SUBJECTIVE IMPRESSIONS OF FRESHNESS IN RELATION TO ENVIRONMENTAL CONDITIONS

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I. Introduction

There is now general agreement that the chief causes of discomfort in crowded and badly ventilated rooms are excessive warmth and stagnation of the air. A further cause of unpleasantness when the fresh-air supply is inadequate is the presence of body odours; but even when odours are imperceptible the physical conditions of the environment may cause discomfort. The effect of the physical environment on comfort is twofold: it affects the subjective feeling of warmth, and it also determines whether the air seems invigorating or oppressive, fresh or stuffy.

In recent years much attention has been given to the relation between environmental warmth and human comfort. The factors which together constitute the thermal environment and influence subjective sensations of warmth are the temperature, humidity and velocity of the air, and the radiation from the solid surroundings. In a recent study of the comfort of persons engaged in sedentary or very light industrial work the relative effects of these several factors on sensations of warmth were estimated (Bedford, 1936).

These thermal factors also influence subjective impressions of freshness, but in different degree. Impressions of the freshness or stuffiness of an atmosphere are not the same as sensations of warmth. The two are correlated, for stuffiness is often experienced in a warm room, while a cool room tends to feel fresh. Yet of two rooms, both equally warm, one may seem fresh and the other stuffy.

Observations made some years ago (Vernon, Bedford & Warner, 1926) showed that the rate of air movement is one of the factors chiefly responsible for this difference. It appeared that the invigorating effect of air currents depends not only on their average velocity but also on their variability, and the strong influence of temperature on feelings of freshness was also apparent. Some time ago the Joint Committee of the Industrial Health Research Board and the Building Research Board on Research in Heating and Ventilation expressed a desire for further information on the relation of subjective impressions of freshness to environmental conditions, and as a first step we undertook to make a fresh analysis of the observational data referred to above to see whether firmer conclusions could be drawn from them. This paper describes the results of that re-examination.

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II. CORRELATION OF SUBJECTIVE IMPRESSIONS OF FRESHNESS WITH ATMOSPHERIC CONDITIONS

During a field study in a number of factories two observers independently recorded their impressions as to the freshness or stagnation (or stuffiness) of the atmosphere and then made various instrumental measurements of the atmospheric conditions. The presence or absence of odours was not consciously taken into account by the observers when making their judgments.

The subjective impressions were notes on an agreed scale to which, for convenience of recording and for statistical purposes, numerical marks were assigned. The scale used was:

Subjective impression of freshness	Marks assigned
Very stagnant (or very stuffy)	0
Very stagnant to stagnant	1
Stagnant (or stuffy)	2
Stagnant to medium	3
Medium	4
Medium to fresh	5
Fresh	6
Fresh to very fresh	7
Very fresh	8

The marks assigned by the two investigators were afterwards averaged, but there was a very close correspondence between the estimates. In 60% of the observations the estimates were identical, and in a further 21% they differed only by one mark.

During the summer (June–September) 292 observations were made, and 203 observations were made during winter (January–March). In all the observations the air temperature, dry kata-thermometer cooling power, mean air velocity, and variability of air movement were measured. For the last measurement a hot-wire anemometer was used. The anemometer was read at 2 or $2\frac{1}{2}$ sec. intervals for 5 min. periods, and the mean variation of the air velocity was then calculated and expressed as a percentage of the mean velocity. During the winter observations the wet-bulb temperature and the variability of air temperature were also recorded. The fluctuations of air temperature were measured at $2\frac{1}{2}$ sec. intervals by means of a sensitive thermopile.

(1) *The earlier results*

In the earlier paper (1926) the correlation ratio (η) was used as a measure of the association between subjective impressions and atmospheric conditions. It was felt that the correlation coefficient (r) could not be used, since subjective impressions cannot be measured and the numerical scale for expressing sensations was necessarily an arbitrary one. The correlation ratios of the different atmospheric variables on freshness impressions were:

Freshness correlated with	Correlation ratio of atmospheric condition on subjective impressions of freshness in: Summer	Winter
Dry kata-thermometer cooling power	0·703	0·790
Air temperature	0·531	0·740
Wet-bulb temperature	—	0·739
Air velocity	0·569	0·381
Mean variation (%) of air velocity	0·365	0·418
Mean variation of air temperature	—	0·422

These ratios indicate a fairly close association between sensations and temperature, and between sensations and air velocity. From a consideration of the tabulated data it was concluded that variability of air movement had a moderate influence on subjective impressions during the summer observations, increasing variability causing an impression of greater freshness, but the winter data were less conclusive. There was a positive correlation between temperature variations and air velocity, and it was thought that this association might account for the apparent effect of temperature variations on sensations.

(2) *Results of new analysis*

In a report by one of us (Bedford, 1936) on the thermal comfort of factory workers the validity of the use of the correlation coefficient as a measure of the association between thermal conditions and comfort votes was discussed. It was shown that there was a linear relation between the arbitrary scale of comfort votes used and environmental conditions, and it was assumed that the linear relation justified the use of the method of partial correlation for the further examination of the relation between comfort votes and environmental conditions. Similar treatment has been used in the fresh analysis. Unfortunately, some of the original data are no longer available, and the numbers of records are reduced to ninety-one for the summer observations and 146 for the winter ones.

The ranges of atmospheric conditions encountered are shown in Table I.

Table I. *Ranges of atmospheric conditions encountered*

	Summer			Winter		
Variable	Range	Mean	Standard deviation	Range	Mean	Standard deviation
Air temperature, ° F.	58–88	71	5·9	50–74	61	4·5
Air velocity, ft./min.	10–130	45	23	10–180	30	23
Dry kata-thermometer cooling power	1·5–8	5·3	1·3	4–12	6·9	1·2
Mean variation of air velocity, % of mean velocity	15–80	33	10·6	10–75	29	10·8
Relative humidity, %	—	—	—	40–85	60	8·4
Effective temperature, ° F.	—	—	—	48–70	59	3·9
Mean variation of air temperature, ° F.	—	—	—	0–2·2	0·4	0·4

The coefficients of correlation between impressions of freshness and atmospheric conditions appear in Table II. In the bottom line of the table the

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standard errors for a correlation coefficient of zero are given. All the coefficients in the table are greater than twice these values and are therefore statistically significant.

Table II. *Correlation of subjective impressions of freshness with atmospheric conditions*

Freshness impressions correlated with	Correlation coefficient (r) Summer observations	Winter observations
Air temperature	−0·47	−0·73
Air velocity	+0·30	+0·35
Dry kata-thermometer cooling power	+0·66	+0·80
Mean variation (%) of air velocity	+0·60	+0·28
Relative humidity	—	+0·19
Effective temperature	—	−0·80
Mean variation of air temperature	—	+0·23
No. of observations	91	146
Standard error	±0·106	±0·083

Regression diagrams show that in each case the association between the numerical scale of freshness impressions and the atmospheric variable concerned is substantially linear. The coefficients of the correlation of freshness with air temperature and dry kata-thermometer cooling power in both the summer and the winter observations, and with air velocity in the winter observations, are very similar to the correlation ratios given in the 1926 report and quoted earlier. In these comparisons the reduction in the number of observations has not caused any appreciable difference in the apparent relation between sensory impressions and atmospheric conditions. For the correlation of freshness with air velocity in the summer observations, and with variability of temperature in the winter ones, the coefficients calculated from the reduced number of data are distinctly lower than the original ratios, while in the case of mean variation of air velocity the new coefficient is higher than the corresponding ratio for the summer observations and rather less in the winter ones. It is difficult to offer an explanation for these differences unless they may have arisen through some effect of the change in numbers on the intercorrelation between different atmospheric variables.

(3) *The importance of air movement*

The partial correlation coefficients in Table III show that when air temperature is held constant freshness impressions and average air velocity are more closely related than would be gathered from the zero-order coefficients in Table II.

Table III. *Partial correlation of subjective impressions of freshness with air velocity and air temperature*

Subjective impressions correlated with	Held constant	Partial correlation coefficient Summer observations	Winter observations
Air velocity	Air temperature	+0·62	+0·49
Air temperature	Air velocity	−0·69	−0·78

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The association between subjective impressions and air velocity is greater in the summer observations than in the winter ones, and consideration of the partial regression coefficients shows that a given change of air velocity had more effect on freshness impressions in summer than in winter. In the winter observations, in which the air temperature averaged 61° F., a change of about 40 ft./min. in the velocity increased the freshness by one unit on the arbitrary scale, say from "medium" to "medium to fresh". In summer, when the temperature averaged 71° F., 10° higher than in winter, an increase in freshness equivalent to one unit on the scale accompanied an increase of only about 20 ft./min. in the air velocity. Thus, in these observations the invigorating effect of air movement was more noticeable at high temperatures than at low, whereas when sensations of warmth are considered a given change in the amount of air movement has a greater effect when the temperature is low than when it is high.

The earlier study of warmth sensations and their relation to thermal conditions showed that as an index of warmth the dry kata-thermometer is definitely inferior to equivalent temperature, effective temperature, or even the dry-bulb temperature of the air. Since the data included in the present analysis do not include radiation measurements equivalent temperatures cannot be calculated with accuracy, but the coefficients in Table II show that as an index of freshness, as distinct from warmth, the dry kata-cooling power is as good as effective temperature or air temperature.

As a measure of warmth dry kata-cooling power fails on account of its excessive sensitivity to air movement, but that same sensitivity operates in its favour as an index of freshness. The total correlation (R) of impressions of freshness with air temperature and air velocity is 0·81. This value is almost identical with the zero-order coefficient of 0·80 for freshness and cooling power. When cooling power is kept constant the partial coefficient for the correlation between freshness and air velocity is only $+0{\cdot}13$, and as this is only about one and a half times the standard error of a partial correlation coefficient of zero (S.E. $= \pm 0{\cdot}084$) it is not statistically significant. In these winter observations, therefore, cooling power made adequate allowance for the effects of air movement, and individual impressions of freshness could have been predicted as well from it as from separate measurements of air temperature and velocity.

In the summer observations, however, when air movement had a greater effect, even the kata-thermometer did not make sufficient allowance for it. With constant cooling power there is still a residual correlation of $+0{\cdot}50 \pm 0{\cdot}11$ between freshness impressions and air velocity, and the regression constant shows that with the same cooling power a change of one sensation unit accompanied a change of about 30 ft./min. in the air velocity.

Provided there is no appreciable difference between the temperature of the air and that of the solid surroundings, effective temperature is a good index of warmth. It makes allowance for the effects of air movement and humidity as well as for those of air temperature. Effective temperatures could not be calculated for the summer observations, but even in the winter observations in which air movement had less effect than in summer, when effective temperature is held constant, there is still a significant partial correlation between impressions of freshness and air velocity ($r = +0{\cdot}29 \pm 0{\cdot}08$). With relative humidity, as well as effective temperature, held constant the residual correlation of freshness with velocity is $+0{\cdot}21 \pm 0{\cdot}08$.

(4) *The effects of variable air currents*

In Table II it is shown that subjective impressions of freshness are significantly correlated with the variability of air movement. Although this variability is expressed as a percentage of the average velocity, it is found that in both the summer and the winter observations there are significant positive correlations between the two. Hence, in order to ascertain whether variability of air movement exerts any real effect on freshness, allowance must be made for the average velocity.

In the summer observations when air temperature and mean velocity are both held constant there is a highly significant partial correlation between freshness and variability of velocity ($r = +0{\cdot}43 \pm 0{\cdot}08$). The regression constant calculated from this coefficient indicates that with the same air temperature and average velocity an increase of about 14% in the mean variation of the air velocity was accompanied by an increase in freshness equal to one unit of the scale.

For the winter observations the zero-order correlation between freshness and variability of air movement is distinctly lower than that for the summer observations (Table II), and when air temperature and mean velocity are kept constant the residual correlation between freshness and velocity variations is insignificant ($r = +0{\cdot}11 \pm 0{\cdot}08$). If such variations had any influence in winter they were of far less importance than in summer. It has already been remarked that the mean air velocity had a less influence in winter than in summer, while, on the other hand, a given temperature change had about 40% more effect on freshness impressions in winter than in summer.

(5) *The effects of temperature variations*

The temperature variations found during the winter observations were only slight. In 30% of the observations the mean variation of temperature was less than 0·2° F., and in 73% below 0·4° F.; only in 4% was it 1° F. or more. Nevertheless, the zero-order correlation with freshness impressions is significant ($r = +0{\cdot}23 \pm 0{\cdot}08$). It happens, however, that in these observations there is a fairly close correlation between temperature variations and air velocity ($r = +0{\cdot}56 \pm 0{\cdot}08$), and when air velocity and mean air temperature are held constant the partial coefficient for freshness and temperature variations ($r = +0{\cdot}08 \pm 0{\cdot}08$) is insignificant. Such slight temperature variations as were met with had no appreciable influence.

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(6) *The influence of atmospheric humidity*

It has been shown (cf. Bedford, 1936) that at the room temperatures commonly encountered in Great Britain during the winter months the effect of humidity on the feeling of warmth is small; but there is evidence that changes in humidity which are insufficient appreciably to affect sensations of warmth may yet have a distinct effect on comfort.

Miura (1931) found that the most comfortable condition of warmth for his American subjects, in still air, was 69° F. with a relative humidity of 50%, or 70° F. with 30% humidity. He concluded that at 70° F. a difference of 20% in the relative humidity was probably beyond the power of perception, yet he reported that at relative humidities of 70% and over an uncomfortable feeling of wetness was experienced at 70° F.

Winslow & Herrington (1935) studied the subjective reactions of a number of subjects to outdoor climatic conditions, and found that relative humidity had a distinct effect. When allowance was made for other factors, sunshine, barometric change and ion-content of the atmosphere being held constant in turn, there was in each case a significant residual correlation between pleasantness and humidity, days of low humidity being pleasanter than humid days.

Markham (1937) expressed the opinion that mental alertness was associated with the lower humidity ranges and lethargy with the higher. He suggested that for mental activity a relative humidity of under 55% was ideal, while for rest and recuperation a higher humidity, possibly in the region of 70%, was desirable.

It appears from our observations that the relative humidity of the air has a real influence on subjective impressions of freshness. The zero-order correlation between freshness impressions and relative humidity shown in Table II indicates that in these observations increased humidity was accompanied by a feeling of greater freshness. That is contrary to what would be expected, and is due to a strong negative correlation between relative humidity and air temperature. When air temperature and velocity are held constant there is a significant partial correlation between freshness impressions and relative humidity ($r = -0{\cdot}24 \pm 0{\cdot}08$) indicating that a humid atmosphere tends to be less stimulating than a dry one.

From the regression constants it appears that, under the conditions covered by the observations, a rise of $8\frac{1}{2}$% in the relative humidity could be compensated for by a fall of 1° F. in the air temperature. This effect of humidity is distinctly greater than would be expected from the results of studies of warmth sensations and environmental conditions. Thus it can be calculated from the data given by one of us (Bedford, 1936) that at about 61° F., the mean temperature experienced in the winter observations, a change of roughly 24% in the relative humidity would be required to compensate for an alteration of only 1° F. in the room temperature, while according to the effective temperature scale about 20% change in the humidity would be necessary. It thus appears

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that a change of humidity which would be insignificant from the standpoint of warmth may have a distinct effect on one's impression of freshness.

When effective temperature is held constant there is a significant correlation ($r = -0{\cdot}24 \pm 0{\cdot}08$) between freshness and relative humidity, but when further allowance is made for the effects of air velocity by keeping velocity as well as effective temperature constant, the residual correlation between freshness impressions and relative humidity ($r = -0{\cdot}14 \pm 0{\cdot}08$) is not statistically significant.

III. The effects of other factors

Although in the observations which have been described attention was paid only to the temperature, humidity, and rate of movement of the air, there are other variables which exert their influence on comfort, and which tend to evoke impressions of stuffiness or of freshness. Principal amongst these are the radiation from the solid surroundings (walls, etc.) and variations between the temperatures at different heights above the floor.

(1) *Radiant heat*

(*a*) *Intensity of radiation.*

The mean intensity of radiant heat at any point in a room is conveniently expressed in terms of the mean radiant temperature, or the mean temperature of the surroundings, which is that uniform temperature at which a black surface would radiate with an intensity equal to the mean observed. This quantity governs the rate at which heat is lost from the body by radiation, and has an important effect on subjective sensations of warmth. Commonly, the mean radiant temperature and the air temperature are very similar, but cases occur in which they differ considerably. In thin-walled structures in severe winter weather the mean radiant temperature may be several degrees below air temperature, while in hot weather, or with certain methods of heating in winter, the air may be distinctly cooler than the surrounding surfaces.

Different combinations of air temperature and mean radiant temperature may yield the same overall degree of warmth, say the same equivalent temperature; for instance, cold walls can be compensated for by an increased air temperature. It does not follow, however, that all combinations of air temperature and mean radiant temperature which give the same equivalent temperature are equally comfortable. In the open we find the combination of cool air and the warmth of the sun's rays most pleasurable; and indoors, too, our sensations are influenced by the balance between the air temperature and the amount of radiant heat. More than 80 years ago the Commissioners of the General Board of Health (1857) advocated as one of the requirements for comfort that the walls of a room be at least as high in temperature as the general temperature of the room, while they included cold walls or floors amongst the conditions which make for discomfort.

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Although we have no statistical evidence to offer on this point, we are convinced that the Commissioners of 1857 were right. In the course of our field investigations we have on a number of occasions experienced feelings of stuffiness at comfortable equivalent temperatures, when we have been unable to find any satisfactory explanation other than the fact that the mean radiant temperature was 6° F. or more below the air temperature.

(*b*) *Quality of radiation.*

According to Sir Leonard Hill (1931, 1934) not only the quantity of radiant heat but also its quality is of importance. Hill has put forward the view that some kinds of radiation, acting reflexly on the skin, produce congestion of the membranes of the air passages and cause feelings of stuffiness, while some persons even experience difficulty in breathing through the nose. Other kinds of radiation are said to relieve this congestion. The nose-shutting rays are said to be those from dark or dull sources, such as steam pipes or the commoner types of electric fire, while the nose-opening rays are those from brighter sources such as the sun, the electric arc, or the newer types of gas fire.

Other workers (Dufton & Bedford, 1933; Winslow, Greenburg & Herrington, 1934) have confirmed that radiant heat can cause narrowing of the nasal airway, but it has been suggested that only peculiarly sensitive people are likely to suffer inconvenience from this case.

On the question whether some rays can relieve this congestion there is conflicting evidence. Hill's finding that they can is supported by van Dishoeck (1935) and, quite recently, by Lehmann (1939); while others (Dufton & Bedford, 1933; Winslow *et al.* 1934) find that any form of radiation, or indeed any sudden warming of the skin, even by hot air or hot fomentations, can set up nasal congestion. Lehmann concludes that nose-closing is caused when there is a lessening of the temperature gradient in the skin, such as occurs when the skin surface is warmed. In this he in agreement with Dufton & Bedford, and with Winslow and his co-workers. He disagrees with these workers in his conclusion that short infra-red radiation can relieve the congestion set up by longer infra-red rays. Dufton & Bedford found that short infra-red radiation, or even the direct rays of the sun, would cause congestion, and they failed to find any source of radiation which had the opposite effect. Winslow *et al.* found that the addition of radiation of shorter wave-length to the longer rays was associated in the great majority of their experiments with a further increase in congestion. It is true that on some occasions these authors found that switching on an ordinary electric light was followed by a reduction in the nasal congestion which had already been induced, but in further experiments the clicking of a switch without turning on the light also produced similar results. Hence it appeared that the light antagonism was dependent upon a subjective psychological reaction rather than on any direct response of the skin to specific wave-lengths.

(2) *Temperature gradients*

In 1857, the Commissioners of the General Board of Health on the warming and ventilation of dwellings, said that in a comfortable and healthy apartment the floor should be at the highest temperature in the room, while the temperature should gradually decrease towards the ceiling. The Commissioners made large numbers of observations of the temperatures at different levels in certain rooms. Little attention seems to have been paid to their recommendation, and systems of heating which create very considerable temperature gradients between floor and ceiling have been widely used in industrial buildings.

Such methods of warming, which give distinctly greater warmth about the head than near the floor, are undesirable, for, besides causing the feet to be chilly, such a condition produces distinct feelings of stuffiness. These effects are produced by any local chilling of the feet, whether it be due to temperature gradients or to draughts. Members of Parliament frequently complain about the ventilation of the House of Commons. That Chamber is ventilated by the propulsion of air through the perforated floor and its subsequent extraction through the ceiling, and Sir Leonard Hill (1920, p. 281) ascribes the sensations of stuffiness which are experienced there to the passage of rapid air currents over the feet and legs.

In our field investigations in factories we have frequently encountered systems of heating which have caused the air at head level to be 6–8° F. warmer than that near the floor, while on some occasions we have observed differences as great as 10 or 11° F. In such workrooms we have regularly experienced feelings of stuffiness and have found the conditions distinctly unpleasant. Similar undesirable effects are caused if the head is exposed to excessive radiant heat.

(3) *Atmospheric electricity*

A hundred years or so ago writers on ventilation speculated on the possible bearing of atmospheric electricity on bodily comfort, but it is only in comparatively recent years that exact observations of the electrical state of the atmosphere have been possible.

Yaglou, Benjamin & Choate (1932) have shown that in unoccupied rooms the ionic content of the air is much the same as that out of doors, but in occupied rooms there is a striking decrease in both positive and negative ions. In their experiments the ionic content of room air fell to a very low value immediately after the room was occupied, and that low value was maintained until the occupants left the room. The minimum supply of outdoor air required to maintain the normal ionic content in a crowded room was very high (160 cu. ft./min./person). With the usual air supply of 30 cu. ft./min./person the number of ions was not appreciably greater than when the room was unventilated.

Several investigations have been made of the physiological effects of the ions present in the atmosphere. Winslow & Herrington (1935) found a significant relation between the ionic content of the air and the subjective judgment as to the pleasantness of outdoor conditions. Those days on which the total ion content was high were judged to be unpleasant, irrespective of sunshine and relative humidity. Since the ions in city air are presumably largely made up of vapour particles from heating plants, automobile exhausts and the like, it was believed that the observed correlation was most probably due to the effects of such substances, and perhaps indicated a subtle influence of odour. In another study (Yaglou, Brandt & Benjamin, 1933) persons were exposed to artificially ionized air (small ions) containing from 5000 to 1,500,000 ions/c.c. There appeared to be some freshness in ionized air, particularly with negative ionization, but the effect was not strong enough to suggest a definite improvement in the condition of the air except in a few instances. In other experiments (Brandt, 1933) de-ionization of the air appeared to have no effect.

From the evidence at present available it appears that the differences which normally occur in the electrical state of the air of occupied rooms do not exert any significant influence on subjective sensations; and the results so far obtained do not justify the use of artificial ionization in general ventilation.

(4) *Odours*

In this paper the term "freshness" has been used to denote those properties of the environment which render it invigorating and refreshing, and the effects of various physical factors on subjective impressions have been discussed. It will be agreed that however satisfactory the physical environment may be a room will scarcely be described as refreshing if objectionable odours are present. It is one of the requirements for satisfactory ventilation that the supply of fresh air should be sufficient to keep body odours at an imperceptible level; and, indeed, the various standards of fresh air supply which have from time to time been proposed (Roscoe, 1857; De Chaumont, 1875; Yaglou, Riley & Coggins, 1936) have been based on the quantities found necessary to remove body odours.

With some types of heating apparatus, notably steam pipes and radiators, unpleasant odours may be caused by the contact of organic particles with the heating surfaces, and the feelings of stuffiness which are often associated with the use of such apparatus have been ascribed to these odours. There is also evidence that such odours may have a definite effect on health, for Winslow & Herrington (1936) found that the odour given off from heated house dust, even when not consciously perceived, had a clearly demonstrable effect in reducing the appetite for food.

(5) *Ozone*

In some technical papers, but more frequently in commercial brochures, extravagant statements are made concerning the alleged action of ozone when used in general ventilation.

Ozone can be used as a deodorant, for it destroys, or more probably masks, organic odours, and in concentrations well above the olfactory threshold it has a bactericidal action (Wells & Wells, 1936). But wider claims are often made, that not only is it refreshing but, to quote one brochure, "its marvellous revitalizing powers actually build up the body's resistance to disease".

There appears to be no truth in these claims. High concentrations of ozone are distinctly unpleasant. Lower, but still perceptible, concentrations appear to be agreeable to some persons and to be objectionable to others, the effect being mainly or wholly a psychological one. The addition of ozone to the atmosphere appears to have no beneficial physiological effect (Weiner, 1938).

The position is well summarized in a recent report of the Research Technical Advisory Committee of the American Society of Heating and Ventilating Engineers (1939). The Committee say that: "While ozone has been used in the treatment of certain diseases, there is no evidence that it has a tendency to increase comfort or to benefit health under conditions of normal human occupancy. Little or nothing has been added to the old conclusions of the New York State Commission on Ventilation that in the schoolroom the use of ozone would be objectionable rather than desirable. The practice had its advocates for a period in St Louis, but the expensive apparatus and installation has been completely abandoned." If the ozone masks unpleasant odours it may be beneficial for that reason, but under conditions of ordinary occupancy its use as a masking agent is a poor substitute for good ventilation.

IV. CONCLUSIONS

The maintenance of a suitable degree of warmth is not the only requisite of a really satisfactory system of heating and ventilation. It is not enough to ensure that the equivalent temperature, effective temperature, or other index of warmth is satisfactory, even though such index makes adequate allowance for the thermal effects of the air velocity and other variables. The factors which affect sensations of warmth also influence the invigorating properties of the environment, and help to determine whether a room will arouse feelings of freshness or of stuffiness in the occupants.

From the results of this study some of the requirements for a pleasant and invigorating environment can be stated:

(1) A room should be as cool as is compatible with comfort, since freshness tends to increase as the temperature is reduced.

(2) There should be adequate air movement. During the winter season the air velocity in the ordinary factory averages about 30 ft./min., and in the majority of cases lies between 20 and 40 ft./min. At velocities much below 20 ft./min. feelings of stuffiness are likely to arise. In summer weather, or in hot factories, velocities rather higher than those mentioned are desirable.

(3) The air movement should be variable rather than uniform and monotonous. The body is stimulated by ceaseless change in the environment. Out of doors we are braced by the changing play of the wind, and it is shown earlier in this paper that the variations of air movement which may be encountered indoors exert an invigorating effect. Where ventilation is by open windows the

air movement is likely to be variable, but with some mechanical ventilating systems the air movement is undesirably monotonous. In mechanical installations the air inlets should be so designed, and the velocity of discharge so arranged, that suitable eddying currents are set up.

(4) The relative humidity of the air should be kept reasonably low. It should not exceed 70% and should preferably be much below that value.

(5) The average temperature of the walls and other solid surroundings should not be appreciably lower than that of the air, and should rather be warmer. The combination of cold walls and warm air often causes a feeling of stuffiness.

(6) The air at head level should not be distinctly warmer than that near the floor, and the heads of the occupants should not be exposed to excessive radiant heat.

(7) The air should be free from objectionable odours.

V. Summary

A fresh examination has been made of data obtained some years ago when observations were made of the relation between subjective impressions of freshness and the temperature, velocity and humidity of the air. The results are described, and the bearing of certain other factors on freshness impressions is also discussed. The requirements for a pleasant and invigorating atmosphere are stated.

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