Biometeorology in Occupational Health

DOUGLAS H. K. LEE

Division of Occupational Health, Public Health Service, Cincinnati 2, Ohio

1. Environment-worker relationships

Man is not the creature of his work-place alone; neither are the conditions of his work-place determined solely by the external environment. Bioclimatology, as an interdisciplinary activity, is concerned with all of the environmental factors which affect him as a worker, the modification of the natural environment by the conditions of his living, the effect of the net conditions upon him, and the ways in which their impact upon his efficiency and well-being may be controlled.

Fig. 1 indicates, in diagrammatic fashion, the environmental compartments in which he operates, the barriers between the compartments, the special contributors to the conditions of each, and, by implication, the points at which their ultimate effect upon him may be regulated. In the course of the day, the worker occupies three sets of environments: 1) that of the work-place, 2) that of the home and 3) those of transient nature, such as the vehicle in which he goes to and from work, recreation areas, and civic assemblies.

Each compartment is, to a greater or lesser extent, affected by the natural external environment; each may be separated from the external environment by a more or less complete barrier; each may have certain special sources of heat or cooling, humidity or dehumidification, air movement, etc. All must be taken into account if the significance of the environmental conditions is to be determined; all are the stuff with which bioclimatology is concerned.

2. External environment

Atmospheric factors affecting man include temperature, humidity, air movement, radiant heat, light, sound, normal atmospheric gases, atmospheric contaminant gases, vapors, smokes and dusts, airborne allergens and infective agents, high energy particles, and possibly ionic conditions. For each, we need to know the intensity distribution by area and by time (secular, annual, seasonal, daily, and perhaps smaller periods). These would be most acceptable in statistical notation as means and standard deviations, but for some reason they are usually presented in more cumbersome tables or, at the other extreme, as unqualified mean data. As regards extreme values, often the harbingers of human stress, some indication of frequency, such as the value exceeded less than 5 per cent (or 1 per cent, or 0.1 per cent) of the time, is generally more useful than the more conventional absolute maximum or 'mean maximum.'

Besides the independent values of the factors mentioned, we also need to know the extent to which they occur in combination, such as high temperature and humidity, low temperature and wind. Class frequency tables suffice for these, but more complex combinations are sometimes desired.

Even with modern equipment, the cost and time involved in the acquisition, handling, storage, retrieval, and dissemination of such a mass of data are far from negligible, so that the ultimate purpose dictates the pattern of handling. Unfortunately, the major users have traditionally been meteorologists, and the patterns most suit-
able for them do not always fit biological requirements. This has acted as a deterrent to many biometeorologists and, especially, to those who approach the subject from the physiological side. Some agreement on presentation and simplification, for example of humidity and radiation data, is urgently needed. The substitution of conventional meteorological phenomena, such as ‘fronts,’ for definable combinations of its components, is not always a satisfactory procedure, for although some physiological responses are linked to complex meteorological antecedents, some particular elements rather than the front itself are probably critical. Similarly, it is all very well to associate human responses with a factor, but it is the pattern of component elements that we need to study.

3. Compartmental barriers

The materials and structure of the enclosure constituting house, factory, bus, or recreation hall present a resistance to the penetration of the external environment and permit the building up of a somewhat different internal environment. The mode of permeation of the barrier by both external and internal environmental elements is often complex and needs to be known in relation to the situations prevailing in the given locality. The solar heat load, for example, varies with latitude, cloudiness, wind pattern, type of terrain, and vegetation; infrared heat exchange depends upon prevailing ground and ‘sky’ temperatures, humidity, and atmospheric clarity. The type of material required for roof ‘insulation,’ and the mode of roof structure desirable for minimizing the need for internal adjustment, varies greatly with these factors from place to place. A low thermal diffusivity is desirable for protection against hot desert sunshine, but low conductivity for insulation against subarctic cold. Hot winds are to be excluded in the desert, but air movement encouraged in the humid tropics. Vapor barriers are needed in walls if condensation and freezing are likely.

The shape of a building and its orientation may significantly affect the net solar heat load. For a given floor space, for example, the minimum solar heat load at latitude 30 degrees is achieved by a cubical design, and a slab-type building receives considerably less when its axis is east–west than when it is north–south. Moreover, the former orientation has the advantage of a high solar exposure in winter.

While the relation of a proposed plant to transportation facilities is certainly of considerable importance in the selection of a site, its relation to meteorological factors such as air movement and direction, nature of terrain, prevailing humidity, and sunlight are of some importance for its habitability and need to be taken into consideration.

The final decision on site, layout, structure, and materials belongs in that group of optimization problems familiar in operations research. The economic factors are well known and predominate in such decisions, but the bioclimatic are also important and should be given their rightful place.

4. Intracompartamental conditions

Within the occupational compartment, a large number of circumstances may modify the environment. Since industrial processes almost inevitably involve the utilization of power, heat production is the rule. Should the process depend upon a high temperature at the reaction site, considerably more will be added to the general exothermic background. The impingement of this heat upon the plant space and individuals occupying the space is always of consequence, sometimes of very considerable consequence, as is obvious in the handling of molten metals. The physics of heat transfer from process to individual can be very complex. For the transfer of heat by radiation in a simple situation, such as from a hot door represented as a plane, to man represented as a cylinder, adequate formulae are available, but the situation in many a plant is far more complex than this. A number of surfaces, of various shapes and with complex distributions of surface temperatures, present varying projections to the individual as he goes about his work. It is conceivable that a computer could be called upon to make fairly rigorous calculations, but the practical bioclimatologist needs some much simpler method of estimating the probable incidence of the radiative heat load, and his choice of method will be influenced by how he proposes to use the estimate in determining its significance for man. In some cases, a simple globe thermometer reading will suffice, but in others he will need a plan of the major surfaces, their representative temperatures, and a simplified method of determining the approximate net flux. An increasing range of instruments and methods is becoming available, but the responsibility for choice remains with the bioclimatologist.

In many instances, the source of heat, whether by radiation, conduction, or humidification, is such that its impact upon the individual must, in some way, be attenuated. On general grounds, one
would prefer to effect this attenuation at source, but the purpose of the process must be borne in mind. If heat is a desirable element in the process, and escaped heat means greater fuel consumption, then insulation is certainly desirable, but if the heat is an embarrassment, controlled convection may be the answer. At the other end of the chain, protection may be put on the man in the form of insulative or reflective clothing, but now one must consider the efficiency of that man. He needs freedom of movement to execute his task, ability to control his own thermal state, visibility and audibility to do the job and avoid accident, and a limitation on the weight he has to support.

Intermediate between these two rather passive extremes is manipulation or treatment of the space itself. This reaches its peak in full-scale air conditioning, which is being more and more adopted as it becomes relatively cheaper and as the work force steps up its demand for improved conditions. Ventilation with natural or partially preconditioned air may serve a triple purpose—removal of heat at source, convection of heated air, and evaporative cooling of the man. If properly directed and controlled, it may serve many situations effectively at considerably lower cost than other methods.

Cold work environments present a similar set of considerations, even though the load is of reverse sign. It may appear at first sight that a cold ambient environment is an essential feature of the operation, so that primary emphasis has to be placed on protective clothing, but a good deal more could undoubtedly be done to screen the man from the cold storage space, for example, and have him operate through self-closing apertures with protection only for his hands and arms.

To contaminants already present in the free atmosphere, many more may be added by industrial processes in the form of smokes, vapors, or gases. As with other contaminants, the nature and subsequent fate are affected, to a certain extent, by the temperature and humidity of the air in the vicinity and the distribution by air movement. Interaction of contaminants with each other or with normal atmospheric constituents, may occur, again in association with the prevailing thermal conditions.

To these problems the biometeorologist brings integrated knowledge and methodology not otherwise available.

5. Human factors

The biometeorologist involved in occupational health must, of course, be thoroughly familiar with the relevant environmental elements and factors, and, as we have seen, must achieve an understanding of industrial operations and their constraints, but above all he must have a deep knowledge of man's physiological reactions to environmental stress. This is the basis for his capabilities. It is perhaps easier for a biologist to learn what he needs to know of physical and meteorological information and procedures than for one trained in the physical sciences to acquire a full appreciation of variable biological phenomena.

The link with the physical aspects is made in consideration of man-environment relationships. For thermal factors, this means an understanding of heat transfer by conductive, radiative, and evaporative channels and the influence of clothing, protective covers, activity, posture, and morphology upon such exchanges. From these, he passes to man's primary thermo-regulatory reactions and the regulating mechanism, and thence to the many secondary functional consequences of thermo-regulation, such as cardiovascular sequelae to wide-spread vasodilatation, and endocrine responses to changed water and electrolyte balances. The nature and extent of acclimatization—as for that matter of training—must be understood, as well as an appreciation of potential failures and counteractive measures.

Human reactions to toxic substances may be affected by body temperature, cardiovascular or endocrine responses to heat regulation, alterations in skin permeability accompanying sweating, and metabolic rate. Response to allergens is facilitated by certain industrial materials. Minor irritation to respiratory tissues or skin may be aggravated by low air temperature or low vapor pressure.

For many, all of this may be simply physiology, but for the bioclimatologist, working on occupational health problems, it is antecedent to the ultimate goal—what are the probable effects on worker health and efficiency?

To apply the considerations so far mentioned to this end, the bioclimatologist must pursue at least one more set of considerations—criteria by which he can predict that a given environment, for a given population of defined activities and antecedents, will result in a stated probability of named effects. And there's the rub!

From Haldane's advice to use the wet bulb temperature as an index of hot working condi-
tions on, through kata-thermometer, effective temperature scheme, SR, index, and EPI to the HSI of Belding and Hatch, environmental physiologists have been concerned with devising methods of assessing the significance of the thermal environment for work capacity and heat tolerance. None of the proposals are satisfactory. Some, like the effective temperature scheme, were established empirically on a stated population under stated circumstances and provide no basis for extrapolation to other conditions. Others, like the HSI index, are based on a nude subject and give little opportunity for determining the modifications brought about by clothing. All of them assume quasi-equilibrium conditions, such as are seldom experienced in industry. None are based on the reactions of industrial workers. An experienced physiologist, knowing the reactions reported by various investigators under stated circumstances, can (literally) read between the lines when he plots them on a psychrometric chart and make an informed estimate for a given situation, but one would hope that a better method would be available before long. This is certainly one of the pioneer fringes in which activity is apparent.

For the assessment of the effect of intervals between exposure, one can use the reported studies of Brouha, which rely heavily on pulse rate responses, or one can calculate the probable oscillations in heat storage in the clothing and superficial tissues and estimate the interval conditions necessary to prevent undesired cumulative storage.

Threshold limits for toxic substances have been published by various authoritative bodies, notably the American Conference of Governmental Industrial Hygienists, but they must be interpreted with due regard to the environmental conditions under which the exposure takes place, as well as the probable duration of exposure, rate of work, and other factors affecting dose acquisition.

Included in the responses to thermal environments are some relatively simple measures of psycho-motor performance, but very little definitive work has been reported on the influence of psychological conditions or motivations on response to or tolerance of heat and cold, although their importance seems to be well grounded in experience. Evidence is not lacking, either, that thermal conditions affect the acceptability of work environments, or, conversely, that they are brought into question when dissatisfaction is engendered by other less visible or less admissible causes. Considerably more quantitative and reliable information is needed on the interaction between psychological and physical causes of stress and between behavioral and physical expressions of strain before these complex problems can be adequately answered. It makes little difference whether the biometeorologist is willing to subsume the psychological under his prefix, or whether he prefers to leave them for a ‘behavioral’ colleague—in the end the two sets of problems must be examined together in terms of the total environment. The increasing reliance by industry upon automation, information handling, critical technology, and community satisfaction are more than sufficient to demand that our concepts of both biology and the environment be interpreted in the broadest terms.

6. Summary

Each of the three types of space occupied by the worker in the course of the twenty-four hours—work-space, home, and special purpose compartments—is affected by the external environment. The biometeorologist concerned with the health and efficiency of the worker must take into account the distribution patterns of meteorological elements in the free atmosphere, the properties of building structures which control the impact of those elements upon the worker, the properties of clothing and protective additions coming between the man and his immediate environment, and the ultimate effect of all of these upon the worker. This calls for a thorough training in physiology, extensive instruction in and familiarity with meteorological factors, an understanding of heat transfer through materials, and an appreciation of industrial methods and operations. Armed with this knowledge he can play a key role in the prosecution of occupational health.