

DESIGNING FOR PEOPLE: WHAT DO BUILDING OCCUPANTS REALLY WANT?

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ABSTRACT:

Modern buildings' environmental impacts threaten global environmental health. Population growth and increased access to and use of current building technology are not sustainable. People are often not in control of their building environments and, as a result, are less satisfied with them. When people control their indoor environments, they are more likely to be satisfied with them. This paper questions many of the prevailing assumptions and practices that are resulting in energy intensive, unsatisfying, and in many cases uncomfortable, unhealthy, and unproductive building environments. Then it describes a direction for more satisfying, less resource intensive solutions to providing building occupants what they want while lessening buildings' impacts on the environment.

INDEX TERMS

Indoor Environmental Quality, Occupant Control, Comfort, Satisfaction

INTRODUCTION

"We shape our buildings, and afterwards, our buildings shape us." (Winston S. Churchill)

"You can't always get what you want...but if you try some time, you just might find, you get what you need." (The Rolling Stones)

Liberally paraphrasing Brager and deDear (2003), What constitutes a "Healthy building"? "The answer to this deceptively simple question has profound implications for the way we design and operate buildings, the amount of energy required to build, operate, and maintain them, and the resulting impacts on the quality of both the natural and built environments." We face a major crisis as we head into the 21st Century. Humanity's rapid consumption of natural resources, emission of pollution and creation of waste overstress the planet's environment. Encroachment on undeveloped lands alters habitats necessary to support the biological diversity that thrived on the planet a few short years ago. Societies are developing and using modern technologies at an ever-increasing rate. Growing population and the growing fraction of people with access to energy services and other environmentally-limited and -limiting resources and technologies result in unsustainable stresses on the environment.

The results of current levels of consumption and waste producing lifestyles are already evident in an unprecedented and accelerating rate of biodiversity loss, damage to the earth's atmosphere including the creation of the ozone hole over the Antarctic region, apparent human-induced global climate change, and increased occurrence of toxic and persistent pollutants in soil, water and air. It is difficult to see how this trend of environmental degradation will be stopped and reversed -- as it must be for human life on earth to become sustainable. Our buildings account for up to 40% (or more) of the total environmental burdens

of modern societies, and even buildings in developing countries account for similar fractions of total national environmental burdens.

In spite of their enormous impacts on the environment, modern buildings generally fail to provide all their occupants with the safety, health, and comfort that are expected. A significant fraction of building occupants are uncomfortable, dissatisfied, or even ill from the effects of modern buildings. On average, roughly 30% of office workers report experiencing frequently one or more symptoms of the so-called Sick Building Syndrome (also described as non-specific, building-related symptoms). The situation in schools appears even worse as they are under increasing financial pressures to reduce construction, operation, and maintenance costs as well as energy consumption

Why are buildings that require so much “*ecospace*” (the burden on the environment) so unfriendly to their occupants? Do buildings provide the environments they are designed to provide? Do such environments actually provide for the safety, health, and comfort of the occupants? Are occupants getting what they want? If not, why not?

Control of the Indoor Environment

A dominant assumption in the design of many modern buildings is that indoor environmental parameters can and must be carefully controlled to within the limits established in the prevalent codes, standards, and guidelines. For the indoor environment, these focus on four major categories: air quality, thermal conditions, illumination, and acoustics. These four categories are usually treated as distinct and unconnected. In fact, they are all inter-related and combine to determine the effects of the building on the occupants (Levin, 1995a, b). For example, lighting – either through windows or by electrical means -- affects thermal conditions and energy consumption; thermal conditions affect air quality and its perception by occupants; ventilation systems produce noise that can be beneficial or harmful, depending on the system and the building context. Modern architectural and engineering practice has spawned specialists for each of the major environmental categories whereas in historical times the architect addressed the entire building and its indoor environmental quality. This proliferation of specialists leaves the architect to coordinate inputs from a variety of disciplinary specialists who independently seek to optimize those factors within the scope of their increasingly narrow discipline.

How Did Buildings Go Wrong?

Historically, architects were not just concerned with the aesthetic aspects of the building, primarily its shell; they addressed all aspects of building performance, albeit with far simpler requirements and none or little of the currently prevalent forms of environmental control “technology” (Banham, 1984). Even until a few short decades ago, the levels of thermal comfort, illumination, and air quality generally expected and required of buildings were vastly different from today’s requirements. Expectation played and (not unimportantly) still plays an essential role in determining the performance standards to which buildings are designed. Additional clothing, local heat sources, and acceptance of far lower or higher temperatures were norms as were far lower illumination levels and ventilation through available windows.

Ancient buildings and many so-called traditional or vernacular forms of architecture were often far more massive than their modern counterparts. In temperate and cold climates, massive structures stored heat in the daytime when it was available from the sun or from fires inside the structure, then released it at night when temperatures were lower. In hot climates, the mass of the structure, shading, and coupling the structure to the earth provided more even temperatures over the course of the diurnal cycle. Designers did not need to concern themselves much with illumination as portable light sources such as oil lamps or candles supplemented daylight when necessary. The form of the structure and its major materials were

strongly linked to thermal comfort, illumination, acoustic, and ventilation design (Banham, 1984; Rapoport, 1969). Most people in the world still live with simpler expectations of environmental control in their buildings, and the basic building form is climate responsive (Olgyay, 1963; Rudofsky, 1965; Rapoport, 1969; Koenigsberger et al, 1978; Banham, 1984).

During the past two centuries, architects abandoned their historical responsibility for providing thermal control and illumination by the design of the basic structure itself, yet they continued to focus on formal considerations. Designing structures (most of which became far less massive) without focusing on environmental conditions meant that buildings were far less “naturally” comfortable, and it became necessary for engineers and plumbers to take over the job of designing building services (Banham, 1984). As a result, in recent years there has been a proliferation of specialties resulting in an almost unmanageable coordination problem, and so, architects have become managers of the process rather than the true building designers.

Designers and builders still have a choice between two fundamentally different types of buildings. The first -- usually “heavy” buildings -- that are naturally comfortable or, at least, by virtue of their basic form and materials, have smaller “natural” interior temperature variations during a 24-hour period. These traditional forms require less energy inputs to modify their internal thermal conditions and illumination during daylight hours. The second type of building, far more common today, are buildings that are generally lightweight and have very large “natural” variations in interior thermal conditions so that they require significant energy inputs to be within the commonly defined acceptable thermal comfort range. To provide temperature control and outdoor air ventilation, there is a trend toward sealing the exterior envelope and using mechanical means for thermal conditioning and ventilation while electric illumination dominates the provision of light (Banham, 1984). These are far more energy intensive approaches to environmental control than traditional means, and as the application of these technologies is extended to a larger fraction of an ever-growing global population, the impacts of buildings on greenhouse gas emissions and climate become increasingly unsustainable (Levin, 2003).

Do Today’s Buildings Meet Their Occupants’ Needs?

The four major categories of indoor environmental control are air quality, thermal conditions, illumination, and acoustics. How are our buildings today performing?

- Currently, design standards for thermal comfort (*e.g.*, ASHRAE Standard 55 and ISO Standard 7760) provide guidance that promise comfortable conditions for no more than 80% to 90% of occupants in centrally-ventilated and climate-controlled buildings.
- Indoor air quality standards generally rely on outdoor air ventilation to control concentrations of contaminants indoors. Even with much higher than recommended ventilation rates, occupants report poor air quality and building-associated discomfort and health symptoms. Moisture accumulation, believed responsible for increased occurrence of mold and bacteria indoors, is strongly associated with higher rates of occupant health problems ranging from asthma to discomfort from odor and irritation.
- Lighting systems in buildings use large amounts of energy to provide illumination in very inefficient and often ineffective ways while producing a significant amount of waste heat requiring even more energy for its removal in most temperate and warm climate conditions.
- Open plan office and school environments, implemented to reduce maintenance and operational costs, have resulted in stress from loss of acoustic and visual privacy, from noise, and from a loss of occupant control over the indoor environment.

Indoor environments can be built today that are capable of sheltering people from the harshest conditions on earth -- at the equator, at the poles, in the desert or high mountains – and even

in the extreme conditions of outer space in space stations and manned spacecraft (Levin, 2000). Yet most people on earth still do not have safe and healthy buildings in spite of the extensive (excessive?) resource use and pollution emissions associated with modern buildings. There are obvious hazards such as radon from the earth, asbestos from fireproofing materials, environmental tobacco smoke from cigarettes, carbon monoxide and respirable particles from heating and cooking fuel combustion, and many more extremely hazardous substances found in our buildings. Due to the combustion of biofuels, the majority of woman in the world are exposed daily to concentrations of respirable particles that are from 10 to 100 or even more than 1000 times higher than levels established as “safe” by the U.S. Environmental Protection Agency (Smith *et al*, 2002; U.S. EPA, 2001). According to estimates by the World Health Organization indoor air pollution accounts for more than 5,000 premature deaths a day on a global scale, most of them in developing countries from low quality solid fuels burned in open fires for heating or cooking. Globally, exposure to these combustion by-products is estimated to cause 36% of all lower respiratory infections and 22% of all chronic obstructive pulmonary disease (WHO, 2002).

Even in the so-called “developed” countries where the resources are available to create safe buildings, there are many more subtle hazards that contribute to unsafe, unhealthy, or uncomfortable buildings (Mendell *et al*, 2002). The focus on providing “comfortable” and “productive” environments that go beyond the minimum needs for safety and health is a luxury of the wealthiest quarter of the world’s population. The costs in terms of environmental impacts from the associated energy and other resource use are borne by all of the earth’s inhabitants, not just by those privileged to benefit from modern, energy-intensive buildings.

The Failure of Current Practice

“I am led to the conclusion, which I trust others will find persuasive, that we are becoming the servants in thought, as in action, of the machine we have created to serve us.” (JK Galbraith, 1968).

Research has shown repeatedly that buildings designed to conform to current standards and guidelines fail to provide occupant satisfaction with one or more of the general indoor environmental parameters – air quality, thermal conditions, illumination, and acoustics. Our guidelines and standards for the indoor environment are based on extensive laboratory and field research with carefully controlled conditions. Subjects in laboratory studies and building occupants in field studies are usually asked to rate or evaluate the indoor environmental condition(s) of interest to the researcher. In some studies, subjects are asked to express their preferences. The questions and options usually begin with a narrow range of options that most often reflect a pre-selection of engineering solutions largely limited to ‘high-tech,’ energy-intensive solutions that are not susceptible to occupant or user control. Thus, the studies fail to reflect accurately individual subjects’ preferences or needs. Rarely are occupants themselves asked what they really want or what is most important to them. Only recently have some researchers begun to ask for occupant preferences.

When People are Free to Choose

Rohles, Woods and Morey (1987, 1989) developed a rating scale for “indoor environment acceptability” by asking building occupants to rate the importance of various environmental parameters. Next the subjects were asked to rate each of the various aspects of the environment. The researchers then weighted the occupants’ responses by their importance ratings for the indoor environmental factor. In this way, the occupants were enabled to

contribute significantly to the interpretation of their responses to the entire indoor environment including all of the major factors studied.

Some researchers now study occupant responses to thermal conditions by asking occupants not only to rate the thermal environment in terms of warmth, coolness, or neutrality, but also to express their preferences through selection of preferred temperatures. Other studies have begun to examine the trade-offs between discomfort from noise versus thermal conditions or air quality (odor, irritation, or some vague combination of the two). In the field of lighting research, individuals are sometimes given the choice to adjust lighting to the levels that they prefer. But in practice, most environmental control technologies do not provide occupants these choices. Fixed lighting systems (*e.g.*, ceiling or furniture-mounted) do not provide this range of options nor the potential efficiency of user-controlled task lamps.

What can be learned by simply observing how people behave in buildings or by asking them what choices they would make about their environments. Nearly everyone would choose an exterior office with windows rather than an interior office without any view to the outside. Most would choose to have windows that open rather than fixed glass or solid walls. In the living and bedroom spaces of residences, many people choose “soft” (often dim) lighting as more comfortable, more relaxing. This usually involves a combination of direct and indirect light sources with a lower background illumination level and more intense light delivered locally where and when it is needed. Such an approach is more energy efficient than brightly illuminating an entire space when only a portion of it is being used.

Lighting and Acoustics

Unlike air quality and thermal comfort that are oriented toward comfort and, to some degree, health, for illumination (visible light is part of the electromagnetic spectrum) and audible sound (part of the mechanical energy spectrum), most of the emphasis for these indoor environmental factors is on their impact on task performance. However, noise and poor lighting conditions can cause annoyance, discomfort, and even health and physiological effects. Of course extreme illumination or noise conditions can cause physiological damage and even functional loss of vision and the sense of hearing. Acoustic and lighting conditions strongly affect performance of tasks involving conversation and visual task performance.

Illumination, of course, is primarily for reading or other visual task performance. Lighting must provide enough contrast and accurate color rendition for common human activities or in special situations, specific activities. For example, physicians are highly dependent on accurate color rendition of a patient’s skin or other body part for accurate diagnoses. Extremely bright light can also cause eye damage while commonly-encountered light pollution or improper illumination (*e.g.*, glare, veiling reflections, color distortion) can hamper visual task performance. Lighting conditions resulting in glare or in eyestrain can result in headaches and stress that cause secondary effects or exacerbate responses to other environmental stressors. (Levin and Duhl, 1984; Levin, 1995a).

For noise, the goal is to avoid interference with conversation or disruption of concentration. The intensity and the spectral distribution of electromagnetic and mechanical energy play a role and can adversely affect health as well as task performance. Loud noise can affect concentration and normal conversation, and very loud noise can cause extreme discomfort, pain, and permanent hearing loss. Noise above certain threshold levels causes headaches, and even louder noise can cause partial or even total hearing loss. Low frequency mechanical energy, also described as rumble or vibration, can cause symptoms such as nausea and headache too (Levin, 1995a).

Standards for acoustic control and illumination

Standards for acoustic control range from avoiding hearing loss from excessively loud noise to supporting normal conversation or learning or even to the special cases of musical concert halls or theatres. In other words, standards and guidelines for illumination and acoustics are highly dependent on the tasks being supported in the indoor environment as well as avoidance of physiological damage (Goromosov, 1968; Levin, 1995a).

Visual acuity and sense of hearing are different among individuals, and so-called “normal” hearing and vision are based on average or median values of healthy young adults. Presbyopia (normal loss of vision with associated with aging) deprives many if not most middle-aged adults of some visual acuity. Presbycusis, defined as the normal loss of hearing that occurs with aging actually might be a civilization disease – that is, unlike Presbyopia, it might occur as a result of damage to our hearing mechanism by exposure to loud noises common in most “modern civilizations.” Nevertheless, most people in modern societies experience some hearing loss as they age.

The Case of Illumination in the San Francisco Main Library

The choices people make in real buildings when the choices are provided to them are very instructive. Diverse environments provide people with opportunities to choose conditions they prefer, where they are most “comfortable.” The San Francisco Main Library contains a wide range of spaces with very different intensities and qualities of illumination from a combination of electric light and daylight ranging from less than 300 lux to well over 1,000 lux on a typical day. It is instructive to observe where people choose to sit in spaces spanning the full range of illumination conditions. The variations include not just the general illumination level (light intensity), but also include the quality of the light (spectral distribution), the control the individual user has over the light with task lamps, the contrast between the local and the general illumination level, the direct experience of light from the sky or the sun, and so forth. On occasions when perhaps only 1/4 of all available seats were occupied, one or more library patrons chose nearly every possible type of situation. Indeed, in the library, all the available options appear to be chosen by at least some patrons.

From this it is clear that there is no single “ideal” condition, no single “preferred” condition for all library patrons. If there were one preferred condition, then all the patrons would be more clustered in the environments providing conditions closest to this theoretical ideal rather than dispersed throughout the library. Of course there are other factors that influence people’s choice of location such as access to certain types of library resources, privacy, seating, and availability of various conditions. But even within somewhat large spaces, there is a very wide range of lighting conditions in the library, and the full range of them are used more or less equally.

Human Response to Light

As with other environmental factors, the human response to illumination is highly dependent on prior experience that influences expectation and establishes the basis for a response that is essentially comparative to what is familiar. Some individuals habitually work at levels of 150 or 200 lux while others normally perform visual tasks at levels of 700 to 1,000 lux or more. This raises questions about the results of laboratory studies of lighting preferences where subjects come from a small or a large range of “background” lighting conditions. Furthermore, individual preferences are not simply matters of preference for intensity or brightness levels: the color temperature or spectrum of the illumination is also important and individual preferences are quite wide (Levin and Duhl, 1984; Levin, 1995a).

One of the problems with studies of people’s lighting preferences is that people tend to prefer what is most familiar to them, what they have available where they spend the majority of their time. Office facility managers have observed that when moving office workers,

regardless of whether they are going from brighter to dimmer or from dimmer to brighter spaces, there is a tendency for occupants to complain about the lighting levels for about three weeks. This suggests that there is an adaptation time on the order of weeks for people to become accustomed to lighting conditions different from what they normally experience. It is important to consider whether similar adaptation time is applicable to noise, air quality, or thermal conditions.

Indoor Air Quality

Individual human sensitivity to odors can vary by a thousand-fold or more. Thus, an odorous chemical may be detected easily by one person while at a concentration 1,000 times higher, not be detected at all by a different person. A chemical contaminant in indoor air could easily be causing nausea in one individual while being completely undetected by another occupant exposed to the same concentration. Chemically sensitive individuals experience a variety of systemic and general symptoms upon exposure to air pollutants that appear to be tolerated well by other individuals. These very large differences among individuals create many challenges for building designers, builders, owners, and operators as well as for the affected occupants themselves. Designing for the average person will simply not be adequate for the more sensitive occupants, and the affected persons have to be provided with special systems to cleanse the air around them or be removed from the problem environment. Writing guidelines to address these special individuals' needs is virtually impossible as their specific sensitivities vary so greatly.

It is widely-believed that poor indoor air quality results in significant levels of building related symptoms (so called "sick building syndrome"). Frequently cited numbers are that 30% of buildings are "sick buildings" as defined by a significant increase in the percentage of building occupants with one or more non-specific, building-related health complaints that are lessened or absent when the affected occupants are outside of the building. In fact, studies have found that 15 to 30% or more of the occupants in most buildings surveyed had one or more building-related non-specific health complaints (WHO, 1984; Bluysen, 1995).

In fact, very poor air quality that may not even be detected by occupants can even have narcotic or other strong physiological effects with extreme cases resulting in death. Odorless, carbon monoxide can cause death, radon can cause lung cancer, *Legionella pneumophila* bacteria can cause pneumonia and Pontiac fever, and many other common indoor air pollutants also present significant hazards to human health. However, in general, short-term effects of commonly encountered indoor air pollutants are primarily odor or irritation but not strongly related to task performance. Chronic exposure to some indoor air pollutants may have serious long-term effects on health ranging from asthma and allergy to cancer and lung disease (WHO, 1984).

Standards for air quality and ventilation

The goal of most indoor air quality standards is to provide comfortable, healthy, and safe environments. The standards generally use a "ventilation rate" approach that specifies quantities of ventilation considered adequate to control human body odor to levels found acceptable to a major fraction of individuals. Comfort is associated with air free of unpleasant or noxious odors. Body odor is considered a reasonable surrogate for metabolism, so other chemicals emitted into indoor air by people are relatively well-controlled by such an approach. However, the ventilation rate approach does not control contaminants from sources unrelated to human metabolic level that are high pollution generators such as tobacco smoking, food preparation, personal hygiene, the use of intensive chemical products (e.g., for personal hygiene, cleaning, or hobbies). The latest version of the ASHRAE ventilation

standard, (Standard 62-2001, Ventilation for Acceptable Indoor Air Quality), also specifies outdoor ventilation rate per unit area to control non-people-related sources of pollutants (ASHRAE, 2001).

Significant disagreement exists among those writing indoor air quality standards regarding the “correct” amount of ventilation necessary to provide “acceptable” indoor air quality. There is also controversy about the definition of what is “acceptable.” ASHRAE has adopted a target of 80% of occupants as a general rule, and in the current version of its Standard 62, has determined that the air only needs to be acceptable to this 80% after people have been in a space long enough to be adapted to the odors that may be present. Adaptation to odor is a well-accepted principle, but some professionals and researchers advocate reaching the 80% level for unadapted individuals, *i.e.*, visitors or occupants first entering the space.

Unlike the human response to odor, the response to irritation does not diminish with time. In contrast to the human response to odor, the irritation response generally increases with time so that standards based on protecting adapted occupants from odor annoyance may be quite inadequate to protect them from irritation.

Principles for Ventilation and Air Quality Standards

A group of leaders of the international indoor air community gathered in Berlin in 1993 under the auspices of the International Academy of Indoor Air Sciences to produce guidelines for ventilation and air quality standards in buildings (Seifert *et al*, 1993). Their recommendations included maximum provision of occupant control. A summary of their recommendations follows:

1. Establish a base ventilation rate taking into account body effluents of the occupants,
2. Ensure that sources have low or non-toxic emissions, or that additional ventilation above the base rate is provided,
3. Consider chemical, sensory, and respiratory loads in an integrated way,
4. Set concentration limits for agents of concern, and,
5. **Provide occupant control whenever possible** [emphasis added].

The Case of Naturally-Ventilated (Passive) Buildings

In naturally-ventilated buildings (sometimes referred to as “passively-ventilated” buildings), where outdoor air ventilation rates are generally half and volatile organic chemical (VOC) concentrations are roughly double those found in mechanically-ventilated buildings, occupants report lower SBS symptom prevalence than in buildings with central heating, ventilating, and air conditioning systems (HVAC). Occupants also report higher levels of thermal comfort under a far wider range of conditions in naturally ventilated buildings. Most such naturally ventilated buildings have operable windows occupants can control. In contrast, engineering solutions to ventilation and thermal control with central HVAC in buildings without operable windows are designed with the expectation that they might deliver thermal comfort and acceptable indoor air quality to 80% of the occupants, even when the systems work properly as designed.

Is it necessary to aim so low in providing control of environmental conditions in buildings? Is there a compelling reason to ignore the available, less energy-intensive, less costly approaches that involve users in the control of their own environments? Why is it that naturally-ventilated buildings with operable windows produce more desirable environments? Naturally ventilated buildings may be noisy due to traffic and other urban noise outside, and if predominantly illuminated with daylight, they may have more uneven illumination among various parts of the space. Thus, it is exactly the opposite of what laboratory and field research has described as the most desirable indoor environment. Why is it so? Answers to

these questions might help us understand better how architects and engineers can design environments that fulfill the aspirations of their occupants.

The Case of Thermal Comfort

An examination of the research basis for thermal comfort design and operation serves as an illustrative case of the way efforts to control the indoor environment through central HVAC systems are not only energy-intensive but also fail to deliver the desired or preferred environment for all occupants. Designs for thermal comfort are usually based on ASHRAE or ISO standards developed on the basis of laboratory and field studies. ASHRAE thermal comfort studies are usually done with a scale that occupants mark with an arrow at the point that "...describes the way you feel overall."

- 1 COLD
- 2 COOL
- 3 SLIGHTLY COOL
- 4 NEUTRAL
- 5 SLIGHTLY WARM
- 6 WARM
- 7 HOT

Figure 1. ASHRAE Thermal Comfort Scale

The results of studies using the scale are a numerical average for a group of study subjects or building occupants. These results are supposed to predict accurately the percentage of subjects that will be satisfied with an environment with the same conditions for occupants with the same activity level and clothing insulation values. Using an empirically derived equation, various environmental and personal factors are entered into a mathematical equation that calculates the "Predicted Mean Vote," (PMV).

The PMV approach has been a source of much confusion for those using it to determine thermal comfort standards for the HVAC industry. It forces judgments that require more precise discrimination than is possible. The standard deviation for comfort votes has been determined to be one full scale unit -- *i.e.*, the 95 % confidence interval (*i.e.*, the mean +/- 2 standard deviations) for a "neutral" comfort vote includes all votes between 2 (cool) and 6 (warm). The impact of this can be seen in Figure 2.

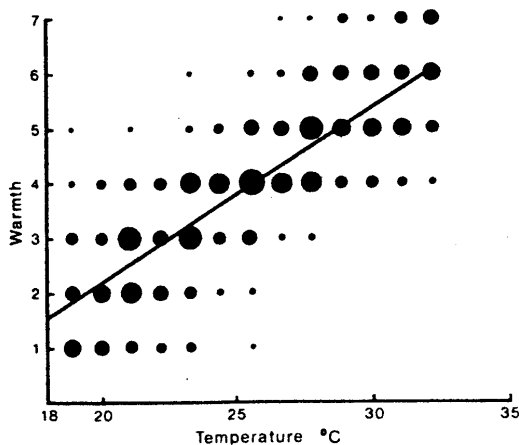


Figure 2. Comfort Vote as a function of the Air Temperature. (from DA McIntyre, 1978, as cited in Goldman, 1999)

The size of each circle in Figure 2 represents the proportion of subjects ($n > 3,000$) voting the specified “warmth” at a given air temperature. The calculated regression coefficient is 0.33 comfort units per °C of air temperature, with a standard deviation between sessions for a given subject of 0.1°C, and within a given test session of 0.8°C both within and between subjects.

In the study whose results are shown in Figure 2, the subjects are seated, quiet, wearing a standardized clothing ensemble consisting of a T-shirt and briefs, long sleeved shirt and pants, and cotton ankle sox without shoes. The subjects voted at regular intervals during each 3 hour exposure. The results of the study were that 80% of the occupants were within thermal neutrality (the psychological sensation of neutrality) within a 3.3 °C temperature range from 22.2 to 25.6 °C, but only when the other critical factors were as defined for the study – RH=40%, air speed = 0.2 m/s, mean radiant temperature (MRT) = T_a , clothing insulation value = 0.6 clo, and activity level = 1 MET (Goldman, 1999).

Of course with higher activity levels, higher clothing insulation value, or higher relative humidity, the acceptable range shifts downward, etc. And with less clothing, a higher air speed or lower clothing insulation values, the entire range shifts upward. So, the results really depend greatly on conditions that are not controllable exclusively by occupants or by engineers. But in general, the occupants actually have more control or play a bigger role than the engineers because their activity level and their clothing are not controllable by the engineer. Furthermore, with the addition of operable windows or small personal fans, occupants can often affect air speed. By adjusting window shades or curtains, they may also be able to affect surface radiant temperatures as well as indoor air temperature. In the end, it appears foolish to believe that an engineering solution without occupant participation can yield more satisfactory results than one with occupant control.

Thermal Adaptation

Brager and de Dear reviewed the extensive literature on thermal adaptation in indoor environments (1998) and discussed the implications (2003). They found many limitations in the use of the heat balance model when used as a design tool including the need for the designer to anticipate what average clothing values and metabolic rate values could be expected in a building under design. Even when applied to occupied buildings where the metabolic rate and clothing insulation can be observed, heat balance models frequently fail accurately to describe or predict thermal comfort. There are a number of explanations offered including inaccurate observations of occupant activity or clothing insulation level, chair insulation value, non-uniformity of thermal conditions; modeling assumptions including steady state conditions; and, thermal adaptation.

Occupants adapt to the thermal conditions in their environments in three ways:

- o Behavioral feedback -- Adjustment
- o Physiological feedback -- Acclimatization
- o Psychological feedback -- Habituation and expectation

Brager and de Dear (1998) found that a range of complex factors not accounted for in the heat balance models might influence human response to conditions in real buildings. These include demographics (gender, age, culture, economic status), context (building design, building function, season, climate, semantics), environmental interactions (lighting, acoustics, indoor air quality), and cognition (attitude, preference, and expectations). While the factors that have been tested have been demonstrated repeatedly as irrelevant to the subjects’ comfort responses in the contrived setting of the climate chamber, many researchers and practitioners suspect that non-thermal factors are important in real building environments. For example, it

has been suggested that the impact of one's perception of control is a particularly important influence -- psychologists have clearly demonstrated that adverse or noxious stimuli are less irritating if the subject perceives she/he has control over them. Both humans and laboratory animals have diminished defenses against infectious agents when under stress.

An alternative to conventional comfort theory suggested by Brager and de Dear is that people play important roles in creating their own thermal preferences by their interactions with the environment, or by modifying their own behavior, or by gradually adapting their expectations to match the thermal environment. Interest in the "adaptive" theory of thermal comfort began in the mid-70's after the global oil crisis, and it has recently regained momentum due to concerns about the relationship of energy consumption and global climate change. Allowing people greater control over their own indoor environment, and allowing temperatures to more closely track patterns in outdoor climate, can have significant, positive impacts on both improving comfort, reducing energy consumption, and altering the way buildings are designed and operated (Brager and de Dear, 1998).

THE IMPORTANCE OF USER CONTROL

If users are allowed to participate in the process of determining the characteristics of their environment, they are far more likely to be satisfied and comfortable. As appears to be the case for thermal comfort, increasing user control over the indoor environment potentially provides greater occupant comfort and satisfaction with lighting, acoustics, and indoor air quality. In fact, when users control aspects of their environment that are important to them, the reported SBS symptom rates are often lower and workers' estimate their building's impact on their productivity is more beneficial (Raw et al, 1990). If users don't control some important characteristics of their indoor environment, it is virtually impossible to create conditions that will satisfy the vast majority of occupants (Stolwijk, 1984). So why, then, don't building designs simply enable users/occupants to control the fundamental decisions about their indoor environment, at least those that are easy for users to control?

Historically important methods of environmental control by occupants have included (among others) operable windows, window shades and blinds, task lamps, local heating devices, and personal fans. (See Table 1 for a more detailed list of occupant/user control technologies and what it is that they control.) These means of occupant control can enhance user selection of light intensity and spectral quality; view to the outdoors, local air movement, temperature, among many others. Other controls available to many occupants of traditional, private (separately-enclosed) offices include closing a door to adjust both audio and visual privacy and, in some cases, air quality and thermal conditions. Because many strategies and technologies that increase user control require less energy intensive technologies and avoid the need for centralized control, such systems are potentially less costly to construct and less costly to operate. They are also less susceptible to catastrophic failure that can result in very uncomfortable or unhealthy conditions or even require evacuation of a building.

Table 1. Examples of user controlled technologies for the indoor environment

<i>Technology</i>	<i>Controls</i>
Operable windows	Ventilation, thermal environment, air quality
Task lamps	Light intensity, angle of incidence (glare)
Window shades, blinds	Illumination level, solar penetration, thermal conditions
Local radiant heaters, ("coolers"?)	Thermal conditions
Personal fans	Air movement, thermal comfort, background noise
Personal air supply	Ventilation, air quality, air movement, thermal comfort

Why is occupant control so important?

As long ago as the 1950s, researchers began to document the advantages of occupant control of the environment. There is evidence that health, productivity, and comfort all are improved by providing environmental control to office workers (Raw *et al*, 1990). It is well known that a lack of control over one's environment produces stress (Aronoff and Kaplan, 1995). Stress from environmental factors results from the impingement of the environment on physiological systems, perception of the environment, or some combination of the two. Under psychological stress, bodily defenses against environmental insults (*e.g.*, infectious agents, toxic or irritating chemicals, glare, loud noise) are diminished (Kalat, 1992). Students had less chemical defenses in their saliva during finals when compared to levels collected earlier in the school semester. Laboratory animals under stressful conditions manifest aggressive behavior and avoid copulation (Proshansky *et al*, 1970; Porteus, 1977). So, when people are not in control of their environment, they are more stressed and, therefore, have less effective physiological defenses against hostile environmental conditions (Dubos, 1965).

The General Case for User Control

Paraphrasing British architect and philosopher of housing, John F. C. Turner (1972), when designers and building operators cannot or will not provide basic safe, comfortable, and healthy conditions for building occupants, they should not interfere with occupants' efforts to provide these conditions for themselves. In fact, when building designers and operators can't deliver comfort and satisfaction to the vast majority of building occupants, designers and operators should do everything possible to facilitate user or occupant control of indoor environments in order to maximize occupants' satisfaction. Turner believed that the occupants could make better choices regarding the use of scarce resources because they were more invested in the outcome than professionals who define or design the living environments but fail to do so in a satisfactory manner.

People Are Not All Alike

To any designer interested in optimizing occupant satisfaction, comfort, and health, perhaps the most compelling argument in favor of user control resides in the enormous inter-individual differences among people. Figure 3 graphically depicts the diversity among people and shows that an abstracted "bell-shaped curve" with standard deviations delineated will inevitably exclude some people whose individual (deviant) characteristics are excluded from the statistical summary of the group. These differences make it highly unlikely that any given set of environmental conditions will satisfy the vast majority of occupants.

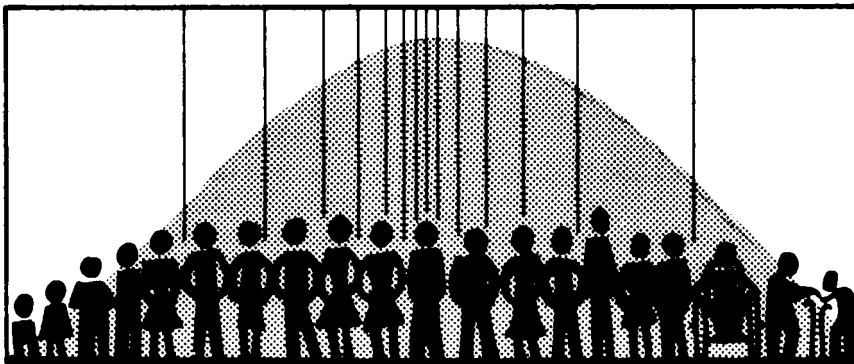


Figure 3. All people are not alike. (Source: Rubin and Elder, 1980).

One's experience of a place is a multivariate phenomenon that reflects the degree to which the place supports a person's objectives and expectations. People are not all alike. The objectives and expectations in any population of building occupants are likely to vary considerably. For this reason, researchers tend to use groups of subjects, often very large numbers of individuals in order to derive a statistically valid representation of the group response. However, this tendency to find the statistically significant average response or range of responses always necessarily leaves out the individuals at the edges or extremes of the range of conditions. And a decision to design an environment to satisfy 80% of the occupants is implicitly a decision to leave 20% dissatisfied. This may seem "reasonable" on a statistical basis, but it is not "acceptable" on an individual basis for those individuals who are left out of the "satisfied" group.

The role of occupants and "user control"

Standards-setting groups and designers often complain that they can't achieve good environmental quality because they can't control occupant behavior. If the environment is unsuitable, occupants will do what they can and what they must in order to adapt the environment to their needs and preferences. They will try to adapt their clothing, their behavior, and their environment to satisfy their needs. So designers do everything they can to minimize the opportunities for occupants to affect the indoor environment. Opportunities for opening and closing windows or window shades or blinds, for example, is rarely built into the concept for environmental control in modern office buildings. Yet these means of controlling the illumination indoors are examples of ways in which occupants can adjust the conditions to suit themselves best.

Who decides what for whom?

Turner said that the most important question to ask about the system providing housing for people is "Who decides what for whom?" It was Turner's thesis that the greater degree of control occupants had over the factors that mattered most to them, the greater would be their satisfaction with their housing (Turner, 1972). Liberally paraphrasing Turner, we put forward the following hypothesis:

When building occupants control the major decisions and are free to make their own contributions in the creation and management of their houses, offices, schools, etc., both this process and the environment produced stimulate individual and social well-being. When people have neither control over nor responsibility for key decisions in the process, on the other hand, building environments may instead become barriers to personal fulfillment and burdens on the economy.

Writing about housing and poverty, Turner wrote that "... autonomy increases quantity: in any context, it increases meaning." In 1965 Albert Wilson wrote about this same subject in *The Voice of the Villas*:

"It is not the discomfort of the physical situation the people of the *villas* feel most bitterly – it is the humiliation of being denied the opportunity of doing for themselves what they are quite able to do." (Wilson, 1965)

Advocates of User Control

In his Plenary Lecture at "Indoor Air '84" in Stockholm, Jan Stolwijk of Yale University said that user control was the only means to satisfy the vast majority of building occupants (1984). At that time, his view was not widely accepted nor oft repeated in the indoor air community.

Others who followed worked to develop means for increasing user control. Audrey Kaplan, working on Canadian government buildings, designed an experimental personal work station (FUNDI) that maximized individual user control over local environmental quality (Kaplan, 1987, 1992; Aronoff and Kaplan, 1995). The German company, Kranz, manufactured components for desktop ventilation air delivery that would be adjustable by the occupants themselves. Later Honeywell's Personal Environmental Module (PEM) adapted many of the designs of Kaplan and Kranz to create a user controlled module that would affect air quality, thermal conditions, lighting, and noise. David Wyon designed an air delivery unit that fits underneath the desk to try to optimize thermal comfort. Professor Ole Fanger now advocates the use of personal ventilation systems to improve occupant satisfaction, comfort, and productivity.

In their report of a research agenda developed by Fisk and co-workers for 44 state energy agencies, investigation of individual control was strongly advocated. They said there is sufficient evidence to support the assumption that providing individuals with control over their personal environment is the only way to achieve occupant satisfaction rates approaching 100%. They noted the perception that individual control inevitably increases both complexity and first cost, they indicated that information on performance of such systems is essential to determine the benefits and life cycle paybacks of such investments. (Fisk *et al*, 2002). In their discussion of user control, the authors reflected an assumption that the environmental control would be through mechanical means rather than passive or natural means (such as operable windows, etc.).

Why Not Occupant Control? – The Underlying Assumptions

The assumption that the building should shelter from the elements and enemies has led in Western architecture to the imposition of a strong barrier between the building and the outside. Engineers took responsibility for “protecting” us from the elements and creating a “synthetic” environment. There is currently a prevalent assumption that building designs must use centrally controlled HVAC systems to control the indoor environment and provide uniform conditions to all occupants in all parts of the building. In part this assumption is based on the belief that we can design any form of building and then fix its indoor environment with technology. This reflects the engineering bias that solutions should be engineered technology rather than overall building (architectural) design. The process of development itself allows developers to optimize their own interests rather than what occupants might want. Real estate values impel design of massive structures that fill the available land area rather than more traditional forms and designs that articulated the perimeter in relation to the interior served by its windows.

The potential role of the occupants in controlling the environment tends to be diminished by assumptions that the specified environmental conditions must be achieved by a building's design, equipment, and operation – in modern buildings, controlled by computers. Architects have given over responsibility for the indoor environment to a variety of engineers and other consultants. It is generally assumed that this can be done well enough to satisfy as many occupants as need to be satisfied.

What fraction of occupants should designers attempt to “satisfy.” The guidelines and standards related to thermal comfort and the research that supports them suggest that even in the carefully controlled environments using central HVAC, not more than 80 to 90% of the occupants will be satisfied with the thermal environment. Why are designers willing to attempt to satisfy only 80 to 90% of the occupants? If occupant satisfaction with air quality and thermal conditions is higher when they are in control, why shouldn't they be given more control?

The building against nature

Isolating humans from nature deprives us of the contact with the outdoors that is essential to our fundamental relationship with the earth. It reinforces illusions that man can have ‘dominion over the earth.’ So fantastic is this illusion that we now see huge investments being made in the planning of space colonies, totally “artificial” environments in which all human needs will be supplied by devices of human creation. This planning is built on the myth that we are capable of replacing “nature’s services” (Daily, 1997). This assumption that humans can create everything needed to sustain human life represents the extreme or *reductio ad absurdum* extension of the biblical dominion fallacy.

“The use of massive air conditioning plants to correct an ill-conceived environment does not differ in principle from the use of a masonry façade to hide an unnecessarily ugly concrete structure.” (Cowan, 1966.)

Fundamental Choices

Basic decisions made about buildings at the beginning of their planning and design determine much of what follows during the rest of their useful lives. These decisions include site selection and the placement and orientation of the building on the site; the overall size, shape, massing, and openings; ventilation, thermal control, and illumination strategies; and, dominant structural and non-structural materials. How far from the windows is the most distant occupant’s space? Nearly all of these have important consequences for the control of indoor environmental quality. Most of them are very hard to change once determined. They govern energy performance within relatively narrow ranges, and, in most cases, severely limit the range of choices available to architects and engineers as they attempt to produce safe, comfortable, and healthy buildings.

There are connections between the fundamental choices cited above, occupant control, and who decides what for whom? Besides determining the means to control the indoor environment, there are also critical decisions about the target values for control and who will exercise authority to effectuate the control. As Turner pointed out, decisions made by occupants/users are more likely to result in their satisfaction with the results.

An occupant-oriented design process would value the connections to nature, elaborate on how to solve the problem, and draw from historic precedents. The reason to design buildings more in harmony with nature (shape, openings, etc.) is because presumably it will have a positive impact on the quality of the indoor environment and the well being of the occupants. Rather than build a box and apply the necessary technology to control and condition the indoor environment, designers can build the form that works best without applied technology and use technology (only as necessary) with maximum occupant control as a supplement to what can be accomplished with building form and occupant control.

A building ecology approach

A “building ecology” approach (Levin, 1981, 1995b, 2000) places the occupants in a key position in relation to the building and the larger environment. The basis for building ecology as an approach to understanding buildings is that the building, the occupants, and the larger environment are all interdependent and in dynamic interaction. An integrated analysis of this “system” of building, environment, and occupants can produce far richer solutions that are less harmful to either the occupants or the environment. As has been found in pollution prevention and prudent avoidance risk management, reduction or elimination of resource consumption and pollution emission is likely to be more economical in the long run and may even be more economical in the short run. The result can be a model that can successfully guide the building design.

PRESCRIPTION FOR ENVIRONMENTALLY-RESPONSIBLE BUILDING PRACTICES THAT ARE GOOD FOR THEIR OCCUPANTS

There are a number of practices that can successfully reduce the cost of buildings to their owners, operators, and the environment while enhancing the indoor environmental quality and the satisfaction of occupants. These are suggested by the list in Table 2.

Table 2. Examples of environmentally responsible building practices

Overall design concept in harmony and cooperation with the outdoor environment
Occupant control of major indoor environmental control technologies, devices
Natural ventilation (including through operable windows)
Daylight illumination as a major light source
Local thermal control or modification (fans, local radiant heating or cooling)
Windows with views to the outdoors, visibility accessible to all occupants
Internal and external shading and sun control devices to adjust or limit solar and daylight penetration

CONCLUSION

Buildings are major contributors to human impacts on the environment. With projected population growth and increased access to modern technologies, Earth's environment simply cannot afford such environmentally expensive buildings. It appears that the vast majority of building occupants are not now nor can they be satisfied only by engineered indoor environments without significant involvement in the control of those environments. Involving the users in the control of their own environment is essential to achieving a higher level of occupant satisfaction with the indoor environment. It also appears that many if not most user-controlled solutions to indoor environmental control are less costly in financial and energy terms. Ultimately, provision of indoor environmental quality that will achieve the highest level of occupant satisfaction and the lowest impact on the environment must radically increase the use of so-called "passive" and "user-controlled" technologies, many of which are widely used in historically important examples. By integrating the analysis of the interactions between building, occupants, and the larger environment, researchers and designers will model successfully the fundamental relationships that should drive our design.

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