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The Ergonomics of Healthy Buildings: Overcoming Barriers to Productivity

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ABSTRACT

A healthy building must provide what each individual user of the building requires of it. As there are innumerable reasons for different users to have different requirements, and almost as many reasons for a given user to have different requirements at different times, this implies that the user must have a degree of control over what the healthy building provides for him. Even intelligent buildings cannot act intelligently unless they are given all relevant information, and there is no way that this can be done other than by involving the user. Interindividual differences can be due to age, sex, skinfold thickness, personality, physical handicap, allergy, or hypersensitivity. Differences between occasions for the same user can be due to clothing, activity, fatigue, thermal history, recent exposure to pollutants, or current state of health. No building control system, however computerized, has access to any of this information. The user is in possession of this information but is often poorly informed about the building. He often has no idea of how the building is supposed to work, no information about how well it is working, and no means of affecting the environment it provides. Thus both the building and the user lack information that is potentially crucial for the user's health. This is why most buildings are not healthy buildings, and often present barriers to productivity. The solution lies in designing the building to provide channels for the communication identified above as being necessary for health; as the building cannot be given the relevant information about each user, the user must be given the relevant information about the building. Healthy buildings must provide the user with insight, information, and influence. Active steps must be taken by the building operator to give users more insight into the possibilities and limitations of the building systems, more information about what is happening (including ways of inspecting the air intake of the building, ways of sampling the quality of the air at various points on its way through the airways of the building toward their own airways, and more influence, that is, more degrees of freedom to experiment until they themselves find out how to remove barriers to health and productivity).

INTRODUCTION

Imagine the following future scenario: research has led to the development of a "nutritional index" that takes account of the major parameters by which diet can be described—energy, protein, carbohydrates, fiber, cholesterol, vitamins, trace elements, and even flavor and texture can be quantified as discrete dimensions—and an equation has been derived, based on the replies given by literally thousands of experimental subjects who experienced a wide variety of diets, and in each case were able to ask for "a little more" or "a little less" until they were unable to decide which they would prefer. The nutritional index equation can predict what proportion of a given group will be satisfied with a given diet. Under the well-controlled conditions of the experiment, no differences in preferred diet were found as a function of age, sex, race, time of day, etc., although the activity level of the subjects and the clothing insulation they wore naturally had large effects. For any given combination of activity and clothing insulation, it is therefore possible, with the help of the equation, to define a range of diets that will satisfy, say, 80% of the population. It has been decided that in view of the importance of food conservation for the economy, the currently very large differences in food consumption between individuals and between families that are, for all intents and purposes, identical cannot be allowed to continue. Optimal food conservation can best be achieved by removing all individual choice and serving a diet with PPD (predicted percentage dissatisfied) equal to 20%. The various components of the diet can be adjusted to use available raw materials while maintaining PPD = 20% for each combination of clothing and activity level applicable to a given consumer group. It has been suggested that in buildings where clothing and activity levels are known, the equation could be used to program food dispensers in each room. The "intelligent building" could then ensure an optimal diet for all while maximizing food conservation at all times.

The above prescriptive approach is in fact already in operation in buildings. This paper will argue that it is as ludicrously wrong for energy and thermal environment as it is for food and diet in the above analogy.

BARRIERS

The following barriers to health, comfort, and productivity will be identified:

1. User substitution by simple rules (USSR, for short).
2. The dictatorship of the group.
3. Prescriptive standards.
4. The 80% tolerance zone.
5. "Intelligent buildings."
6. The GIGO principle of computer science (garbage in, garbage out).

USSR

Even very sophisticated control apparatuses for energy use in buildings, for the "optimization" of the thermal environment, must act on the basis of crude assumptions and models of group behavior that were incorporated at the design stage. To the extent

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that these are wrong or inadequate, energy use will always be suboptimal, often causing unnecessary discomfort, inconvenience, and reduced performance and even health for individual occupants whose activities and requirements differ from those assumed. Design-stage energy conservation can work well only if individual differences in behavior and in response to indoor climate are small. Where they are large, as in the case of allergies or hypersensitivities, or where basic assumptions are wrong, as in the case of people working late or on weekends, USSR is a barrier to health, comfort, and productivity.

Group vs. Individual

The dictatorship of the group can have serious consequences for the individual, as in the operation of USSR. The "simple rules" are, of course, based on studies of group behavior and group requirements. Demands for individualization are called "utopian" on the grounds that "information on individual requirements cannot be made available to building systems computers" and, in any case, "buildings cannot affect individual micro-climates unless each person has his or her own room. Thus, individuals must be treated as identical members of a group. Practical, nonutopian solutions to these difficulties will be outlined below.

Prescriptive Standards

Prescriptive standards in the building field are often formulated as minimum standards, but have come to be used as target standards. In the absence of other quality guidelines, builders need only ensure that their product "fulfills building standards" and can then proceed to compete in terms of price. The result is often that users have to contend with buildings that are designed to operate at the minimum standard, with no margin to accommodate user requirements that sometimes or always would require a higher standard. Prescriptive standards should therefore also prescribe margins of individual adjustment, and a group optimum as well as a group minimum standard.

80% Tolerance Zones

McIntyre (1978) has estimated that thermal comfort responses are as variable between occasions for the same person as they are between people. The fact that 80% of a group is predicted to be satisfied within a calculated range of conditions does not necessarily mean that most people will always be satisfied, the implication being that there is no satisfying some people. On the contrary, most people will at some time be dissatisfied with the 80% tolerance zone. The factors leading to individual differences, and to individual variation, are set out below.

Intelligent Buildings

The current trend in so-called "intelligent" buildings is not toward better ways of accommodating individual differences, but in the opposite direction, toward the irrational, frustrating imposition of prescribed thermal environments administered by computers oblivious of our individual differences and beyond our control.

The GIGO Principle

Even if the simple rules that substitute for users in the minds of intelligent buildings are correct, even if they were to be made so complicated that they were theoretically adequate, the input information would be based largely on assumptions about individual users. The GIGO principle states plausibly enough that if the data input to a computer is garbage, the output will also be garbage.

INDIVIDUAL DIFFERENCES

Human requirements of the indoor environment differ because of age, gender, skinfold thickness, personality, physical disability, allergy, hypersensitivity, and habit. Interpersonal differences in environmental effects on performance have been reviewed by Wyon et al. (1982). The building systems computer knows nothing for certain about these characteristics of its users.

INDIVIDUAL VARIATION

Individual requirements may differ between occasions for the same person because of clothing, activity, fatigue, recent thermal history, recent exposure to pollutants, and current state of health and mood (e.g., frustration and hostility toward the building, and boredom or interest in the work to be performed). The building systems computer knows nothing of these factors. The application of simple rules to arrive at user requirements will therefore often result in a mismatch between calculated and actual user requirements.

DECREASED PRODUCTIVITY

Productivity is decreased by 100% in the case of death or absence from work. Both may be caused by accidental injury resulting from human error, the risk of which is increased under unsuitable working conditions. Sickness absence, due to building-related illness, and voluntary absence due to intense dislike of working conditions similarly lead to a 100% decrease in individual productivity. Long before an individual gets sick or stays home, productivity may be substantially reduced due to the sick building syndrome (SBS), which includes such aspects as lethargy, fatigue, and headache, any one of which can lead to productivity decrements above 50%. Similarly, a preoccupation with staying well, safe, and comfortable despite a difference of opinion with the building systems computer can amount to a full-time secondary task that demands up to 50% of available effort, initiative, and ingenuity. Finally, decrements in performance in the region of 10% to 30% can result from the distraction of thermal discomfort, the lethargy and reduced motivation accompanying an environmentally induced state of low arousal, or the overarousal induced by certain other combinations of environmental factors, such as noise, heat, excessive illumination, or mucosal irritants.

MEASURES OF PRODUCTIVITY

Experiments will eventually have to be performed to demonstrate the magnitude of indoor environmental effects upon productivity. This will require the use of measures of productivity. The recording of accidents and injuries is very time-consuming, and experiments using such measures come close to being unethical even if all of the experimental changes introduced are for the better. Why then were not such changes also introduced in the reference conditions? Studies of discomfort and of SBS are once removed from the expected decrease in productivity, although Raw et al. (1990) were able to derive a relationship between SBS symptoms and self-estimates of productivity. Studies of sickness absence due to SBS are valid to the extent that the diagnosis is correct, and Preller et al. (1990) showed that this measure of productivity loss was decreased by 34% in offices where individual control of the thermal climate was possible. Direct measures of performance, focusing on component skills crucial to productivity, are valid to the extent that key activities can be identified. There are numerous studies showing thermal effects on performance, summarized by Wyon (1986), though apparently none as yet using air quality parameters as the independent variables. Overall measures of productivity tend to be affected by so many extraneous factors that the effects of naturally occurring variations in environmental conditions would be difficult to distinguish, and the possibility that productivity really would be decreased by experimentally introduced changes is a financial disincentive to allowing such direct field experiments to take place. For the present, therefore, sickness absence and measurement of component skills seem to be the only viable alternatives to subjective self-estimates of productivity, which are fatally flawed in that they will always reflect users' own expectations of cause and effect, in addition to any actual causation. The removal of barriers to productivity must, in the meantime, proceed on a rational basis, pending a demonstration of the quantitative size of effects on productivity.

OVERCOMING BARRIERS

If the prescriptive group approach is unable to accommodate individual differences in human requirements of the indoor environment and gives rise to the six barriers to health, comfort, and productivity identified above, it must be replaced by another approach. It should be adequately clear from the above analysis that the building cannot be supplied with all the relevant information regarding individual differences, but the building and its systems will always be the effective determinant of individual microclimatic conditions. The user must therefore be given the relevant information about the building, especially about its possibilities and its limitations. A measure of control can then be delegated to the user. However, the user at present often has no idea even of how the building is supposed to work, no information on how well it is in fact working, and no influence on any aspect of its function, except, residually, the anarchic possibility of opening a window, which is often against the rules. Overcoming barriers to productivity therefore requires the building operator to take active steps to provide the user with more insight, more information, and more influence. How this might be achieved is outlined in the following sections.

Insight

User insight into the building systems can be increased by means of an introductory course and the provision of a handbook. Vehicles are very similar to each other, but no one expects to be able to drive one without an introductory course or to buy one without a comprehensive handbook. Even VCRs come with bulky handbooks. Buildings are usually very different from each other, but handbooks and introductory courses are not usually provided for them, although they cost many times more than a vehicle or a VCR. Information on the building should also be displayed on bulletin boards, properly formulated for the lay user, showing perhaps the location of the airways of the building and the sampling ports referred to below. Cutaway models of the building, its air-handling system, and individual heating and ventilating devices would increase user insight into their possibilities and limitations. Visits to the plantroom and the air-intake site would similarly increase user insight.

Information

Users should have access at any time to a display of on-line information about the relevant aspects of building system operation, including room temperature, supply and exhaust temperature for the room, relative humidity, CO_2 ppm, liters per second of air supply, and fresh air proportion. The display could be in a lobby or corridor or available on any networked VDU. This feedback information is a pre-condition for any learning of the consequences of user influence, and is essential for user experimentation with available degrees of freedom.

Users should always be able to inspect air ducts and the air intake site. Sampling ports should be provided at various points in the building and their location clearly marked on planes displayed on a bulletin board to enable users to sniff the air on its way through the airways of the building toward their own airways. Allergics can have thresholds of sensitivity a million times lower than those of normal people and can be relied upon to use these early-warning sources of information. They will voluntarily fulfill the warning function of the miners' canary, and may then be viewed by building operators as an asset rather than as a liability. Users should also be informed of the design limits of each room, perhaps by means of a mandatory notice by the door, analogous to those in elevators. Users expect and respect notice of an elevator's design limitations: they do not expect one to lift twelve people safely if it is rated for six. They might then cease to expect a room designed for "6 people or 600 watts" to cope with 12 people and as many computers. It is understood that the elevator is guaranteed to lift the specified number of people, but the room specification should guarantee to maintain room temperature and CO_2 levels, at the very least, within stated ranges for the specified loading. Users could then use the on-line display to perform simple checks on building system function. The formulation of user-verifiable guarantees of this kind would open new channels of communication between building users and operators, whereas guarantees of the small-print variety would provide more work for lawyers than benefit for the user.

Influence

User influence is increased by the appointment of a user representative whose function is to be more informed than the rest, and to enhance communication between building operator and users, in both directions. User representatives with this function are already in place at all Swedish places of work: they are known as "skyddsombud," and are a kind of lay safety engineer. Users turn to them for practical help and information in all matters regarding safety, including thermal climate and indoor air quality. Users should also have a list of telephone numbers so that they can report building faults and initiate maintenance, repair, and cleaning as and when it is required, instead of having to complain ineffectually until routine inspection also discovers the need. Users should have as much control over their microclimate as can reasonably be devised, and should know how to operate the controls. They should be able to inspect the nearest upstream filter, be able to check the pressure drop over it, and initiate a filter change if one is required; they are the people actually breathing the air. It should not be impossible to design filters that users themselves can change as required. Although this sounds impossible, users should also be able to add air inlets and outlets as required, and to move them around so as to furnish the room with air, thus avoiding drafts where they wish to work. They should similarly be able to install point exhaust, as in a factory, so that machines such as computers, copiers, and fax machines do not load the room system by contributing heat or air pollution. The air used by these machines to remove excess heat often smells of hot plastic and the fire retardants used to coat electronic components: it should not reenter the room, but should be removed by a point exhaust duct, wherever it is situated in the room. Impossible in an office? Raised-floor systems offer the possibility of siting air inlets and outlets freely and of installing point exhaust ducts discreetly connecting each machine to the floor. Users should be able to requisition the appropriate inlet, outlet, and point exhaust devices and move floor-tile-mounted units around as they see fit. Workstation HVAC, otherwise known as an environmentally responsive workstation (ERW), the ultimate in individual microclimate control, is also easier to install in combination with a raised-floor ventilation system.

INDIVIDUAL MICROCLIMATE CONTROL

As soon as two people must share the same room, conflicts arise that can be barriers to productivity. Whereas one person may be draft-sensitive, another may be allergic. The former wants less fresh air, the latter wants more. One may feel cold, the other hot, for perfectly understandable reasons as set out above. Even if the room has its own climatic system, it will be impossible to agree on the control settings. Other conflicts may exist even for one person: as warm air rises, it is difficult to keep a cool head without getting cold feet. That is, the thermal profile has the wrong slope. Workstation HVAC can address these problems, providing each user with additional sources of heating and cooling power, arranged so as to correct the thermal profile experienced by the user, and to provide the option of additional fresh air delivered to the breathing zone. These options must be completely under user control, and so arranged that they neither affect the microclimate of any other user in the room nor the room climate itself to any extent. The room system is then relegated to a background function, which it can perform better. Workplace HVAC systems should shut down automatically when the user is absent. A system with these characteristics has been developed within the Swedish National Board of Public Building (Byggnadsstyrelsen, the Swedish GSA) and has been described by Wyon et al. (1991).

CONCLUSION

Barriers to productivity can be removed in healthy buildings by adopting a radical alternative strategy based on getting the user back into the system, rather than engineering him out. Arguments for this approach were put forward by Wyon (1988), some of which, including the food analogy, have been repeated here. Practical means exist today for implementing this strategy. The continuation of the present prescriptive, group-based approach that ignores individual differences will result in many more sick buildings and more barriers to productivity.

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