COMFORT:

A review of philosophies and paradigms

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March 2004

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Introduction

The term 'comfort' might be used to describe a feeling of contentment, a sense of cosiness, or a state of physical and mental well-being.[1] Our own concern is with how different meanings of comfort have come to define indoor environments and the strategies for thermal regulation they embody. Meanings of comfort have changed dramatically over the last century, with considerable implications for indoor environmental management and energy demand. The purpose of this literature review is to explore the scientific and philosophical assumptions on which various definitions of comfort are based and consider how these have framed debates about the construction and management of indoor conditions.

Our interest in 'comfort' is inspired by concerns over climate change. The conditions people have come to expect indoors, and the heating and cooling technologies that sustain these, already make heavy demands on the world's energy resources. Current standards of comfort are unlikely to be sustainable in future, especially if maintaining these means the increased uptake of air-conditioning to manage the effects of global warming. This makes the evaluation of alternative philosophies of comfort that might support less resource intensive strategies of thermal regulation more pressing than ever.

Questions of comfort have been addressed by physiologists, biologists, anthropologists, historians, sociologists, epidemiologists, geographers and urban planners. Our approach is to take stock of how representatives from these disciplines have enrolled and promoted different concepts of comfort and for what purpose. Rather than focus on the technical detail of the different accounts, our aim is to map principal lines of enquiry, and consider how these intersect overall to shape ideas about the indoor environment. In reviewing the variety of perspectives on offer and comparing underlying philosophies and paradigms, we show how different meanings of comfort have been socially produced and how certain definitions have fallen in and out of favour.

Our analysis of this material also reveals significant differences in the conceptualisation of relations between humans and the 'natural' environment.

[1] Comfort does not always have positive connotations and in some contexts is associated with complacency and laziness. For example, in the world of management studies, being in the 'comfort zone' is represented as a threat to worker productivity and organisational efficiency (Bardwick 1995, O'Toole 1995).

Opinions concerning how much heat or cold is a good thing for human bodies, how much climatic variation is acceptable or what constitutes a "good" or "bad" spell of weather for individuals or societies, vary considerably. Revisiting these fundamental questions is especially relevant in the context of climate change.

In identifying different families of ideas about comfort and showing how these relate to each other we provide a useful resource with which to reflect on the state of interdisciplinary debate about the indoor environment; past, present and future. In turn this review will provide the basis for further examination of how different comfort paradigms have influenced the shape of indoor environments and the specification of heating and cooling systems in practice.[2]

To begin we set out the parameters of our literature review into the meaning and character of comfort, and explain what we included and excluded, and how we chose to organise the eclectic and extensive selection of material at our disposal.

Comfort research

Comfort is a contested and controversial field with differences reflecting alternative disciplinary philosophies and approaches. In developing this literature review we have tried to include a variety of materials that capture the principal strands of disciplinary debates.[3] Our interest is in examining the relationship *between* comfort, technologies, humans and their environments. As such, we omit from our review, purely technical research, including studies designed to test or model the performance of buildings or specific ventilation, cooling or heating technologies.

A number of reviews of physiological and psychological work on thermal comfort already exist (Brager and de Dear 1998, Humphreys 1976, Oseland and Humphreys 1994), but we want to go beyond these to explore ideas about the historical and cultural definition and construction of comfort from across the social sciences. How are thermal needs structured by the commercial objectives of provider groups? What are the global politics of comfort provision? What is the cultural and symbolic significance of comfort to different consumers? How is comfort associated with the health and well being of society as a whole? These are just some of the questions and issues that sociologists, geographers, epidemiologists, anthropologists and historians have addressed.

Historical research relevant to comfort falls into one of two broad groups. Engineering-based histories typically offer accounts of the quest for comfort and the role of key innovators and technologies in this process (Donaldson and Nagengast 1994, Pauken 1999, Roberts 1997). Meanwhile, social historians, like Crowley (2001) and Rybczynski (1987), look at how ideologies and technologies

[2] This is the objective of the next stage of our research in which we interview those involved in the design, specification and construction of buildings in the UK

[3] This literature review forms a companion piece to our annotated bibliography of comfort research (also available on the project website).

of comfort have co-evolved within society. Such authors suggest that comfort is as much a cultural phenomenon as a technical innovation.

Contributions from the building, natural and engineering sciences are abundant – a bibliographic search on Science Direct identifies over 2000 articles related to "thermal comfort" during the last 10 years. A review of article abstracts reveals a number of studies reporting the findings of physiological and ergonomic experiments designed to test the responses of humans to different thermal stimuli and changing physical conditions within laboratories (Havenith et al 2002, Parsons 2002). These studies are useful in defining and refining the biological, physical and physiological parameters of comfort and accounting for differences related to factors such as gender, disability or age. Field studies of the thermal performance of buildings and the comfort perceptions of occupants also abound and offer further insights into the physiological and psychological variables that influence definitions of comfort in the real world (Busch 1992, Nicol et al 1999, Stoops 2000).

Research on the interaction between the indoor and outdoor environment, and the relationship between buildings, climate and culture is also relevant (Aronin 1953, Givoni 1976, Olgyay 1963). Architects, planners and geographers have all examined the extent to which urban form and function (e.g. green spaces, building density or street layout) and distinct micro-climatic conditions (e.g. wind tunnels or heat islands) interact to create zones of thermal diversity within cities and how this influences the perceptions and actions of those who use these spaces (Eliasson 2000, Steemers 2003, Zacharias et al 2001). Another tradition combines architectural and anthropological knowledge to analyse the religious, spiritual, symbolic and folk theories of urban or building design that embody different understandings of what comfort is and how it might be achieved (Rapoport 1969, 1980).

Comfort is also associated with human health – defined not just as the absence of disease but in terms of a total sense of physical, mental and social well-being (World Health Organisation 1946). Epidemiological studies have identified significant risk factors to human health associated with everyday technologies used to provide comfort in different environments (e.g. open fires, air-conditioning and evaporative coolers) (Bruce et al 2000, Ezzati and Kammen 2001). Investigations of heat waves or cold snaps have shown that extreme climatic conditions challenge perceptions of comfort and associated risks amongst different social groups (Klinenberg 2002, Semenza and Rubin 1996). A number of epidemiological and socio-economic studies have also addressed issues of fuel poverty (Boardman 1991, Healy and Clinch 2002, Rose et al 1989, Salvage 1993, Wilkinson et al 2001).

Although contributions from the non-social sciences dominate our aim is to draw together social scientific research. As well as searching bibliographic databases, we contacted social scientists working in the field, asking them to identify key articles and critical issues. This led us to historical, anthropological and sociological material, including: cross-cultural analyses of changing conventions

of heating, cooling and sweating (Aaland 1978, Wilhite et al 1996a); historical studies of the construction and normalisation of comfort related technology and practice (Ackermann 2002, Cooper 1998, Shove 2003); and, investigations of social variation in the use of household technologies (Kempton et al 1992, Lutzenhiser 1992). Such material offers important insights into the dynamics of comfort and processes of divergence and convergence in relation to thermal norms and expectations.

Finally, we identified recent work on the relationship between comfort, energy conservation and climate change. Since the 1970s environmental economists and sociologists have been concerned with the long term implications of changing comfort expectations and practices of heating and cooling for patterns of energy consumption and demand (Cooper 1982, McGeevor 1982). More recently, concerns over climate change and escalating CO_2 emissions have prompted environmental engineers and economists to produce models to help predict what future outdoor conditions might be like and what this might mean for the definition of comfort and specification of the indoor environment.

The following sections explore these different families of literature in more detail and consider the evolution of particular sets of arguments and debates. Our review is organised around six broad themes:

1. Comfort, technology and society
2. Comfort and the indoor environment
3. Comfort and the outdoor climate
4. Comfort, health and well being
5. Comfort, culture and social convention
6. Comfort and climate change

Each theme incorporates contributions from different disciplines. First we consider how historians have represented the relationship between meanings of comfort and the evolution of technologies and society. Next we consider the ways in which the building, engineering and natural sciences have defined and analysed thermal comfort in the indoor environment. Going beyond the building envelope, our third theme incorporates ideas from architects, geographers and urban planners about how outdoor climatic conditions influence the definition and achievement of comfort. The relationship between health and human comfort, as understood by epidemiologists, medical and social scientists is the subject of theme 4. The ideas of anthropologists and sociologists dominate theme 5, which examines social and cultural conventions of comfort. Finally, we focus specifically on the issue of comfort and climate change.

In organising material within each theme, we distinguish between underlying ideologies, methodological orientations and scales of analysis. Physiological enquiries generally evaluate comfort in terms of a relationship between human beings and their immediate environment. Sociological investigations emphasise the extent to which people and buildings co-evolve within society and how comfort is socially constructed. Geographers typically take the view that comfort

relates to the changing relationship between indoor and outdoor environments and how people mediate between these. In our review these different approaches are distinguished and elucidated. Within each category and sub-category we have tried to include the most important articles and more unusual contributions that add new dimensions to established debates.

1. Comfort, technology and society

Engineering-based histories: the quest for comfort

Historians like Roberts represent comfort as the end point of a technological quest, driven by advances in engineering (Roberts 1997). Innovations in air-conditioning and other forms of heating, cooling or ventilation are essentially viewed as the technological solution to the problem of producing environmental conditions that are beneficial for human health, comfort and productivity. Nagengast (1999), writing about the development of air-conditioning in the early 20th Century in the United States, has described how mechanical systems were perfected such that a once expensive and problematic curiosity evolved into "comfort air-conditioning" for all. Further studies in this vein show how mechanical systems of cooling came to transform expectations of comfort in all sectors of daily life – including factories, movie theatres, schools, offices, cars and homes (Arnold 1999, Donaldson and Nagengast 1994, Janssen 1999, Pauken 1999).

In the historical accounts of engineers, comfort is generally presumed to be a definable human condition or attribute, with each new innovation bringing society closer to the achievement of ideal indoor conditions. Starting from a different set of assumptions, social historians take comfort to be a malleable construct and social achievement. Their accounts show how ideologies and meanings of "comfort" have changed over time, and how different definitions fall in and out of favour.

Social histories: the construction and invention of comfort

A number of social historians have explored the ambitions and practices of engineers and scientists involved in the construction of heating and cooling devices and associated practices (Cowan 1983, Forty 1986, Wright 1964). Wright (1964) describes the contribution made by key innovators, including Benjamin Franklin and Count Rumford (the 'apostle of comfort') to the development of early household heating devices, including fires, stoves and chimneys. Shove (2003) suggests that the efforts of these early pioneers were guided more by an interest in the physics of thermal efficiency and by a desire to perfect and promote the performance of specific heating devices than by issues of comfort. Once established within homes, however, such heating and cooling devices have a long-lasting influence on the organisation of social activities. For example, Canter et al (1974) suggest that the open fire and hearth have remained a focal

point for family life in many UK homes, despite the advent of central heating systems.

In the foreword to his book "Home: a short history of an idea", Rybczynski discusses the poverty of architectural ideas about meanings of comfort, and asks, "what is comfort beyond the comfort zone?" (Rybczynski 1986: pix).[4] Focusing on what comfort has come to mean in the context of the home, he describes a concept that has evolved with the changing history of ideas about privacy, austerity, efficiency, domesticity and modernity. Cultural ideas like comfort, Rybczynski concludes, have a life that is measured in centuries. Also exploring the changing meaning of comfort in Anglo-American society, Crowley considers the earlier spiritual association of the term comfort through to its modern incarnation as "self-conscious satisfaction with the relationship between one's body and its immediate physical environment" (Crowley 2001: 142).

Rybczynski (1986) makes the further point that, since the 1920s, comfort has changed not only qualitatively but also quantitatively. Technological developments, he argues, have had a special position in shaping the recent history and physical reality of comfort and in turning it into a mass commodity. Cooper (1998) also explains how American air-conditioning manufacturers in the 1920s were interested in defining a set of environmental conditions that would sell, transforming comfort into a commodity that could be actively marketed, promoted, desired and delivered. According to Ackermann (2002), the development of air-conditioning has had a particularly profound influence on the social perceptions and expectations of American consumers regarding the definition of comfort, and especially its relation to cooling. Writing in 1992, Prins argued that many Americans have become addicted to air-conditioning and "coolth" (Prins 1992: 251).

Accounts such as these suggest that meanings of comfort are historically malleable, and that there are significant differences in what counts as normal in any one culture at any particular time. By implication innovators and technologies play an important role in making as well as meeting needs.

In the next section we show how researchers from the building, engineering and natural sciences have defined thermal comfort.

2. Comfort and the indoor environment

Since the 1920s, researchers in the engineering and building sciences have aimed to define the physiological and psychological parameters of comfort in order to determine the conditions to be achieved by those involved in specifying technologies and buildings.

[4] The "Comfort Zone" was defined by Houghton and Yaglou (1923) (American Society of Heating and Ventilation Engineers) and specifies the 'ideal' climate based on physiological measurements.

Defining comfort

Laboratory studies of comfort

Some of the earliest physiological studies involved experiments on human subjects in controlled laboratory environments. Informed by the theory of 'heat-balance' their aim was to record the biological and natural limits of human comfort. As Brager and de Dear explain: "Heat balance models view the person as a passive recipient of thermal stimuli and are based on the assumption that the effects of a given thermal environment are mediated exclusively by the physics of heat and mass exchanges between the body and the environment" (Brager and de Dear 1998: 84). Heat-balance models have since provided the basis for further physiological experiments, which have been used to develop technical standards that define conditions of thermal comfort (Fanger 1970; Nevins and Gagge 1972).

Writing in 1970, Fanger argued that knowledge of thermal comfort conditions was inadequate for environmental engineers involved in the specification of heating, cooling or ventilation technologies and indoor climates (Fanger 1970). Taking subjects' expressions of "thermal neutrality" to be indicative of comfort, Fanger developed his own "comfort equation", this method being used to define the combined conditions (i.e. air temperature, mean radiant temperature, relative air velocity and humidity level) in which the highest proportion of people are likely to be comfortable, for any specified level of activity and clothing (Fanger 1970). The Predicted Mean Vote (PMV) developed by Fanger provides a method by which the quality of indoor environments can be rated in practice and the degree of occupant discomfort assessed.

Physiological and ergonomic experiments have refined the biological, physical and physiological parameters of comfort and accounted for differences related to factors such as gender, disability, age or activity levels (Havenith et al 2002, Parsons 2002). One set of studies has focused on the question of how to define and provide comfort in extreme rather than 'ordinary' or average conditions (Parsons 1993). Another tradition has examined the relation between human comfort and the thermal properties of clothing in different test environments (Fourt and Hollies 1971, Goldsmith 1960, Hollies and Goldman 1978, Newburgh 1968). The results of such experiments have been used to specify types of clothing that will provide protection and comfort in a variety of environments (e.g. for military personnel or factory workers).

Laboratory experiments of thermal response or perception provide averaged results that have been incorporated into design codes and standards. However, they reveal little about how human beings define and experience comfort, or about how perceptions and expectations interact. A second body of physiological and psychological research aims to account for variations in thermal comfort conditions and perceptions within buildings. Field studies in this tradition challenge the validity of relatively 'fixed' concepts of thermal comfort, such as those based on heat-balance equations. These results have led some researchers

to develop more 'adaptive' models that account for multivariate and dynamic human experiences in the real world (de Dear 1994).

Field studies of comfort

Humphreys and Nicol (1998) cite Bedford's work on the comfort of factory workers in the 1930s as one of the first studies of people in their "natural habitats". Since this date, field studies have been used to qualify, refine or refute physiological or engineering based models of thermal preference and need.[5]

One objective has been to analyse variations in definitions and expectations of thermal comfort that fall outside the margins of comfort zones, defined on the basis of experimental research. A number of these studies record significant differences between comfort values based on Fanger's predicted mean vote (PMV) and actual perceptions of comfort in office environments (Humphreys 1994, Stoops 2002). Oseland (1995) has also recorded differences in the thermal sensation votes of the same group of people (with the same clothing and activity levels) in comfort chambers, homes and offices, noting a poor correlation with predicted values and suggesting that people's perceptions of comfort are influenced by the type of environment they inhabit.

Researchers examining meanings and perceptions of thermal comfort in different cultures and climatic conditions have also disputed conventional methods for measuring and recording thermal comfort. They do so with reference to evidence showing that people of different cultures consider themselves comfortable across a wide range of temperatures.[6] Nicol et al found Pakistani office workers reported being comfortable at temperatures of up to 31°C and that preferred indoor temperatures varied with climate and season (Nicol et al 1999, Nicol and Roaf 1996). People have also reported being comfortable indoors at around 6°C during an Antarctic winter (Goldsmith 1960). A study by Busch shows that office workers in Thailand were comfortable at higher indoor temperatures than those working in more temperate regions (Busch 1992). Focusing on the relation between thermal expectations and changing weather conditions, Stoops indicates that Portuguese office workers are content with a much wider range of seasonal variation (up to 5 °C) than Swedes, who do not expect indoor temperatures to waver by more than half a degree (Stoops 2002). The results of these field studies imply that universal methods for measuring and calculating comfort and the design standards they support are inadequate because they fail to account for cultural or climatic variation in peoples' interpretations of comfort.

Another set of field studies has examined differences in thermal perceptions and practices between the occupants of artificially and naturally ventilated buildings, again recording variations related to cultural expectations and climatic conditions

[5] The UK Building Research Establishment has carried out a substantive body of work in this vein since the 1960s.

[6] Humphreys (1976) provides a useful catalogue of field studies reporting different expectations of comfort worldwide.

(de Dear and Auliciems 1988). In their investigation of the attitudes and perceptions of Australian office workers in three climatically disparate cities (Darwin, Brisbane and Melbourne), de Dear and Auliciems note significant differences in "benchmarks" of comfort between those in air-conditioned and passively ventilated buildings. Specifically, those with no experience of air-conditioned offices stated they preferred passively ventilated environments even when these recorded the hottest conditions.

The wealth of evidence generated by field studies has helped to develop what Humphreys and Nicol (1998) term an 'adaptive' approach, where comfort is understood as a dynamic achievement rather than a definable condition or attribute. If comfort is thought of as a definable condition, the aim is to design indoor environments that deliver it. For engineers and designers this often means the specification of indoor temperatures at around 21 degrees centigrade, in line with the output of Fanger's equation. Those who consider comfort as an adaptive achievement favour quite different methods of defining comfort and of specifying indoor conditions.

Comfort and adaptation

Humphreys (1995) argues that people are not inert recipients of the environment, but interact with it to optimise their own conditions. The objective for thermal comfort researchers is thus to observe the daily routines, practices and habits of building occupants to see how they modify and adjust their environments to achieve comfort (Humphreys 1995). From this perspective, the challenge for engineers and designers is to specify an environment in which people can make themselves comfortable. Put slightly differently, the aim is to provide opportunity for the alleviation of discomfort (Leaman and Bordass 1995).

The issue of just how much individual choice or control over the indoor environment is practical or desirable has been the subject of extensive debate amongst those that see comfort as an adaptive achievement. In a study of office buildings in Israel, Paciuk (1990) argues that there is a strong relationship between perceived control of the thermal environment and occupant satisfaction. Leaman and Bordass (2000) suggest that people are more tolerant of indoor conditions the more control opportunities (e.g. switches, blinds and opening windows) they have available to them.

Examining strategies of adaptation and coping amongst office workers in the Pacific Northwest, Heerwagen and Diamond (1992) conclude that comfort maintenance is a highly reflective activity and that people prefer to change conditions themselves rather than have a building "decide" what to do. Too much individual control though is not always regarded as a good thing. Thinking more broadly about the relationship between thermal control and human productivity, Heerwagen and Diamond imagine a scenario in which people who might never need to leave their desks to find fresh air or a cool breeze, become what they refer to as "desk potatoes". It has also been suggested that by offering clients and users unprecedented levels of choice and control, building designers

and researchers side-step responsibilities for providing sustainable living and working environments (Shove 2003).

The aim of laboratory experiments and field studies is to define the parameters of comfort and develop methods for specifying and achieving comfortable conditions. These programmes of research have an important influence on building standards. In the following section, we present recent arguments relating to the standardisation of thermal comfort.

Comfort and standardisation

Janda and Busch (1994) have described the extent to which standards developed by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) inform national building codes across the world and are critical in defining acceptable thermal conditions for human occupancy. Given the central role of these standards in specifying indoor environmental conditions there has been a great deal of interest in how they are defined and which models of thermal comfort they support.

Brager and de Dear (1998) suggest that design standards have traditionally been based on the concept of comfort as a uniform thermal condition. The environmental costs of maintaining conditions of comfort are high, not least because: "the conventional application of fixed comfort standards, as described by ASHRAE, CIBSE and other regulating institutions would preclude passive cooling as an alternative to air-conditioning and commit our future to a lifetime of high energy use" (Baker 1993: 130).

Oseland and Humphreys (1993) also make the point that passive design strategies require different types of thermal comfort information to that produced for air-conditioned buildings. This argument is supported by Fountain et al (1996) who suggest that set point temperatures may be acceptable in air-conditioned buildings where people do not expect to self-regulate, but are inappropriate for naturally ventilated buildings. Such accounts suggest that it is important to consider the assumptions built into existing standards and to be clear about the specific environments to which they apply.

Field studies of occupant behaviour suggest that standards have their own self-fulfilling momentum. For example, Baker (1993) argues that the very existence of definable standards for mechanically cooled buildings may have been the main cause for the proliferation of air conditioning. Meanwhile, Humphreys comments that: "if the standard says you ought to have 22°C, you design for 22, run at 22 and people adapt to 22 and you find that people are happy at 22°C. However, this does not mean that 22°C is necessary, you could have gone for 20 or probably 24°C" (quote in Oseland and Humphreys 1994: 71)

Such observations are supported by empirical evidence. For example, de Dear's comparative study of workers employed in international style office buildings found that both Singaporeans and Danes responded in a manner consistent with

Fanger's model (de Dear 1994). However, in their naturally ventilated homes, Singaporean's responded quite differently and inconsistently with the prediction of these models. As de Dear explains, such findings raise issues about whether employees' expectations have changed *because* of the spread of mechanical heating and cooling in office environments.

Although disputing the suitability of current standards, especially for naturally ventilated buildings, there is widespread agreement among 'adaptive' thermal comfort researchers that some form of standardisation is required (Brager and de Dear 2000, Nicol et al 1995, Nicol and Humphreys 2002). In offices, in particular, the prospect of unconstrained personal adaptation is considered untenable. One person's breeze may be regarded as another person's draught, and even where individual control systems are favoured there are still decisions to be made about the sizing of heating and cooling systems and the design of the building as a whole.

For many thermal comfort researchers, the challenge is to develop culturally and climatically appropriate opportunities for people to make themselves comfortable (Nicol et al 1999). However, the extent to which more liberal design criteria can be established is widely debated (Baker and Standeven 1996, Nicol et al 1995).

One approach has been to develop design standards based on research showing how people adapt to changing indoor and outdoor environmental conditions. Nicol et al (1995) have argued that a prerequisite for the formulation of such standards is to generate more knowledge about the thermal performance of naturally ventilated buildings. Cena (1994) also suggests that standardised methods for field studies need to be developed in order to compare cultural and climatic differences in thermal perception and account for differences in the expectations people have of home and work environments. This is considered necessary for the development of a more rigorous set of adaptive guidelines that can be used for building design in different contexts (Cena, 1994).

In pursuing such objectives, de Dear and Brager (1998) have collated results from field studies in buildings across the world. Humphreys and Nicol (2002) have used this data to calculate PMV values at the higher and lower extremes of Fanger's original thermal sensation scale. The results of this exercise are intended to facilitate the development of design guidelines that allow for the influence of climatic variation and opportunities for personal adjustment on definitions of comfort.

The families of ideas reviewed so far show thermal comfort to be a contested field in which different disciplines accentuate different aspects of relations between human bodies, technologies and indoor environments. Histories of technology purport to show how successive innovations have helped to achieve comfort in all walks of life, without questioning what comfort is, how it is defined or how the end-goal of optimal comfort came to be established. These questions have been addressed by physiologists and ergonomists, who have defined and quantified comfort by testing the responses of human subjects in

laboratories and workplaces. With equal rigour, researchers have undertaken extensive field surveys of occupant perceptions in the real world. In the course of these enquiries, basic heat-balance equations have been extended, refined and occasionally supplanted with models of comfort that better account for the dynamics and diversity of thermal experience. Contradictions and discrepancies between studies have also ignited debates about the relevance of design standards and the scientific models and assumptions on which they are based.

In the next section we examine arguments from architecture, geography and urban planning about how understandings of indoor comfort relate to the weather outside.

3. Comfort and the outdoor climate

Comfort, climate and human performance

According to Ackermann, studies of the relationship between climate and comfort originate around the 1920s with the work of geographers, such as Ellsworth Huntington (Ackermann 2002). Huntington argued that human productivity was directly linked to climatic regimes and that those people living in "inferior" hot or humid environments were unable to advance as far along the road to civilisation as those living in more temperate regions (Huntington 1924). As Ackermann suggests, the theory advanced by Huntington carries with it strong imperialist overtones and perpetuates stereotypes about the relationship between race, heat and advancement.

Ackermann also explains how such arguments provided the "scientific" basis and legitimacy needed for the expansion of air-conditioning, both in the US and globally. Rather than succumbing or surrendering to heat, the idea was that Europeans and Americans should seek to control the weather. For example, Brooks (1950) argued that climate was "an enemy" of economic efficiency and productivity, the ill effects of which must be controlled or minimised through clothing, sanitation or air conditioning. In such accounts, air conditioning is represented as "a tool that would allow all humanity to progress beyond the accidents of climate" (Ackermann 2002: 41).

Imperialistic arguments about climate and human progress are now widely refuted, but the notion that the outdoor climate affects human performance has persisted. Writing in the early 1970s, Auliciems argued that a detailed understanding of the atmospheric influences affecting human productivity was required in order to achieve optimal thermal comfort conditions (Auliciems 1972). In a study of processes of physiological and behavioural thermoregulation amongst schoolchildren in the UK, Auliciems concludes that changing weather patterns influence comfort and work efficiency. In this account, the achievement of comfort relates to the individual control of classroom conditions and the revision of "entrenched and archaic concepts of 'proper' clothing" (Auliciems 1972: 138).

Field studies, like that conducted by Auliciems, routinely incorporate outdoor climate as one of the variables influencing human productivity and comfort indoors. However, Givoni's book entitled "Man, Climate and Architecture" is regarded as one of the first substantive attempts to synthesise research on the physical environment with physiological research on thermal comfort. Specifically, Givoni argues that design standards based on the results of Fanger's comfort equation, may need to be to adjusted to account for local variations in outdoor climatic conditions (Givoni 1976, 1998).

Olgyay (1963), meanwhile, defines a "bio-climatic" model, incorporating biological, meteorological and engineering concepts, with the specific aim of guiding building practice and styles in different climatic regimes. Such models are intended to provide a basis for the specification of comfort conditions in buildings in different climatic zones. Other broadly 'bio-climatic' studies have taken a different approach, focusing on how to define and achieve comfort in entire urban environments rather than in specific buildings (Eliasson 2000, Golany 1996, Steemers 2003, Svennson and Eliasson 2002).

Defining and achieving comfort in urban environments

Golany (1996) argues that whilst there has been considerable literature published on the subject of climate and single building design, there are few contributions focused at the neighbourhood or city level. As a consequence, outdoor spaces have received little attention resulting in climatically deficient designs that have a detrimental influence on human health, indoor comfort and social conditions (Golany 1996). De Schiller and Evans (1998) also note that cities subject to very different climatic conditions worldwide are often designed in a remarkably similar way. Together these authors suggest that theories from urban climatology and geography, and lessons learnt from indigenous urban design, might be used to help refine definitions of comfort and better provide for the needs of urban dwellers.

A number of recent field studies have attempted to redress the apparent deficit in knowledge about the influence of urban environments on thermal comfort. Steemers (2003), for example, considers how urban form (e.g. building density or patterns of transportation) influence the comfort perceptions of workers and patterns of energy use in different types of office buildings. In a study of activities in urban open spaces, Zacharias et al (2001) show how different combinations of temperature, sunlight, humidity and wind create variable sensations and generate distinct types of behaviour. Elsewhere, Svensson and Eliasson (2002) look at how changes in temperature generated by different sorts of urban environments (e.g. heat or cool islands) influence energy use and air quality. Further studies have considered the role of 'transition' spaces, which form a boundary between indoor and outdoor climates, in framing perceptions of comfort (Jitkhajornwanich and Pitts 2002).

This literature offers important insights into the interaction between indoor and outdoor environments, and between specific buildings and the cities in which they co-exist. It also shows how expectations and perceptions of comfort relate to the movement of people through the different micro-climatic regimes encountered in the course of a day – e.g. homes, bus stops, trains, cars, open spaces, foyers and offices. In each of these environments conventions of comfort and methods of evaluation and control differ widely.

Although different in scope and scale to the physiological experiments described earlier, many micro-climatic studies share the ambition of defining conditions in which people will be comfortable and of designing environments that approximate to these conditions. Designers and planners use bio-climatic models to refine specifications to suit the predicted requirements of specific urban zones. Although these models characterise climatic variation they assume standardised human needs.

Other strands of anthropological and architectural research suggest that understanding the definition and achievement of comfort requires closer inspection of cultural variation and of the social, economic and symbolic significance of the indoor environment.

Designing for climatic and cultural variation

Since the 1970s, a new wave of architectural literature has reflected changing concerns and conceptions regarding the environmental performance of buildings and their relation to the local cultures and contexts in which they are embedded (Fitch 1972, Heschong 1979). Ideas from anthropology have also been enrolled to develop more integrated or holistic theories in which the built environment is regarded not only as a form of shelter or a safe haven, but as something that is imbued with symbolic status, cultural meaning and social value (Rapoport 1969, 1976).

This line of thinking challenges the idea that comfort should be defined as a state of thermal neutrality. Heschong (1979) vividly describes socially and culturally distinct ways of achieving "thermal delight" (e.g. promenading, sitting in a shaded courtyard, moving to foothills in summer) and the immense variety of heating and cooling systems involved (e.g. fires, saunas, gardens).[7] Such strategies and systems of thermal regulation, Heschong argues, should not be designed out of existence in the name of a thermally neutral world. In terms of achieving comfort, Heschong advocates passive design approaches that not only meet thermal needs, but also resurrect thermal coping and sensing strategies and open up new dimensions of architectural experience.

Writing in 1972, Fitch observes that the design of many modern American buildings reflects an architectural "obsession" with aesthetics rather than with

[7] Also, see Reynolds (2002) on spiritual role of courtyards in supporting the rituals of everyday life and Rajala (2000) on the use of saunas as a source of thermal delight.

what is good for human productivity in a broader sense. Buildings, Fitch suggests, need to be designed not just to avoid absolute and traumatic levels of thermal stress (as defined by physiology), but to account for socially defined and culturally relative standards of health, amenity and efficiency. This is regarded as crucial if the great "paradox" of modern approaches to building design is to be avoided: "that the same mechanical systems which give us clean, conditioned air inside the building are simultaneously polluting the outside environment" (Fitch 1972: 36). Fitch concludes that: "With the complexity of modern building we need nature more than ever before. It is not a question of air-conditioning versus sea breezes, or fluorescent tubes versus the sun. It is rather a necessity for integrating the two at the highest possible level" (Fitch 1972: 237).

Although many architects have argued for more culturally sensitive approaches to building design, Rapoport (1969, 1976) goes a step further. Combining perspectives from architecture and anthropology, he represents houses as complex cultural phenomenon, rather than stand-alone structures that exist apart from society. Rapoport (1969) considers how differences in house form and type not only reflect physical requirements for comfort or the advance of technical innovation, but also relate to distinct cultural values and expectations. For example, in Cambodia certain religious groups see shade from trees as unlucky and discount sitting under them as a strategy for keeping out of the sun. In North Africa the spread of European style houses (without courtyards) is associated with issues of modernity, status and symbolism as much as with physical comfort. Rapoport suggests that many aspects of building design fall outside the frames of reference of psychological, physiological or bio-climatic models.

As well as acknowledging the historical and cultural context in which buildings are developed, studies like Rapoport's have implications for the framing of questions of comfort and for associated methods of enquiry. In other words, the aim is to look at what people already have, what works well for them, and what characteristics of people and social groups are important in shaping environments, rather than focusing on quantifiable or standardised definitions of comfort as guide to what should be provided. Evans (1980) makes the further point that traditional houses represent the result of many years or centuries of optimisation in relation to materials, social organisation, labour practices and climatic conditions. As such, they can provide useful lessons for building designers, even if they cannot provide a straightforward template for modern living (Evans 1980). However, as Saleh explains, very often the social and cultural heritage of traditional building design is bypassed in the rush to modernise and adopt imported notions of users and standards of comfort (Saleh 2001).

The positions represented here suggest comfort is culturally and climatically defined and show how specific approaches to building design reflect accepted ideas about what is an appropriate or 'good' environment in different contexts. The design features of good or comfortable buildings depend on ideas about what is modern, prestigious or culturally acceptable. As such the authors acknowledge that a 'comfortable' building in one setting might be totally unsatisfactory to those in other cultures or communities.

In section 5, we consider culturally informed perspectives about the meaning and achievement of comfort. Before doing so we consider the relationship between comfort, human health and well-being.

4. Comfort, health and well-being

The achievement of certain standards of comfort is often considered a vital ingredient for the maintenance of human health (defined as a total sense of physical, mental and social well-being). However, ideas about the sorts of conditions (social, environmental and economic) that might be required to achieve healthy bodies or minds diverge considerably and have been the subject of investigations initiated by epidemiologists, environmental scientists and economists.

Indoor air pollution, comfort and health

All over the world, the methods used to heat and cool indoor environments have come under scrutiny. Many epidemiological investigations have the purpose of elucidating the relationship between specific indoor environmental conditions and patterns of illness, disease and death. A study by Ezzati and Kammen (2001) quantifies the effects of exposure to indoor air pollution from biomass combustion for acute respiratory infections in developing countries. Another study by Jaber and Probert (2001) examines how the increased use of open fires and portable stoves in Jordan has led to an increase in the numbers of people who die each year from inhalation of fumes and gaseous pollutants. The potential link between air-conditioning systems and legionnaires disease is another area that has attracted attention (Fisher-Hoch et al 1981, Hedges and Roser 1991). Meanwhile, Larson and Rosen, have examined the economic ability or propensity of households in developing countries to invest in interventions that alleviate the effects of indoor air pollution (Larson and Rosen 2002).

Together these studies point to the need to extend meanings of comfort to account for both the thermal and atmospheric quality of the indoor environment. The specification of a 'good' building in effect depends on an assessment of the total environment and on how far occupants can adapt to a continually changing landscape of risk.

Building and medical scientists have turned their attention to modern-day phenomena, such as sick-building syndrome (SBS), a controversial condition most often associated with artificially ventilated office buildings (Clements-Croome 2000, Kroeling 1988, Wargocki et al 2002). Kroeling compares a number of surveys of 'disorders' and complaints regarding comfort, well-being and health in air-conditioned buildings. The results show that, compared to a control study of a conventional non-conditioned building, those in air-conditioned environments complained significantly more frequently of a tendency to colds,

dry throats, headaches and irritability. Respondents also reported being affected by not being able to open windows, and by dry air and draughts (Kroeling 1988).

Wargocki et al (2002) review scientific material on the effects of ventilation on human health, comfort and productivity in non-industrial indoor environments (e.g. offices, schools and homes). On the basis of current physiological and epidemiological evidence, they suggest that ventilation and air quality requirements embodied in many existing building standards are inadequate and may increase the risk of sick-building syndrome symptoms (Wargocki et al 2002). An alternative explanation is offered by Raw (1992), who argues that phenomena like SBS may relate more to peoples' perceptions of control over the indoor environment.

Saunders (2002) argues that 'unhealthy' indoor environments are a social and political rather than a psychological or physical issue. Using the allegory of the "boiled frog syndrome", he makes the claim that humans in their quest for greater comforts are creating ever more unhealthy environments in which to live and work.[8] Air-conditioning is singled out as a particular danger, being associated with the construction of sealed boxes that exacerbate health and environmental problems, both indoors and outdoors.

In Saunders' account, consumer expectations drive changing specifications of comfort and contribute to unhealthy conditions in buildings. Socio-economic investigations of fuel poverty or affordable warmth suggest that there is a great deal of disparity in the extent to which different social groups exercise control or choice over their indoor environment.

Comfort, health and social inequality

A number of socio-economic studies have focused on the influence of cold homes on the health and well being of vulnerable groups, including the elderly or fuel poor (Boardman 1991, Salvage 1993, Wilkinson 2001). Boardman (1991) argues that "fuel poor" households in the UK are currently limited in their ability to achieve comfort (defined as an average room temperature of 21^{o}C) because of behavioural, financial and technical constraints. In a study of domestic conditions in Northern Ireland, Healy and Clinch (2002) report that over a half of elderly households studied recorded "inadequate" ambient temperatures during the winter. Rose et al also highlight differences in temperatures in different parts of the house. In their study of comfort and fuel use in 14 South London pensioners' flats they found that living rooms temperatures in the afternoons and evenings fluctuated between 17 to 24 degrees centigrade, while temperatures in bathrooms and bedrooms were sometimes as low as 2 to 5 degrees centigrade. These

[8] "A frog jumps into a pot of water which is gradually being heated. As the water gets warmer, the frog adjusts its body temperature and continues to adjust to the increasing water temperature until, ultimately the frog is boiled alive" (Saunders 2002). Saunders suggests that, like frogs, humans keep adjusting to ecological hazards in order to satisfy demands for grater comfort, convenience and easier living.

studies are typically motivated by an interest in providing affordable comfort for vulnerable groups (Rose et al 1989).

Epidemiologists and medical scientists have examined the relationship between extreme thermal conditions and patterns of heat or cold related deaths. Semenza et al conducted a study of heat-related deaths during a record-breaking hot spell in Chicago in 1995 (Semenza and Rubin 1996). Their study shows that those most at risk of dying were people with pre-existing medical conditions, who were socially isolated and did not have access to air-conditioning. Another study of heat stroke patients in Taiwan during the summer of 1998 shows that those who fell ill were mostly middle-class, living in inner urban areas and were not socially isolated (How et al 2000). These studies suggest that heat-related illness or mortality should be viewed as a complex medical, social, economic and environmental phenomenon the effects of which vary widely in different contexts.

This is a contested field, for there are different views about what sorts of conditions are healthy for bodies and minds, and whether perceptions of 'bad' environments or 'sick' buildings relate to the actual conditions recorded indoors. Studies of fuel poor households represent "comfort" as a standardised target. Others, like Saunders suggest, that standards of comfort are being driven upwards with detrimental implications for human health and the environment. Investigations of extreme events show that there are physical limits beyond which humans can no longer survive, but that comfort is socially and collectively negotiated. These studies also show how important access to social and technical infrastructures has become in maintaining human health.

Many of the studies reviewed so far have focused on individual bodies either in comfort chambers or as occupants of offices, schools, homes, or open spaces. Some have represented individuals as aggregated physiological beings, others as active occupants or citizen-consumers who adapt and control their own destinies at work, home and play. In some cases cultural and social contexts have also been examined, but usually only in relation to distinct building "envelopes" or urban "micro-climates". In the next section, we review socio-cultural and socio-technical concepts of comfort that generate a distinctly different understanding of inter-relationships between humans, buildings, technologies and the wider social, political and natural environment.

5. Comfort, culture and social convention

Sociological and anthropological contributions on the subject of thermal comfort have been relatively limited compared to those from the building, natural and engineering sciences. There are, however, several studies of how people actually manage their homes and the heating and cooling technologies they contain.

Household variation in comfort standards and practices

The socio-economic studies we have reviewed so far focus on peoples' ability to achieve comfort, assuming this to equate with a standard indoor temperature of around 21-22^{o}C (Boardman 1991, Healy and Clinch 2002). However, sociological and anthropological studies of energy using behaviour suggest that expectations of comfort vary widely, even in situations where households have similar levels of income and access to infrastructures and services (Lutzenhiser 1992, Kempton et al 1992, Kempton and Lutzenhiser 1982, Wilk and Wilhite 1987). In other words, households achieve comfort in their own terms, without complying with 'universally' defined standards.

Ethnographic studies of the heating and cooling practices of families living in similar dwellings and within seemingly homogenous neighbourhoods reveal wide variation in the meaning and achievement of comfort (Diamond 1987, Hackett and Lutzenhiser 1991, Kempton et al 1992, Kempton and Krabacher 1987, Weihl 1987).

One study by Kempton and Krabacher (1987) explores trends in thermostat management in seven households over a two-year period, and reports great diversity in average winter thermostat settings (ranging from 64 to 74^{o}F). Interviews with families also revealed a wide variety of different strategies for keeping warm such as wearing more clothing, covering oneself with a blanket, or moving to a warmer room in the house. Weihl monitored the use of space heating systems in four residences during the winter of 1983-84, noting a significant relationship between the complexity of daily schedules and thermostat setting behaviour. Wiehl argues that thermostat controls need to be designed to correspond better with patterns of daily family life (Weihl 1987).

Kempton et al (1992) investigated room air-conditioner use in a multi-family apartment in New Jersey, United States. The study showed how the use of air-conditioner controls was influenced by many social and cultural factors, including daily schedules, folk theories and personal beliefs. In an earlier study, Kempton and Montgomery (1982) explain that household or 'folk' knowledge of natural and technological systems is often at odds with the understandings of engineers or designers. For example, households may choose to open windows in air-conditioned homes in ways that make no thermodynamic sense but are consistent with what they have always done.

These sociological and anthropological investigations of variations in household technologies and practices remind us that the day-to-day management of the indoor environment is not an isolated enterprise, cut off from the rest of social life. Household strategies are not only based on what engineers or economists consider as 'rational' behaviour, but also depend on folk theories of how homes should be managed and on the complex interplay of gender and power relations between household members. Comfort in such situations is tied to issues of social status and is governed by what is considered socially appropriate in a particular community or family. Many aspects of routine consumption, including practices of heating and cooling, carry social meaning and significance – the intention is not only to meet thermal needs, but also to fulfil symbolic and

aesthetic dimensions. In the following section we consider some of the ways in which comfort is defined by cultural norms, collective conventions and symbolic values.

Comfort as a matter of social and cultural convention

Cross-cultural variation in heating and cooling technologies and practices

Wilhite et al's (1996b) study of energy using practices in Japanese and Norwegian households highlights important cross-cultural differences in heating and cooling habits. In Norway, the researchers found it was common to heat all rooms creating a thermally consistent environment in which to move around. In Japanese households it was more common to use technologies, such as the "kotatsu" – a small heating unit placed under a table – designed to heat individual bodies rather than surrounding spaces. In both cases, strategies of heating were related to culturally relative ideas about comfort, as well as to routine forms of social interaction, with the kotatsu also providing a focal point for family life.

Reflecting on the "tantalising findings" of previous studies showing that Swedes use only 60 per cent as much energy as Americans despite maintaining a notoriously high standard of living, Erickson (1987) explores the cultural shaping of household energy use. Examining household activities in dwellings in two Swedish and American towns, Erickson concludes that cultural conventions explain differences in energy use. Specifically, the Swedish concept of "lagom", interpreted as a moral code about communal rights, appears to temper energy use. Certain respondents invoked this concept when explaining that it was important to take only what they regarded as a fair share of resources (Erickson 1987).

Clothing conventions, fashion and comfort

Thinking more broadly about socio-cultural strategies for keeping warm or cool, it is relevant to consider clothing conventions. In observing that Canadians appear to wear more woolly sweaters than American neighbours just across the border, Cena (1994) implies that clothing conventions have a social and cultural as well as physical dimension. To date, however, there have been few efforts to explore the relationship between clothing habits and fashions, strategies of thermal regulation and socio-cultural expectations.

Physiological and ergonomic researchers have examined the relation between clothing and perceptions of thermal comfort, but these largely technical contributions tell us nothing about changing fashions and the achievement of comfort in different cultural contexts (Fourt and Hollies 1971, Hollies and Goldman 1978, Goldsmith 1960, Newburgh 1949).

Socio-psychological studies of clothing and human behaviour typically represent clothing "choices" as a function of fashion and social status (e.g. the desire to

"make an impression"), taking little or no account of its role in managing or mediating thermal comfort. Ryan goes so far as to suggests that: "if human beings were not reacting to other human beings in social situations then there would be no need for clothing, beyond perhaps protection from the cold" (Ryan 1966: 2).

Conventions of sweating, control of bodies and comfort

From a physiological perspective sweat is essential for the thermo-regulation of bodies (Givoni 1976). Yet, we know little about how social conventions of sweating influence peoples' activities in different cultures or situations and how this affects technologies and practices of thermal comfort.

Aaland has investigated the pleasures and practices of "sweat bathing" in different cultures – from the Finnish sauna, to the Islamic Hamman and American sweat lodge – and shows how different conventions of sweating relate to distinct medicinal, spiritual and social values (Aaland 1978). In Finland, for example, the tradition is one in which people sweat together in communal saunas. Such examples suggest that sweating is not always something to be disguised. Aaland concludes that such preferences are often ignored in an age of anti-perspirants and air-conditioners.

Prins also comments that it is not self-evident that air-conditioning in hot places makes life more agreeable, explaining that the body is provided with its own rather efficient cooling mechanism. Sweating, Prins argues, makes human bodies wet, smelly *and* comfortable, whilst air-conditioning is designed to keep bodies dry and free of natural odour (Prins 1992). Prins further suggests that the aim of air-conditioning is to discipline bodies, such that they have no excuse to stop working. Such narratives imply that technologies of comfort are designed to control humans and in the process even out variations of culture and convention.

Changing conventions of comfort

Studies of social and cultural convention show expectations of comfort to be highly diverse, but there is also evidence to suggest that definitions of comfort are converging around the world. As noted, building scientists have argued that thermal standards tend to be self-fulfilling, such that expectations converge around certain norms (e.g. 21-22°C) (Baker 1993, Oseland and Humphreys 1994). Thinking more globally, social researchers like Wilhite suggest that conventions of comfort are converging around "Western" standards (Wilhite et al 1996b).

Reflecting on the spread of air-conditioning in the United States, Cooper (1998) explains how manufacturers and engineers defined and marketed the concept of an optimal indoor environment to the American public. The cultural implications of mass marketing air-conditioning and the appropriation of westernised clothing standards in tropical regions, has been addressed by Aghemabiese et al (1996).

Many people from tropical climates are, they argue, currently uncomfortable with air-conditioning but accept it all the same. Wilhite et al (1996a) examine the extent to which changing patterns of energy use in Japan, especially those associated with the increased uptake of air-conditioning, relate to the importation of Americanised values of cooling relayed through advertising.

In his study of the Chicago heat wave, Klinenberg describes how social conventions and strategies of coping with heat have changed over the last few decades with significant social and environmental implications. In extreme weather events during the 1960s and 1970s people often slept outdoors and cooled off in public fountains or baths (Klinenberg 2002). In the 1995 heat wave, strategies were noticeably different, most people choosing to stay indoors and switch on the air-conditioning (a tactic that resulted in pressure on electricity networks and widespread power cuts). In highlighting these differences Klinenberg concludes that achieving comfort is increasingly seen as a matter for individual rather than social regulation. Furthermore, Klinenberg's study shows how people's ability to cope with extreme hot or cold spells is intimately connected to changing patterns of social organisation and urban life.

The social and cultural ideas discussed so far imply that comfort is a matter of social and collective negotiation. Our literature review also unearthed research which suggests that definitions of comfort are constructed by institutions and embodied in socio-technical systems.

In a study of the UK building industry, Guy and Shove (2000) have shown how certain ideas about thermal comfort and energy efficiency have evolved and how these have been appropriated by building practitioners involved in sustainable construction. In the process some technologies or techniques become embodied in the built environment at the expense of others. As Rohracher suggests (2001) the real environmental challenge is one of transforming institutional practice, integrating supply chain actors, developing markets for ecological buildings services and involving consumers in the innovation process.

In the last section, we discuss a selection of material that explicitly examines the challenges involved in creating future environments that are comfortable and sustainable in the context of rapid and long-term climate change.

6. Comfort and climate change

Cooper argues that creating habitable spaces has become synonymous with the consumption of fossil fuels, partly as a result of the drive for optimal indoor conditions (Cooper 1982). Further, Shove (2003) suggests that maintaining indoor comfort standards, as enshrined in the codes produced by organisations like ASHRAE, commits society to dangerously unsustainable patterns of energy use. If responses to climate change mean that people over the world expect their homes to be mechanically cooled or heated to create a uniform indoor environment existing environmental problems will be exacerbated. In the wake of such

concerns, social and environmental scientists have begun to re-examine standards and expectations of comfort.

Pretlove and Oreszczyn (1998) explain that buildings are designed for a specific climate, yet they often have a lifetime of more than 100 years. They suggest that many existing buildings will no longer be able to provide thermal comfort under changing climatic conditions and new design standards that allow buildings to operate over a range of climatic conditions might be required (Pretlove and Oreszczyn 1998).

Technologies or design features currently considered efficient might prove to be less so in future. Orme et al (2003) suggest that building regulations currently favouring high levels of insulation and air-tightness may result in overheating in the future. As a consequence, artificial cooling might be required to dispose of heat gains. A study by Babcock and Irving shows that so-called 'passive' design features, like conservatories, are often cooled in summer and heated in winter. Energy consumption attributed to these spaces is likely to increase considerably in the future (Babcock and Irving 2003).

Garvin et al examine the possible impact of climate change on comfort conditions in buildings and on the health of occupants. One of the concerns raised is that rising temperatures and more humid environments will increase the risk of air-borne infection (such as legionella) or contribute further to reported incidences of sick building syndrome (Garvin et al 1998). Studies of extreme events, like heat waves, also highlight some of the health implications and social and technical adjustments that might be required to cope with climate change and suggest that changes at the institutional and infrastructural level will be required (Klinenberg 2002).

Engineers and economists have developed predictive models to try and assess the implications of global climate change for the indoor environment (Cullen 2001, Pretlove and Oreszczyn 1998). In combining the results of these models with different economic, social and technological scenarios, these authors specify the indoor conditions that will need to be provided in future all other things (including contemporary conventions of comfort) being equal. In formulating possible strategies and responses, distinctions have been made between rapid and gradual climate change. In respect of sudden or extreme events, it has been argued that mitigation measures may be required. For more gradual or step changes, the scope for adaptation is seen to be greater.

One of the strategies proposed for coping with climate change is to improve the energy efficiency of buildings, such that standards might be maintained in less demanding ways. This is the approach taken by Milne and Boardman (2000) who suggest that a high proportion of the heat gained from improving the energy efficiency of homes can be taken as improved 'comfort' rather than as energy savings (Milne and Boardman 2000). The evaluation of savings in comfort or energy is based on the assumption that comfort standards will remain the same.

Surveys of conditions in households suggest that expectations and standards of comfort are changing. Recent surveys of UK homes estimate a steady increase in average temperatures, with living rooms now routinely heated above the accepted standard of 21-22^{O}C (Walter et al 2000). If the objective of policy makers is to meet comfort standards whatever these may be, then the implications of such trends for household energy demand are considerable. The extent to which standards and expectations of comfort might change in future and how this will influence the appropriateness of different strategies of thermal regulation is another consideration.

To finish, we reflect on the dominant lines of debate identified in this review and what these mean for the issues and challenges ahead.

Comfort paradigms and future trajectories

The definition and provision of comfort is controversial and contested issue, but one that is of immense importance to the construction of sustainable buildings, cities, lifestyles and societies. In looking at how comfort is currently understood by researchers working in different disciplines, and in mapping different lines of enquiry and debate we have shown that particular interpretations of comfort are literally embodied in buildings.

Our review shows that there are many different ways of conceptualising, defining and analysing comfort. These inform different approaches to building design and to the achievement of comfort in the real world.

If comfort is conceived of as a natural state of affairs there is no need to question or re-evaluate peoples' thermal requirements. Having unquestioningly accepted that comfort exists the challenge is to find more efficient and less environmentally damaging ways of meeting these needs. For those supporting this position, technology (including more energy efficient air-conditioning) is a key part of the solution.

Building and environmental scientists subscribing to an 'adaptive' model take a more relaxed approach to the definition of comfort. Although comfort is still regarded as a definable condition, the idea that standards are fixed or that 'thermal neutrality' is the only goal is challenged. From this perspective, the challenge for those designing indoor and urban environments is to provide healthy indoor conditions that offer sensory stimulation and extensive adaptive opportunity.

Comfort is a highly complex and diverse phenomenon the meaning of which depends on the social context in which it is defined and constructed. Issues of lifestyle, fashion, convention, obligation and convenience influence expectations of comfort and the strategies of thermo-regulation considered 'natural' or 'normal'. Comfort is also a commercial and political achievement as witnessed in the mass marketing and diffusion of Westernised standards across the world.

From this perspective, the task ahead is to redefine meanings of comfort so as to prevent unsustainable expectations taking hold or becoming a self-fulfilling prophecy.

Acknowledgements

This paper forms part of our project "Future Comforts: re-conditioning urban environments", which is funded under the UK Economic and Social Research Council (ESRC) Environment and Human Behaviour programme (Grant Number: RES-221-25-0005). We would like to thank the following for providing the ideas and references that helped us to produce this paper: Reuben Deumling, Rick Diamond, Bruce Hackett, Willett Kempton, Loren Lutzenhiser, Mithra Moezzi, Lee Schipper, Hal Wilhite, Rick Wilk and members of the UK Thermal Comfort Interest Group. In compiling this literature review (and accompanying bibliography) we used a variety of on-line databases and search engines including: Web of Science, Science Direct, Academic Science Publishers and Geobase. We have also used the websites of CIBSE, ASHRAE, DEFRA, RIBA, BRE and BSRIA to find other relevant material on thermal comfort.

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