significance of the humidity of the air, it is necessary to keep in mind that the primary need for ventilation is to remove superfluous heat from the body. Recent investigations have emphasized this. In the now familiar experiments of Paul in Flügge's laboratory, while he remained for four hours breathing the same air over and over again when the temperature and humidity were low, with the temperature above 70°F. and the humidity above 72%, serious symptoms appeared and he was on the verge of collapse in 15 minutes. When in this condition he put his head out of the cabinet and breathed fresh air it did him no good, since an increase of the body temperature was apparently the cause of the symptoms. In the high temperature of some schoolrooms and public halls, as suggested by the experiments by Paul, probably an abnormal increase of the body temperature, what Paul called *Wärmestauung*, occurs. The serious effects of this were demonstrated by Paul's experiments, and ordinary observation shows the same. Where people are crowded into an enclosed space, fainting not infrequently occurs, and this is apparently often due to the abnormal increase of the body temperature. In such cases what happens is probably this:—The increased temperature produces an increase in metabolism and the oxygen supply is not equal to the demand; hence the disastrous results. (2, p. 57).

Lee (8a) has brought together a large number of facts bearing on the effect of increased temperature and increased humidity, and forms the following conclusion:—"From these various observational and experimental data it may be inferred, if not with certainty at least with a high degree of probability, that the subjection of a body to an external temperature and humidity sufficient to raise the internal temperature to a pathological degree causes metabolic changes, the nature of which is not yet known, but which interfere profoundly with the normal working of internal mechanisms."

Lee also recalled the fact that Alexander von Humboldt more than 100 years ago observed that heat increased the

action of various chemical substances on certain forms of living matter such as the heart and the motor nerves. Many investigators have studied this and it is recognized as a general law that at a higher temperature the action of poisons is more intense. It has been suggested that this law applies to the effect of fatigue toxins. Patrizi suggests that this is the reason for the great susceptibility of the human muscles to fatigue when subjected to hot baths. In the case of excessive temperature and humidity we have the fatigue toxins as well as an overheated body, and in proportion as the internal temperature rises the toxicity of the fatigue substance is more and more increased.

Huntington has given a similar explanation of the effects of excessive temperature. He says:

"Physiologists are not yet fully agreed as to the cause of the phenomena shown . . . although there is little doubt as to the general facts that they imply. One hypothesis may be briefly stated. According to Pütter's summary, the most probable explanation is that activity goes on increasing according to the ordinary chemical law until it becomes so great that the organism is not capable of absorbing the necessary oxygen. That is, at a low temperature the creature easily gets what oxygen it needs, and gives it out again in the form of carbon dioxide or of other oxidized products which remove the waste substances from the body. As the temperature rises, the normal increase in chemical activity takes place, the animal is still able to get rid of all its waste products, and thus its life processes are strengthened. With a further rise of temperature a change sets in. The chemical processes which break down the tissues of the body become still more active, but the supply of waste products to be eliminated by oxidation becomes so great that they cannot all be removed. This is because in every organism there is a distinct limit to the amount of oxygen which the creature can mechanically convey to different portions within a specified time. If the supply of oxygen is not sufficient to oxidize all the waste products, some of these will remain in the system. They act as poisons. Their first effect is to diminish the organism's activity. If they accumulate to too great an extent death ensues." (7, p. 107.)

What happens in such extremes of temperature and humidity suggests the point of view for considering ventilation. Dr. Lee sums up the facts, as he sees them, as follows:¹ "When an individual is subjected to an atmosphere that is charged with an excessively high temperature and high humidity, his bodily temperature is raised, his working power

¹ *Am. Jour. of Public Health*, 1912, p. 870.

becomes limited, and there is an early oncoming of fatigue. In addition to the normal fatigue substances there are present other substances, products of an abnormal metabolism, perhaps of increased protein disintegration, which likewise act as fatigue substances. Both the normal and the pathological fatigue substances act toxically to diminish the activity of the tissues, and such fatiguing action is rendered greater by reason of the abnormally high internal temperature that is present."

Thus we see the serious results that occur when the temperature of the body is raised above normal, when there is a storing up of heat in the body, as in Paul's experiments in the glass cabinet. Nature has a very elaborate mechanism for maintaining the body at normal temperature. When there is excess of heat the blood is rushed to the surface and cooled. When one is cold, the blood is withdrawn from the surface and heat is conserved. As Sherrington has put it:

"The temperature of the blood as a whole will depend on how large a fraction of it is cooled by streaming through the skin. The regulation of that quantity is a main means of regulating the deep temperature. It is common experience that we flush after entering a warm room. That is, the blood-vessels of the skin dilate. A larger portion of the total blood streams through the cool skin-zone of the body; the escape of heat from the body is more free; this counteracts the tendency for the internal temperature to rise in the warm surrounding. The skin becomes warmer but the internal temperature remains unaltered, or often is a little lowered from over-compensation."

Thus it is vitally essential that the superfluous heat be eliminated from the body. The success or the failure of the body in accomplishing this purpose depends as well on the humidity of the external air as on its temperature as will be apparent from a little consideration.

The humidity of the air has two opposite effects. The first effect of increased moisture in the air is to increase the conductivity of the air for heat and thus to favor the transfer of heat from the body to the air. This is a cooling influence. The other effect of moisture in the air is to check the evaporation of moisture from the body, and thus to check the elimination of heat from the body. This we may refer to as an important heating influence. Whether the moisture in the air serves to cool the body or to heat the body depends on the relation of these two different effects of humidity. At a temperature below 60°, since under ordinary conditions of rest there is practically no perspiration, the dominant if not the exclusive effect of humidity in the air is to increase the conductivity of the air

for heat and hence to cool the body. Above 70° the dominant effect of moisture in the air is likely to be the heating effect decreasing the evaporation. This more than offsets the effect of the increased conductivity of moist air, hence it tends to heat the body.

The greater absolute humidity for a given relative humidity at the higher temperature is also an important factor in relation to respiration; but the relation between the cooling influence by conduction and the heating influence from the checking of evaporation seems to be the prime factor. As Professor Hough says:²

"Humidity influences the output of heat from the body in two very different ways: It increases the conductivity of the atmosphere for heat—a cooling influence; and it interferes with the evaporation of perspiration—a heating influence. What the net result will be depends on which of these influences of humidity is predominant. Below 70° the second, or heating, effect drops out, because so little perspiration is then secreted, and a high degree of moisture chills the skin, as shown by the familiar effect of an east wind in winter along our northern Atlantic coast. Above 70°, on the other hand, because conduction is slower, it becomes necessary to evaporate perspiration and at these temperatures humidity heats the skin. Between these lower and higher ranges of temperature, there is a neutral region at which high humidity has comparatively little effect. This region is about 68 or 70°. We have only to appeal to our own experience to see that high humidity chills the body at 65°, while it is hardly noticeable (in the absence of muscular activity) at 70°."

But in another important way the humidity of the atmosphere affects the elimination of heat from the body, namely, by its effect upon the amount of moisture eliminated by the lungs. Normally in an ordinary atmosphere the body throws off a large amount of heat from the lungs in respiration. The importance of the absolute humidity in relation to health depends upon the fact that it conditions the amount of moisture taken from the body in the process of respiration. Harris and Benedict³ estimate that under the conditions of their experiments with human subjects at rest, 10% of the total heat is lost by evaporation of water from the lungs while 12.3% is lost by evaporation from the skin. Air taken into the lungs contains varying amounts of moisture depending upon the temperature and humidity of the atmosphere. The amount of moisture taken from the body in the

² *Amer. Jour. of Public Health*, 1910, p. 268.

³ *A Biometric Study of Basal Metabolism*, p. 197.

processes of respiration equals the amount given off by the lungs in expiration minus the amount taken into the lungs by inspiration. That is, if the air is cold and dry, as in this climate usually in the winter, little moisture is inhaled and a relatively large amount of moisture is given off from the lungs. If the air is hot and humid, very little moisture is eliminated from the lungs.

In other words, the moisture taken from the lungs is equal to the difference between the absolute humidity of the air inspired and that of the air expired. If the absolute humidity of the air breathed is low, a large amount of moisture is taken from the body in the process of respiration. If the absolute humidity is high, little is taken from the body.

With a moderate temperature and humidity an adult gives off from the lungs, according to Rubner, in one hour:

Rest	17g
Deep breathing	19g
Reading	28g
Singing	34g

In case of an individual for whom these figures represent the facts the amount taken from the body is this amount minus whatever is inspired.

With an atmosphere nearly saturated and a moderately high temperature, say 80° , the amount of moisture taken from the lungs is correspondingly reduced, and such an atmosphere is oppressive. A person ill with fever in a hot muggy day can be greatly relieved by letting him breathe air that has been forced through a large piece of ice by an electric fan. By this means the temperature of the air is reduced far below the point of precipitation and the absolute humidity correspondingly reduced.

Other conditions being constant, upon the *relative humidity* depends the amount of moisture evaporated from the skin. Hence this is an important factor in determining the temperature of the body. With a temperature of 85°F. , for example, and a relative humidity of 90%, the body is surrounded as it were with a steam jacket and it is hard for it to rid itself of its superfluous heat. Thus Paul in his experiments with the glass cabinet found, as already noted, that with a temperature of 60°F. , if the humidity was not more than 47% to 72%, he could remain for hours in the cabinet without discomfort; but with a humidity of 72% to 92% and a temperature of 68° to 86° , serious symptoms appeared in 15 minutes. But there was another interesting feature of this experiment; when on the verge of collapse, he started an electric fan, and the disagree-

able symptoms disappeared; for this stirred up the air and increased the evaporation from the body. (2, p. 57.)

Thus the absolute necessity of eliminating the superfluous heat from the body and the need of a suitable humidity of the atmosphere in order to favor the regulation of the body temperature give us the primary reasons for ventilation. In spite of all our lack of knowledge in regard to the problems of expired air there is apparently a practical consensus on this point as regards ventilation. The following is a good example of the opinions held.

Professor C. E. A. Winslow writes: "The chief factors for air conditioning for the living machine, *which in most cases far outweigh all other factors put together* are the temperature and humidity of the air." And again he says: "The sensations experienced in a badly ventilated room and the serious effects which such a room exerts upon health and efficiency are primarily due to the warmth and stagnation of the air and to its high humidity." (14, p. 828.)

Thus humidity is an essential point to be considered in ventilation. Ordinarily the air of inhabited rooms must be changed to keep the humidity at an optimum. To determine the optimum humidity for intellectual work is not an easy task. The chief factor to be considered is probably the effect on metabolism, appearing temporarily as comfort, permanently in an effect on health.

Several investigations have been made to determine "sensible" humidity. These indicate that the variations within the limits of comfort are rather wide. Rubner (12) made experiments with a man in the respiration chamber for the purpose of solving this problem. The general results were as follows: At low temperature, 14-15C. (52 to 59F.), dry air is more agreeable than moist. Between 24° and 29°C. (75 to 84 F.) dry air appears cooler than moist. High temperatures are not uncomfortable if the air is very dry. Visible sweat begins at 29C. (84F.) with a relative humidity of 22%. A relative humidity of 96% with a temperature of 24C. (75F) is unendurable for any length of time.

Observation too, shows that many persons are uncomfortable in a dry atmosphere. Lack of humidity is supposed by many to produce nervousness. If we pass beyond the mere question of comfort we have little direct evidence of what constitutes the optimum. But from our present point of view of the physiological significance of humidity in the air we may consider some of the important investigations.

Huntington (7, p. 85) studied the relation of the humidity to the efficiency of factory workers. He found efficiency at

a minimum in January and July and at a maximum in May and November. He notes that a sharp distinction should be made between the humidity of the outside air and that indoors. In his own study he did not find that humidity was responsible for fluctuations except as it was influenced by temperature. The inside humidity he thinks is an important factor in causing the low efficiency of mid-winter; but the average humidity of the outside air from season to season does not, he thinks, vary in such a way as to cause maxima in May and November, and minima in January and July.

Huntington reported that in spring and fall with temperature ranges from freezing to 70° with an average of 50° the best work is performed with a relative humidity of 75%. Neither the wet days nor the dry days are the best. A hot damp day, as everybody knows, is debilitating. The majority of the dampest days in summer are comparatively cool and the coolness counteracts the humidity and efficiency increases, hence Huntington concluded that with an average temperature of 65° a relative humidity of about 60% is desirable, and he says: "The most unmistakable feature of the curves as a whole is that they show a diminution of work in very dry weather." (7, p. 87).

Bearing still more directly on our problem are the investigations of the New York Commission on Ventilation. In their earlier tests the Commission studied the effect of humidity only incidentally; but no influence appeared. The general result as reported by Prof. Palmer was as follows: (9, p. 56)

"The effect of air conditions on mental proficiency was observed by giving the subjects standard psychological tests, such as adding columns of figures, mental multiplication, naming opposites of words, typewriting and cancelling numbers. The average scores in these various tests were found to be about equal regardless of the temperature or the absence of ample ventilation. Even a hot moist room, 86 degrees, which caused profuse perspiration and very positive discomfort, failed to lower the standard of efficient work. The scores fell off perceptibly, however, in the hot room, when the subjects were allowed to work or not as they pleased. No such change was noted when the air supply was reduced to a minimum. In fact, the average result of daily votes in one series indicated a greater degree of comfort with no air supplied at all than on the days with ample ventilation. The room temperature in both cases was kept at 68°."

The investigations by the New York Commission were made upon over a hundred different subjects, men and women,

working for periods approximating a day or half a day of ordinary factory work under carefully controlled atmospheric conditions in specially constructed experimental rooms at the College of the City of New York. Physical and mental tasks of various kinds were given and careful physiological and psychological observations of the bodily condition and the efficiency in both mental and physical work were made. As Dr. Winslow sums up the results: (14, p. 829)

"These experiments showed that stale rebreathed air containing 20 parts or more of carbon dioxid and all the organic and other substances commonly present in such air had no harmful effect on any of the physiological conditions studied, nor on the power or inclination to do mental or physical work, nor even on the comfort of the subjects as indicated by their average vote,—provided the temperature was not allowed to rise as it would generally do in such a room under ordinary conditions. There was, however, a slight but distinct diminution in the appetite for food in the stale air."

"The power to do either mental or physical work when concentrating for a short period under a strong stimulus was not diminished in these experiments even by the extreme condition of 30° C. (86° F.) with 80 per cent relative humidity. This coincides with practical experience, for we are all aware that heat, unless very extreme, is no hindrance to absorbing intellectual work and no bar to a good game of tennis."

"On the other hand warm air, whether stale or fresh, produced distinct and clearly marked physiological reactions. At a temperature of 24° C. (75° F.) with 50 per cent relative humidity the rectal body temperature was .2° C. higher and at a temperature of 30° C. (86° F.) with 80 per cent relative humidity, it was .5° C. higher than at 20° C. (68° F.) with 50 per cent relative humidity. The reclining pulse rate was 5 beats higher and the standing pulse rate 12 beats higher at 24° C. (75° F.) the reclining pulse rate 8 beats higher and the standing pulse rate 17 beats higher at 30° C. (86° F.) than 20° C. (68° F.)."

In the special investigation of the effects of humidity tests were made of addition, aiming, hand steadiness, tapping, type-writing, arm steadiness, mirror tracing, industrial fatigue, reflex wink, and eyelid tremor. The tests were made twice or three times a day with a temperature of 75°F. and 50% of relative humidity and 75°F. and 20% relative humidity.

By these tests of nervous and motor control, and by the more strictly intellectual tests no influence of excessive dryness during the two weeks' exposure, or during the working day could be detected.

Classes also were arranged at each end of the building, those at one end having a dry air, those at the other, a moist air. That is, in the words of the report, "Several classes at one end of a floor were subjected to moist atmosphere, and classes at the other end to naturally dry air." The pupils in these classes were of the same grade of mentality and physical and social status. (10, p. 14)

The physical condition of the children and the percentage of attendance showed no difference in the two groups of rooms. And on the basis of similar mental tests the experimenters concluded that no appreciable difference was found.

The experimenters did not conclude from these results that ventilation is an unimportant matter. Dr. Stecher writes in closing her monograph as follows: (10)

"Still, our finding that individuals put under certain controlled conditions react or fail to react in certain ways is by no means to be taken as sanction for all sorts of uncomfortable ventilation conditions. It must be remembered that in isolating the factor of humidity, we did not attempt to reproduce the conditions that go to make up a crowded, ill-smelling and excessively hot room. The very fact that the method of ventilating the experimental chamber produced a normal amount of air movement tended to alleviate the discomfort that would ordinarily be felt in a closed room under a 75°, 20 per cent condition."

It should be noted that these experiments give results which apply of course only within the range of humidity tested, and for the length of time the experiment was continued and the other conditions of the investigation. They tested low humidity, that is, of 20% as compared with what was deemed an optimum humidity, namely 50%. Further experiments are especially desirable to test an optimum humidity of 50% compared with a high humidity, say of 85 or above and also with a higher temperature, say a temperature of 75° such as is often found in schoolrooms and offices.

These experiments conducted by the New York Commission and reported by Miss Stecher were carried out with great care to control conditions, to give suitable instructions, to make the mental conditions favorable by arousing interest and the right attitudes in the subjects. They did not, however, concern all the important psychological factors involved. Especially is this true as regards suggestion. It would seem especially desirable that further investigation should be made with the special aim of determining the influence of this distinctly psychological factor in conditions where changes of humidity are concerned.

That many people are specially susceptible to suggestion from air conditions is shown by many observations and by the reports of many students. Note especially the comfort which many persons take from having a bowl of water or the like on the radiator in a hot room, and further, the very beneficial results reported by many from the use of some of the patent devices for moistening the air. That these favorable

results are due to suggestion rather than to the water evaporated is indicated in the first place by such experiments as those of Professor Loveland which showed that the ordinary radiator pan or vessels of water placed about the room change the humidity of the air only a fraction of 1%.

The observations made by Watt (13) and other enthusiasts cannot be doubted. But the psychologist naturally inquires if the good results of increased humidity reported were not in part due to suggestion. With the enthusiasm of their teacher the students in Watt's school would probably do better work when he, as he says, "turned on the steam," whether this were done literally or figuratively.

In their earlier tests the New York Commission studied the effect of morbidity only incidentally, but no appreciable effect of changes in humidity were observed.

The results found by the Commission should be considered in connection with such studies of the health of school children as those made by Dr. Josephine Baker (1) in the New York schools, who found an enormous increase in respiratory disorders in mechanically ventilated schoolrooms as compared with the open-window naturally ventilated rooms. The chief defect of the investigations of the New York Commission as described in these preliminary reports appears to be that they have not yet extended their study to the deeper effects of variations in air conditions on metabolism and the permanent health of the workers. That these deeper effects are the significant ones for hygiene is indicated not only, as we have seen, by the physiological effects of excessive heat and humidity, but is also suggested by the significant statement of the Commission that a loss of appetite was noted among their workers in unfavorable air conditions.

The outstanding facts emphasized by recent investigations are the following:

(1) The effect of bad air upon health and efficiency is due to physical conditions of heat, humidity, and lack of cutaneous stimulation rather than to chemical or bacteriological factors. The outcome of many recent investigations is to emphasize this point.

(2) The stagnant air in unventilated rooms apparently exerts an influence upon health and efficiency. In such an atmosphere there is a lack of normal cutaneous and nervous stimulation; and apparently, as indicated by the health of patients in hospitals and pupils in public schools, the health as well as the comfort of the occupants of rooms with stagnant air is distinctly affected. Moving air from open window

ventilation or even from the presence of an electric fan is distinctly beneficial, providing a healthful stimulus.

(3) Recent investigations, especially experiments carried on by the New York Commission on Ventilation, indicate surprisingly little effect upon the ability to do mental work from lack of ventilation. While excess of temperature affects the physiological functions, as already noted, the ability to do mental work seems to be practically as great with excess of humidity, and even of temperature, under the conditions of the experiments performed by them. The unfortunate results of bad air, apart from the direct physiological effects of overheating seem to be due largely to the mental attitude, distraction, and in case of many persons, the great discomfort, caused by suggestion, association, or conditioned reflexes, that occur under such conditions. In other words, the mental factor likely to be present in badly ventilated rooms seems to be much more important than is ordinarily supposed.

(4) The recent investigations corroborate and emphasize what has long been known, that the CO_2 and other poisonous chemical substances present in bad air have little if any appreciable effect.

(5) In order to get to close quarters with the effects of bad ventilation, further studies should be made of the deeper physiological effects upon metabolism and the general health, especially from continuous work in bad air conditions.

PRACTICAL SUGGESTIONS

While we do not know very accurately about the matter, there is good reason to believe that a low humidity as well as a high humidity are both injurious to the health. The schoolroom problem is not a simple one. Besides the weather conditions and the heating and ventilating we have to consider the children as heat and moisture producing organisms.

Selter^{*} assumes that an increase of humidity due to the children in a schoolroom cannot be avoided. One school child gives off per hour about 20 gr., an adult about 60 gr. of water in the form of watery vapor. This would amount in case of 50 children and a teacher to 1060 gr. or 5 gr. per cubic meter of the schoolroom. If we assume a temperature of 18°C . and a humidity of 50% at the beginning of the instruction then the moisture would rise at the end of the hour to 83% on the supposition that the temperature remains constant at 18° . If one would use the humidity as a gauge for reckoning the amount of air to be added, then in the case of cold outdoor air one would need to add only a very little air by ventilation in

^{*} Handbuch, p. 92.

order to keep the humidity from going above 60%, but in case of a high external temperature one would need to add very much air by ventilation. For example in case of an outdoor temperature of 5°C. and 80% of humidity changing the air once would be enough. In case of an outdoor temperature of 12° and 80% of humidity one would need to change the air twice; with an external temperature of 14° sufficient air could not be added to keep the humidity below 60%.

Selter's figures represent at most only one situation, but they illustrate a factor in the problem often neglected.

In regard to this whole matter, also, it should be remembered that an optimum humidity is merely one among many essential conditions; and great care may well be taken in statements concerning the humidity of the air in a schoolroom. The humidity is an essential factor in determining the optimum temperature; suitable temperature and humidity are inseparably connected as the primary ends of ventilation; and all the factors involved in the problem should be considered.

In the present condition of our knowledge it appears that with too dry an atmosphere injury is done to the throats and noses of some at least of the children; that in hot weather too moist an atmosphere checks the normal evaporation and elimination of heat from the body and is depressing. Until further studies have been made, schoolroom air with a temperature of 68°F. to 70°F. should have a relative humidity of 45 to 60%. A temperature of 65 to 68 with a humidity of 50 to 60% would probably be better.

Practical schemes for increasing the humidity of the air of schoolrooms are apt to fail because few people realize the great quantity of water that must be added to the air of a room when it is dry in order to produce an optimum humidity. This is well illustrated by experiments cited by Dr. Bruner.

"A few years ago some careful experiments on humidifying air were made by Professor Loveland at the University of Nebraska. These covered thirty days. Two seven-room houses, alike in construction and each heated by a hot-air furnace of the same make, were selected for experimentation. It was found that to raise the relative humidity of one 10 per cent above the other, as indicated by the hygrometer—i. e., from 20% to 30%—it was necessary to evaporate sixty-four gallons of water daily. It was further demonstrated that the ordinary furnace or radiator pan, or vessels of water placed about rooms, affect the humidity so little that it is not registered by the hygrometer. . . Most persons will testify to feeling a considerable difference in the character of the air as a result

of such evaporating devices, but the difference is unquestionably psychological rather than physical."⁵

To show the amount of moisture necessary to keep the air of a large building at a relative humidity of 50% in dry weather, Dr. Bruner gives the following example:

"The air in the American Bell Telephone building at Boston is kept at a relative humidity of 50% by injecting into the entering hot-air current a jet of steam; 675 gallons of water (twenty-two barrels) in the form of steam is required for this purpose every ten hours."

Many practical experiments in schoolrooms have shown that in the northern parts of this country in the winter months the air is apt to be very dry, and that pupils are comfortable at a lower temperature than the usual standard of 70° F. if the humidity can be increased. An interesting example of these studies may be cited.

Professor Brown⁶ of the Worcester Normal School made tests a few years ago in various rooms in that building, and he reported as follows:

"Last year a jet of steam was turned into the ventilating shaft of the Normal School building and by regulating the supply the humidity of the main hall was raised to between 50 and 60 per cent. The increase of water vapor thus obtained allowed us to live in a temperature of from 64 to 66 degrees in comfort. On one or two occasions the curious condition resulted that the hall, perhaps moistened to the point of enervation, seemed comfortable at 61 degrees when a recitation room in which no moisture entered was reported cold at 65 degrees."

The condition of the atmosphere in most school rooms in this part of the country during the winter season is very dry. Mr. Brown says, comparing them to a desert:

"Now when we consider that the dry region of Asia, the Trans-Caspian Desert, has a range of humidity from nineteen to forty-five per cent; in Africa, Tripoli has a humidity of thirty-three per cent in August; and the Kufra Oasis, Sahara, twenty-seven per cent; Lahore, India, thirty-three per cent; and in our own country the dry Death Valley, California, has for five months a mean of twenty-three per cent, and Pueblo, Colorado, a mean annually of forty-six per cent, we realize that a schoolroom at thirty-seven per cent is not better than a desert."

On the other hand, we may perhaps from the results thus far obtained conclude that the actual ability to do mental work in such processes as adding is not materially decreased during a short period by working in an unduly high temperature and high humidity; but the amount of work done under ordinary conditions, where the subjects are prone to give way to their feelings; that is, the work done under ordinary school-

⁵ Bruner, *Proc. N. E. A.*, 1911, p. 894-5.

⁶ *Worcester Bulletin*, Nov. 16, 1912.

room conditions, is likely to be greatly decreased by a temperature and humidity that vary considerably from the optimum.

While the results of experiments seem to show no effect of dryness of the atmosphere down to 20% humidity on the amount of work that can be done, there does seem to be, on the other hand, a good deal of evidence that such conditions of the air create discomfort, and especially is it true at the other extreme, that great discomfort is caused by extreme humidity. Most people are so governed by their feelings that this discomfort is likely under ordinary conditions to decrease one's efficiency for work, however true it may be that under laboratory conditions one may be able to do as much work as usual.

Whatever the possibilities of doing a normal amount of work under adverse air conditions, in the ordinary work of the school it is desirable that children should be comfortable; and there are plenty of opportunities for developing will power and a wholesome attitude of meeting difficulties without resorting to an excess of temperature or of humidity. It is desirable that the developing brain of the child, the most marvelous and most complicated machine of which we have any knowledge, should do its work at least with conditions that do not tend to distraction. The habits of work formed under such conditions are better than those formed where the mental work is done with discomfort. Again in the practical work of the school, when discipline goes wrong and children misbehave or become nervous, the teacher should seek for the cause, and one of the first things to do is to look at the thermometer and note the other air conditions. It is usually better to improve the discipline by letting in fresh air than by the use of sarcasm or the rod.

At first sight it is difficult to understand why some people are so seriously affected by excess of humidity in the atmosphere. The sticky humid days of midsummer are disagreeable to anyone; but in case of some individuals they are the cause of much lassitude and depression. Probably some children form conditioned reflexes to a humid atmosphere as a conditioned stimulus. If this occurs we have a natural explanation of the idiosyncracies of certain nervous people to the weather. The way such reflexes might be formed is obvious.

Suppose a child happens to have a slight physical disorder, indigestion, headache or the like, on a muggy humid day. The indigestion is the cause of the headache and other uncomfortable symptoms. Naturally enough in case of nervous children a single experience of this kind might be enough to cause the association of the humid weather with the indigestion as a conditioned stimulus; and in case of normal children,

if this experience happened two or three times, the weather condition might naturally become associated with the indigestion, so that thereafter when such humid weather occurred, even without the indigestion, the same physical symptoms of depression, headache and the like might occur as conditioned reflexes.

Probably, however, the excess of temperature does to a certain degree affect the brain directly by causing changes in metabolism. The experiments by the New York Commission strongly suggest that excess of temperature or the bad odors of stale air, or both these together modify the general metabolism, since, as we have seen, these investigators found that by working in bad air and overheated conditions the appetite of their subjects was diminished. Thus, while for the time being no appreciable effect on the working ability was noticed, probably continued work in these conditions would be injurious to the health and decrease the efficiency.

The reason, then, that changes in temperature and humidity have an effect on the mental activity would seem to be threefold: first, because excess of temperature and humidity affects the general metabolism, and along with this the metabolism of the brain; second, the excess of temperature causes discomfort, distraction of attention, and the like; third, the idiosyncracies of some individuals apparently make them especially susceptible to weather conditions, by suggestion, the forming of conditioned reflexes, or the like.

CONCLUSIONS

The main points in regard to humidity may be summed up briefly as follows:

1. The higher the temperature the greater the amount of moisture that a given atmosphere or a given space can contain.
2. What constitutes an optimum humidity depends upon the temperature.
3. Absolute and relative humidity are to be distinguished. The absolute humidity is the actual amount of moisture contained in a given space or atmosphere, the relative humidity is the ratio of this actual amount of moisture contained in a given space to the possible amount that can be contained at the saturation point, and this is usually stated in per cent.
4. The absolute humidity is an important factor in determining the elimination of heat from the body in the process of respiration, because the amount of moisture taken from the lungs is equal to the amount expired minus what is inspired at the given temperature and humidity.

5. The relative humidity is important for health because it also is an important factor in determining the elimination of heat from the body.

6. The humidity in the atmosphere has two different effects. For example, an increase in the humidity increases the conductivity of the air for heat and thus favors the transfer of heat from the body—a cooling effect. On the other hand an increase in the humidity decreases the evaporation from the body, which is of course a heating effect. The actual effect of the humidity of the air at any given moment will depend on the relation of these two factors. This fact explains many of the puzzles in regard to humidity.

7. In this part of the country the air in most schoolrooms in the winter is usually too dry.

8. Observation seems to have shown also that injurious effects upon the mucous membrane of the throat and respiratory tract result from continued breathing of an extremely dry atmosphere, and that such conditions may cause inflammation and irritation of the throat and bronchial tubes. The question of causal relation here, however, has not been adequately studied.

9. A very high humidity with a low temperature makes one chilly. With a high temperature it is oppressive. With a temperature even of 80° and 100% of humidity it seems almost intolerable.

10. Probably there is an optimum humidity for the best physiological condition and for efficient mental work, although this probably ranges within rather wide limits.

There is no consensus in regard to the optimum humidity. Rubner, who has studied the matter for years, advises: At 20 C, 30% — 60%; Uffelmann, 40% — 75%. In this country we may well adopt a relative humidity varying from 45% — 65% as representing the optimum. The range of comfort is very wide, perhaps from 45% — 75%.

11. The organism apparently has great power of adaptability to changes in the temperature and humidity of the air.

12. Changes in humidity are likely to have an exaggerated effect upon some individuals on account of suggestion.

13. It should be kept in mind that the special significance of an optimum humidity comes from its connection with the conditions of temperature. The investigations by the New York Commission concern merely humidity with what may be considered a fairly optimum temperature.

14. Although the experimental evidence is small, it seems clear that an optimum humidity is an important condition of efficient brain activity.

15. Until further investigations are made, the optimum humidity for a schoolroom with a temperature of 68 to 70° would seem to be a relative humidity of 45 to 60%.

16. The experimental evidence, especially that furnished by the experiments of Lehmann and Pedersen, indicates that there may be optima for different occupations.

17. Most of the devices for humidifying the air of a separate room are of little value because they supply too little moisture.

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