Editorial.

RECENT RESEARCHES ON THE VENTILATION AND HEATING OF FACTORIES, SCHOOLS AND OTHER DWELLINGS.

UNTIL comparatively recent times the idea of ventilation was limited to the replacement of vitiated air by fresh air, and legal standards were formulated in terms of chemical purity of the air. Mainly owing to the work of Dr. Leonard Hill, temperature, humidity and especially air movement are now considered important factors. Neither the chemical purity nor the air temperature, wet or dry bulb, is an index of the physiological effects of the physical environment. Air movement must be taken into account and Dr. Hill has invented the kata-thermometer by which the cooling power of the air can be measured directly.

In 1923 the Industrial Fatigue Research Board decided to start an investigation into the physiological aspects of ventilation and the work was entrusted to Dr. Vernon and Dr. T. Bedford. They first devised a new table of air velocities based on a calibration of the kata-thermometer and made observations with the object of finding out how far the objective indications of the kata-thermometer corresponded with actual sensations of comfort. They then proceeded to make a physiological study of the ventilation and heating in certain factories and the results were published in 1926. They were in favour of natural ventilation where possible, but found that some exhaust system was necessary in certain circumstances and especially in winter when windows had to be closed. Ordinary shafts surmounted by louvres or cowls are not sufficiently powerful and are liable to cause down-draughts of cold air. They must be assisted by mechanical means. Extraction of air should never under ordinary circumstances be at floor level as it increases the draught about the feet of the workers. When extraction shafts are erected in the middle of workrooms the gratings should be only 7 ft. to 8 ft. above the floor, instead of 10 ft. The exhaust would then increase the air movement about the head of the workers. When dust and heavy vapours have to be removed there must be some extraction at floor level, but special heating arrangements should then be made to keep the feet of the workers warm.

Where natural ventilation with moderate exhaust cannot be satisfactorily employed, plenum ventilation discharging the hot air at floor level and not overhead has given good results. In factories where dusty processes are carried on, such discharge at floor level cannot be permitted, but even then the ducts may be placed a few inches above the floor and the entering air can be deflected upwards by a baffle plate. In any case the opening of the ducts should not be more than 6 inches in diameter, otherwise they cause objectionable draughts. Such a plenum system may give rise to a large temperature gradient, and it might be preferable to start a system of fan extraction with a heating system placed near, or under the floor. The hot-air radiators should be kept at a low temperature, otherwise the heated columns of air rise rapidly to the ceiling. Steam pipes are the worst offenders in this respect, though some overhead piping is often desirable to prevent down-draughts from skylights.

Overhead plenum installations are bad, as they may produce a difference of temperature between floor level and that at 10 feet of from 11° to 21°; they often produce great discomfort to the workers, as with a high temperature above the head there is usually a rapid fall of temperature from head level to the floor and consequent cold feet. When the heating is placed near the floor there is a low temperature gradient with a difference of temperature of only 1° to 2° between floor and head levels, when the heating is under the floor the difference is less than 1°. With natural systems of ventilation the air felt rather more fresh than in plenum systems and was more humid.

In 1928 the Industrial Fatigue Research Board issued a report by Dr. Vernon on the physiological effects of radiant heating in various buildings. In the introduction to the report, Dr. Vernon says there is a widespread belief that radiant heat from gas fires and coal fires is more pleasant and exhilarating to the human organism than heat from hot-water pipes and radiators, as these transmit heat mainly by convection currents of hot air and only in a minor degree by radiation. Plenum hot air heating yields an even smaller fraction of radiant heat and is still less in favour.

As gas fires and coal fires are not suitable for the heating of large buildings, Dr. Vernon proceeded to study the panel system of radiant heating which was patented by Barker in 1908. This system has developed greatly of recent years and has for the most part taken the form of ceiling heating, which might be considered wrong in principle, as in his previous report Dr. Vernon insisted that the source of heat should be as near the floor as possible. This conclusion is correct when applied to plenum systems, hot-water radiators, and exposed steam and hot-water pipes which set up convection currents rising to the upper parts of the room. In the panel system, however, the heat is wholly radiant; and there is practically no stratum of hot air below a ceiling panel and no convection currents form to carry away the heat. When the panel is in a wall only sixty per cent of the heat is radiant.

In offices and other buildings heated by concealed panels in the ceiling or wall, Dr. Vernon found a remarkable uniformity in the distribution of heat, the air temperature may be steady to within 1° all over the room at all levels. Owing to the radiation the walls, floor and ceiling are about 3° hotter than the air, while in rooms heated by hot-water radiators the walls, etc., are 3° cooler than the air. The most obvious merit of the panel system is the equal distribution of heat all over the room. Barker considered that the feeling of comfort in a room is measured less by the air temperature than by the amount and the character of the radiation, and it has been claimed by some engineers that the radiant warmth from a ceiling-heated room approximates closely to that produced by sunshine. For this claim, Dr. Vernon has been able to obtain little support. He was unable to detect the radiant heat unless close to the heated surface.

Barker also stated that radiant systems are more economical than convection systems. This is probably true of steam-heated pipes, where much of the heat is wasted in the upper layers of the room. But with low temperature radiators installed close to the floor there is a more even distribution of heat, and there is no reason to suppose that such a system is less economical than a panel system, indeed there may be less loss of heat through the walls than in a panel system.

Dr. Vernon and his co-workers thought that the panel system would be suitable for factories, but as there was at the time no factory so heated they were unable to make any direct experiments to ascertain its effect on the workpeople.

This year Dr. Vernon and Dr. Bedford have issued a report on further investigations on the panel system of heating which were designed to yield more extensive evidence of the effects of radiant heating. The actual effects produced can be ascertained only by making series of comparable observations under the various systems of heating. The influence of the systems of heating upon the surface temperature of the head, hands and feet was ascertained by means of a Moll thermopile, which is a very accurate instrument and has the advantage that the galvanometer attached to it reaches its maximum deflection in about seven seconds. The deflections were converted into temperatures by calibrations made against a lamp-black surface which was found to have the same emissivity as that of the skin.

The temperature of the mouth was also taken with a clinical thermometer and tests of manual dexterity at the different temperatures of the rooms were also made.

Sensations of air temperature and air movement were noted and for the most part ran parallel. Too warm air usually felt stagnant and too cold air usually felt fresh.

A comparison of the effects produced by under-floor heating and by stove-heating was made in the new schools recently erected by the Derbyshire County Council. In the classrooms with under-floor heating the heating is effected by 2-inch hot water pipes which are 16 inches apart and are supplied from a $3\frac{1}{2}$-inch pipe which runs horizontally along one or two walls of each classroom at a height of $7\frac{1}{4}$ feet above the floor. They maintain the floor at a temperature of 63° to 76° F. One of these classrooms was used by the committee and compared with a stove-heated classroom which was heated by an anthracite stove ; direct radiation from the stove to the subject of the experiment was prevented by a screen and the air temperature was maintained by convection currents from the stove. The ventilation was so arranged that the dry kata cooling power was the same in the two rooms. When the cooling power was 6·5° the floor temperature of the floor-heated room was 19° F. higher than the stove-heated room, at 6 in. above the floor the air temperature was 6° warmer than in the stove-heated room, but at head level was only 1° warmer. The velocity of the air in the floor-heated room was nearly double that in the stove-heated room.

As regards the effects of the atmospheric conditions on the skin temperatures of the observers, it was noted that the forehead temperature remained steady throughout the experiment of three hours and was 1° lower in the stove-heated than in the floor-heated room. The other surface temperatures fell steadily throughout the three hours. The finger and palm temperatures in the two rooms corresponded fairly well, but the foot temperature was 5° lower in the stove-heated room. This difference was the direct effort of the warm floor.

At equal cooling powers the air in the floor-heated room felt warmer and less in motion than the air in the stove-heated room.

A comparison of effects produced by panel heating and by protected gas fire heating was then made by the same observers in another school near London. In the panel heated schoolroom the panels were exposed in the ceiling and had an average temperature of 112° F. In addition to the panels a 3½-in. hot water supply pipe ran on each side of the room just below the level of the swivel windows.

In the schoolroom heated by a gas-fire direct radiation on the subjects was prevented by the interposition of a wooden screen; at a cooling power of 6·8° the forehead and palm temperatures were much the same in the two rooms, but in the gas-fire room the finger temperature was 4° lower and the foot temperature 4° higher than in the panel-heated room. The gas-fire room felt 1° cooler than the panel-heated room.

In previous experiments the investigators found that rooms heated by an anthracite stove and hot water radiators felt 0·7° cooler than those heated by wall panels and ceiling panels, but these panels were concealed. They conclude that the radiation from hot-water-fed panels causes an extra heating effect on the individuals subjected to it corresponding to an increase of 1° F. air temperature. In other words a slightly lower cooling power is consistent with comfort in panel-heated rooms.

These low temperature radiation systems of heating have the further advantage of inducing a very even distribution of air temperature, together with a floor temperature which is about 3° higher than the air above it.

In considering a system of ventilation attention must be paid to the manual dexterity of the individuals subjected to it. The fingers of workmen, clerks, and children must not be so cooled that they lose speed in manual work, writing, etc. By means of a chain assembling test performed at twenty-minute intervals the observers found that after three hours in air at a cooling power of 10·1° which felt much too cold, the hand temperature fell to 70° and there was a loss of twelve per cent in speed of performance. A repetition of the test on three boys indicated a similar loss of dexterity.

The effect of atmospheric conditions on the hand temperature of 175 children attending semi-open-air schools, panel-heated and ordinary schools, was next investigated and it was found that this temperature varied with the cooling power of the air and it was found that, at a cooling power of 14·4°, 87 per cent of the children had a hand temperature below 70°, which was considered the lowest temperature compatible with school efficiency.

Observations on the hand temperature of 115 children attending practically unheated open-air schools showed that the temperatures were 5° higher than those shown by children in artificially heated schools at equal cooling powers. This was probably due to the fact that the children in the open-air schools were specially fed, warmly clothed and only worked for short periods with alternating periods of physical exercise. By means of canvas blinds the cooling power of the air in open-air schools can be reduced to half that experienced in open-air sheds. Nevertheless the efficiency of the children in very cold weather was only half that of children in heated schools.

There is evidence to show that the health of children is influenced by the atmospheric conditions of the school which they attend and variations in health may be shown by the attendance rate of the children. Dr. Vernon and Dr. Bedford studied the attendance data from April 26 to March 29 of thirty Derbyshire schools and conclude that it is not permissible to assume that the whole of the absenteeism is due to sickness. The absenteeism (7·6 per cent) was lowest at ordinary schools with good cross ventilation and highest (10·2 per cent) at badly ventilated schools, whilst at floor-heated semi-open-air schools it was 8·4 per cent. Absenteeism is considerably influenced by temperature. At unheated open-air schools only half the children attended during a spell of very cold weather, but this was not entirely due to ill-health, but to the restraining action of the parents. In schools kept at 63·4° absenteeism was 8·9 per cent, at 58·5° it was 11·1 per cent, and 11·6 per cent in those at 55·7°.

Drs. Vernon and Bedford state that the most important question raised in their report is the substitution of open-air schools for schools of the ordinary type. They have shown that children attending open-air schools work with only half the efficiency of those in warmed schools, and require to be specially fed and clothed.

They ask, cannot the principle be applied in a less drastic manner so as to retain its advantages without its disadvantages? An answer to this question is given by the semi-open-air schools in Derbyshire. It has been shown there that if the children are to attain full efficiency in writing and drawing, and absenteeism is to be kept at the lowest possible figure, then the air temperature of the schools must be kept at about 60° and certainly not below 55°, and the cooling power must not exceed 8°. Drs. Vernon and Bedford state that if the under-floor system or ceiling-panel system in semi-open-air schools were increased in power the schools could be maintained at a higher temperature without diminishing the air movement consequent on open windows and doors. Probably the best system of heating would be a combination of the under-floor and ceiling-panel systems. By careful arrangements of doors and windows, the cooling power of the room should be kept as equal as possible, and the children should never sit at their work for more than an hour at a time, when there should be a ten minutes' interval for physical exercise. If the children could be provided with a good meal they would require less warmth in the school-room.

The objection of parents to sending their children to open-air schools might, to some extent, be overcome by heating the schools by the under-floor system; the feet of the children would be kept warm and the artificial heat not wasted so much as it is by other methods. Moderately heated ceiling panels would be useless, as they warm the surfaces radiated against only 1° to 3° above the surrounding air. Anthracite stoves and hot-water pipes would be of little use as they warm only the children in their immediate neighbourhood.

As regards the substitution of under-floor heating or ceiling-panel heating for the hot-water pipes and stoves now in use, Drs. Vernon and Bedford point out that compared with convection heating the under-floor system has the advantage of heating the air 2·5° and the ceiling-panel system 1°, and both cause a more uniform distribution of heat and keep the feet warmer than the head. They also do not take up valuable space and are more suitable for classrooms with glazed swing doors on two sides than hot-water pipes and radiators. The investigators prefer ceiling-heating to floor-heating for most purposes, though not for open-air schools. Neither system is perfect, and requires to be assisted by hot-water pipes under windows to prevent down-draughts.

They consider that under-floor heating is not suited for factories where the floor is much occupied by machinery, but if the floor is clear, and especially in workrooms where the doors are constantly being opened to admit material, and down-draughts are frequent, a heated floor would prove most acceptable.

The semi-open-air method would not be suitable for most industries, as dust-laden gusts of air are inevitable when the doors are opened, and would interfere with most processes.