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COMFORT THEORY AND PRACTICE: BARRIERS TO THE CONSERVATION OF ENERGY BY BUILDING OCCUPANTS

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SUMMARY

Three related issues are examined in this paper. First, international developments in the theoretical bases of comfort research over the past twenty-five years are outlined. Secondly, practical applications of the findings of that research, in Britain over the last fifteen years, to designing systems for controlling environmental conditions in buildings are considered. Thirdly, the implications of comfort theory and practice for attempts to conserve energy in non-domestic buildings are discussed. It is concluded that, because of developments which have occurred during this period, there now exist deeply entrenched but restricted notions about the nature of comfort itself, and about how, and by whom, acceptable environmental conditions should be created and maintained in such buildings. The existence of these notions facilitates expropriation from building occupants of their autonomy to control their own immediate environment and its transference, by means of automated and centralised environmental control systems, to technical specialists.

INTRODUCTION

> 'There is an underlying assumption that the best thermal environment never needs to be noticed and that once an objectively "comfortable" thermal environment has been provided, all of our thermal needs will have been met. The use of all our extremely sophisticated environmental control systems is directed to this one end—to provide standard comfort zone conditions. . . . [But] the thermal environment also has the potential for sensuality, cultural roles, and symbolism that need not, indeed should not, be designed out of existence in the name of a thermally neutral world.' (Heschong, 1979, pp. 16–17).

Four years ago in Britain, the Working Party on Buildings of the Advisory Council on Energy Conservation (1978, pp. 10–11) recommended to government that the ability to control environmental conditions in non-domestic buildings should be removed from the majority of their occupants and, by automation and centralisation, be placed in the hands of such buildings' owners or managers. In this paper, I

COOPER, I.

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have sought both to trace some of the strands of thinking which underlie the formulation of this advice and to suggest some of its social implications for the conservation of energy in non-domestic buildings. In part, the advice which the Working Party offered reflects, and so reinforces, government's prevailing conviction that only those motivated by economic self-interest should be allowed to control energy consumption in buildings.[1] But, beyond this economic reasoning, their advice also springs from what are now deeply entrenched notions arising from building science about the nature of comfort itself and about how, and by whom, comfortable conditions should be provided within buildings. One of my primary purposes in what follows is to outline developments in building science and design practice, predominantly over the past 10 to 15 years, which have led to the creation of a narrow concept of what comfort means to people in buildings—a concept which fails to encompass the plethora of features which may render internal environments acceptable or unacceptable to those who use them. I have also attempted to illustrate that, when applied in practice, this limited concept of comfort has resulted in the construction of a demeaning and dehumanised specification of the relationship which should exist between people and the buildings that they occupy. My final purpose in this paper is to suggest that, for those who are anxious to engender or implant feelings of responsibility for energy conservation in the minds of occupants of non-domestic buildings, these developments in comfort theory and practice may prove counter-productive. They may do so because they appear to accord neither with people's expectations about, nor with their preferences for, internal environments in which they wish to live or work.

Thermal comfort has come to be treated as a discrete phenomenon, defined, as Wyon (1980, p. 47) explained, as the absence of discomfort:[2]

> 'This negative definition defines a no-complaints zone that permits a certain latitude for variations in the thermal climate even for an individual. However, thermal comfort is sometimes defined as the state where a subject cannot decide whether he would like the temperature raised or lowered even if pressed. This point can be found fairly exactly by experiment.'

Work on thermal comfort is described by Markus and Morris (1980, p. 37) as one of the oldest areas of building science. And, according to Fisk (1980, p. 1) 'traditional' comfort theory is:[3]

> '... largely a pragmatic exercise aimed to reduce the term to an engineering model, for the purpose of engineering design. In developing that theory many of the finer nuances of "comfort" have to be lost.'

Similarly, Hawkes (1975, p. 40) remarked that:

> '... the emphasis of research to aid the design of the thermal environment has been to devis techniques for the estimation of the demand which will be made on environmental control syst able heating, cooling and ventilation. This has, quite reasonably, meant that there has been a relationship between the state of the systems technology and both the prediction methods used and design objectives which are specified.'

Designing internal environments has become the specialised responsibility of environmental engineers: the latter are required, McIntyre (1973, p. 67) explained, to produce a thermal environment:

> '... which is the optimum for the occupants of the conditioned space. [The engineer] ... designs the services to give a set of values of the appropriate physical variables, i.e. air and radiant temperature, relative humidity and air velocity. The design values of these parameters are obtained from our knowledge of human requirements for thermal comfort.'

Such knowledge is seen as arising from the findings of building science: design of internal environments has been identified as 'the principal scientific problem of architecture' (Cowan 1978, p. 217).

Because of the source of these findings, the understanding required for the provision of comfortable conditions in buildings has come to be regarded as lying within the domain of building science and, more specifically, within the custody of comfort theorists and practitioners. Because of their specialist knowledge, the latter alone are deemed qualified to specify what comfort means and how comfortable conditions should be provided. Due to this appropriation of responsibility, production and control of comfort has become divorced from those who occupy the internal environments which buildings afford. Instead, comfort has been transformed into a commodity[4] produced for occupants: it is no longer viewed as an objective towards which they may strive, if they so choose, by employing means placed at their disposal by designers in order to enable them to do so. Now comfort is translated into a piece of marketable merchandise, manufactured by members of design professions: it has become the province and preserve, not of building users, but of those who design on their behalf. Hence, as Koenigsberger *et al.* (1973, p. 41) explained:

> 'The task of the designer is to create the best possible indoor climate ... the occupants of a building judge the quality of the design from a physical, as well as an emotional, point of view. Accumulated sensations of well-being or discomfort contribute to our total verdict on the house in which we live and the school, office or factory where we work. It is a challenge for the designer to strive towards the optimum of total comfort, which may be defined as the sensation of complete physical and mental well-being.'

More than two decades ago, Hardy (1958, p. 758) proposed that one of the main functions of a building should be the provision and maintenance of an *artificial*

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[1] I have examined some of the bases and implications of this reasoning elsewhere (Cooper, 1982*a*).

[2] Elsewhere, Wyon (1973, p. 45) remarked that: 'This somewhat negative approach is taken up in the absence of any understanding of what combination of thermal factors would produce positive comfort....'

[3] And it is here that the theory's influence rests, for, as Thorley (1969, p. 17) contended, 'The system designer places great reliance on data which is presented to him concerning the subjective assessment of comfort and the behaviour of buildings in which systems are installed ... since he gets little, if any, feedback relating to the installation he has designed.'

[4] For as Fanger (1973, p. 3) identified. 'Thermal comfort is the commodity being produced and the product sold by the heating and air-conditioning industry. It is no wonder, therefore, that this industry has for a long time been interested in research and the identification of the "commodity" it desires to produce.'

climate[5] suited to the needs of its inhabitants. Conditions of thermal comfort in buildings are governed, he argued, by three factors: first, the physiological state of their occupants; secondly, the thermal characteristics of their enclosures or external envelopes, and, thirdly, by the method via which heat is introduced (or removed) from their internal environments. During the last 15 years, there has been a discernible tendency for designers to turn towards, perhaps even for them to afford primacy to, this third factor in their attempts to construct and maintain comfortable indoor conditions. Concomitantly, designers of non-domestic buildings have tended to rely, despite the so-called *energy crisis* of 1973, on artificial environments which are dependent on—which, indeed, are inseparable throughout the year from—the consumption of energy in order to make their buildings habitable. Thus, in the course of describing the Chartered Institute of Building Service's energy code for buildings, Peach (1980, p. 39) assumed that:

> 'In simple terms, in order to attain and maintain a comfortable environment inside the building, energy is added and distributed internally....'

Comfort has become synonymous with, and is regarded as hingeing upon, the consumption of applied energy; that is, energy consumed by machines, by mechanical services, by heating and ventilating systems. One consequence of this emphasis is, Sherratt (1976, p. ix) indicated, that:

> 'Between 40 and 50 per cent of all the energy consumed is used for controlling the environment in buildings by means of heating, lighting and air-conditioning. Environmental control constitutes by far the largest single use of our available energy and is essentially the area with the greatest potential for savings to be made.'

Commenting on contemporary trends in building design in North America more than 50 years ago, Mumford (1924, p. 175) argued that it is unnecessary to dwell upon the way in which supposedly technical developments take away from people whom they are designed to serve any semblance of dignity as human beings. Rather, he added:

> '...it is perhaps inevitable that mechanical achievements in a thoroughly dehumanised society, should, no doubt unconsciously, achieve this very purpose.'

While I can sympathise with Mumford's sentiments, I resist the quietism seemingly implicit in his response. It is necessary to dwell on, to draw attention to, so-called technical *improvements* which are dehumanising. And, for this reason, it is necessary to scrutinise developments in building science and in design practice in Britain over the last two decades. For, as Grenfell-Baines (1978, pp. 163–4) concluded, in the provision of internal environments:

> 'Critical design decisions will be those which influence the balance between centralisation and decentralisation. Methods of collection, distribution and control must be evaluated and a balance reached between efficiency and humanity.... Technology is an instrument, it is our objectives and our approach to achieving them which are the vital subjects for discussion....'

The comparatively recent perception of a need to conserve energy in buildings may throw open for discussion and reappraisal many issues previously taken for granted. Amongst these should be included, I would contend, both the nature of comfort and what people regard as acceptable internal environments in buildings. One means of generating such discussion and of instigating debate is to make explicit those assumptions and value-judgements which currently underlie comfort theory and practice in Britain. It is to this end that I have addressed the remainder of this paper.

THE PHYSIOLOGICAL MODEL OF HUMAN COMFORT

Physiological approaches to human comfort tend not, as Fisk (1980, p. 2) observed, to be applied directly to building design. Rather, they have been used in the assessment of stress conditions in extreme environments, such as in coal mining or in furnace work. Nevertheless, physiological theory remains important, Fisk contended, because it has been employed as the foundation for relating the physical parameters of an environment to the thermal state of its occupants. According to this theory, (ASHRAE, 1965, pp. 66 and 102),[6] body temperature is dependent on the maintenance of a balance between heat production and heat loss. Heat is produced within a person's body as a result of oxidation of food elements. And this maintains body temperature above that of the surrounding air in cool or cold environments. However, simultaneous processes are also operating to transfer body heat to the surrounding environment; principal among these are radiation, convection, evaporative cooling and conduction (Koenigsberger *et al.*, 1973, p. 13). So, since body temperature has to be maintained within a finite range, heat production has to be balanced by heat loss. Physiologically, comfort is held (Morcas-Asaad, 1978, p. 34) to be a condition in which an individual's thermoregulatory mechanisms are in a state of minimal activity. For, within the range of conditions necessary for survival, lies a smaller range which people judge to be comfortable; that is, they feel neither too warm nor too cold but *thermally neutral* (Markus and Morris, 1980, p. 34). And they experience sensations of warmth or cold when their sense organs are stimulated (Bedford, 1948, p. 108). These sense organs, or receptors, consist of specialised groups of cells which react to changes in

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[5] Similarly, four years later, Chrenko (1962, p. 63) contended that it is a mistake to suppose that the purpose of designing an internal environment is that: '...ideal conditions should approximate as closely as possible a sunny day.... The objective of heating and ventilation is not to bring outdoor conditions indoors. The art of heating is to adapt indoor conditions to indoor life ... [and] the design of a comfortable indoor environment depends on principles which are based on physics, physiology and psychology.'

[6] The handbook of the American Society of Heating, Refrigerating and Air-conditioning Engineers, designed as '...a guide for people who design and build climate control systems.' (Kennedy, 1970, p. 645).

their thermal environment. As a consequence, Bedford commented:

> 'Sensation depends on a changing environment. If the body remains perfectly in equilibrium with its surroundings so that no changes occur in the temperature of the skin or the deeper tissues, the thermal receptors are not stimulated and no sensation of warmth or cold is evoked. Then the subject will feel "comfortable"....'

But the maintenance of thermal comfort is not seen as implying that environmental conditions should be sustained at constant levels. For an individual's thermoregulatory mechanisms are capable of providing physical comfort within a range (or zone) of conditions (Morcas-Asaad, 1978, p. 34). Indeed, slight fluctuations in the latter are held to be invigorating and beneficial since they are seen as preventing feelings of monotony. Hence a range of thermal requirements for building occupants can be specified within which variations and fluctuations are acceptable. This range is termed either the *comfort* or *lack of discomfort* zone. Sensations of discomfort may be experienced when one or more of the pertinent physical parameters deviates outside this zone.[7]

So, in the design of internal environments for human occupation, provision has to be made (Bruce, 1960, p. 1) for a controlled and adequate rate of heat loss from a building's occupants. And this heat loss can be controlled by adjustments to internal environmental conditions. There are, Chrenko (1962, p. 64) suggested, at least six physical factors to be considered in the assessment of the thermal environment within a building; the temperature, humidity, and speed of movement, of the air; the radiant temperature of surrounding surfaces; the incidence of solar radiation, and the rate of ventilation. Of these factors, the importance of the four most frequently cited—radiant temperatures, air temperature, humidity and movement—has been recognised for over 60 years (Bedford, 1961, p. 290). Air temperature affects the conductive transfer of heat from an individual's skin and clothing surfaces; it also influences heat loss by dry respiration (Markus and Morris, 1980, p. 42). Air movement both affects heat lost by convection and modifies the rate of evaporation from the surface of a person's body. The mean radiant temperature of an environment[8] influences heat lost from the body by radiation while the moisture content of the air affects, not only the rate of evaporation from the skin, but also evaporation from the lungs and diffusion of vapour through the skin.

Working within this physical/physiological tradition, Fanger (1970, p. 13) asserted that *indoor* climate can be defined as:

> '... the collective whole of all the physical properties in a room which influence a person via his heat loss and respiration.'

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[7] And, O'Sullivan (1975, pp. 48–9) argued, 'If there is a primary correlate [of environmental conditions] with human comfort it is certainly air movement ... in as much as it has the smallest tolerance in the "lack of discomfort" zone, in producing complaints of stuffiness on the one side and "draughts" on the other.'

[8] The Chartered Institute of Building Services (CIBS) Guide (1978, pp. A1–6) noted that, 'People's thermal comfort depends significantly on the radiation exchange between them and their surroundings. To describe this balance the concept of mean radiant temperature is used. The mean radiant temperature at a point within an enclosure is a function of the areas, shapes, surface temperatures and emissivities of the enclosing elements viewed from that point.'

The definition provides, he contended (p. 5), a 'rational basis' for establishing thermal comfort conditions: its underlying idea is that the combined thermal effect of all the physical factors in an environment is of 'prime importance' for an individual's thermal state and comfort.[9] From this standpoint, a comfortable environment is attained (Kinzey and Sharp, 1965, p. 13) when each of the pertinent physical factors possesses 'properly related physical values'; that is, comfort occurs when:

> '... air temperature, humidity, mean radiant temperature, and air motion are appropriately related in value to produce a sensation of comfort in the human individual.'

Consequently, it is recognised (Givoni, 1976, p. 75) as impossible to express human responses to the thermal environments of buildings as functions of a single physical factor. Instead, the latter are viewed as acting on people simultaneously, with the effect of any one of them being dependent on the corresponding values of the others. As a result, it has been held essential to evaluate the combined effects of physical factors on people's physiological and sensory responses in order to express combinations of these factors in terms of a single number, known as the *thermal index*.

As the history of this field of research reveals (Bedford, 1948 and 1961; Bruce, 1960; Markus and Morris, 1980), considerable effort has been expended in attempts to produce a unified means of representing thermal comfort, specifically in developing an index which would, in a single numerical value, combine the effects of all the requisite physical variables.[10] Perhaps pre-eminent among these is the *Scale of Effective Temperature* developed in the early 1920's through a series of experiments conducted in the laboratories of the American Society of Heating and Air-Conditioning Engineers (Houghten and Yaglou, 1923).[11] This scale represents, Cowan (1966, p. 101) stated:

> '... the temperature of still air saturated with water vapour which gives to a group of people the same subjective comfort sensation as the air in another similar room with certain temperature, humidity and air movement. The physical measurement of dry-bulb temperature, wet-bulb temperature and air speed are thus reduced to a single numerical criterion.'

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[9] But, while a person's sensations of comfort or discomfort are seen as depending primarily on physical, climatic variables, thermal preferences are also held to be influenced by a number of subjective or individual factors. As Bedford (1948, p. 86) remarked, three decades ago, 'Our feelings of warmth are not dependent solely on the temperature of the environment. Differences in clothing, in muscular activity, in nutrition, age and general bodily build, and, not least, in acclimitization will all tend to influence the feelings of warmth experienced by different persons in the same environment....'

[10] Gagge *et al.* (1973, p. 229) asserted that, 'All indices of environmental stress fall in one of two categories—the *empirical*, which are variations of the old ET, and the *rational*, which are based on the heat balance equation....' For the sake of analytical convenience, if not clarity, this distinction between empirical and putatively rational indices is maintained in this section (see below).

[11] As Koenigsberger *et al.* (1973, p. 55) described, 'In most of these experiments special rooms were built and used, in which many sets of indoor climatic conditions could be produced at will. A number of experimental subjects were located in the room, and they were asked to record their subjective reactions on a questionnaire after each variation in the conditions, according to a set scale extending from very hot to very cold. The many answers were then evaluated systematically, and the results plotted on a graph, in most cases producing a nomogram which defines experimentally found relationships.'

The Effective Temperature (ET), derived from this series of experiments, was described (ASHRAE, 1965, pp. 66 and 107) as an 'empirical sensory index'. The subjective responses of groups of individuals to variations in temperature, humidity and air movement were studied and combinations of these physical factors which elicited the same feeling of warmth were then assigned the same effective temperature value. The scale was originally defined by *equal comfort lines*,[12] straight lines drawn on a psychometric chart (see Fig. 1). No account was taken, however, in the construction of the scale of radiation effects. But during the Second World War, an urgent need was perceived for a scale of warmth which would do so (Bedford, 1961, p. 304). An amendment to the calculation of Effective Temperature—a globe thermometer reading in the place of air temperature—was proposed (Bedford, 1946) and the values so obtained became known as the *Corrected Effective Temperature* (CET). This is similar to the former scale in that both relate to people wearing particular amounts of clothing and engaged in specific levels of activity, but the corrected scale contains appropriate modifications for air movement and radiation effects. Although the latter scale is currently in wide use,[13]

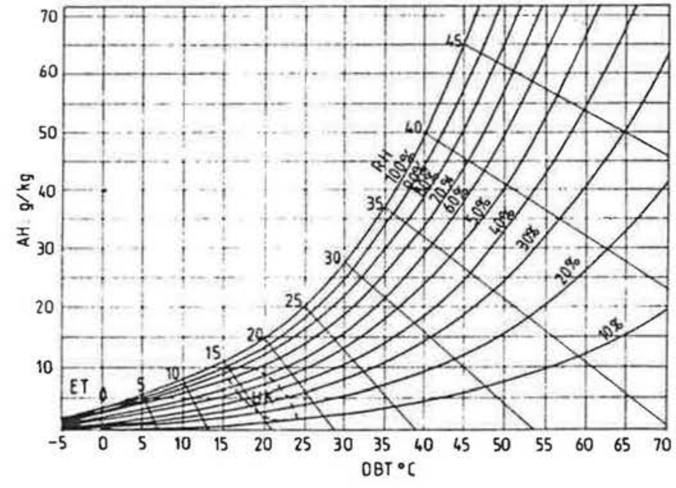

Fig. 1. A psychometric chart based on the Scale of Effective Temperature showing the UK comfort zone. (Taken from Koenigsberger *et al.* (1973, p. 48).

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[12] Hence, as Kinzey and Sharp (1965, p. 15) stressed, 'It is important to realise that the effective temperature line is really an equivalent comfort line, the term, temperature, being a misnomer.'

[13] For practical purposes, Brearley (1972, p. 101) commented: '... whilst ET and CET are excellent indices for an initial thermal assessment of an environment, for exposures of more that 15 minutes the scales are heavily biased by the effect of humidity at temperatures within the control range, and for long exposures, dry-bulb temperature alone is a reliable index of thermal comfort.'

such scales have been criticised: they do not, Burberry (1970, p. 47) contended:

> '... solve the problem of defining human comfort since they mask in one unified value directional variations of radiation, temperature gradients in the air and other factors which could cause unsatisfactory conditions.'

Subsequently, further related indices have been produced. The first of these was the *New Effective Temperature* (ET*) (Gagge and Nishi, 1974). This index has been defined by Markus and Morris (1980, p. 48) as:

> '... the uniform temperature of an imaginary enclosure at 50 per cent relative humidity in which man will exchange the same total heat by radiation, convection and evaporation, at the same skin temperature and skin wettedness which occur in the actual environment.'

In other words, the index is intended as a single measure thermally equivalent to the air temperature, radiation and humidity actually existing in a given environment, while the air velocities in that environment and those in the scale are the same. These researchers also derived the ***Standard Effective Temperature*** (SET*) which they (Gagge *et al.*, 1973, p. 242), described as:

> '... a rationally derived temperature index of man's thermal environment based on the physics of man's heat exchange, and his physiological and psychophysical responses.'

This last index has been adopted by the ASHRAE, is already widely used and is viewed as being supported by 'widescale experimental and theoretical work' (Markus and Morris, 1980, p. 48).

Associated work, conducted by Fanger both in the AHSRAE Laboratory at Kansas State University and in the Environmental Test Chamber at the Technical University of Denmark, resulted in the production of a series of *comfort equations*.[14] When they first appeared (Fanger, 1967), these were regarded (Chrenko, 1974, p. 37) as a considerable advance on previous work in the field since they took into

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[14] His 'desired general comfort equation' was given by the formula (1970, p. 42)

$$\begin{aligned}\frac{M}{A_{\mathrm{Du}}}(1-\eta)-0{\cdot}35\left[43-0{\cdot}061\frac{M}{A_{\mathrm{Du}}}(1-\eta)-p_a\right]\\ -0{\cdot}42\left[\frac{M}{A_{\mathrm{Du}}}(1-\eta)-50\right]-0{\cdot}0023\frac{M}{A_{\mathrm{Du}}}(44-p_a)-0{\cdot}0014\frac{M}{A_{\mathrm{Du}}}(34-t_a)\\ =3{\cdot}4\times10^{-8}f_{\mathrm{cl}}[(t_{\mathrm{cl}}+273)^4-(t_{\mathrm{mrt}}+273)^4]+f_{\mathrm{cl}}h_c(t_{\mathrm{cl}}-t_a)\end{aligned}$$

where the comfort equation contains the following variables: $I_{\mathrm{cl}}, f_{\mathrm{cl}}$ (a function of the type of clothing); $M/A_{\mathrm{Du}}, \eta, v$ (a function of the type of activity); and $v, t_a, p_a, t_{\mathrm{mrt}}$ (environmental variables).

A simplified version of this was later proposed by McIntyre (1973, p. 68) who explained, 'For a given combination of metabolic rate and clothing insulation, it is possible to predict the subjective temperature of the environment which is required for comfort. The comfort temperature has been established experimentally.... The result may be expressed in the equation

$$T_{\mathrm{sub}}=33{\cdot}5-3I_{\mathrm{cl}}-(0{\cdot}08+0{\cdot}05I_{\mathrm{cl}})M_s.\text{'}$$

McIntyre (p. 69) indicated that, 'ultimately', this comfort equation is based on the comfort votes of individuals who, during climate chamber experiments, were asked to indicate their 'feelings' by using the seven-point Bedford Scale (described later).

account variations in people's activities and clothing—by including in the equations values for metabolic rate, the surface area of the human body, the percentage of the body covered and the thermal resistance of clothing worn—in addition to values for air velocity, air (or dry-bulb) temperature, mean radiant temperature and the vapour pressure in the air (which determines relative humidity) (Cowan, 1978, pp. 223–4). By measuring these physical and physiological variables, Fanger derived his *Comfort Diagrams* (see Fig. 2). And so, by dint of 'comprehensive research' in this field, it is now said to be feasible (Fanger, 1978, p. 155) to predict those combinations of physical factors which provide *thermal neutrality*[15] for people engaged in given activities and wearing given amounts of clothing. As a result, it is said to be possible to predict (Fanger, 1970, p. 19) quantitative conditions for optimal thermal comfort by calculating all the combinations of physical variables which will create those conditions.

It should be apparent that, as Markus and Morris (1980, p. 52) recognised, this approach to the evaluation and construction of internal thermal environments requires:

> '... acceptance of a theoretical standpoint with regard to the definition, and hence the measurement, or even the measurability, of "comfort" itself.'

This standpoint, which is experimentally grounded, revolves around a limited concept of how people assess environments in which they live and work. Such assessments are, it is insisted,[16] primarily the outcome of—and are, in effect, determined by—the interaction of a specifiable set of physical and physiological variables operating in internal environments. One significant result of the adoption of this reductionist position is that comfort can be conceived of, not just as amenable to quantitative measurement, but as responsive to statistical manipulation and so to prediction. Thus it is held that optimal conditions can now be specified for human comfort, provided only that the levels of activity engaged in, and the amounts of clothing worn by, occupants in buildings are included in the calculations.

SUBJECTIVE RESPONSES TO COMFORT

While changes in body temperature or pulse rate can provide useful scales for evaluating the effects of thermal stress on a person's body, there is no precise physiological observation by which comfort can be evaluated (ASHRAE, 1965, pp. 66 and 109). So, because 'no reliable objective' measurement of comfort has been

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[15] However, Fanger acknowledged that, '... thermal neutrality for the body in general is not always sufficient to provide thermal comfort for man. It is a further requirement that no discomfort is created due to local heating or cooling of the body. This may be caused by an asymmetric radiant field, a local convective cooling of the body (e.g. draught), by contact with a warm or cool floor or by a vertical temperature gradient.'

[16] See, for example, Fanger's dismissal, in the appended discussion, of Rohles' (1980) suggestion that psychological variables might override physical factors in determining people's perceptions of comfort.

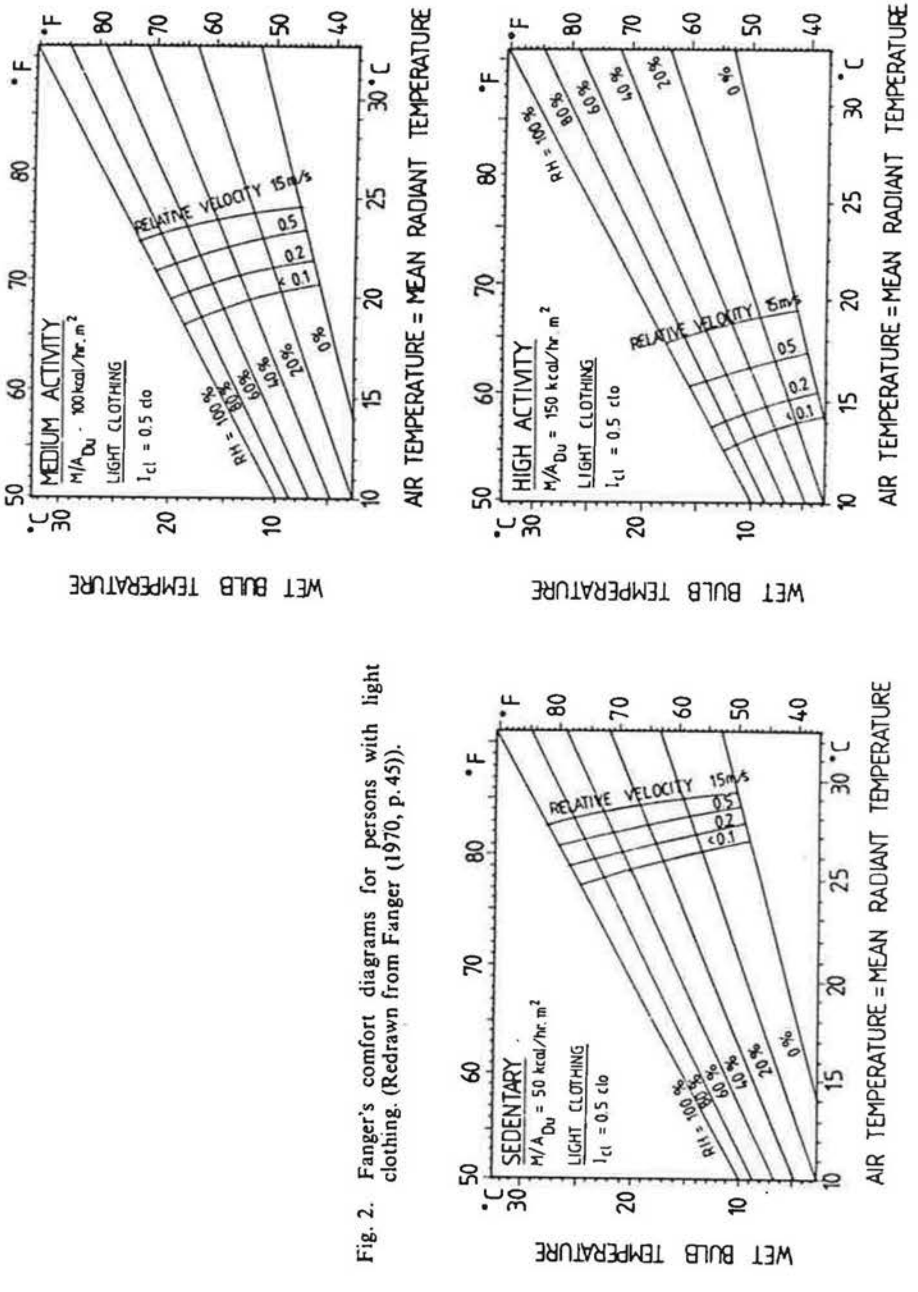

Fig. 2. Fanger's comfort diagrams for persons with light clothing. (Redrawn from Fanger (1970, p. 45)).

found, comfort studies *have had* to be based on people's subjective responses. For, as Thornley (1969, pp. 19–20) observed:

> 'The human body is the most sensitive and responsive device we have for the measurement of comfort. . . . It would be convenient if a piece of laboratory equipment (or better still a field measuring instrument) could be devised which would behave and respond in precisely the same way to its environment as does the human body. Such an instrument is not available and is unlikely to be produced.'

In the past, Chrenko (1962, p. 65) recorded that the simplest way of dealing with psychological aspects of comfort was to ignore them completely: people's feelings of warmth and comfort were assumed to be so obtuse and variable that nothing profitable would come of attempting to assess them. Consequently, he remarked, physiologists preferred to measure skin temperature while physicists, such as Dufton (1931), sought the construction of instruments which would 'tell the right answer'. However, Chrenko argued, criteria for the assessment of warmth and comfort *must* be based on human sensations. For, while it is sometimes said that the warmth of a room may be measured with a thermometer:

> 'The room does not experience warmth but the human occupant does. The thermometer indicates the temperature of the room only; and it is the occupant of the room who decides whether he is warm or not.'

So, Chrenko (1955, p. 293) observed:

> '. . . if a man feels warm or comfortable or otherwise, then he is.'

Taken at its face value, Chrenko's observation would seem to imply acceptance of the implications of Thomas' seminal dictum (Thomas, 1928, p. 572):

> 'If men define situations as real they are real in their consequences.'

Comfort research could, concomitantly, be expected to focus on subjective processes, including socially constructed meanings, that intervene between objective stimuli and human responses. For, seemingly inherent in Chrenko's remark is a concept of human beings as more than mere mechanisms. Such an interpretation is, however, belied by the research techniques described as suitable for the assessment of people's responses to thermal environments (see below).

Unlike physiological responses, which may be measured 'objectively' (Givoni, 1976, pp. 53–4), determination of subjective sensory responses depends on self-evaluation by people exposed to given environments. This evaluation is not regarded as unequivocal but as varying between different individuals and also with the same individual over time. Indeed McIntyre (1978*b*, p. 215) noted that:

> 'The variability in warmth votes given by one person on different occasions is as high as the variability of votes between different people.'

To circumvent this variability, behavioural approaches have been adopted for studying human comfort.[17] These have included, Markus and Morris (1980, p. 52)

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[17] See, for example, Griffiths (1970).

catalogued: measurement of people's sweat rate, oxygen consumption and activity adjustment, analysis of the amounts of clothing worn and observation of people's choices in setting thermal controls and opening windows. While such approaches are described as complex, they are also, Markus and Morris maintained, 'ideally suited' for field studies because they:

> '. . . involve no interference with the normal routines of life; in fact, if carefully done, [they] . . . can be carried out by totally unobtrusive methods.'

In stark contrast, as McIntyre (1978*b*, p. 222) noted, the method of *direct determination* of preferred temperature has also been employed. This was pioneered by Fanger (1973) in his work in the Environment Test Chamber at the Technical University of Denmark. In this approach to comfort research, McIntyre stated:

> '. . . a subject's preferred temperature [is elicited] by *allowing him to request* changes in chamber temperature until he is satisfied' (emphasis added).

The wording of McIntyre's description is revealing: it is symptomatic of the potentially benevolent, but fundamentally paternalistic and patronising, stance which comfort researchers appear to adopt towards their 'subjects'. Even in an experimental situation, direct determination might be expected to mean that people directly determine for themselves, by requisite adjustment of controls, the environmental conditions they seek. Instead, researchers 'allow' them to 'request' such adjustments to be made on their behalf by others. Such vocabulary is significant because it makes explicit the passive rôle ascribed to people, by comfort theorists, in the construction of internal thermal environments: a rôle which has influenced—and continues to have implications for—comfort practice (see below).

More commonly, however, comfort studies tend to be based on what Markus and Morris (1980, p. 52) labelled as 'simpler semantic' techniques in which people are asked to express their feelings about an environment in words.[18] There are, Humphreys (1976*a*, p. 34) advised, two basic types of semantic study; those conducted in the field and those which take place in environmental test chambers. In field studies, respondents continue their normal occupations in normal surroundings (Humphreys, 1975, p. 1), except for those 'slight intrusions' which are necessary when measurements are taken or subjective responses recorded. Usually, in field studies, Humphreys stated:

> '. . . no attempt is made to control the environmental conditions. The experimenter deliberately refrains from making any alterations so that his results are applicable to normal conditions encountered by his respondents during the season of study. In this way the studies gain in realism but lose some of the advantages of planned experimental design. It would generally be true to say that they are not so much experiments as surveys accompanied by measurement.'

The second type of study, which is viewed (Humphreys, 1976*a*, p. 34) as involving

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[18] Indeed, McIntyre (1978*b*, p. 215) commented that, 'Asking people how warm they feel must be one of the most prevalent forms of psychophysical activity, though one that is practised more often by engineers than by psychologists.'

more sophisticated equipment, depends on the use of a test chamber in which 'the relevant physical variables' can be controlled.[19] Both approaches are held to have advantages. In field studies, a large number of subjects may be investigated whose responses are thus seen as more representative of the population at large: on the debit side, physical variables in such studies tend to be less well known or controlled. Conversely, while test chamber experiments are presented as more 'artificial', they are commended as increasing researchers' ability to manipulate physical variables. Nevertheless, it should be noted, Chrenko (1955, p. 282) stressed:

> '...the main difference between the field investigation and the laboratory study is that while environmental conditions may be controlled by the experimenter in the laboratory, they are not normally in control outside it.'

Traditionally, Griffiths and Boyce (1971, p. 457) suggested, thermal comfort has been measured by the use of subjective assessment techniques. And, typically, Griffith (1970, p. 30) noted, such studies have proceeded by correlation of what have come to be known as *comfort* votes (Bedford, 1961, p. 298) with physical data about thermal environments. Subjects are asked (Fanger, 1973, p. 5) to vote on their thermal sensations on suitable psycho-physical scales, while, at the same time, measurements are taken of the ambient thermal climate to which they are exposed.[20] Their replies are then statistically correlated (Griffiths, 1971, p. 45) with measurements made at this point of questioning. People are asked to express their feelings about an environment in a 'controlled manner' (Fisk, 1980, p. 4) by choosing between pre-determined words, a process described as 'prompted voting'. Although warmth cannot be measured like temperature, Chrenko (1962, p. 65) maintained that this does not mean that it cannot be assessed. But, he argued, for such assessment to be possible, a necessary first step:

> '... is the assignment of numbers to the sensations. The result is that the sensations can be correlated with the physical environment and the physical measurement can then be used to assess the subjective reactions.'

For, since the term *warmth* has been invested with a 'scientific meaning' (Bedford, 1961, p. 301), quantitative assessment of people's subjective reactions is held to be preferable (Chrenko, 1955, p. 285). So subjective estimates of warmth are--and have been for over 50 years (McIntyre, 1978*b*, p. 215)—obtained by means of *comfort* scales. Subjects are asked, not to identify temperatures, but to categorise sensations. Hence, for example, subjects may be placed in an environmentally controlled chamber and, as O'Callaghan (1978, p. 50) explained:

> '... as primary parameters are adjusted singly, [subjects] are asked to vote at hourly intervals. The data are statistically averaged and an effective temperature scale is assigned to the range of conditions imposed during the test. The occupant is thus used as a thermometer which responds to the rates of heat loss or gain between the body and its environment, the subjective rating representing the response "read out".'

Conversely, subjective assessments may be collected via fieldwork, as in Bedford's pioneering study of the comfort of female workers engaged in light industry.[21] Here factory workers were questioned as to their sensations of warmth. Each person was asked, Chrenko (1955, p. 283) related, if she felt comfortably warm. If she did not, she was then asked to say whether she felt too warm or cold, and then whether she felt just definitely too warm (or cool) or much too warm (or cool). If she replied that she felt comfortable, she was asked if she were really quite comfortable or whether she would have the room slightly warmer or cooler. As this account reveals, Bedford did not present his comfort scale (see Table 1) directly to his respondents: rather he asked them about their state of comfort and then classified their replies according to his scale.[22] The information so collected was then tabulated in the form of correlation Tables, showing, for each sensation of warmth on the scale, the frequency of occurrence at various temperatures (Bedford, 1961, p. 292). This, in primitive form, was progenitor to subsequent research work on the subjective assessment of comfort. Since then however, it has become common practice (Markus and Morris, 1980, pp. 52–3) to present respondents with actual rating

TABLE 1

COMFORT AND THERMAL SENSATION SCALES

Bedford		*ASHRAE*		
Much too warm	1	Cold	1	+3
Too warm	2	Cool	2	+2
Comfortably warm	3	Slightly cool	3	+1
Comfortable	4	Neutral	4	0
Comfortably cool	5	Slightly warm	5	−1
Too cool	6	Warm	6	−2
Much too cool	7	Hot	7	−3

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[19] This, McIntyre (1978*a*, p. 102) asserted, is probably the most familiar method of comfort research. '...being the method used at K.S.U. [Kansas State University] on which much of the ASHRAE standards are based. Subjects are exposed to a given temperature in an environment for a set exposure time. At the end of the period they indicate sensations on a rating scale. By exposing a large number of subjects to a range of temperatures it is possible to construct a picture of how sensation varies with temperature.'

[20] Thermal comfort studies have usually, McIntyre and Griffiths (1974, p. 120) commented, concentrated on investigating people's responses to steady state conditions. 'Very little experimental work has intentionally involved exposing people to changing conditions, although, particularly with modern light-weight building structures, temperatures are often variable quantities.' They distinguished between three types of temperature change. First, step changes which occur, for example, when a person moves between rooms with different thermal conditions. Secondly, cyclical changes which occur, for example, when a temperature fluctuates between the limits of a thermostat's differential. And, thirdly, simple linear ramp or 'monotonic' temperature changes such as a temperature gain or loss within a building during its period of occupation.

[21] Reported in Vernon *et al.* (1926).

[22] As Wilkinson (1974, p. 750) recorded, Teicher (1967) questioned the validity of such responses, For: 'If the people sitting in the same room are asked to rate its temperature in terms of, for example, the Bedford 7 point scale, they may both rate the room "uncomfortably warm", but this does not necessarily mean that they would both take the trouble to leave the room in search of somewhere cooler.' As a consequence of this criticism, Teicher called for votes given by people on subjective rating scales to be validated in terms of their empirical behaviour.

scales. These frequently take the form of fixed alternative questions employing semantic differentials (see Table 2). People are asked to express impressions of an environment on a linear scale in which numbers are fitted to phrases.[23] In the construction of such scales it appears to be assumed that intervals between phrases used are equal and hence that they merit equal numerical intervals of unity. Similarly, it is assumed that people's subjective responses bear a constant relationship to their physiological state. Moreover, comfort is viewed as a 'quantal' response to thermal environments (Chrenko, 1974, p. 134); that is, a response which does or does not occur.[24] And the vocabulary used by researchers, to which their subjects must respond, is seen as a link forged from shared understanding. But, as Markus and Morris (1980, pp. 53–4) observed, if understanding is not shared but differs:

TABLE 2
SEMANTIC DIFFERENTIALS USED IN COMFORT RESEARCH
(Taken from Rohles (1980, p. 547)

According to the instructions, place a check between each pair of adjectives at the location that best describes how you feel:

Comfortable	__:__:__:__	Uncomfortable
Bad temperature	__:__:__:__	Good temperature
Pleasant	__:__:__:__	Unpleasant
Good ventilation	__:__:__:__	Poor ventilation
Unacceptable	__:__:__:__	Acceptable
Uncomfortable temperature	__:__:__:__	Comfortable temperature
Satisfied	__:__:__:__	Dissatisfied

> '... then the answers from different respondents do not necessarily mean exactly the same thing—a point to which little attention has been paid in classical thermal comfort work.'

Despite such occasional expressions of doubt or misgivings, faith in the validity of comfort scales would appear to continue unabated. Indeed, some of their proponents are prepared to make extremely specific claims about the precision of this quantitative approach to measuring comfort. For example, Givoni (1976, p. 56) claimed, not simply that people's thermal responses can be numerically graded according to the severity of their sensation of cold or warmth, but that:

> 'Experience has shown that a person can distinguish not only between the various levels but also determine intermediate levels such as 4·2 (not entirely comfortable but definitely not slightly warm) or 4·7 (less than slightly warm but definitely not comfortable) or 4·5 (somewhere in between).'

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[23] The semantic differential is, Osgood *et al.* (1975, p. 20) suggested: '... essentially a combination of controlled association and scaling procedures. We provide the subject with a concept to be differentiated and a set of bipolar adjectival scales against which to do it, *his only task being* to indicate ... the direction of his association and its intensity on a seven-step scale' (emphasis added).

[24] Chrenko continued: 'The question arose as to where the line [between comfort and discomfort] should be drawn across the scale of sensation and this did not present any difficulty, since by definition one cannot be thermally uncomfortable in the range from "comfortably cool" to "comfortably warm". Outside this range a given individual subject must be thermally uncomfortable.' This reasoning has led to intervals 3, 4 and 5 being classified as the comfort zone.

Two forms of seven-point rating scale are used, Humphreys (1975, p. 2) stated, about equally; the *Bedford* scale and the *ASHRAE* scale (see Table 1). The former is a combined estimate of warmth and comfort, a feature which, Humphreys (p. 3) noted, has been:

> '... criticised on the ground that the relation between the two is not necessarily constant. Others have considered this objection is outweighed by the practical advantage of being able to use one scale instead of two.'

The Bedford scale, McIntyre (1978*b*, p. 215) objected, also suggests evaluation in the use of the word 'too'. By contrast, the ASHRAE scale contains no explicit reference to either comfort or pleasantness. Despite these variations, however, there appears to be no difference in performance between the written forms of the two scales (Humphreys, 1975, p. 15). In field studies, at least, varying methods have been employed for presenting these scales to respondents. In some, the question posed has referred to the state of the room occupied by respondents; in others it has been used to refer to the thermal state of occupants themselves. Humphreys (p. 4) commented that:

> 'Although the distinction is subtle, it does occur in common speech, for example in the query "is it hot in here, or is it just me"?'

Similarly, methods employed for collecting responses have also varied. On occasion, they have been obtained during individual interviews with scales being presented as a structured series of questions. But, where repeated responses have been required from the same respondents, voting slips, cards, or even automatic desk-top recording instruments, have been used (Humphreys and Nicol, 1971). Both seven-point scales are designed to be symmetrical about a *neutral* or *comfortable* category. And this is sometimes emphasised by numbering scales, not from 1 to 7, but from +3 to −3, just as the wording of the category descriptions is also symmetrical in the qualifying adjectives used. This approach to numbering may also reflect the practical purpose which underlies the use of such scales; for, as McIntyre (1978*b*, p. 215) asserted:

> 'It is generally assumed that [the category numbered 0 or] 4 is what we are after; i.e., that the goal of the environmental engineer is to produce an environment which will result in a mean Bedford vote of 4.'

Despite this purpose, he acknowledged that the central neutral point on such scales does not necessarily represent people's *preferred* temperature: the latter, he explained (McIntyre, 1978*a*, p. 102):

> '... is the temperature at which a subject requests no change in temperature. It is found experimentally by the method of direct determination, or in a questionnaire study by asking a question of the form "would you like the temperature in here to be: 'Higher', 'Just as it is' or 'Lower'?".'

Explanation of this discrepancy may spring, McIntyre (p. 105) proposed, from the connotations of the words 'warm' and 'cool'. For people in cold climates are seen (McIntyre, 1978*b*, p. 215) as preferring a temperature sensation which they would describe as being on the warm side of neutral, while people in warm climates are said to prefer a sensation on the cool side.

Since the Bedford and ASHRAE scales are constructed from categories that can be unambiguously ordered, information collected using them is at an ordinal level of measurement. And, as such, it is amenable to the performance of *non-parametric* statistics.[25] However, since the goal of comfort work is (McIntyre, 1978*b*, p. 216) to be able 'to predict' people's comfort, it is necessary to be able to work 'in terms of the parameters of the distribution of votes'. But, in order to be able to do so, it has to be assumed that comfort votes represent a level of measurement amenable to *parametric* statistics, such as, for example, the use of multiple regression analysis—'the most widely practised statistical technique for dealing with the variation of warmth votes with temperature' (McIntyre, 1978*b*, p. 217). However, use of this statistical technique is dependent on scales being treated as of equal interval. For, once this assumption is made, it then becomes possible to combine votes and so to represent their arithmetic mean. Hence, if a change from a vote in category 3 to a vote in category 4 reflected the same change in sensation as a change from 4 to 5, then it would be possible to establish a *rating* scale and so obtain the 'psychological width' of categories. And, indeed, in order to enable comfort predictions to be generated, it is currently assumed as 'a working hypothesis' that a seven-point scale does have equal category width. This is not an assumption, however, which the scale's original composer was disposed to accept. Instead, Bedford (1936, p. 19) argued that, while:

> 'For the purpose of statistical treatment it is convenient to assign numerical value to . . . [people's comfort votes], and in this way we get a scale of sensations of warmth. . . . It is realised that any statistical treatment using a numerical scale of comfort must be carried out with the full recognition that the scale is an arbitrary one. We cannot say that in one environment we feel twice as comfortable as in another, nor can it be assumed that the steps necessarily indicate equal values of sensation.'

THE METHODOLOGICAL BASIS OF COMFORT RESEARCH

Reduced to essentials, the concept of 'man–environment' relations which underpins the approach to comfort research outlined above seems simple, unambiguous and mechanistic. Comfort and discomfort are seen as quantal conditions arising directly, and specifically, from people's thermal sensations. Perceptions of warmth or cold, which seemingly alone determine whether people judge environments they occupy as 'comfortable', result from neural activity. This originates, it is said (Givoni, 1976, p. 55), in people's nerve endings which act as thermal receptors. Thermal sensations are induced through physiological mechanisms set in operation by physical stimuli in internal environments. And it is these stimuli which give rise to responses—feelings of warmth or cold, comfort or discomfort—in what theorists may describe (Griffiths and Boyce, 1971, p. 458) as 'the organism'. As this latter term suggests, comfort is viewed as an asocial, depersonalised phenomenon, as a mechanistic, involuntary product of a process where (Willey, 1980, p. 119):

> 'A set of environmental disturbances, *B*, impinge on a person, interacting with the set of physiological variables, *C*, which determine his state of comfort and well-being.'

Comfort is not seen as situationally specific, as a phenomenon whose meaning is defined and redefined by building occupants themselves in the light of the particular circumstances in which they happen to find themselves. Instead, it is a universal, the product of a finite, closed system. For comfort research is based on a stark, unequivocal and uncompromising stimulus–response model: people are posited to be passive recipients of thermal stimuli in their environments which cause them to feel comfortable or uncomfortable.[26] Hence comfort is reduced solely to a question of thermal sensation. And it is this simplistic theoretical stance which is proffered (Fanger, 1970, p. 5) as providing the *rational* basis of comfort research.

Nevertheless, neither the putative internal logic of this stance, nor its consistent reinforcement over many decades through extensive experimental work, preclude the possibility that it constitutes an *irrational* depiction of the real world. For its mechanistic simplicity reveals a refusal to accept the complexity of—because of the interplay between social and physical forces within—internal environments in buildings. On the contrary, 'like positivism, it preserves its virginity by declining to consider anything outside its own narrow bounds'.[27] Comfort theory is based on the reductionist premise that environments can meaningfully be atomised, be reduced to constituent elements, such as the so-called *thermal environment*, each with independent existence and capable of being labelled and treated discretely. And only by perpetration of this ploy is it possible to maintain that thermal parameters alone determine how people evaluate thermal aspects of those internal environments in which they live and work without recourse or reference to other physical—let alone social, economic or political—considerations which might be expected to confound this simplistic stimulus–response model. Moreover, as Harris (1977)

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[25] For, associated with every statistical test, is a model and measurement requirement. Consequently, any particular test is valid under certain conditions, and its model and measurement requirements specify those conditions. As Siegel (1956, p. 19) indicated, two such statistical models exist, parametric and non-parametric. It is questionable whether the statistical tests employed in comfort research are applicable, given the level of measurement that may, legitimately, be ascribed to comfort scaling (see, for example, Selltiz *et al.*, 1969, pp. 195–8).

[26] As a consequence, and perhaps as a necessary corollary, of this stance, comfort researchers—and those who put their formulations into practice—have also come to regard the occupants of buildings as passive recipients of internal environments composed of thermal stimuli engineered and controlled on their behalf by others (see later).

[27] A description originally applied to Wilson (1976, p. xx) to literary pessimism in the twentieth century (Lipman and Harris, 1980, p. 71).

observed, this model appears to invert relations between an environment and people who occupy it since:

> '. . . it is the former which is posited as doing, acting, transforming, while the latter are acted upon, have things done to them, are transformed. In short, such a theoretical perspective inverts subject and object, attributes of the former are assigned to the latter. The physical environment is given characteristics normally associated with people, while the latter are seen as objects in and for the physical environment'.

Because of this inversion, comfort theorists—in common with other researchers in the field of 'man–environment' relations (Lipman and Harris, 1980, p. 71)—treat people, the subjects of their research, as objects. Relations between people and thermal environments are seen as unidirectional: people are regarded as passive objects whose responses are moulded by the interplay of thermal stimuli in their environments. As a corollary, comfort researchers, like fellow environmental psychologists, adopt a 'natural science methodology' for their investigations because they appear to assume that:

> '. . . the lived relationships of their subjects do not differ in kind and quality from the relationships and events studied by natural scientists. They assume that the concepts and techniques appropriate for studying objects are similarly applicable to the study of people. . . .'

So, for comfort theorists, people are passive objects, the recipients of thermal stimuli that evoke given responses which take the form of scaleable thermal sensations. People are not seen as active social agents who construct their own definitions of what comfort means to them and who, in so doing, create their own criteria by which to evaluate the acceptability of the internal environments they occupy. Moreover, because of their preferred research techniques, comfort researchers reinforce their own preconceptions and pre-occupations as to the nature of comfort while, simultaneously, stifling the possibility for their respondents to contradict these by expressing their own, alternative conceptions. For, as Harris (1977) commented, if social research techniques represent attempts to facilitate dialogue between researcher and researched, different techniques impose different constraints on such dialogue. Questionnaires, and especially those composed of semantic differentials, tend, because of their construction, to impose tight constraints on communication between the two parties involved. In comfort research, methods for collecting data consist of a pre-determined number of questions, arranged around a pre-determined topic—defined by researchers—which is not necessarily congruent with the experience, perceptions, expectations, aspirations or interests of those being researched. Moreover, answers to these questions have to be confined to pre-determined forms, to points on a scale of warmth or comfort: dialogue is restricted to a tick or a cross which respondents must place next to the *appropriate* point on the scale. In other words, research techniques employed by comfort theorists take for granted the existence and nature of the phenomenon which they are used to investigate. Similarly, they restrict respondents to answers which lie within, and so reinforce, what comfort theorists conceive comfort to be. Comfort theory and its research techniques are mutually supportive and self-fulfilling: taken together, they represent complementary manifestations of the same closed system. However, as Fisk (1980, p. 7) stated,

> 'It must be remembered that an occupant's judgement of a diffuse sensation such as thermal neutrality is easily coloured in a field context by other factors. A deep plan office, for example, may accentuate feelings of exposure crowding and limited air supply and generate a thermal response consistent with those factors, *especially when the occupants are expressing their feelings in their own words*.' (emphasis added).

People's perceptions of, and their definitions of, the meaning of comfort may well be context specific and related to physical and social factors over and above thermal stimuli. If people are allowed to express themselves in their own words, and if they are enabled to generate their own standards for evaluating the internal environment they occupy, then a building's occupants may employ criteria wider than the reductionist definition of comfort traditionally imposed upon them by the research techniques employed by comfort theorists. Such criteria may involve not simply evaluation of the acceptability of the levels of particular physical factors such as temperature or air movement. In addition, they may include judgements about: how effective and reliable the heating and ventilating systems are which produce those levels; how responsive such systems are to control by occupants themselves and, thus, how sensitive such systems are to the occupant's own perceptions of their needs, not just at different times of the year or at different times of the day, but in the light of their changing aims and objectives (Cooper, 1979, pp. 36–7).

The theoretical adequacy of environmental models which are incapable of accounting for action by which a building's occupants might seek to modify their environment have been criticised, even by those whose work appears to lie inside developments of the stimulus-response tradition (for example, Hawkes and Willey, 1977). According to Nicol and Humphreys (1973, p. 264), people relate to their thermal environment through their aim of maintaining a satisfactory body temperature. This, they contended, is the underlying function of physiological thermo-regulation. But, they added:

> 'A person who feels too hot or too cold will usually make some change in his clothing, posture or activity, in order to become comfortable again. He might also make use of any available environmental controls. . . . Subjective warmth should, therefore, be seen as an active link in the control system, and not merely as a passive response to the thermal environment.'

Further, Nicol and Humphreys (p. 265) suggested there are three ways in which people may voluntarily adjust their flow of metabolic heat to an internal environment: first, by alterations in metabolic rate per unit body surface area brought about by changing their posture or activity; secondly, by changes in the amount of insulation provided by the clothes they choose to wear and, thirdly, by making changes to their thermal environment. If, they argued, subjective warmth is part of a mechanism for controlling thermal environments, then it should be expected that people will take action to cool a hot room or warm a cold one. Consequently, they postulated (p. 268):

> 'The response made by an individual to any particular stimulus will depend upon social conditions. These give rise to pressures which might modify the response or place limits on its extent. The amount an individual can change his clothing, the number of different activities possible and the use he can make of environmental controls, will all depend on social circumstances.'

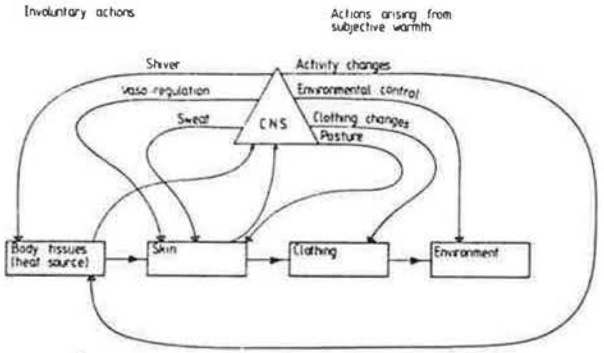

Fig. 3. Comfort as part of a 'self-regulating control system'. —▶— Heat flow, —>— information, —▷— actions, CNS central nervous system. (Redrawn from Nicol and Humphreys (1973, p. 265).

Accordingly, they argued (p. 271), if a *self-regulating control* system is working to secure thermal comfort—see Fig. 3—the whole system will, in any case, tend towards its own optimum:

> 'The problem then becomes one of providing circumstances in which it may do so easily . . . and this tends to direct interest to the control of the thermal environment rather than to the precise fixing of optima.'

However, it should be noted that their argument is based on an assumption (p. 268) that:

> 'Heating and ventilating systems . . . are designed to make use of the fact that some measure of control will be executed by occupants.'

And it is a major theme of this paper that, due to the pursuit of energy conservation, this assumption may become untenable. For it is not just being urged that buildings should be designed so that their heating and ventilating systems are proofed against their occupants' ability to exercise the measure of control assumed by Nicol and Humphreys. Further, it has also been mooted by McNall (1979, p. 817) that even decisions over the amount of clothing which occupants wear in the interests of thermal comfort should be made subject to the dicta of thermostats operated by microprocessors. Thus, in the future, it would seem, environmental control—even to the extent of such *fine tuning* as how much clothing to wear—is not to be a province of autonomous action for building occupants: instead, it may become the subject of prescriptions delivered by automated systems.

DESIGN STANDARDS

The quantitative, statistical and predictive bias discernible in comfort research is partially explicable by the relationship which theory bears to practice. Conventionally, Fisk (1980, p. 7) maintained, comfort theory has been employed to derive standards which can be applied by practitioners in order to produce suitable internal environments (for occupants wearing specific levels of clothing and engaged in particular types of activity). Indeed, the 'success' of this theory is seen by Fisk (p. 1) as being evidenced by the relative ease with which professional bodies have drawn up schedules of physical measures for internal environments at which designers are expected to aim. In other words, the primary purpose of comfort theory has been to offer practical guidance for the 'assembly of hardware'—both in terms of a building's fabric and its plant—which will constitute its system of environmental control. From this standpoint, as Kinzey and Sharp (1965, p. 9) explained, the first step towards 'the successful solution' of problems concerning thermal control in enclosed spaces is the setting of *appropriate design standards*. To this end, they advised:

> 'It is necessary to decide the proper quantitative values for air temperature humidity, rate of ventilation and air movement, surface temperatures, surface thermal reflectivity, and any other factors influencing the nature of the thermal environment. The values must be set in terms of the need which is usually the matter of providing human comfort.'

Then, once these design conditions have been established, they become 'the yardstick' by which selection, sizing and operation of heating and ventilating equipment—in conjunction with controlling devices provided by a building's external envelope—are judged in terms of their capacity to provide 'the desired environment' in an adroit and economic manner. In addition, the procedure which designers should follow in order to select 'the optimum thermal conditions' to suit the occupants of a building has been specified by McIntyre (1973, p. 71). First, designers should estimate, from the known or intended use of a building, the average metabolic rate of its occupants. Secondly, they should estimate the insulation value of the clothing which its occupants are likely to wear. Thirdly, they should calculate—using a comfort equation of the kind previously cited—the subjective temperature required. Heating and ventilating systems should then be designed to provide a suitable combination of air temperature, mean radiant temperature and air speed, all of which will combine to give the *correct* subjective temperature.

The attraction, and apparent utility, of design standards and procedures which seemingly reduce human comfort to an engineering problem that can be resolved by simple calculation should be evident. For they would appear to provide a firm and rational foundation on which to anchor practical action in the real world. However, apart from the inadequacies (discussed above) of the theoretical base from which they spring, design standards have been criticised, since the perception of a need for energy conservation, on more pragmatic grounds. For the design conditions which such standards and procedures presuppose are merely, Fisk (1980, p. 1) noted, a convention whose purpose is to enable designers to form a consistent image of what they are attempting to achieve. In practice, he contended, they are 'fallacious' since:

> 'There is no reason to suppose that they represent an accurate model of realised use and hence of realised energy consumption.'

A similar judgement was offered by the Working Group on Buildings of the government's Advisory Council on Energy Conservation which observed (1978, p. 9):

> 'The engineer generally chooses and sizes a system to "design targets" rather than to "operating targets" and this very approach can lead to the production of inadequate control and the limitation of management opportunities.'

Despite such criticism, the use of design standards has become and remains the foundation, the bedrock of current comfort practice (see Table 3). Indeed, Hawkes (1979, p. 149) suggested that the development of *precise* quantitative specifications for the whole of the internal environment has been the 'most significant' trend in design standards in the post-war years.[28] These represent the outcome of what Langdon (1973, pp. 97–8) described as a comprehensive, theoretically orientated approach aimed at creating a positively *good* environment:

> 'Over the past few decades we have seen a considerable change in attitude to problems of design in the built environment on the part of architects, engineers and administrators, and, in particular, to the way the standards and criteria are established . . . this has come about for a number of reasons; first, the desire to improve standards of physical and social well-being, secondly, the growth in scale and complexity of building, and this relates not merely to their size but also to the degree of control we wish to exercise over the environment.'

As a consequence, Langdon contended, discomfort in buildings is no longer taken for granted, nor is it accepted.[29] In order for this change to occur, buildings and their designers:

> '. . . have had to pass from reliance on implicit, traditional norms to explicit criteria resting on an empirical, factual basis.'

Two consequences of this change are apparent in comfort theory and practice. First, comfort calculations—and thus standards generated from them—are designed for populations rather than individuals. Secondly, they are framed so as to lead to optimal solutions rather than to a 'bank of comfort conditions' (Griffiths, 1970, p. 31). It has long been held a mistake (Bedford, 1948, p. 88) to rely on personal feelings of comfort for the latter are seen as being obtuse, variable and undeveloped

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[28] Such design standards have tended to be more demanding than those specified by government. In the past, the few *statutory* standards relating to environmental conditions in buildings have been concerned with requirements for health, safety and comfort by imposing minimum levels for temperature and lighting. Examples may be found in the Standards for School Premises Regulations, 1959, the Factories Act, 1961, the Offices, Shops and Railway Premises Act, 1963, and in the Mandatory Space Heating, Minimum Standards for New Housing, 1968. More recently, legislation has been introduced which is specifically aimed at conserving energy by imposing maximum levels for internal temperatures, see the Fuel and Electricity (Heating) (Control) Order, 1974 and its 1980 amendment.

[29] For example, Fox (1965, p. 2) argued: 'Studies of conditions in offices have shown that poor ventilation and temperatures which are too high or too low result in loss of efficiency, discontent and increased rates of accident and sickness. They can also affect the supply of labour, since workers nowadays expect a higher standard of comfort than they used to, and if it is not provided they go elsewhere.'

in many people. And, because of the diversity of opinion that exists to which environmental conditions are conducive to comfort, it is regarded (p. 96) as impossible to specify a thermal environment which will please everybody. Instead, it is necessary to ascertain those conditions which are most generally acceptable. Since individuals vary in their reaction to thermal environments, Burberry (1970, p. 49) concluded:

> 'It is possible for different individuals to feel too hot and too cold, respectively in the same thermal conditions. There is no one set of conditions which will satisfy everyone even in one locality. The aim in design is therefore to satisfy a majority and to reduce to a minimum the inevitable proportion of dissatisfied occupants.'

So standards quoted for thermal comfort, as in Table 3, give a particular value for general application. They make no provision for sex or other differences, although women are identified (Kinzey and Sharp, 1965, p. 15) as preferring higher effective temperatures than men, and older people as requiring higher temperatures than young ones. Further, perhaps in response to such reasoning, emphasis has been placed on restricting temperature swings to 'an imperceptible region' (Wyon, 1973, p. 49). Close control of temperatures, even to within ±0·5 °C of a specified optimum, became a 'desirable objective' for comfort practitioners (Page-Shipp, 1979, p. 3) (especially, Loudon (1968, p. 24) noted, in buildings with *controlled environments*, see below). In part, this goal of (minimising complaints by) restricting temperature swings may derive from the narrow and static conception of comfort—i.e. thermal neutrality—fostered by comfort research. For, while the latter, and its findings, apply to the *steady state*, as Griffiths (1971, p. 45) observed:

> '. . . heating systems do not generally apply to the steady state but cut in and out to maintain some approximation to it.'

On the contrary, Wyon (1973, p. 47) stated, not only are such systems themselves subject to cyclical variations, but manual operations of radiators, thermostats, doors and windows can also give rise to large variations in indoor climate. Hence, despite the 'common assumption' by heating and ventilating engineers that a uniform room temperature is necessary for a given activity, constant temperatures are, Wyon stressed, exceptions rather than the rule. As a result, adjustment to temperature swings is a part of the everyday experience of building occupants. Nevertheless, amongst comfort practitioners, Chrenko (1974, p. 142) remarked, the 'perfect indoor environment' came to be characterised by completely uniform conditions within an enclosed space. Moreover, deviations from these supposedly ideal conditions were assumed to be associated with more discomfort. In their pursuit of such optimal, unvarying temperatures, practitioners may have been seduced by the apparent precision of comfort theory into attempting to simulate the carefully controlled uniform conditions obtainable within experimental chambers by comfort researchers. For it should be noted that the design standards offered to practitioners are themselves based on the experimental conditions.

TABLE 3

DESIGN STANDARDS RECOMMENDED BY THE CHARTERED INSTITUTE OF BUILDING SERVICES
(Taken with permission, from CIBS (1978, pp. A1–5))
Recommended design values for dry resultant temperature

Type of building	t_{res}/°C
Art galleries and museums	20
Assembly halls, lecture halls	18
Banking halls:	
Large (height >4 m)	20
Small (height <4 m)	20
Bars	18
Canteens and dining rooms	20
Churches and chapels:	
Up to 7000 m^3	18
>7000 m^3	18
Vestries	20
Dining and banqueting halls	21
Exhibition halls:	
Large (height >4 m)	18
Small (height <4 m)	18
Factories:	
Sedentary work	19
Light work	16
Heavy work	13
Fire stations; ambulance stations:	
Appliance rooms	15
Watch rooms	20
Recreation rooms	18
Flats, residences, and hostels:	
Living rooms	21
Bedrooms	18
Bed-sitting rooms	21
Bathrooms	22
Lavatories and cloakrooms	18
Service rooms	16
Staircases and corridors	16
Entrance halls and foyers	16
Public rooms	21
Gymnasia	16
Hospitals:	
Corridors	16
Offices	20
Operating theatre suite	18–21
Stores	15
Wards and patient areas	18
Waiting rooms	18
Hotels:	
Bedrooms (standard)	22
Bedrooms (luxury)	24
Public rooms	21
Staircases and corridors	18
Entrance halls and foyers	18
Laboratories	20
Law Courts	20
Libraries:	
Reading rooms (height >4 m)	20
(height <4 m)	20
Stack rooms	18
Store rooms	15
Offices:	
General	20
Private	20
Stores	15
Police stations:	
Cells	18
Restaurants and tea shops	18
Schools and colleges:	
Classrooms	18
Lecture rooms	18
Studios	18
Shops and showrooms:	
Small	18
Large	18
Department store	18
Fitting rooms	21
Store rooms	15
Sports pavilions:	
Dressing rooms	21
Swimming baths:	
Changing rooms	22
Bath hall	26
Warehouses:	
Working and packing spaces	16
Storage space	13

Pursuit of ideal conditions, of optimum solutions, has become subjected to criticism as comfort researchers responded to this development in comfort practice.[30] For instance, Givoni (1976, p. 54) argued that maintaining thermal comfort does not imply that environmental conditions should be kept constantly at a precise level. Rather, there are held to be both psychological and physiological arguments against such an approach. For, people's thermo-regulatory systems are:

> '...capable of achieving comfort within a given zone of conditions. In addition, some fluctuations in indoor conditions, such as temperature and particularly air velocity, are beneficial as they prevent a monotonous feeling. Such fluctuations are important for increasing the effectiveness of thermo-regulatory mechanisms, in particular the vasomotor system and the sensitivity of the thermoreceptors of the nervous system. Therefore the thermal requirement could be specified in terms of average values, with the acceptance of some variations and fluctuations.'

Accordingly, it is currently advised (Markus and Morris, 1980, p. 62) that, for the benefit of both comfort and performance, some limited variation in the environmental conditions which people experience is acceptable, even desirable, since:

> 'In real buildings, and out-of-doors ... there is continuous variation in space and time. This is not only caused by climatic changes and by built form, but also by activity, posture and adjustment to clothing. These are part of normal experience and in fact contribute to the infinitely varied experiences which result from the complexity of all environments.'

When design standards are discussed, it is frequently observed that there has been a marked trend during this century towards higher indoor temperatures in developed countries (e.g., Thornley, 1969; Jamieson, 1976; Hawkes, 1979; Fisk, 1980 and Rohles, 1980). Thus, Rohles noted (p. 542) that, in North America, the ASHVE/ASHRAE's recommended standard for winter comfort was 17·8 °C in 1924, 18·9 °C in 1925, 20 °C in 1941, and 25 °C in 1960.[31] Similarly, in Britain, Jamieson (1976, p. 2) remarked:

> 'In the 'thirties, we used to heat offices to 15·5 °C or occasionally to 16·6 °C. Many factory buildings were then totally unheated or had a few coke stores to take the edge off the temperature. Offices have recently crept up to 21 °C.'

Similarly, Hawkes (1979, p. 149) recorded that temperatures recommended for school classrooms in 1947 were 15·6°–17·5 °C while, by 1976, the standard had risen to 18 °C. Varied explanations have been offered for this trend. McNall *et al.* (1968, p. iv.2.2) attributed it to a widespread use of lighter clothing and an increase in 'well-designed' heating systems. Wyon (1973, pp. 49–50) agreed, at least to the extent of

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[30] Especially, that is, since the advent of the so-called *energy* crisis. For example, Page-Shipp (1979, pp. 3–4) contended that, 'The energy cost to achieve this level of comfort was, sometimes legitimately, regarded as small.... Escalating energy costs have, however, necessitated a reappraisal of this approach.... Considerable economies can be affected [*sic*] by allowing air temperatures to fluctuate several degrees about an ideal value. This is clearly a *prima facie* case for considering this option. There is also some evidence (for example, Wyon, 1976) that moderate deviations from ideal comfort conditions actually promote productivity.'

[31] The American Society of Heating and Ventilating Engineers was later superceded by the ASHRAE.

identifying heating and ventilating engineers as having contributed to its underlying causes. He contended that:

> 'Engineers have seen it as their task to provide the temperatures that are wanted, and their goal has been a minimum number of complaints.'

And, he argued, people's subjective assessment of discomfort due to cold increases more rapidly than their assessment of discomfort due to overheating with deviation from *the optimum*. This phenomenon, he proposed, may be the 'driving factor' behind the trend. For, since discomfort due to cold may be expected to give rise to more complaints than discomfort due to overheating:

> 'Engineers can thus decrease the number of complaints by increasing the temperature whereupon a new acclimatisation takes place, probably by means of altering clothing and behaviour patterns, and the cycle can recommence.'

Fisk (1980, p. 7) also supported explanations which focus on prevailing 'norms' of dress and activity levels. It is these norms and behavioural restrictions, he argued, which have altered. And, as clothes have become more lightweight, internal temperatures have had to rise in order to compensate and maintain comfort conditions. O'Callaghan (1978, p. 43) concurred and indicted engineers as responsible for the drift towards lightweight clothing. Unfortunately, he contended:

> '... thermal comfort has become a commodity produced by the service industries and marketed and sold by the heating, ventilating, air-conditioning and insulating engineers. Thus, whereas in the past individuals relied upon clothing to maintain thermal equilibrium, recent trends depend on the production of artificial interior climates. Thermal isolation is therefore purchased more expensively from the building services engineer than from the tailor.'

Whatever the origins of these changes, it should be evident that current design standards for comfort are not absolutes. Rather, it has to be recognised, as Banham (1969, p. 277) indicated, that there are no absolute environmental standards for human beings because:

> '... the environmental needs of the whole living man are variable in sickness and in health, youth and age, education and culture, physical and social circumstances.'

Nor are standards relative simply in the sense that they may alter over time. They are also relative in that they are social constructs which reflect the beliefs, values, expectations and aspirations of those who construct them. Accordingly, access to comfort is—like access to other scarce commodities or resources in our society—both an economic consideration and a privilege, a barometer both of affluence and of social standing. Hence, the CIBS recommended (1978, p. A1–5) (see Table 4), that the design value for the dry resultant temperature in *luxury* hotel bedrooms should be 24 °C, in *standard* hotel bedrooms 22 °C, but 18 °C in police station cells and in domestic bedrooms. And, because they are social constructs, and because energy is now to be conserved, it is understandable that not just the immutability of such design standards for comfort should be questioned, but even the need for close control over environmental conditions within buildings (Fisk, 1980, p. 2). For example, Humphreys (1979, p. 13) argued that field studies show that comfort temperatures are not constant. On the contrary, they vary systematically with climate and season, according to the temperature to which people are accustomed. And, as a result of the energy crisis, it is now explained that:

> 'These variations in comfort temperatures have obvious implications for energy saving. If people can be perfectly comfortable at indoor temperatures which are lower than at present customary, then savings are possible.'

Moreover, Humphreys concluded that much of the variation in comfort temperatures discerned in field studies is attributable to variations in the amount of clothing worn by occupants. Thus, outdoor temperature is presented as influencing comfort (p. 15), particularly in 'free-running' buildings,[32] because it affects both indoor temperature and the clothing people wear. Hence, Humphreys (1976, p. 11) contended:

> 'If... it proves necessary to heat a building in winter or cool it in summer... an indoor temperature which varies with the season, besides being more economical on the use of fuel, is seen to be more satisfactory for the comfort of occupants.'

CONTROLLED ENVIRONMENTS IN BUILDINGS

It may prove helpful to try to view implementation of comfort theory and accompanying changes in comfort practice, particularly the emergence of *controlled environments* in buildings, against a backcloth which depicts both developments in relations between those occupational groups involved in designing buildings and transformations in their respective areas of authority and responsibility. In the past, Burberry (1978, pp. 143–4) contended, the essential form of buildings was primarily governed, not by aesthetics, style, structural or economic considerations, but by the necessity to provide natural light and ventilation. Now, however, because of developments in technology, there is a choice;[33] that is:

> 'An entirely artificial environment can be provided if it is desired.... The technological possibility is real.... The development of central heating, mechanical ventilation and refrigeration have made it possible to maintain standards of comfort in buildings without the need to consider external influences in the basic design. This has resulted from the very recent availability of cheap energy.'

Before the advent of such technical possibilities, at the start of this century, the dominant approach to building in Europe still revolved around heavy, heat-conserving, heat-insulating forms of construction. Into these buildings, mechanical aids were admitted by those who controlled design 'grudgingly, almost as an

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[32] That is, buildings in which no energy is being consumed by heating or cooling appliances (Humphreys, 1976, p. 2).

[33] This choice, and its attendant 'adventures' in mechanical and electrical controls over environmental conditions in buildings have been regarded, as Banham (1975, p. 20) recorded: '... at various times with enthusiasm and disapproval, have been seen as the salvation of architecture or its destruction, and have become a matter of general concern because of uncertainty about the future and the capacity of our energy supplies ... consequently, escalating demand for fuels and water has raised understandable doubts whether this kind of environmental management can be supported much longer. On the other hand, the increased comfort, convenience and cleanliness it has brought into buildings represents a human good that even convinced ecologists seem unwilling to give up.'

admission of failure' (Banham, 1975, p. 14).[34] Perhaps as a direct inheritance of this stance, during this century architects as an organised professional group have lost, abrogated or ceded responsibility for control of environmental conditions within buildings to other members of design teams (variously described as heating and ventilating engineers, building services engineers or environmental engineers).[35] This group of designers which replaced architects are, Banham (1969) suggested:

> '... by training, and their backgrounds—educational, social and cultural ... likely to be totally different from those of the architects whom they advise, their basic disciplines are usually analytical and mathematical and contain little that architects would recognise as "design".'

This division of responsibilities has been labelled an historical 'accident' by Hawkes (1975, p. 40). As a consequence of this accident, he maintained, design of internal environments within buildings has become based on the assumption that 'environmental shortcomings' will be ameliorated by inputs from mechanical and electrical services (rather than inputs from, say, a building's fabric, or from its form or orientation). One feature of this 'predominant attitude' to environmental control is, Hawkes observed:

> '... the constant implication that ... [environmental control] depends substantially on engineering installations. The effect is that the design of a building is sub-divided into engineering and architectural components.'

During this century, then, building design became divided into discrete parts (Radford and Gero, 1980, p. 3). As means of environmental control, the effects of building fabric and the effects of mechanical services were divorced:[36]

> 'One was the domain of the architect and the other the domain of the mechanical engineering consultant. Indeed, in thermal design the effect of the building came to be regarded as part of the problem rather than part of the solution and the whole responsibility for maintaining comfortable thermal conditions was placed on mechanical services.'

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[34] In planning these buildings, some provision had to be made for marginal consumption of 'environmental power', such as chimneys for smoke and channels for water. But such provisions were, Banham (1969, p. 22) argued: '... of little consequence either in outlay or visible bulk; architecture could continue to treat them as matters for footnotes and appendices.'

[35] Accordingly, Banham (1969, pp. 267–8) proposed more than a decade ago that: '... the architect as we know him at present, the purveyor of primarily structural solutions, is only one of a number of competing environmentalists, and what he has to offer no longer carries the authority of either necessity or unique cultural approval.'

Nor has this redistribution of responsibility been limited to Europe. Rather it was presaged by changes in North America where, Mumford (1924, pp. 163–5) recorded over fifty years ago that: 'A modern building is an establishment devoted to the manufacture of light, the circulation of air, the maintenance of a uniform temperature, and the vertical transformation of its occupants.... Instead of the architect paying attention to exposure, natural circulation, and direct daylight, and making a layout which will achieve these necessary ends.... Where the natural factors are flouted or neglected, the engineer is ready to provide a mechanical substitute—"just as good as the original" and much more expensive.'

[36] In practice, as Willey (1980, p. 124) remarked: '[Environmental] Control Systems differ from one situation to another.... In some climates it is possible to employ fabric without plant, provided the fabric is appropriately detailed and orientated, and control systems employing plant without fabric have been envisaged (Banham, 1969, p. 285). The extent of automatic controls varies widely, as does the extent to which the building's occupants may be able to regulate their own environment behaviourally and thereby their comfort and well-being.'

And, in the course of this century, it became customary to regard design as 'a linear process' (Hardy, 1971, p. 25) in which architects alone 'designed' buildings, and into which other specialists 'fed' information that allowed those buildings to be structured and equipped. In this process, Hardy suggested, architects produced initial sketch schemes which they then passed on to various consultants at succeeding stages as designing proceeded; that is:

> 'The traditional design process was such that the architect produced a basic design scheme, which was then handed over to a structural engineer who designed a suitable structure. A heating and ventilating engineer then designed the thermal plant and finally a lighting engineer designed an artificial lighting scheme.... In all these stages the design decisions made by the specialists had already been severely restricted by the [architect's] original building design.'

The validity of this linear approach to design was questioned, in the 1960's and early 1970's, following what was seen as an increase in the 'percentage of new buildings which failed to provide an acceptable environment for their occupants' due to 'a deterioration in the internal thermal conditions in buildings, during a period of considerable technological development' (Hardy, 1975, p. 7).[37] To replace the blamed, and so discredited, linear process, a new, 'logical' design philosophy was proselytised; a philosophy which, as Hardy (p. 14) indicated, was founded on the tenet that since:

> 'The environmental performance of a building is the result of the interaction of the building enclosure and its installed services ... therefore all those involved in the design of a building should work together from the commencement of the project, as it is the basic early design decisions which are the most important and the consultants should be able to advise the architects on the environmental consequences of his design decisions.'

However, this revised method of working involved more than just closer, earlier and better integrated relations between members of design teams. Its effective operation would also appear to have depended on a redistribution of power within design teams so that, if it became necessary, architects' initial proposals could be amended, perhaps even vetoed and over-ruled, by other team members. In this sense, the new approach to planning meant not only that architects ceded responsibility for designing environmental conditions within buildings. In addition, they had to abrogate their ultimate authority, they had to give up their positions as ultimate arbiters in design teams, so relinquishing control not simply over *early* design

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[37] Such failure also tended to be attributed to *lightweight* forms of contemporary constructions. For example, Langdon (1973, p. 105) observed: 'The "modern" lightweight building of the type that has become characteristic of many schools, hospitals and offices is well equipped to generate enough heat to overcome thermal losses, but, since it has a large glass area and is of lightweight construction, it tends to be thermally unstable. Having little thermal capacity it responds rapidly to solar inputs while the large glazed areas emphasise the "greenhouse effect". In addition, it is poorly equipped with regulatory controls—radiators and convectors are relatively insensitive to temperature changes and convectors have extremely poor feedback characteristics.'

And this apportionment of blame helps, at least in part, to explain the later emphasis on heavyweight, minimally glazed, buildings, with thermally stable environments, which emerged when *integrated environmental design* was put into practice as the alternative approach to design.

decisions but over the design of buildings as a whole.[38] Hence forward, as Mitchell and Leary (1975, p. 17) propounded:

> '... there can be little doubt that real improvements in environmental quality can only be brought about by the application of a philosophy which combines modern building science with a team approach—a philosophy given many names, but now generally referred to as "Integrated Environmental Design".'

This philosophy, they added (p. 18) is:

> '... concerned essentially with the setting and attainment of standards ... the most critical early decisions are those concerned with physical standards: What will be the aim? Those concerned with thermal comfort are reasonably well known and understood; the air temperature must be well controlled; the relative humidity may range over quite a large range ... and the air movement must be random and fairly low. Radiant heat exchanges all primarily depend on building design, and will only cause real concern if large glass areas are used.'

In other words, integration of design was presented not as simply dependent on restructuring design teams, but as requiring the adoption of what Hardy and O'Sullivan (1968, p. 340) described as a 'radical design technique'. This radicalism lay, at least partially, in acceptance of what O'Sullivan (1975, p. 54) termed 'the idea of "controllable" buildings'. For, in the implementation of this new philosophy, the environmental function of buildings was to be upgraded from the mere provision of 'climatic protection' to the production of 'controlled environments' (Brundrett, 1974, p. 365). And, in the latter, temperature, humidity and air movement would be controlled, as Randell and Mitchell (1969, p. 4) recorded:

> '... within specified limits ... [for] the object is ... to establish a stable thermal environment which satisfies the majority of occupants, with respect to comfort, under all the climatic conditions to which the building is subjected.'

Four 'principles' were enunciated, by O'Sullivan (1975, p. 71), whose implementation would result in the desired stability: '(1) Better thermal design of buildings to reduce heating and cooling loads. (2) Better plant to make the most of building design. (3) Better air flow design to reduce the fan-loading. (4) Realistic lighting loads.'

In future, Hardy and O'Sullivan (1968, p. 338) argued, two important factors should determine attitudes towards designing the fabric of buildings and their associated mechanical plant. The first of these should be a desire to attain 'a high quality of thermal environment' for building occupants:

> '... so that not only are complaints of thermal discomfort reduced to a minimum but also so that in workplaces efficiency is increased and staff turnover reduced....'

The second should be a desire that these improved conditions be achieved without a marked increase in either the cost of buildings or in their subsequent energy consumption.[39] And, because the 'most important' decision affecting 'climatic modification' in buildings is, they proposed (p. 340) the ratio of the area of glazing to opaque wall:

> 'The basic design action must therefore be to reduce the area of glass to a realistic minimum, while at the same time improving the thermal capacity of the wall itself....'

One result of the application of this philosophy was the appearance of a new type of building, a new 'stereotype'; that is, there appeared a new version of what Hawkes (1976, pp. 465–6) described as:

> '... a generally held notion about the nature of a good solution to any recurrent design problem....'

Buildings which followed this stereotype had a distinct form and shape. They tended to be cuboid, with compact plan forms (see Fig. 4). Their windows were sealed because, as Hardy and O'Sullivan (1968, p. 341) explained:[40]

> '... if mechanical ventilation is accepted room depths and building widths need no longer be restricted by the requirements of cross ventilation.'

In addition, windows were designed only to afford a directional component of daylight. Their area was reduced to approximately 20 per cent of the external facades of buildings. Consequently, planar illumination was provided by electrical

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[38] Developments in *building science* in general (as well as in comfort theory in particular) were heralded as pressuring architects to accept this reduced rôle and status. For instance, Hardy (1975, p. 13) proposed that: 'Research into the physics of building performance and the psychology of human response to the built environment has ... produced new design information for architects. Such information, however, tends to add to the complexity of the design process as it has emphasised the inter-relationship between all the factors that are concerned in the environmental performance of the building. It has become virtually impossible for a single person to design a building in isolation from the consultants who can make an important contribution to the design.'

[39] For that same year Millbank (1968, p. 1) argued: 'Whereas in non-conditioned buildings [i.e. those without controlled environments] the cost of fuel for heating may be quite small, in air-conditioned buildings the additional power required needed to operate pumps, fans and refrigeration increases electricity consumption, and consequently increases the operating costs to be set against the provision of a more controlled thermal environment.'

Despite this increase in energy consumption, Edwards (1973, p. 33) claimed that: 'Over the last five years there has been a dramatic swing upwards in the number of commercial buildings that are air-conditioned. In North-West Europe the demand is now such that if a building is not provided with air-conditioning the developer is unlikely to reap an appropriate return in rentals and could possibly be under-investing.'

Similarly, Randell and Mitchell (1969, p. 4) concluded that 'no-one' would doubt the desirability of air-conditioning but they might question whether its cost was justified. However, they maintained that: 'If the building itself is designed as an air-conditioned building, and the whole design *integrated*, then the total cost of the building and its engineering services together need not necessarily be higher than that of a traditional building with air-conditioning,' (emphasis added).

'Total integrated design' and 'total costing', they argued (p. 14), would eliminate the cost premium attached to air-conditioning. These statements are cited in order to illustrate that it is against a financial background, as well as against developments in technology and building science, that the evolution of *integrated environmental design* and of *controlled environments* should be viewed.

[40] Moreover, in this situation, they added, '... there would appear to be no case for installing openable windows other than the means of access for cleaning the interior [sic].... *Control of the thermal environment therefore becomes greatly simplified and the energy requirements reduced*' (emphasis added).

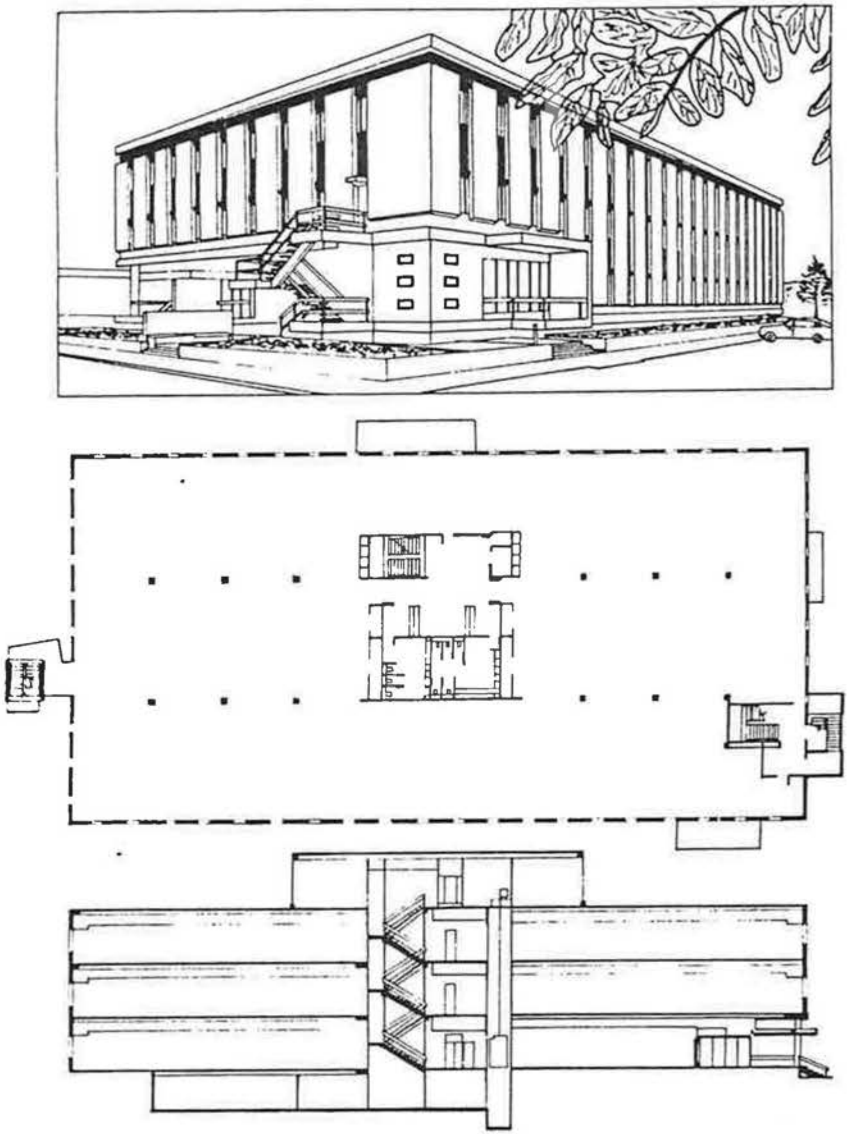

Fig. 4. A 'planned environment'. 'The Avonbank office block is a thermally efficient building designed with the occupants' needs firmly in mind. A three-storey block covering an area of 5264 m^2, it utilises a heat recovery air-conditioning system to maximise the effects of internal heat gains for heating the building.

'The design of the building enables a heat balance to be maintained down to an outside temperature of −4·4 °C (24 °F). Heat gains from lights, occupants and machinery are recovered through the light fittings, the air being filtered, cooled or heated, and returned to the offices. Control conditions 21 °C 50 per cent RH, ± 1 °C, ± 5 per cent RH.'

(Taken from promotional leaflets from the Electricity Council.)

lighting since, Hardy and O'Sullivan maintained:

> 'If electric light is considered acceptable during daylight hours, then buildings . . . can have rooms as deep as 32 ft compared with 20 ft for the daylit room. . . . Therefore such buildings could be 75 ft wide, resulting in a reduction in the external wall area over a given floor area ... regardless of ceiling height. Theoretically, this would reduce the cost per ft^2 of floor area and if the central areas of such buildings, depending on their use, were acceptable with a total artificial environment then buildings would become more cube-like in form with greatly increased climatic modification characteristics.'

In cross-section, these buildings were deep, composed of large internal spaces[41] with low ceiling heights. This meant that, since natural ventilation could no longer achieve sufficient rates of air changes or movement, these large, low spaces required mechanically assisted ventilation. Finally, the thermal properties of the fabric of such buildings was, O'Sullivan (1975, p. 71) suggested:

> '. . . designed to give the best possible combined performances in terms of [reducing] heat loss, heat gain, temperature swing, and [maximising] human "comfort". . . .'

In short, then, the eschewing of natural lighting and ventilation intrinsic to this approach to designing buildings necessitated their replacement by limited areas of sealed glazing, dependence on permanent artificial lighting, mechanical ventilation and energy recycling and recovery. This represented, as Hawkes (1975, p. 4) observed, a significant shift emphasis in building design towards 'artificial' environments; a shift which reflected, *inter alia*, the demise of daylighting as an 'adequate' source of working illumination. In this sense, buildings resulting from the practice of this new design philosophy represent an embrace of, indeed a celebration of, the potential of artificiality extended by both technological innovation and, perhaps more importantly, the plentiful availability of seemingly secure supplies of energy. For, in these buildings, Hawkes (1975, p. 41) attested:

> '. . . the building envelope is arguably there to protect the [environmental control] systems and it is these which have almost the entire responsibility for the environmental comfort of the occupant. The building has become primarily a product of engineering design.'

This was a significant development in building design in Britain because, as Hawkes

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[41] For, as Mitchell and Leary (1975, p. 31) observed; 'much of the reasoning' of integrated environmental design: '. . . reaches its logical conclusion in the open-planned office, where high thermal efficiency can combine with optimum system design and relatively small loads to produce an inexpensive installation providing high quality performance.'

Similarly, Langdon (1973, pp. 102–3) contended; 'The open-plan building not only makes better use of its internal space because of the lower proportion of voids—these can be as high as 30 per cent in a compartmented block. It is also a more efficient structure because of its greater block depth. . . . This means that it is more thermally efficient with smaller heat losses and gains, and easier to maintain at a stable temperature. . . . These simple facts have become the basis for what has been graced by the title "integrated design".'

However, it should be noted that, as Hardy (1975, pp. 10–11) acknowledged: 'The change from sub-divided offices to open plan may also be the cause of the reduction in the number satisfied with the thermal environment. In the small office the occupants have some control over the temperature and the rate of ventilation by opening windows. In the large office the thermal environment is outside the control of the occupants.'

(1980, p. 4) commented, the approach to environmental control in buildings which has tended to predominate (as in other temperate climates) has been dependent on the selective admission into buildings of substantial elements of their external environments. This tendency is denied and reversed in buildings with controlled environments. Instead, these buildings exhibit what Hawkes described (p. 3) as an 'exclusive mode' of environmental control,[42] that is, in such buildings:

> '... the building envelope [is used] to exclude the effects of the external environment upon internal conditions.'

And inside such buildings, Willey (1979, p. 279) noted, internal environments were created which are characterised, not just by tight control over, and uniformity of, physical conditions, but by the inability of occupants to alter those conditions.

Such buildings are, as O'Sullivan (1975, p. 71) remarked:

> '... more properly described as controlled experiments built through the process of Integrated Design.'

For the notion of controlled environments in buildings implies more than regulation of physical factors, such as temperature, in order to produce stable and uniform conditions. Intrinsically, it also involves control of building environmental conditions. Intrinsically, it also involves control of building occupants in order to prevent stability and uniformity being disrupted by people seeking to alter environmental conditions to suit their own aspirations and expectations.[43] In this way, at least, the emergence in Britain of controlled environments in buildings over the past 15 years or so may be interpreted as a logical expression of—perhaps even a necessary consequence of—the application of comfort theory to practice.

The prescriptions laid down in this approach to how buildings should be designed have not been presented for consideration here because a significant number of buildings have been constructed in accordance with its precepts.[44] Nor has it been subjected to scrutiny solely because it illustrates, perhaps epitomises *par excellence*, the exercise of that comprehensive, theoretically orientated approach to design, grounded in the findings of building science, which Langdon (1973, pp. 97–8) identified as having arisen since the war.[45] Rather, an outline of these prescriptions has been offered because it reveals that the provision of 'comfortable' internal conditions in buildings is not simply a matter of applying neutral technical information in order to facilitate the execution of technical decisions. For what should also be evident from the outline is that such decisions are grounded on evaluative assumptions, on value judgements, made by comfort practitioners. These assumptions and judgements involve choices about the relations which practitioners deem should obtain between people and environments they occupy. And, underpinning these judgements, there appears to be the notion that designing is an act of benevolent paternalism through which designers provide people with what they need by supplying them with pre-determined, finite and optimal solutions. Where such solutions cannot satisfy everybody, as in the case of thermal comfort, practitioners—acting as beneficient dictators—apply a *utilitarian* principle;[46] the greatest happiness of the greatest number is sought instead. Thus comfort is a commodity produced, granted and extended to building occupants through the specialist skill and expertise of comfort practitioners. It is the latter who define, on the basis of the prevailing consensus of comfort theory, *what is best*. And it is they who then engineer and construct stable, uniform and unyielding internal environments which impose this definition on those who occupy them. Design is not viewed as an activity intended to enable or allow people to decide for themselves what comfort means to them in the light of their changing experience and understanding of their own physical and social contexts. Nor has it come to be regarded as an activity aimed at enabling occupants, by providing them with the means, to fulfil their own aspirations and expectations. On the contrary, as far as occupants are concerned, environmental conditions in buildings are to be given, fixed and

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[42] Perhaps part of the rationale underlying the adoption of the exclusive mode employed in buildings with controlled environments lies in Thornley's (1969, p. 19) remarks. He argued that: 'Factors directly affecting thermal comfort of the human are air temperature, moisture content of the air, radiant exchange and air movement. It is the air-conditioning engineer's job to decide on values for these factors, and design a system to maintain them within practical and economic limits, when the outside environment for most of the time (and in some cases continually) *will be hostile to this endeavour*' (emphasis added).

Nature is seen, then, as hostile to the maintenance of comfortable indoor conditions. But, as Dixon (1975, pp. 3–4) suggested: 'It could be argued that people who live in a temperate climate, such as the United Kingdom, prefer to work in naturally lit and naturally ventilated, rather than air-conditioned surroundings. And it is possible to design a building with a glass/wall ratio that will satisfy this preference without the penalties associated with excessive glass area.'

For people may prefer, perhaps even expect, to work in buildings whose internal environments result from selective admission of benign components of their external climate rather than in buildings which treat nature as hostile, as something to be excluded. Nor should this preference or expectation prove impossible to accommodate since, as Hawkes (1980, p. 4) commented, in temperate climates: '... it should be possible for the building fabric alone to provide a comfortable environment for a substantial part of the year.'

[43] In practice, however, it seems (O'Sullivan and Austin, 1976, p. 10) that while buildings with controlled environments may perform as predicted when empty, once occupants are admitted: '... the pattern of [building] use offsets the energy design savings.'

People, it would appear, may prove more difficult to control than heating and ventilating systems.

[44] However, a disproportionate amount of attention has, arguably, been addressed by the architectural and engineering press to the few that have been built.

[45] Although, as Hardy (1971, p. 25) realised, part of their importance does lie here: '... integrated design ... will have a considerable influence on buildings in the future and will avoid the environmental failures which have arisen in the past, due to the neglect of the designers to utilise the design information available to them.'

[46] Bentham proposed, in his *Introduction to the principles of morals and legislation* (1789), that the greatest happiness of all those whose interest is in question is the only right, proper and universally desirable end of human action in every situation, particularly for a functionary or set of functionaries who exercise power over others on their behalf (see Parekh, 1973, p. 66). And, as Rosenberg (1974, pp. 38–9) remarked, Benthamism was an ideology which was used, in nineteenth century England, to justify the introduction of 'the centralised and bureaucratic machinery of the state'. Comfort theory has played a similar role in legitimising the centralisation of environmental control in buildings.

immutable. Occupants can either accept them or complain. For, as Chrenko (1955, p. 286) advised:

> 'The ordinary man and woman can talk about their sensations of warmth . . . and if they think that a given environment is unpleasant they can, and do, say so. Moreover, if people are uncomfortable they tend to complain and it behoves the heating and ventilating engineer to pay attention. . . .'

People have thus come to be perceived as beneficiaries of internal environments beyond their control, passive recipients of environmental conditions composed and regulated by others. And such is the passivity of the rôle assigned to them that complaint is envisaged as the last avenue of action remaining open to them.

SOCIAL IMPLICATIONS FOR ENERGY CONSERVATION

To summarise, one of my main purposes in this review paper has been to illustrate that, prior to the so-called *energy crisis* of 1973, it is possible to identify a number of disparate strands in the development of comfort theory and practice. These strands converge and intertwine to form a new and demeaning definition of the relationship that should obtain between people and buildings. One prerequisite of this new definition appears to be that comfort is endowed with a specific (but limited) scientific meaning which involves the phenomenon being reduced to a matter of thermal sensations. The latter are, in turn, seen as being determined primarily, and—for practical purposes, due to the disregard of other pertinent factors—exclusively, by physiological mechanisms set into operation by physical stimuli. This reductionism renders comfort amenable to quantification, and thus to statistical manipulation, and hence to prediction. And, because of this predictive capacity, building science is seen as having *rationalised* comfort. For the phenomenon can now be defined in terms of (apparently) precise, finite and quantitative standards. In this way, the 'utilitarian eye of the engineer' (Mumford, 1924, pp. 156–7):

> '. . . whose interest in human beings as loads, weights, and stresses, or as units, pays no attention to their qualitative demands as human beings. . . .'

has scientised, and by so doing dehumanised, the provision of comfortable indoor conditions. In turn, existence of seemingly precise standards has enabled optimal solutions to be generated for internal environments. The identifying traits of these optimal environments are that they are stable, uniform and artificial. Moreover, they are products of a particular approach to design; an approach which results in buildings whose internal environments are dependent on the consumption of applied energy throughout the year, regardless of the clemency of external climate. And, in such buildings, there is not only close control over environmental conditions, but over occupants as well.[47] For, without this control, occupants might endanger the imposed stability and uniformity of their environmental conditions by pursuing their own perceptions of their needs and interests. So comfort has to be provided for them, has to be imposed upon them by those who know best, by comfort practitioners. Thus, prior to the energy crisis, this revised approach to designing internal environments—grounded on supposedly value-free, technical information derived from building science—changed, distorted and debased this important facet of relations between people and the buildings they occupy.

Manifestly, there may be comfort theorists or practitioners who do not accept that these developments are improvements or that they represent progress, either in terms of providing comfort or conserving energy. For example, Wyon (1974, p. 25) argued that:

> 'Designers have for too long taken what might be called the "zoo keeper approach" to the occupants of their buildings—they have reserved the right to decide what environment is right for the occupants *en masse*. Their control circuits have become steadily more complicated, and have taken more and more of the important decisions to alter the environment in buildings.'

But, he added:

> 'One forgets that these omnipotent control circuits not only have very simple models of reality, but also have developed only rudimentary sensory systems. They act on very crude data input from blind sensors tacked here and there onto walls. . . . They lack understanding and foresight—the occupants have it.'

Accordingly, Wyon suggested that:

> 'Instead of building closed feedback loops via simple sensors, designers should aim to provide the user with the necessary information for an informed control decision, and the means to effectuate it. This would facilitate the development of a much wider range of strategies to optimise, and thereby minimise, the energy input to the environment in buildings.'

However, the limited indications available in Britain to date suggest that, at least as far as non-domestic buildings are concerned, Wyon's plea (p. 14) 'to get the user back into control' has passed unheeded. For instance, examples recently selected by the Royal Institute of British Architects (RIBA) to illustrate 'energy-conscious design'—that is, 'buildings designed with particular attention to the conservation of energy and use of fuel' (Kasabov, 1979, p. 5)—reveal that designers have tended to turn to sealed, often deep plan, buildings with controlled environments, regulated by centralised and automated controls, in their attempts to reduce consumption of energy. Nor is this trend unlikely to diminish or be reversed. Rather, Jackman (1980, p. 1) claimed:

> '. . . the application of micro-processor based products in building environment control . . . will become the largest growth area seen by "control system manufacturers", "building designers", and "building owners/occupiers", over the period of the immediate next two years, continuing with infinite progress over the decade.'

In the future, an 'economic solution' to energy conservation in non-domestic buildings will be found (Gray, 1980, p. 1) in the use of more automation, in the employment of *Centralised Energy Management Systems*. For, as Fielden (1980, p. 3) observed:

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[47] For instance, Thornley (1969, p. 32) remarked that: 'In the air conditioned building of today we have removed the right of the occupant (often a crude and wasteful right) to adjust his environment by opening windows, closing radiator valves, putting more or less coal on the fire. Without local control of the system, the only limited course open to the occupant for adjustment would be the removal of clothing.'

> 'An automation system allows new environmental regimes to be introduced, individual freedoms and responsibilities to be reassigned and performance improvements to be closely monitored . . . the system is only a tool by which management can implement and monitor new operational strategies. Building operation is no longer necessarily wholly subsequent to its primary function or to the wishes of its occupants.'

Such automation of environmental control will, Fielden added (p. 5), enable 'central management' to assume responsibility for energy conservation in buildings where:

> '. . . they cannot easily remove long standing autonomy and responsibility from the local building users. . . . This situation is well illustrated in the case of prisons, schools and hospitals, in all of which local management has long enjoyed freedom of action. *Where energy is concerned, such freedom is a luxury which we can ill afford*' (emphasis added).

Patently such a prescription for conserving energy is based not only on a complete, and one-sided, identification by those who design environmental control systems with the interests of those whom Fielden termed central management. It is also founded on the value-judgement that the 'autonomy' and 'freedom of action' of building occupants are, as Rose (1980, p. 4) maintained, a '*main wastage area*' which 'must be controlled'. In this sense, since the energy crisis, the motivating force behind the introduction of controlled environments into buildings would appear to have shifted, to have changed. Prior to 1973, this introduction sprang, as Hardy and O'Sullivan (1968, p. 338) proposed, from 'a desire' to attain a 'high quality of thermal environment' for building occupants. However, since 1973, it has come to be rationalised in terms of a redistribution of power; that is, a redistribution of who should control the consumption of energy—and thereby the maintenance of environmental conditions—in non-domestic buildings. The primacy originally afforded to providing comfort for occupants has been submerged, has disappeared. In its place, controlled environments are now extolled and promoted because they are seen as allowing this objective to be submerged and subjugated to a new-found imperative—that of conserving energy by restraining occupants from (altering their environmental conditions and thereby from) affecting energy consumption. For, as the Advisory Council on Energy Conservation (1978, p. 11) itself explained, 'controllability' is 'the key' to conservation in buildings because control enables consumption to be 'managed effectively'. Moreover, 'in the last resort', control is seen as permitting managerial staff to conserve fuel by lowering internal temperatures and comfort standards—action which would be necessary, the Council advised, as a crisis measure.

By such means, energy conservation in non-domestic buildings has been reduced to, and has been cast as, a managerial problem. And, by this manoeuvre, implications raised by explicitly treating conservation as a social and political issue concerned with conflicts of interest have been ignored or side-stepped. As a result, energy consumption is to be abated simply by introducing more sophisticated control systems operated by building owners, or by their managerial or technical staff. Hence, conservation of energy in non-domestic buildings is presented as being dependent on a redistribution of power. In other words, and expressed more bluntly, it is seen as resting on an expropriation of autonomy—of the freedom of action to alter their environmental conditions—from building occupants. And this redistribution is to be achieved by designers, by comfort practitioners presiding over the installation of centralised energy management systems.[48] In this sense, design is once again revealed as a dictatorial activity. This time, however, it may be interpreted as less benevolently intentioned, especially when seen from the standpoint of building occupants. And, viewed from this perspective, findings generated by building science since the war, far from being value-free, have culminated in a comfort theory whose practice is promoted as a means of social control. That is to say, as I have noted elsewhere (Cooper, 1982*a*, p. 39), designers are no longer being exhorted or encouraged simply to practise their skills in order to produce acceptable indoor conditions by regulating heating, lighting and ventilation. Now their purpose is also to include regulating people's behaviour: their aim is to be widened so that they can determine who can and who cannot contribute to energy conservation. As a result of these changes in objective, comfort practice has been redefined as an attempt at behaviour modification, as an experiment in social engineering.

It is doubtful whether automated control systems—those apparent mechanical improvements on which the success of this experiment in social engineering depends—would have been accepted by Mumford (1924, pp. 165–6) as 'a triumph of human effort'. On the contrary, it is probable that such 'improvements' would, as he said of comparable developments in his own time:

> '. . . stand for its comprehensive misapplication. Where an inventive age follows methods which have no relation to an intelligent and human existence, an imaginative one would not be caught by the necessity. By turning our environment over to the machine we have robbed the machine of the one promise it held out—that of enabling us to humanise more thoroughly the details of our existence.'

Of necessity, the outcome of this experiment remains open to debate. However, Rubin[49] (1976, p. 2) observed that 'engineering' solutions which focus on 'hardware' appear to address short term goals (i.e. saving energy) without appropriate consideration being given to their long-term implications. While they are directed towards modifying 'building design parameters', they do not pay sufficient attention to their possible effects on occupants. Indeed, Rubin concluded that such hardware, engineering solutions:

> '. . . appear designed to rather arbitrarily modify the human based design criteria developed slowly over the years in ways that are likely to compromise the quality of the environment from the standpoint of building users. Is the design profession so bankrupt of ideas that some proposed "solutions" to problems of energy conservation require building occupants to "bear the brunt" of building environments which do not conform to present day criteria for acceptable buildings?'

The closing sentiments of this statement can be employed to expose and highlight

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[48] For a more detailed treatment of this issue, see Cooper (1982*b*).

[49] Writing on behalf of the American National Standards Bureau, a division of the US Department of Commerce.

latent questions whose answers may, in the medium to long term, prove significant for those who seek to procure conservation by imposing technical solutions. Amongst these might be included—Are controlled environments acceptable to building occupants?[50] Or would they prefer to live and work in buildings with natural environments—that is, in buildings based on selective, rather than exclusive, modes of environmental control? Will occupants accept expropriation of their autonomy, of their freedom of action to alter their environmental conditions, solely in order that building owners and managers may (save money and) conserve energy? In addition if, eventually, they are 'successfully' dispossessed of this autonomy, what will be the consequences, what will be the effects on their perceptions of, and on their feelings of responsibility towards, managerial attempts to save energy in buildings they occupy?

Given what Haigh (1982, p. 45) described as 'our scant understanding' of how people respond to environmental controls in buildings, each of these questions remains open to conjecture, open to surmise. Her investigations of how users respond to and use the environmental controls available to them led her (p. 61) to conclude that, for occupants, ability to control their surroundings is 'a psychological necessity'. Regardless of whether ability to do so is a necessity, or, indeed, a 'right' as Thornley (1969, p. 32) suggested (see above), people do appear to have expectations and preferences concerning characteristics of internal environments they wish to occupy. For instance, O'Sullivan *et al.* (1980, p. 5) recorded that:

> '. . . people do want some part in the control of heating and ventilation. "Overt" waste is unanimously criticised and its existence lowers the motivation for economy in other areas. "Excessive" use of electric lights are thought wasteful. They do expect to be able to open windows in summer and accept that one should wear warmer clothes in winter. . . . It is expected that the building will be warm and dry when it is cold and wet outside, but it is also appreciated that when it is very cold, it is not going to be too warm inside. It is considered profligate to be too hot as a result of the heating system.'

Buildings whose internal environments fail to meet these expectations and preferences may aggravate their occupants' perception of, and acceptance of responsibility for, conservation of energy within them. Such buildings may do so because, as McGeevor (1979, p. 7) attested, technical, hardware solutions which restrict people's freedom to control their environment may:

> '. . . break down the informal norms against waste which play an important, though largely unrecognised, part in energy conservation. There may be a social hitch to the technical fix.'

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[50] For as Langdon (1973, p. 106) noted, 'building technology' played a leading part in engendering the changes which can be identified as having led to this exclusive mode of environmental control: he commented: '. . . for, while concern with overheating has played a vital part in advancing knowledge of human factors in this area, the problems which have provided this food for thought are those thrown up by technology and not ones raised initially through the attempt to cater more effectively to human social needs.'

Indeed, he affirmed (p. 104) that: '. . . to be frank, nobody knows if people really want to pass their working lives in deep-plan buildings with restricted fenestration, nor were such structures evolved to meet any such requirements.'

More recently, Lovelock (1980, p. 25) acknowledged that while: 'One would think that when moving into a sophisticated air-conditioned office the persons concerned would be highly delighted with what they find. The anomaly is that the reverse is the case which is perhaps difficult to grasp.'

For those whose ultimate aim is to persuade people to accept the necessity of conserving energy in non-domestic buildings, the introduction of controlled environments, and of centralised energy management systems, may prove, in the medium to long run, counter-productive. Deprived of, and denied, the means and experience of altering their environmental conditions, occupants may respond by feeling that they have also been relieved of responsibility to ensure that energy consumption is reduced. Indeed, they may no longer feel obliged to save energy: they may retaliate by deciding that conservation is not their concern. And, as Fielden (1980, p. 5) recognised:

> '. . . even the smartest automation system can be defeated by those not on its side.'

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ANALYTICAL EVALUATION OF A SOLAR ENERGY SAND COLLECTOR WITH AND WITHOUT MOVEABLE INSULATION

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SUMMARY

An analysis of a solar energy collector consisting of a network of pipes buried in a mass of sand, the top surface of which is fixed, blackened and glazed, is presented. A theoretical model has been developed to take into account the effect of covering the system with insulation during off-sunshine hours. To study the system quantitatively, numerical calculations have been performed for the heat flux taken away by the flowing fluid through the pipes corresponding to a typical winter's day in New Delhi—i.e. the 11th of January, 1974. The effect of various parameters on the efficiency of the system has been studied.

NOMENCLATURE

A	Collector area (m^2).
C_1, C_2	Specific heat of the sand (J/kg °C).
C_3	Specific heat of the insulation (J/kg °C).
h_c	Heat transfer coefficient between the heated surface and the flowing water (W/m^2 °C).
h_i	Heat transfer coefficient between the insulation and the atmospheric air (W/m^2 °C).
$h(t)$	Heat transfer coefficient between the absorbing glazed surface and the ambient air (W/m^2 °C).
K_1, K_2	Thermal conductivity of the sand (W/m °C).
K_3	Thermal conductivity of the insulation (W/m °C).
l_1	Thickness of the upper layer of the sand (m).
l_2	Thickness of the lower layer of the sand (m).
l_3	Thickness of the insulation (m).

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