Dynamic thermal comfort conditions in architecture

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ABSTRACT: This paper will outline a research project currently being undertaken at The University of Melbourne aimed at developing a dynamic model of architectural comfort. Much of the energy used in buildings goes to providing suitable levels of environmental provision – light, heat and air – for building occupants. In terms of thermal performance, the levels have been determined principally through research by air-conditioning engineers (ASHRAE), and are based largely on the steady state equations of thermal comfort established by P.O. Fanger in Denmark. Steady state conditions are not only expensive to maintain in terms of energy costs, they also underestimate human adaptability to indoor climate and fail to respond to local climatic variation. They are also inconsistent with current office design, where increased mobility resulting from computer and telephone technologies has led to models of space provision that allow for worker movement between workstations, meeting areas, and other formal and informal spaces. The aim of the project is to investigate preference for, and tolerance of, ‘dynamic’ comfort conditions in buildings, ie variation to temperature and wind speed resulting from inhabitant activity, such as moving to another space (indoor/outdoor), opening or closing windows, or adjusting temperature settings. By correlating thermal comfort data with user behaviour, it is hoped that a more comprehensive picture of thermal comfort will be developed, taking into account frequency distributions and rates of change of temperature and air movement, that will assist in the implementation of natural ventilation systems. The project will explore the degree to which spatial and temporal variation correspond with natural variation due to external weather conditions, and in doing so, will attempt to develop a model of comfort that more accurately reflects the human need for variation in sensory experience.

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INTRODUCTION

The construction and operation of buildings accounts for about half of Australia’s total energy use. Most of that energy is needed to provide suitable levels of environmental provision – light, heat and air – for building occupants. In terms of thermal performance, the levels have been determined principally through research by air-conditioning engineers (as published by ASHRAE), and are based largely on the steady state equations of thermal comfort, established by P.O. Fanger in Denmark, using figures for Predicted Mean Vote / Predicted Percentage Dissatisfied (PMV/PPD) (Fanger, 1970). In recent years, a range of initiatives have been undertaken to reduce dependency on active environmental systems, and to make better use of daylighting and natural ventilation in the workplace. The move towards ‘sustainability’ involves a decreasing reliance on active systems while maintaining expected standards of environmental provision. Extensive research is currently being undertaken around the world into ‘double-skin’ facades and ‘mixed mode’ systems that allow operable windows to work in combination with HVAC units.

While many of these standards were aimed at achieving efficiency for active environmental control systems, another key motivation was the improvement of worker efficiency by ensuring appropriate comfort levels and avoiding disruption caused by variation in environmental conditions. The specification of environmental factors in terms of minimum levels or suitable range is as much a consequence of the technology used to achieve them as of the human sensory factors to which they respond. Uniform levels can be seen as a way to maximise safety and comfort, but can also be seen to maximise productivity by minimising distraction. Moreover, such uniform levels are no longer consistent with current work practices, where computer and telephone technologies have allowed increased mobility and reduced dependence on printed information.

THE NEW WORKPLACE

These new technologies have been dramatically affected modes of work and workplace inhabitation. Architects have responded to these influences by developing dynamic models of space provision, acknowledging temporal change as workers move between workstations, meeting areas, and other formal and informal spaces. Pioneering in this area is British firm DEGW, and founding partner Francis Duffy (Duffy, 1997). Duffy has explored workplace design in terms of both different activity types and different rates of change of building elements. Based upon a hierarchical model of ecosystems developed by R.V. O’Neill et al (O’Neill, DeAngelis, Wade, and Allen, 1996), Duffy describes various ‘layers of longevity’ of a building that are renewed at different rates, consisting of site, structure, skin, services, space plan, and ‘stuff’. This dynamic model of building ecology recognises the effect of changing patterns of use, social structure, or service technologies on workplace provision. The next logical step is to extend this model to include daily or hourly changes to thermal comfort conditions necessary to maintain a vibrant work environment. Buildings such as Campus MLC in Sydney and the National Australia Bank building at Melbourne Docklands, both by Bigh Voller Nield, provide a range of work spaces from open-plan
offices to meeting rooms, café/kitchen areas, and breakout spaces that cater for varying activities throughout the working day. Instead of conditioning each of these spaces to the same thermal comfort conditions, it may be possible to introduce variation appropriate to the various activities and their duration.

ADAPTATION AND USER CONTROL

Some progress has been made in recent years to more closely link comfort conditions with local climate through what is known as the ‘adaptive’ model, in which comfort temperatures are correlated with mean daily external temperatures. Nicol and Humphreys, for example, argue that thermal comfort ought to be seen as a behavioural response to climate rather than a matter of physiology, and that comfort temperatures should be seen as flexible rather than fixed (Nicol et al, 1995). According to Humphreys, straightforward application of the Fanger equation underestimates human adaptability to indoor climate by about 50%, leading to excessive energy use and inappropriate design. He suggests that while the adaptive method promotes a closer correspondence between indoor and outdoor temperatures, it may be necessary to limit rates of change caused by sharp changes in weather, and that the determination of suitable rates of change is an area requiring further research (Humphries, 1995).

Another significant area of research is that of user involvement in environmental control, pioneered by Dean Hawkes and colleagues at the Martin Centre at the University of Cambridge. Hawkes argues that comfort has both a spatial and a temporal dimension, as users respond to different weather conditions or different activities by adjusting clothing levels, temperature settings, window openings, or by moving to another space (Hawkes, 1997). An example is the study by Diane Haigh of five primary schools in Essex more than twenty years ago (Haigh, 1982). While broad patterns were consistent with expected thermal comfort levels, more immediate changes, such as to occupancy or activity levels, or varying weather conditions, were often met with changes to windows, doors, lights or heating.

These changes, writes Haigh, were an essential part of the teaching environment, welcomed and sought by staff in their broader goal of creating a learning environment. She writes: “We have seen that the internal environment of buildings, contradicting conventional wisdom, is required to vary. Occupants encourage changing conditions as a stimulus to activity. [...]The maintenance of comfort conditions might be considered a primary motive, but comfort is a fluid concept” (Haigh 1982).

Unfortunately, these changes to environmental conditions were not easily related to energy savings, since users had no feedback mechanism to let them know the implications of their actions in terms of the amount of energy consumed. The changes undertaken by teachers to the learning environment were intended to provide greater thermal comfort, not to minimise energy use. Also, since the changes were made by the teacher on behalf of the students, the study shows the need for different models of environmental control for spaces with multiple inhabitants, such as classrooms, courthouses, open plan offices.

SENSORY ISSUES

The importance of understanding rates of change is also noted by John Berry, who suggests that while most building occupants are unable to judge absolute levels of temperature or lighting, they are able to detect changes in level of the smallest order. He argues, however, that changes due to natural phenomena are tolerated far more than those arising from artificial systems, which tended to result from system failure, such as a faulty light fitting (Berry, 1982). Berry does suggest a limit to temperature variation, of 1½°C per hour.

The idea of variation to thermal comfort conditions reflects Lisa Heschong’s description of the need for ‘thermal delight’ in architecture (Heschong, 1979). Similarly, Ong has argued that well designed spaces should be able to provide different thermal conditions in the one location (Ong 1997). While environmental design has tended to focus on reducing environmental stimulation, Ong suggests the need for heterogeneous conditions that reflect the complexity of our sensory experience, allowing users to seek various environmental conditions according to their particular needs at a given time. Ong proposes a model of comfort based upon stress, such that environmental variation beyond a particular level constitutes a ‘stressful’ condition that can be easily alleviated by adjustment to clothing level, activity, passive or active heating/cooling mechanisms. However, when that situation is compounded by other stresses – an inability to change the environment, or by other workplace stresses such as undertaking a difficult task or meeting a deadline – it may lead to a condition of discomfort. Significantly, stress can just as easily be induced by too little stimulation as it can by too much.

TEMPORAL MODELS

Many authors note a greater tolerance of variation resulting from naturally ventilation than from air-conditioning. Forward, in particular, describes the idea of a ‘comfort zone’ as meaningless in a naturally ventilated building. “As the resultant environment is variable, time becomes an important parameter in defining performance criteria. Frequency distributions of temperatures are more important than absolute measures” (Forward, 1995). Humphreys, critical of the use of climate chamber studies, instead promotes a view of thermal comfort based upon field studies that can allow for the influence of time on thermal behaviour (Humphreys, 1992).

Relating thermal comfort to external conditions is justified in part by the clothing level of inhabitants. Yet it may also reflect the need for a level of sensory engagement with a perceived external condition, such as that provided by views. The psychological benefit of a visual connection to the exterior may well be multiplied when extended to other senses, such as smell or hearing. Studies undertaken to determine preferred types of view, suggests a preference for spaces that are accessible for recreation activities (Kaplan and Kaplan, 1989). Yet it may also be possible that views are appreciated for environmental clues, such as changing patterns of light and air movement made visible through the movement of foliage.

A project by Fergus Nicol and Susan Roaf carried out in Pakistan in 1993-94 sought to provide a more accurate model of individual comfort conditions through the use of a portable data logger, about the size of a briefcase (Nicol and Roaf, 1996). The data logger recorded temperature, humidity and wind-speed data every 5 minutes, which was correlated with survey forms recording perceived comfort, clothing and activity level, and skin moisture. Based upon this study, Nicol and Roaf recommended an indoor comfort temperature of 17
+ 0.38x mean outdoor temperature for the preceding month (°C). More recently, a project by Richard de Dear into an ‘Adaptive Model of Thermal Comfort’ used a comparative study of thermal comfort data from 26 cities around the world to provide indoor comfort temperatures correlated with external climatic conditions (de Dear and Brager, 1998). While both of these projects lead to varying indoor comfort temperatures, they do so only in response to external conditions, and not to spatial or temporal variation of activity.

THE CURRENT PROJECT

In a project currently being carried out at the University of Melbourne, portable data loggers are being used to model changing thermal comfort conditions resulting from inhabitant movement between spaces. The aim of the project is to investigate preference for, and tolerance of, ‘dynamic’ comfort conditions in buildings, ie variation to temperature and wind speed resulting from inhabitant activity, such as moving to another space (indoor/outdoor), opening or closing windows, or adjusting temperature settings. By correlating user movement with data collected using body-mounted equipment, it is hoped that a clearer picture of comfort conditions will be developed that takes account the need for environmental stimulus described in many of the studies above. This research should therefore lead to conditions of comfort that can be more easily achieved with passive ventilation or mixed mode systems.

The basic task is to investigate user response to patterns of environmental variation in order to determine differences between those that are welcomed, those that are tolerated, and those that cause distraction. The study will consist of the collection of data for a period of one week at a naturally ventilated building in Melbourne, repeated four times throughout a one year period to reflect seasonal variation. The data will be recorded on logging equipment carried by the research assistant whilst using ‘shadow’ techniques, observing and mimicking the behaviour of building occupants by moving between workstations, meetings, photocopy rooms, etc. This will be complemented by weather data collected on site, as well as limited questionnaires recording occupant comfort levels over the test period. This method relies upon an assumption, following Humphries, that the comfort level of occupants is behaviourally determined, ie, that people who are dissatisfied with thermal conditions will ‘vote with their feet’ by temporarily moving to another space. The questionnaires will be used to provide preference data, namely whether the subjects are in fact ‘comfortable’ at any given time, and whether their behaviour is motivated by a desire to change comfort conditions. The data will be analysed to determine rates of change and frequency distributions resulting from user behaviour in order to establish a temporal model of thermal comfort conditions. A typical limitation in most thermal comfort studies is the variation in tolerance of different building users. Fanger’s work for example, suggests that even at optimal conditions, a small percentage of people will be dissatisfied. While this project will attempt to document changes to comfort conditions brought about intentionally or otherwise by user activity, these would certainly not be the same for every building user. At this stage, however, the project is intended to establish a temporal model, giving frequency distributions or rates of change for a single user, which can be compared against existing steady state data.

REFERENCES