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SPECIFYING INDOOR ENVIRONMENT DESIGN CRITERIA

T. D. J. Clements-Croome

Department of Construction Management and Engineering
The University of Reading, UK

ABSTRACT

Buildings are designed to suit climate in which they are located and the functions for which they are intended. There is a unique relationship between an individual, the environment and the building they inhabit. Everyday experiences tell us that there are a host of factors which are relevant to this concept. The difficulties of specifying the indoor climate of buildings arise from many causes. The obvious one is that there are many factors contributing towards the indoor environment and therefore the human response is difficult to assess in establishing design information for one particular variable, such as temperature or air movement. The effect of an environment at any moment is dependant on ones past experiences and people are not passive recipients of their environment, but adapt physiologically and behaviourially. The author proposes that comfort should be viewed more in the context of well-being and hence link the quality of the indoor environment with employee productivity. At present standards highlight comfort as a neutral non-intrusive experience. This paper suggests a more original way would be to design using preferred environmental settings which would give stimulating, rather than neutral environments. Standards based on comfort criteria do not produce satisfactory environments.

BACKGROUND

The body has five basic senses - sight, hearing, touch, smell and taste. They are part of a physiological-psychological system which regulates the human response to environmental stimuli. People react individually and any particular response may be a transient one or one that becomes an experience stored in the longterm memory. The building and its environment, the social ambience, the work and its management process, all trigger the response system. The senses are to be enjoyed, but can also be employed to achieve fulfilment in work. In order for this to happen the mind needs to reach a high level of concentration. The quality of environment can make it easier for the senses to be used effectively and enjoyably. For example the visual responses depend not only on the level of light but also on the daylight wavelength content, vector-scalar ratio, balance of shadow and light, colour and the glare index. Brightness, hue, saturation and chroma are quality factors. Similarly, sound must be at a suitable level for hearing but the frequency content and spatial response are evaluated too in the auditory system. In the case of the thermal environment, air and radiant temperatures, air movement, solar radiation, moisture content and pollutants all affect the respiratory and thermo-regulatory systems resulting in subjective feelings of freshness and general thermal acceptability. It is impossible and undesirable to incorporate all this fine detail into a standard, which can only be a coarse baseline needing flexible and common-sense interpretation by the designer.

Standards aim to set acceptable conditions for various combinations of circumstances. The difficulties of specifying the indoor climate of buildings arise from many causes. The obvious one is that there are many factors contributing towards indoor environment and therefore the human response is difficult to assess in establishing design information for one particular variable, such as temperature or air movement, especially as the response combines physiological and psychological reactions to the environment.

A broader level of understanding is needed when interpreting the word *acceptable* so as to reflect not only the scientific basis of environmental specification but also cultural and social aspects. The language of sustainable buildings is about climatically sensitive structures, flexibility and adaptability. Often design standards are too fixed. Criteria could be more malleable but this requires an approach which can focus upon cultural variability of building occupants and upon their creative, multi-dimensional interaction with the built environment. Patterns of energy consumption for example depend on people's decisions which are rooted in attitudes and actions. Ultimately a series of decisions, some of which become habits, constitute a lifestyle.

Standards need to be durable over time but presented in a flexible manner so that they can be updated as information becomes available. It is also equally important that the standards should be user friendly and easily accessible for the designer. Algorithms for example are a good way of summarising decision-making procedures and for testing alternative solutions. There also needs to be interactive links clearly indicated with other national or international standards. In the case of international documentation the regional variations need to be highlighted. The legal implications of using standards always need clarification.

To demonstrate the difficulties of writing standards consider the case of fresh air ventilation rates in single and landscaped offices. The following table gives the comparison across several countries and it can be seen that the variations will have a significant effect on energy and comfort. International harmonisation is essential.

COUNTRY	**Minimum Fresh Air Ventilation Rate in Offices l/s per m^2 floor**		**Reference (year)**
	Single (0.1 person per m^2)	**Landscaped (0.07person per m^2)**	
Germany	1.1	1.6	DIN1946 (1993)
UK	-	1.3	CIBSE Guide(1978)
France	0.7	0.5	
Scandinavia	1.4 - 3.2	1.2 - 2.7	SCANVAC Guidelines (1991)
Norway	1.1	1.0	NKB 61E (1991)
Finland	1.0	1.5	Building Code D2 (1987)
USA	1.0	0.7	ASHRAE 62 (1989)

Table 1: Minimum fresh air ventilation rates.

If there is world-wide interest in environmental sustainability there needs to be a coherent formulation about ventilation. The European guidelines are attempting to do this via CEN/TC/156/Working Group 6 and it has been proposed that there should be three categories to cover levels of 15%, 20% and 30% people dissatisfied respectively. In the case of a single office this would mean having ventilation rates of 3.3, 1.1 and 0.8 l/s m^2 floor and for landscaped offices values of 2.8, 1.2 and 0.7 1/s m^2 floor. In addition to this basic ventilation rate to dilute the odours from occupants, there needs to be allowances for smoking and contamination by the building materials.

This particular example shows how the original work of Yaglou in 1936 needs to be changed as knowledge has increased, and the use of a much wider range of building materials has become common practice. There needs to be a continual updating of ventilation standards. The decision to have smoking in an establishment is one that is taken by the client and will reflect social attitudes in society at a particular time. The possibility of contamination by the ventilation system itself can be prevented by a preventative maintenance programme. Knowledge about the emissions of building materials will rapidly increase as measurement procedures become standardised and also more sensitive by the use of infra-red detection systems and chromatography.

PRESENT STANDARDS

We need to assess if a comfortable indoor environment is a necessity for the occupants good health and high productivity. We may need to redefine comfort in terms of well-being. There are three current standards providing guidance for the assessment of occupant comfort: ASHRAE standard 55-92 (ASHRAE, 1992); ASHRAE Standard 62-89 (ASHRAE, 1989); and ISO Standard 7730 (ISO, 1984). They all emphasise thermal comfor [illegible] han overall comfort. Based on Fanger's PMV/PPD model, the [illegible] hermal comfort standard ISO 7730 has been updated, but [illegible] as the new prestandard pr ENV 1752 *Ventilation for B* [illegible] *s: Des* [illegible] *for the Indoor Environment* because it is felt that there [illegible] oo much la [illegible] y data that has not been fully validated in the field. Th [illegible] proposed sta [illegible] on indoor climate is based on the work of Fanger (1970). [illegible] here has been [illegible] ady stream of notable laboratory work emanating from his laboratory since [illegible] t time and the key references to this are in the *ASHRAE Handbook on Fundamentals 1993 Chapter 8.*

Healthy buildings require adequate quantities of fresh air, but the precise amount of fresh air is difficult to estimate. Fanger (1988) has quantified air pollution sources by comparing them with a sedentary person in thermal comfort. The *olf* is defined as the emission rate of air pollutants from a standard person. The percentage of people dissatisfied (PPD) with the emissions of one person in a laboratory chamber as a function of fresh air ventilation rate (q in l/s x olf) can be assessed from:

$PPD = 395 \exp(-1.83q^{0.26})$ for $q > 0.332$; $D = 100$ for $q < 0.322$

A *decipol* scale has been derived where the decipol is the perceived air pollution in a space with a pollution source of one olf ventilated by 10 l/s of unpolluted air. Steady state conditions and complete mixing are assumed. On this basis healthy buildings are defined as those which have a decipol level of one and below, whereas sick buildings are defined as those which have a decipol value of about 8 to 10 or above.

A panel of judges sample the air in the environment. It may be that we need to develop some form of analysis using gas chromatography as an objective basis for assessing the amount of fresh air required in a building. Nevertheless, attention has been drawn to the fact that not only people, but building materials and ventilation systems themselves contribute towards the pollutants in an environment, a fact that is recognised in the draft ASHRAE Standard 62-1989R *Ventilation for Acceptable Indoor Air Quality*. The effect of smoking has been emphasised over the years, but the importance of building materials is a newer aspect that needs to be taken into account. With regard to the airflow system maintenance is vitally important. In drafting pr ENV 1752 across many European countries, it became clear that the fresh air requirements in different countries varied considerably and also there still remains much work to be done to ascertain the correct amount of fresh air needed in spaces which are naturally ventilated, mechanically ventilated or airconditioned.

The steady state energy model representing the heat exchange between the body and its surroundings usually assumes that the body is in a state of thermal equilibrium with negligible heat storage. Various thermal exchanges by sensible heat loss from the skin; evaporative heat loss and respiratory losses result in a total skin heat loss and from there some assumptions have to be made with respect to the clothing of the body covering most of the skins surface. Further assumptions have to be made with regard to metabolic heat generation for various activities. Hence it is not surprising that there is some considerable variation between individuals with respect to judgement of temperature since the basic physiological responses differ widely for individuals. Peoples sensitivities vary considerably. Age, adaptation,sex,seasonal and circadian rhythms, local thermal discomfort, radiant asymmetry, temperature gradients, air quality, thermal conduction,posture,all vary from one individual to another. Whilst accepting that no single environment is judged satisfactorily by everybody, even if they are wearing identical clothing and performing the same activity, the comfort zone specified in ASHRAE Standard 55-92 is based on 90% acceptance or 10% dissatisfied. Fanger (1982) related the predicted percentage dissatisfied (PPD) to the predicted mean vote (PMV) as follows:-

$$PPD = 100 - 95 \exp [-(0.03353 PMV^4 + 0.2179 PMV^2)]$$

where dissatisfied is defined as anybody not voting either -1, 1 or 0. A PPD of 10% to corresponds to the PMV range of + 0.5, - 0.5 and it should be noted that even with a PMV=0 about 5% of the people are dissatisfied.

The draft European standard (pr ENV 1752) prescribes a PPD for the human body as a whole and does not assess local discomfort. Three quality categories are described. Category A corresponds to less than 15% PPD; category B for PPD less than 20% and quality category C for less than 30% as judged for the whole body. Local discomfort criteria are then defined for draft, temperature gradient, warm or cold floors and radiant asymmetry. The difficulties become apparent because it is very problematic to try and define so many variables in such a precise manner especially in a naturally ventilated building. In a laboratory situation this is nearly possible, but even then difficulties arise because of variations between subjects being tested.

What kinds of variation can one expect between field tests and Fanger's prediction? Measurements made in various lecture rooms at the University of Reading show that there is a notable difference between judgements made at head and foot level, and the slopes of the line between thermal sensation and air temperature differ by as much as 2°C for the field tests and the laborato[illegible] prediction (Croome 1992). This becomes more evident above 22°C. In a more general context one can see by comparing the work of Gagge (1986) [illegible] Fanger (1970) with measured data by Brager (1992) that again there [illegible] significant differences between the field and laboratory data. The practic[illegible] effects of these differences are that even at 1°C difference between laborator[illegible] predictions and field measurements there is a potential energy saving [illegible] 6-8%; with a 2°C difference the amount of energy saving rises to bet[illegible] 2 and 16%. Clothing variations of 0.1 clo can effect 4-5% energy savings [illegible]

Current comfort standards prescribe a static "*ideal*" temperature [illegible] be maintained uniformly over space and over time. This is unrealistic [illegible] lead to wasteful fuel consumption. The experience of an environment at any moment is dependant on ones past experiences and so a time sequence analysis is important as people adapt physiologically and behaviourally in accordance with changes, expectations and preferences. There is growing dissatisfaction with the static comfort temperatures predicted using traditional models based on heat balance theory and laboratory data. This is coupled with concern about the increasing amounts of energy required for maintaining the thermal environment in buildings and its attendant environmental impacts. Static indoor temperature standards encourage the use of high-energy environmental control strategies and exclude options for which temperature variation is either inevitable or desirable, (e.g. many passive, energy-conserving solutions, or innovative mechanical environmental control strategies). In comparison, an adaptable (or a variable) temperature standard that recommends temperatures which reflect the climate surrounding the building would reduce the indoor-outdoor temperature differential and could be expected to reduce energy requirements considerably (Auliciems 1990).

Humphreys and Nicol (1995) has collated data from numerous field studies made in several countries which demonstrate that most of the variation in the indoor temperature required for comfort can be explained by the changes in the monthly mean out door temperature. For the case of free-running buildings, there is a strong linear correlation between monthly mean outdoor temperature and the indoor comfort temperature; recent work suggests that the exponentially weighted running mean outdoor temperature may improve the correlation further. De Dear and Auliciems (1985) analysed a large number of field surveys, and derived another comfort temperature equation based on mean outdoor temperature.

The adaptive approach recognises that people use numerous strategies to achieve thermal comfort. They are not inert recipients of the environment, but interact with it to optimise their conditions. The adaptive, people-centred way of regarding thermal comfort suggests that it would be advantageous to re-formulate temperature standards for buildings, so that they reflect the empirical relation between climate and thermal comfort and make due allowances for human adaptability.

The ASHRAE Standard-55 has a rudimentary allowance for climate, in that it advocates temperatures which differ between summer and winter. Adaptive results can be used to refine this allowance by linking the indoor comfort temperature to the outdoor temperature throughout its seasonal and geographical variation. This would result in increased design flexibility without reducing user satisfaction. It could also lead to reducing the capacity of installed heating and cooling plant, and thus save energy.

For the case of free-running buildings, there is a strong linear correlation between monthly mean outdoor temperature and the indoor comfort temperature, whereas for other buildings there is a fairly strong curvilinear relationship which can be improved if the mean daily maximum temperature of the hottest month is used as an additional predictor. Statistical analysis of the field data showed that for free-running buildings (Humphreys,1970):

$$\theta_n = 11.9 + 0.534 * \theta_o$$

Where θ_n is the predicted neutral temperature for thermal comfort and θ_o is the mean outdoor temperature for the months being considered; this regression equation has a coefficient of correlation equal to 0.97 and range of application is: $10\ ^{o}C < \theta_{o} < 33\ ^{o}C$.

The indoor environment is affected by building construction as well as the services systems. Buildings have an infiltration characteristic; well insulated buildings usually have higher internal surface temperatures and are warmer. Massive buildings are usually cooler than lighter ones. Warm moist atmospheres can directly contribute to sick building syndrome but also indirectly, because they can encourage microbial growth, and thus affect concentrations of air pollutants. Air movement has an effect on thermal comfort, but it may have an independent effect on some symptoms because it effects heat, moisture and pollutant distribution. Indoor environment is a dynamic combination of physical, chemical, social, and biological factors, which in total affect human health, well-being and comfort. Standards need to reflect these issues.

Abdou and Lorsch (1994) conclude that temperatures which provide optimum comfort may not necessarily give rise to maximum efficiency in terms of work output. The difficulty here is that this may be true for relatively short periods of time, but if a person is feeling uncomfortable over a long period of time it may lead to a decrement in work performance. However, there is a need for more research in this area. It almost seems that for optimum work performance a keen sharp environment is needed which fluctuates between comfort and slight cool discomfort. Abdou and Lorsch (1994) conclude that *in many case studies occupants have been highly dissatisfied with their environment, even though measurements have indicated that current standards were being met.* This highlights the need to review standards and the basis on which they are made. Exactly the same conclusion is made by Donnini et al (1994).

CONCLUSIONS

Comfort should be viewed in the context of well-being and hence link the quality of the indoor environment with employee productivity. It is proposed that research is needed in the following areas:

- The meaning of comfort and the differences between the terms comfortable, acceptable, preferable and tolerable thermal environments.
- The link between productivity, well-being and comfort or discomfort.
- The relationship between thermal comfort and other design requirements such as air quality, noise and light.
- Assessment of the Analytic Hierarchy Process (Li 1996) for studying the interaction of environment with productivity thus establishing the priority factors for the design process.

- Optimal design and the relationship between temperature, economics, health, productivity, energy use and comfort within the overall context of the management and production processes.

There is a need to develop an empirical model to enable greater understanding of *multi-sensory* well-being of occupants under *realistic* dynamic working conditions and to develop a correlation between *multi-sensory* occupant comfort, well-being and productivity. Most work concentrates on thermal comfort for groups of people and this is unrealistic for a basis of environmental design. This alternative holistic approach will enable standards to be evolved which are realistic and recognise the combined value of low energy, health, comfort and productivity in various situations.

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