THERMAL COMFORT

Background document C for the 40% House report

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INTRODUCTION

This paper is based on the Comfort and Temperature Workshop held in support of the 40% House project at Linacre College, Oxford in October 2003. It is supplemented with work carried out for the ECI by Rebecca White on the 2003 heat wave, with comments on some of the literature on thermal comfort, and with some material from a workshop held by the ESRC-funded 'Future Comforts' project in London in January 2004.

Temperatures quoted are 24-hour means unless otherwise stated.

THEORETICAL BACKGROUND TO THE DEBATE

There is no absolute standard of thermal comfort. This is not surprising, as humans can and do live in a range of climates from the tropics to high latitudes. An internationally-accepted definition of thermal comfort, used by ASHRAE, is 'that condition of mind which expresses satisfaction with the thermal environment' (ISO 7330). Perceptions of this environment are affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing. More general definitions of comfort include a sense of relaxation and freedom from worry or pain.

A controversy between the *heat-balance approach* and the *adaptive approach* has dominated the development of thermal comfort science. It has largely been concerned with offices rather than domestic premises, but has implications for the residential sector. This debate was the main theme of a conference on *Moving thermal comfort standards into the 21st century*, held in Windsor in April 2001. (See *Energy and Buildings* **4** (6), July 2002, for the papers presented at the conference.)

The heat-balance approach

The current international thermal comfort standard used by ASHRAE[1] (ISO 7730) is based on experiments in climate chambers, many of which were completed in the 1960s. This approach combines the theory of heat transfer with the physiology of thermoregulation to determine a range of comfort temperatures which occupants of buildings will find comfortable. The range is determined by a 'PMV' (predicted mean vote), derived from studies of individuals in tightly controlled conditions. According to advocates, it is feasible and desirable to engineer buildings to provide thermal comfort within the narrow range of temperatures derived from such experiments.

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[1] ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers. Its purpose is 'to advance technology for the public's benefit, a mission it fulfils through research, standards writing, publishing and continuing education'. It has more than 50,000 members in more than 120 nations and sets the most widely-used international standards for buildings. The British standard is set by CIBSE and reflects British housing conditions more closely.

This can include air-conditioning as well as heating, and can provide better temperature control than could be obtained from opening windows.

The adaptive approach

This approach is based on field surveys of thermal comfort and demonstrates that people are more tolerant of temperature changes than laboratory studies suggest: they consciously and unconsciously act to affect the heat balance of the body (behavioural thermoregulation). These actions may change metabolic heat production (changing activity or doing something more or less vigorously), the rate of heat loss from the body (clothing, posture) or the thermal environment (windows, doors, blinds, fans, thermostat adjustment) (Humphreys, 1994). Comfort may therefore be achieved in a wider range of temperatures than predicted by ASHRAE when it is *something that individuals achieve for themselves*. Adaptive variables are extremely important in 'free running' buildings – those without active heating or cooling systems (Nicol, Raja et al. 1999). People in such buildings need to be able to control their immediate environment by opening and closing windows, dressing in such a way as to maximise comfort indoors and outdoors, and using shading as necessary. Research into the comfort levels of sedentary individuals at home, at work and in a climate chamber, shows that simply being 'at home', in an environment that is familiar and under control, is conducive to comfort and makes people less sensitive to temperature (Oseland 1995).

Advocates of the adaptive approach argue that the heat-balance approach can become unduly normative. For example, when people in hot climates say that they do not experience discomfort at temperatures classified as 'severe' according to the heat-balance model, this can be ascribed to their 'low expectations' of comfort (Fanger and Toftum, 2002). The possibility that these individuals may in fact be comfortable is ignored. Taking this argument further, Stoops (1994) claims that an element of thermal discomfort – thermal experience beyond the normal comfort boundaries – contributes to overall well-being. This is demonstrated by those who exercise vigorously, use saunas and take holidays in the sun or the snow. It is not far-fetched to claim that variation is an element of comfort and that people will choose to avoid thermal monotony (Steemers and Steane, 2004). 'Adaptive thermal comfort is ... a function of the possibilities for change as well as the actual temperatures achieved.' (Nicol and Humphreys, 2002).

In the face of evidence from real-life conditions, the argument goes, the controlled PMV method of estimating comfort levels can be seriously misleading and needs revising (Humphreys and Nicol, 2002). Advocates of the adaptive approach hold that it will eventually be possible to produce thermal standards for buildings that do not resort to specifications of the indoor climate, but use characteristics of a building such as materials, orientation, moveable shading, heating system and controls (Nicol & Humphreys, 2002). If buildings are designed and built to incorporate the right mix of these characteristics, the occupants will be able to make themselves comfortable within them.

Using both approaches

The conference held in Windsor in 2001 attempted to use both heat-balance and adaptive approaches in a complementary manner. 'Emergent system' approaches are becoming very common in other areas of science and may unite a 'research gap'' between the two approaches to comfort. New variables can be used such as 'forgiveness' (the degree of access to building controls), or 'adaptive opportunity' (the ability of occupants to open windows and use fans or shading). A sign that some reconciliation is taking place is the revision of ASHRAE Standard 55 in order to allow wider temperature variation for buildings that are naturally ventilated, in order to make allowance for observed comfort variations (Stoops, 2005). The CIBSE thermal comfort standard is also in the process of revision in a more 'adaptive' direction (Nicol, pers comm.)

EXPERIENCE OF COMFORT AND HEALTH

While comfort cannot be absolutely defined, something can be said about the physiological limits within which humans operate. At the most basic level, there is evidence of a lessening of physical and psychological distress when hard-to-heat housing in the UK is improved to provide a basic standard of ventilation and warmth (Henwood, 1997). This standard is normally taken to be the one set by the World Health Organisation: 21°C for people in a living room and 18°C elsewhere in the home.

The UK has one of the highest levels of excess winter mortality in northern Europe. England and Wales had excess mortality of 23,500 during the winter of Dec 2003-March 2004 (National Statistics press release, 15.10.04). This was a relatively low figure: the average for the previous 8 years was 35,220. There is debate as to the relative influence of external and internal temperatures on mortality, but both appear to be significant and housing conditions are a contributory factor to the high excess mortality (Boardman, 1991; Wilkinson et al, 2001).

There is recent evidence of overheating leading to extreme discomfort and even death in the UK – an estimated 2000 premature deaths during the summer of 2003 (National Statistics press release, 3.10.03). Across Europe, the excess death toll reached around 30,000 (New Scientist, 10.10.2003; UK Met Office press release, 1.12:2004). It is still being debated how many of these deaths would have been preventable with better care of the most vulnerable through family and wider social networks: breakdown of these networks was certainly a major factor in the Chicago heatwave deaths of 1995 (Klinenberg 2002). Most heat-related deaths occur in the first day or two of a period of high temperature, and people over 70 years of age are most at risk (Keatinge 2003). With an ageing population, there is good reason to prepare for higher standards of care for future heatwaves. Air-conditioning is only one such response, and air-conditioning based on fossil fuel consumption is one that, in the longer term, only serves to make the problem worse. In the short term, it diverts attention from alternative adaptive measures.

Perceptions of comfort and their effect on energy consumption

The primary policy challenges involve improving housing conditions so that basic physiological needs are met. However, issues relating to what is *perceived* as comfort (as distinct from what a doctor or engineer might prescribe as comfort), lie beyond these basic needs and are important when considering the prospects for a low-carbon society. At what temperatures are people comfortable enough? Do their perceptions of a comfortable temperature range change with time and, if so, what happens to change those perceptions?

Comfort emerges as a factor in high energy consumption. Surveys of over 500 homes at Twin Rivers in the eastern USA showed that homeowners' summer electricity consumption (and their unwillingness to conserve energy) could best be predicted by comfort and health concerns (Seligman et al, 1978). The greater the importance of personal comfort and 'health' to the household, the higher the consumption for air-conditioning was likely to be.

It seems reasonable to claim that householders may begin to show an interest in reducing energy use once they are over a 'threshold' level of physiological comfort, but that improvements in housing energy efficiency will be taken largely as comfort below that level (Green and Ventris, 1983). Milne and Boardman (2000) reviewed the literature on comfort take-back and estimated that the comfort level temperature at the time of their research was in the region of 19°C, above which 80% of the potential energy saving from efficiency improvements would be realised. Yet there is a growing body of evidence that some householders set their thermostats at temperatures well above 21°C (Alembic, 2002; Pett and Guertler 2004). The design of many thermostats does nothing to discourage this: the range of numbers is commonly from 10 to 30°C. Moreover, thermostats and timers are routinely used in ways that the designers never intended – most often with the thermostats as on-off switches (ibid). People who move into more energy-efficient homes do not necessarily adapt their behaviour to suit the new circumstances: a study in the Netherlands found that 'habits were only changed if the old behaviour caused unacceptable changes in comfort' (Boerakker and Jeeninga, 2005).

So where are our ideas of comfort heading? Technological and cultural pressures (eg building design, dress codes, heating and cooling control systems) are in danger of producing convergence on a very limited range of temperatures that are perceived as 'comfortable', particularly in public buildings such as offices (Shove 2003), which implies both increased indoor temperature control and increased energy use. We do not know how much this will influence temperatures at home, but it seems likely that there will be some effect. For example, an individual is likely to dress in the morning in anticipation of the indoor climate in the workplace and may try to replicate this climate when s/he returns home in the evening.

Some trends are not encouraging – for example, over 80% of US homes are now equipped with air-conditioning. The magazine *House Beautiful* asked readers in the 1940s to consider their regional climate and adapt their homes to it, rather than opting for air-conditioning in all circumstances. But this attempt at leading popular taste away from air-conditioning was defeated by intensive marketing (Ackermann, 2002 and pers comm). Sales of room air-conditioners are rising in the UK and it remains to be seen how far the trend will go.

Yet there is some evidence that individuals dislike being confined in air-conditioned spaces for long periods of time, and that they often prefer natural ventilation for overall comfort (ibid.). One group of researchers demonstrated air-conditioning reductions of around one-third without any loss of perceived comfort, partly by showing videos to householders that made an energy-efficient way of life appear more attractive than a housebound, air-conditioned lifestyle. The 'comfortable temperatures' experienced by their experimental subjects covered a wider range than those obtained in previous laboratory studies (Winett et al, 1982). When air-conditioning use dropped in Californian student apartments after the introduction of individual metering, this did not lead to any complaints of discomfort. It did however lead to a changed way of life, one that involved more interaction with neighbours because the students were no longer living behind closed doors and windows during hot weather (Hackett and Lutzenhiser, 1991). Most of the residents who changed their consumption levels did so by switching off the air conditioning completely, not reducing it incrementally, which suggests that they used their controls in a more all-or-nothing way than was intended by the designers. The students' behaviour strongly suggests that they were willing to accept variable conditions.

None of the above overrides what we know about physiological needs for thermoregulation, but it supports the case for an adaptive approach to comfort. This is particularly important when considering future hot-weather conditions. Even if affordable warmth for all in the UK is realised and winter discomfort becomes a thing of the past, there is the danger that climate change will contribute to continued growth of the market for conventionally-powered air-conditioning, and that experience of air-conditioning in cars and public buildings will contribute to that growth. This means embarking on a destructive positive-feedback cycle.

THE 40% HOUSE COMFORT WORKSHOP

The remainder of this paper summarises, very briefly, a series of presentations and discussion in the *40% House* Comfort Workshop held in October 2003. The aim was to produce estimates of future comfort standards that could be fed into the *40% House* model, and to propose and discuss the background knowledge necessary to understand such estimates. Participants looked at the nature of comfort, how it is achieved, and the design and technological options that are available to provide comfort, along with their energy implications in a changing climate. They also considered the extent of under-heating in UK homes and the implications for average temperatures and the housing stock of overcoming fuel poverty.

Participants in the workshop were

Dr Brenda Boardman, University of Oxford
Hugh Bown, independent energy expert
Heather Chappells, Lancaster University
Rachel Court, University of Warwick
Sarah Darby, University of Oxford
Tina Fawcett, Bartlett, University College London
George Henderson, consultant, ex Building Research Establishment
Trevor Houghton, CAG consultant
Dr Kevin Lane, University of Oxford
Dr Richard Moore, independent housing expert, ex-DETR
Sukumar Natarajan, UMIST
Professor Marcus Newborough, Heriot-Watt University
Professor Fergus Nicol, London Metropolitan University and Oxford Brookes University
Malcolm Orme, FaberMaunsell
Andrew Peacock, Heriot-Watt University
Dr Janet Rudge, London Metropolitan University
Dr Andrew Wright, UMIST

Context: climate change predictions

The latest estimates were that the Gulf Stream will probably continue to flow throughout the 21st century, although there is still the possibility that it will cease, leading to much colder winters in the UK. If it does keep flowing, there are likely to be warmer and wetter winters along with warmer and drier summers. With such a scenario, relative humidity (RH) will fall over time although absolute humidity is likely to rise. This is good news in terms of requirements for air-cooling, as people tolerate higher temperatures at low RH than at high RH.

Experiencing and recording temperature and comfort

The simplest way of assessing comfort is to find out what people have to say about it, and this turns out to be closely related to temperature (although there is a tendency to think that the temperature experienced is lower than it is). However, temperature is only one aspect of how users experience a building. Other factors such as humidity, noise, smell and air movement may also affect comfort. People spend roughly 50% of their time at home being sedentary (Boardman 1985). Domestic comfort does therefore require temperatures to be high enough to allow for plenty of inactivity.

We have no good up-to-date figures on temperatures in homes since the national temperature survey that used to be part of the English House Condition Survey (EHCS) was dropped. The last comprehensive set of measured home indoor temperatures in England is from 1996 (Figure 1). It is now necessary to piece together data from relatively small-scale studies in order to estimate trends and the meaning of new developments in home design and technologies.

1986 EHCS - 1st temperature survey
- 1st detailed questions on heating patterns
- 1st fuel consumption survey

1991 EHCS - 1st fuel tariff survey
- 1st full SAP calculation

1996 EHCS - all energy questions continued

2001 (DETR) - Draft Fuel Poverty Strategy

2001 EHCS - all temperature, heating pattern, fuel consumption & tariffs questions omitted

2002+EHCS – Only SAP calculations retained

i.e. No measurement of under-heating since 1996

Figure 1: Temperature surveys in English housing stock since 1986

Source: Richard Moore

Summer comfort and discomfort

Some data were presented at the Oxford workshop from which to assess what a range of acceptable temperatures might be. Comfort was achieved in a Pakistani office building over a wide range of temperatures, from 20-30°C, by using ceiling fans, windows, clothing and drinking water (Figure 2). It was perfectly acceptable to modify clothing according to the outdoor temperature. The running mean of outdoor temperatures affected the adaptation in terms of clothes worn: there would typically be a lag of two days between a change in the weather and a change in the clothing worn to work.

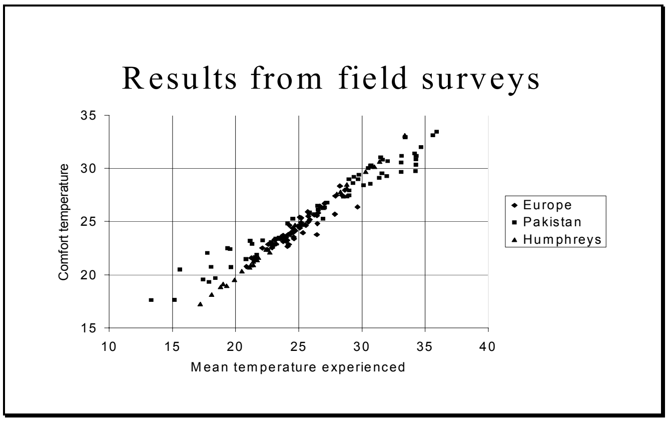

Figure 2: comfort temperatures over a range of outdoor temperatures

Source: Nicol & Humphreys (2002)

In the USA, however, people consider a narrower range of temperatures to be tolerable. There is a strong correlation between cooling degree-days and domestic use of electrical air-conditioning, as shown in Figure 3. When outdoor temperatures rise, air-cooling technology is available, building design is not climate-sensitive and use of air-conditioning is promoted as the norm, people adopt it. Humidity does not appear to make much difference to American use of air-conditioning; neither does climatic variability between regions.

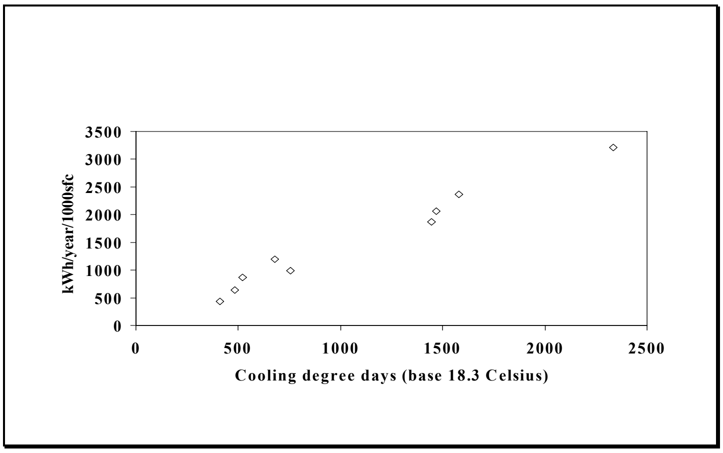

Figure 3: electricity consumption due to air-conditioning in relation to cooling degree days
Source: George Henderson

If air-conditioning in the UK were adopted on the same basis as in the USA, roughly 20% of households in the London area would acquire it soon, although they would not use it often. 80% of people with air-conditioning use it for 20% or less of the time (Carrier Air Conditioning, *Future Comforts* workshop). For the most part, they own mobile units, not to whole-house conditioning systems. Summer temperatures in the south of the UK are close to the threshold for air-conditioning use, by American criteria; ownership could rise steeply in the UK if householders applied the same criteria and there were similar levels of marketing.

A working definition of a heat wave, given by the MET office press officer in 2003 is 'a prolonged period of time (more than two days) during which the maximum day time temperature is over 28°C'. These are the sort of conditions which are most likely to trigger sales of air-conditioning units in the UK. Table 1 gives figures for days in Oxford between 1990 and 2004 when the temperature exceeded 28°C, showing that there were 10 occasions when this happened for three or more days in a row.

Table 1: Days in Oxford when maximum temperature exceeded 28°C

	June	**July**	**August**	**Total**	**consecutive days >28°C**
1990		4	5	9	3+4
1991				0	
1992	1			1	
1993				0	
1994	1	5		6	
1995	3	6	15	24	3+7+3+8
1996	2	3	2	7	
1997			8	8	5
1998			3	3	
1999		3	2	5	4
2000	2			2	
2001	2	5	2	9	
2002		1	1	2	
2003		5	9	14	3+9
2004	2	1	2	5	
Total	**13**	**33**	**49**	**95**	

Source: Radcliffe Meteorological Station, Oxford

A record of cooling degree-days for Royston in Cambridgeshire shows how dramatically the number of degree-days would increase if temperatures rose 2°C higher than they actually did between 2000 and 2003 (Figure 4).

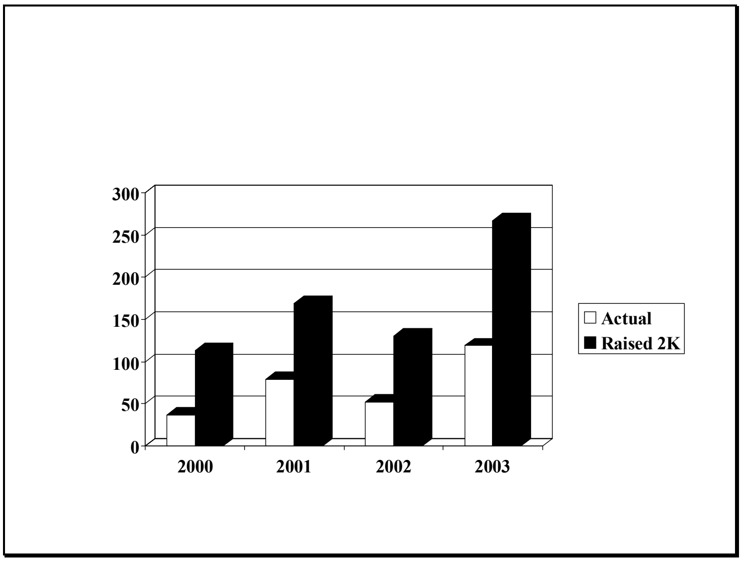

Figure 4: Cooling degree days for Royston at actual and (theoretical) raised temperatures

Source: George Henderson

Below are summaries of some of the actual short-term responses to the heatwaves of 2003, showing a high level of demand for air-conditioners and fans, and the official advice on comfort in workplaces during a heat wave.

Documented responses to extreme hot weather in the UK: from summer 2003

Some news items from the heatwaves of 2003 show the extent and type of challenge to comfort and the ways in which individuals and companies met it:

- Toshiba Air-Conditioning reported that the air-conditioning market was slightly *down* on the previous year, but that 'this summer has seen strong sales, most of which are attributed to the hot weather'.

- B&Q reported that three of the four mobile air-conditioners on sale on their web pages had sold out. A B&Q press release from July stated:

  'B&Q, the UK's largest home improvement retailer, has seen a huge rise in sales for air conditioners. Following another scorching week, sales are 176% higher than from the same week last year. A B&Q spokesperson said: "It's not just air conditioners - we've seen a 185% rise too in desk fans as workers try and keep their cool in the office. As it looks like these hot summer days are here to stay, we've stocked up on our wide variety of fans and air conditioners to ensure we're prepared for more of the same!"'

- Vent-axia, producers of desk fans, exhausted all their stock over the summer. Sales had been very low for the previous three years.

- The Advisory, Conciliatory and Arbitration Service advised that: 'Callers have been asking about maximum temperatures in the workplace and how to deal with sudden absences and lateness arising from travel disruption.' The ACAS helplines gave the following advice, a mix of technical and non-technical measures:

  There is currently no maximum working temperature. To help … employers should try to improve the environment by providing… fans, mobile air conditioning and cool drinks dispensers. They can also let staff take more breaks for drinks or go somewhere cooler.

Rapid growth of air-conditioning in the UK is not inevitable, although some increase can be expected from present trends and in the absence of better strategies for dealing with heat. The UK is subject to European as well as American influences and southern European households show a much less steep curve of air-conditioning ownership in relation to temperature. For the most part, they live with architectural styles and materials that were developed before air-conditioning existed, relying on high thermal mass and the use of trees, shutters, blinds and verandahs to provide shade. In Lyon, France, daytime temperatures of 40°C were reached for around a month during the summer of 2003. While residents reported that the month had been 'difficult', hardly anyone had air-conditioning.

The UK has more to learn about how to keep cool in summer from buildings in southern Europe than from those in the USA. There is still plenty of scope for 'Mediterranean' building styles to be used further north in new buildings as the climate warms, and for adaptations of existing buildings in order to reduce solar heat gains in the summer. The growth of mechanical air-conditioning could be halted by a policy decision to prohibit it, substituting systems such as those used in Switzerland (circulation of cold water through pipes) or the use of evaporative room coolers. The most difficult buildings to keep cool in summer in a warmer climate are likely to be large-windowed blocks of flats in urban areas. For these, some form of cooling using heat pumps may be the best solution.

Avoiding overheating in low-energy housing

Four types of uninhabited test house at BRE were reported on by Malcolm Orme of Faber Maunsell. The type most likely to overheat was a top floor corner flat, followed by a town house, semi-detached and detached house. The most effective cooling strategies were thermal mass and natural night cooling. Thermal mass is extremely difficult to alter once a building is complete, and the night cooling figures assumed that 25% of window areas were kept open, including ground floor windows – often impracticable because of security and noise. The next best strategies – which were also more achievable – were shading and reduced internal gains from efficient lights and appliances (Orme and Palmer 2003).

Where is thermal comfort heading?

The best guess of *40% House* workshop participants was that, under a 'business-as-usual' scenario, domestic temperatures are headed towards an average 22-23^{o}C for around 9 hours a day, the hours of maximum occupancy and activity. They also predicted that there would be some air-conditioning in approximately half of all homes in England and Wales by 2050 under business-as-usual.

There is a significant trend from two heating zones to one, accompanying the moves to central heating and to larger living spaces, sometimes knocked-through. This means that the figure of 22-23^{o}C, which may at first apply only to the main living area of the home, will come to apply to the whole dwelling. In the rest of northern Europe, bedrooms are not designed to be cooler than the rest of the house; the UK is also moving in this direction.

A recurrent theme of the *40% House* workshop (and one emphasised in the *Future Comforts* workshop) was that comfort is not reducible to temperature, or even to a combination of temperature, humidity and air movement. It is important that householders' ability to achieve comfort easily in their surroundings is seen as a vital objective. This means openable windows and very straightforward heating controls. Ventilation systems in highly-insulated homes must not become so sophisticated that they are unintelligible to the people who must live with them day by day. This is a recipe for losing the potential gains from properties that are highly energy-efficient on the drawing board but lose most of those gains when in use.

What factors will most influence thermal comfort in future? Building location and specification will be important factors, with a need for more shading and higher-density building materials, especially in the south. A prohibition on air-conditioning in new buildings is still possible (and was part of the RIBA submission to the pre-2002 review of building standards). As the *Future Comforts* workshop showed, in particular, progress is being made on design for natural ventilation and mixed-mode (natural plus powered) ventilation and cooling. Some of this expertise may be usable in converting wholly air-conditioned buildings to more environmentally-sympathetic systems (Chappells and Shove 2004).

There is likely to be a continuing debate between the proponents of engineered thermal comfort and those of adaptive, low-technology strategies. Participants at the *40% House* and *Future Comforts* workshops were broadly in favour of the latter. This means continued attention to the social dimensions of comfort and to the sequence of decisions which goes into the design, installation and use of appliances and buildings over time.

REFERENCES

Ackermann M (2002) *Cool comfort: America's romance with air-conditioning.* Smithsonian Institution Press, ISBN 1588340406

Alembic Research (2002) *Revisiting Easthall: 10 years on*. Energy Action Scotland, Glasgow.

Boardman B (1985) *Activity levels within the home.* Joint meeting CIB W17/77 - Controlling Internal Environment, Budapest

Boardman (1991) *Fuel poverty: from cold homes to affordable warmth*. Belhaven Press

Boerakker Y and Jeeninga H (2005) *The influence of behaviour on the effectiveness of more stringent standards*. Proceedings, European Council for an Energy-efficient Economy, 2.101

Chappells H and Shove E (2004) Report on the 'Future Comforts' workshop http://www.comp.lancs.ac.uk/sociology/research/projects/futcom/documents/webreport.htm

Energy and Buildings **4**, issue 6, July 2002 – papers from the Windsor conference on thermal comfort

Fanger PO and Toftum J (2002) Extension of the PMV model to non-air-conditioned buildings in warm climates. *Energy and Buildings* **34**, 533-536

Green J and Ventris N (1983) *Attitudes to energy use in a housing action area - methodological issues.* Proceedings of a conference on social research on the use of energy in buildings, ed Bruce Stafford. Conference and seminar papers no 7, Centre for Urban and Regional Studies, University of Birmingham.

Hackett B and Lutzenhiser L (1991) Social structures and economic conduct: interpreting variations in household energy consumption. *Sociological Forum* **6** (3), 449-470.

Henwood M (1997) *Fuel poverty, energy efficiency and health: a report to the EAGA Charitable Trust.* EAGA-CT, Keswick, UK

Humphreys M and Nicol JF (2002) The validity of ISO-PMV for predicting comfort votes in every-day thermal environments. *Energy and Buildings* **34**, 667-684

Keatinge W (2003) Death in heat waves. *British Medical Journal* **327**, 512-3

Klinenberg E (2002) *Heat wave: a social autopsy of disaster in Chicago*. University of Chicago Press. ISBN 0-226-44322-1 and 0-226-44321-3

Milne G and Boardman B (2000) Making cold homes warmer: the effect of energy efficiency improvements in low-income homes. A report to the EAGA Charitable Trust. *Energy Policy* **28** (6-7): 411-424

Nicol JF and Humphreys M (2002) Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings* **34**, 563-572

Nicol JF, Raja IA, Allaudin A and Jamy GN (1999) Climatic variations in comfortable temperatures: the Pakistan projects. *Energy and Buildings* **30***,* 261-279

Orme M and Palmer J (2003) *Control of overheating in future housing – design guidance for low energy strategies*. FaberMaunsell, UK

Oseland NA (1995) Predicted and reported thermal sensation in climate chambers, offices and homes. *Energy and Buildings* **23** (2), 105-115

Pett J and Guertler P (2004) *User behaviour in energy efficient homes.* Phase 2 report for the Housing Corporation and Energy Saving Trust. Association for the Conservation of Energy, London

Seligman C, Darley JM and Becker LJ (1978) Behavioural approaches to residential energy conservation. *Energy and Buildings* **1** (3), 325-337

Shove E (2003) *Comfort, cleanliness and convenience: the social organisation of normality.* Berg Publishers, Oxford

Stoops JL (2004) *A possible connection between thermal comfort and health*. Lawrence Berkeley National Laboratory, paper 55134. http://repositories.cdlib.org/lbnl/LBNL-55134/

Winett RA, Hatcher JW, Fort TR, Leckliter IN, Love SQ, Riley AW and Fishback JA (1982) The effects of videotape modelling and daily feedback on residential electricity conservation, home temperature and humidity, perceived comfort and clothing worn: summer and winter. *Journal of applied behaviour analysis* **15**, 381-402.