Cold Comfort for Kyoto?

Carbon implications from increasing residential cooling demand

A scoping report

Anson Wu and Jacky Pett

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2a Prebend Street
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Fax: 020 7359 0863
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EXECUTIVE SUMMARY

The cooling market, in particular air-conditioning, has been growing rapidly in the UK. People now want more comfort and control of their indoor environment. Simultaneously, climate change models predict uncomfortably hot summers towards 2050. This report investigates how comfort levels and climate change will influence the demand for cooling, and policy options to address UK demand that avoid energy intensive solutions. Particular attention is paid to the residential market because it is expanding fastest.

Rising temperatures

Historical temperature trends show a sustained rise in Central England Temperature of about 1°C since 1980, whilst it has remained approximately stable for the previous 200 years. **South England, already the warmest region, will face the highest temperature increases; between 1-1.5°C in 2020, to 2-3°C in 2050, and 3.5-5 °C in 2080**. If emissions are high, SW England in 2080 could expect daily average temperatures to exceed 30°C about once every ten days with peak daytime temperatures reaching 42°C twice a week.

Whilst cooling degree days are offset by reduced heating degree days the Tyndall Centre found that reduced carbon emissions from heating are far outweighed by the increase in emissions from cooling. **They conclude that technical solutions to managing cooling energy consumption will not be enough, and suggest that further research into adaptive responses to comfort is required**.

Rising air-conditioner use

The air-conditioning market is growing, especially in the domestic sector where there are no precise figures. This is a major barrier to confident policy making. Evidence from the Institute of Refrigeration estimate approximately 10% of non-domestic floor space and less then 0.5% of domestic floor space to be air-conditioned. Forthcoming, **figures from the Market Transformation Programme predict a growth of approx 7% a year to 2010**. Forecasts further forward to 2020, predict cooling to use 25 TWh.

The domestic sector is growing faster than non-domestic and could conceivably change more significantly. **Mobile units are expected to dominate the residential market**. They are likely a 'distress' purchase' – bought during a heat wave or similar – for homes and small businesses, and once bought are likely to be used whenever the temperatures rise, rather than only at the previous peak which brought on the distress factor.

Modelling residential air-conditioner use

A new model was developed to predict residential cooling demand and subsequent energy consumption. Based on four Comfort Scenarios developed by Shove and Chappell, the model predicts the effect of unconstrained growth and possible savings resulting from adaptive responses.

i. **The comfort zone extends** – People are comfortable in a much wider range of indoor temperatures.

ii. **Indoor climates diversify** – There is no demand for any control of indoor climate.

iii. **Standardised efficiency** – In this case conventions of comfort and clothing stabilise and are provided efficiently.

iv. **Escalating demand** – Comfort will be even more demanding than those of today. People expect to be even warmer during the winter and even cooler during the summer.

From experience in Western USA, it is expected that the baseline comfort level will be scenario III or IV.

Four population groups are used to estimate the groups who are likely to consider buying air-conditioning. Population group A is the entire South England population

and the worst case. Each scenario is assigned a threshold temperature at which cooling is demanded by the population.

Group A whole pop^n	Scenario I (26°C)		Scenario III (22°C)		Scenario IV (20°C)	
Year	Energy /TWh	Emission /$MtCO_2$	Energy /TWh	Emission /$MtCO_2$	Energy /TWh	Emission /$MtCO_2$
2020	3.8	1.6	7.6	3.3	11.0	4.9
2050	4.6	2.0	9.1	3.9	14.0	5.9

Energy and carbon impact

If there was unconstrained growth of air-conditioning to meet all cooling demand, by 2020 domestic energy consumption increases by 11 TWh (shown above). Adaptive comfort levels could reduce this to just 3.8TWh under Comfort Scenario I, without low-energy options in place. The Building Regulations in the domestic sector are predicted to save 5.5 $MtCO_2$ (1.5 MtC). **Air-conditioning carbon emissions by 2020 could negate 15% to 90% of the domestic Building Regulations savings**.

The model developed in this research makes many critical assumptions and should be considered a first step. Further work is needed to solidify what is assumed and develop the model further.

Across the whole air-conditioning market, **increased emissions from 2000 of 4.3 $MtCO_2$ by 2010 negate over half of the 7.7 $MtCO_2$ projected savings from the combined 2002 and 2006 Building Regulations**. This is also much larger than 0.85 $MtCO_2$ (0.23 MtC) of cost effective savings by 2020 calculated by Pout *et al.*

Zero energy refurbishment is possible

Furthermore, **Energy consumption can be reduced to almost zero using passive measures**. Hacker *et al*'s dynamic building modelling found the most successful measures were:

- Shading from the sun
- Providing controllable ventilation during the day and high levels of ventilation at night (without compromising building security)
- Using heavier-weight building materials combined with night ventilation, to enable heat to be absorbed and released into the building fabric
- Improving insulation and air-tightness so that undesirable heat-flows can be controlled.

Passive measures can maintain a house in comfortable, but warm, conditions in London until 2050, at which point supplemental air-conditioning may be needed. Installing these measures keeps maximum temperatures below 28°C and net carbon dioxide emissions only exceed the current levels in the 2080s.

Recommendation

Revise Building Regulations

Building Regulations in England and Wales and proposals in Scotland already include a methodology to determine the risk of excessively high indoor temperatures. However, these are only guidelines. Because houses built now are expected to still be standing in 2050, **in South England, mandatory Building Regulations are needed for new dwellings and refurbishments that assess cooling performance, alongside heating, based on future climates**.

Recommendation

Better information about alternative cooling options

In conjunction with refurbishment standards, **better information about alternative cooling options need to be provided**, such as those mentioned earlier. Passive technical measures must take strong priority over active solutions which could be supported through a universal cooling energy efficiency label, comparing technical solutions against each other. The information must also be easy to find, eg on websites and in stores. In particular, energy labels were still not ubiquitous on websites even though they are required legally. **Stores should ensure energy efficiency, sizing guidelines, and best practice operation and maintenance information, are displayed prominently.**

Recommendation

Remove inefficient air-conditioning from the market

Where air-conditioning is needed, it is essential to ensure high efficiency units are used. **Minimum Energy Performance standards (MEPs) have been applied to gas**

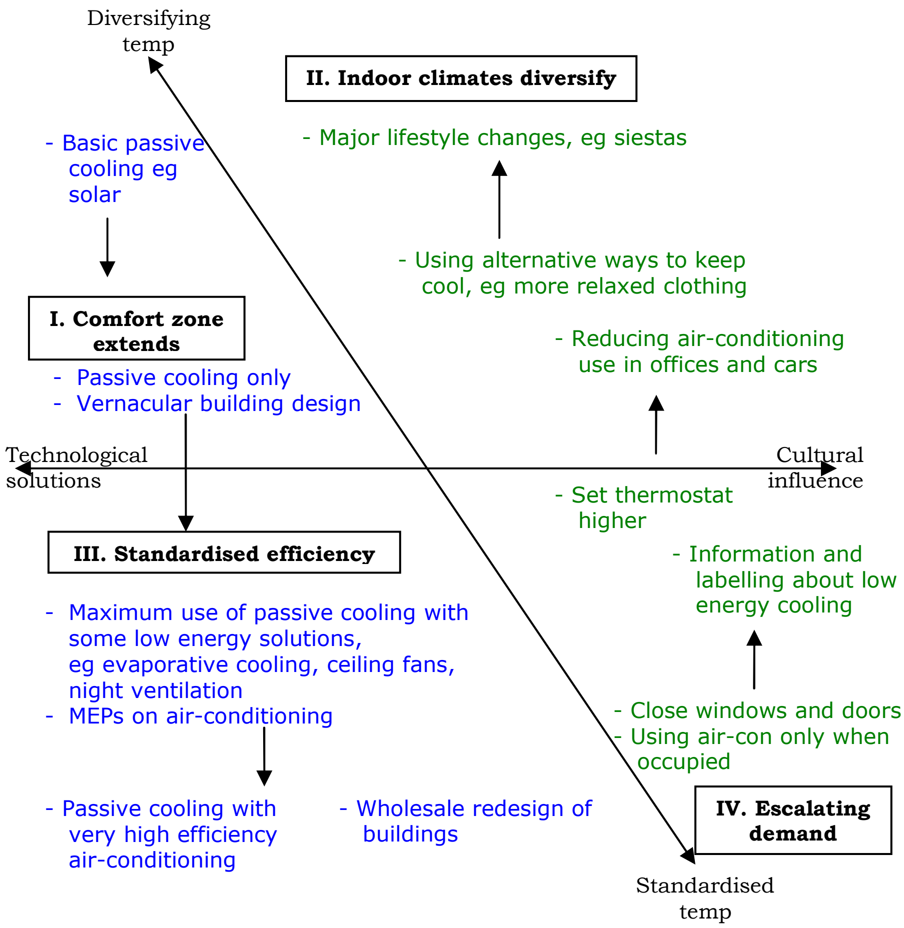
boilers under Building Regulations and need to be applied to cooling appliances. The IEA recommend Least Life Cycle Cost analysis to determine the optimal MEP which balances manufacturer, consumer and environmental concerns. Using 'regulatory best practice' is another option. This uses the best international regulation to set the MEP.

Recommendation

Engaging public and shifting attitudes

However, these implicitly assume that active measures will be used and ensures scenario III is maintained. **Achieving Comfort Scenario I or II will require more innovative approaches to engage the public**. Possible solutions that can be explored include changing fashions, particularly office attire, and reducing air-conditioning in cars and offices which may encourage residential purchases. To realise maximum savings, better awareness of personal carbon use that brings a stronger message home is needed to create a widespread shift in attitudes to comfort. Personal carbon trading or even carbon taxes might be needed to achieve this.

The policy recommendations are summarised in the figure below. The Comfort scenarios are placed in the four sectors defined by comfort temperature and the cultural or technical influence creating the initial attitude. Expectations and practices must be changed first from bottom up (shown in green) to achieve the desired comfort attitudes. Technical solutions can then be applied from top down (shown in blue) to match the Comfort Scenario.



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ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BRE	Building Research Establishment
CDD	Cooling degree days
CET	Central England Temperature
CEPE	Centre for Energy Policy and Economy
CEP	Center for Energy and Processes
CIBSE	Chartered Institute of Building Services Engineers
CO_2	Carbon dioxide
DCLG	Department for Communities and Local Government
Defra	Department for Environment, Food and Rural Affairs
DETR	Department of Environment, Transport and the Regions (now DCLG & Defra)
DSY	Design Summer Year
DTI	Department of Trade and Industry
EEPH	Energy Efficiency Partnership for Homes
EER	Energy Efficiency Rating
EHCS	English House Condition Survey
EIA	Energy Information Administration (US Dept of Energy)
EIBI	Energy in Buildings and Industry
EPBD	Energy Performance of Buildings Directive
GLA	Greater London Authority
GSHP	Ground source heat pump
GWh	GigaWatt hour
HDD	Heating degree day
HVAC	Heating, Ventilation and Air-conditioning
IEA	International Energy Agency
IEECB	International Energy Efficiency in Commercial Buildings
kWh	kiloWatt hour
LLCC	Least Life Cycle Cost
MEP	Minimum Energy Performance
Mt	Megatonne
MTP	Market Transformation Programme
ODPM	Office of the Deputy Prime Minister (now DCLG)
ONS	Office for National Statistics
PJ	PetaJoule
RCEP	Royal Commission on Environment and Pollution
RECS	Residential Energy Consumption Survey
SAP	Standard Assessment Procedure
SBSA	Scottish Building Standards Agency
SECCP	South East Climate Change Partnership
SEER	Seasonal Energy Efficiency Rating
SME	Small and Medium sized Enterprises
TWh	TeraWatt hour
UK	United Kingdom
UKCIP	UK Climate Impacts Programme
USA	United States of America
VA	Voluntary Agreements

1 INTRODUCTION

The cooling and air-conditioning market is growing rapidly as we demand higher standards of living and comfort. Simultaneously, climate change models predict UK temperatures will rise over the next 100 years, with increasingly frequent extreme temperature events. However, there is neither a simple causal relationship nor an equally simple solution. Predicting how demand for cooling will increase and how to prevent associated rises in carbon emissions requires a more detailed study. This report examines the current state of knowledge, its implications and possible policies to steer it towards a low energy path.

In an article for the Energy Efficiency Partnership for Homes, we outlined the drivers for air-conditioning (Partnership Secretariat 2005). We identified the role of air-conditioning in the economic rise of the US American South, as it transformed the heat and humidity into the comfortable working and living spaces needed for an economically viable region. Arizonan summer highs, however, *average* over 40°C, which will not compare to British weather in this century, unless emissions are even higher than the Tyndall Centre's 'High' forecast. Government projections of residential air-conditioning, based on current sales as reported to Parliament (Hansard 2005), show ownership will double before 2020. This worrying statistic could easily underestimate the growth in ownership as the effects of climate change worsen, a wealthier society demands consistently comfortable indoor temperatures, and manufacturers launch aggressive marketing campaigns.

Summer 2003 was the hottest on record and saw 20,000 deaths attributed to the heat wave across Europe. Scientists forecast that summers are set to get hotter and because houses last for around 100 years, planners must take the long view. In this report we review the modelling by the Tyndall Centre that predicts high summer temperatures will become more frequent and overheating, when natural ventilation is insufficient, will become a problem by 2025. CIBSE recommend that for comfort, internal temperatures should not exceed 25°C for more than 5% of the (occupied) year. Under the Tyndall Centre forecast, hours above 25°C rise from under 150 hours now to over 550 hours a year. Maximum temperature in buildings will rise from around 32°C now to 35°C in 2050 and to almost 40°C by 2080, with serious implications for health through heat stress and exhaustion. The UK will not want to gain an international reputation for summer deaths as it currently has for winter excess mortality.

Whilst the occasions of 'near extreme' temperatures will rise in frequency, average summer temperatures would be only three degrees higher; dry and still bearable. But now used to air-conditioning in cars, at work, in shops, hotels and on holiday, people start to expect higher levels of comfort in their homes, demonstrated by a narrow variability of the indoor temperatures. Comfort definitions and theories are examined in this report with a particular view of the desirability of promoting one comfort theory over another, and what policies might be required to persuade people to conserve energy. Disappointingly, the 'quick fix' technology solution appears to becoming more popular than more traditional solutions.

One reason for this is that solutions such as opening windows are overridden by concerns about noise, air quality and security, and design for passive cooling has not been a foremost issue during the last fifty years of house construction. Building trends are now moving towards comfort and indoor environmental quality considerations, but raising the average winter room temperature is not enough; dampness, condensation, draughts, air quality, and, of course, overheating must all be addressed. In searching for a solution that can be retrofitted, the public will turn to systems with which they are familiar, i.e. air-conditioning units. With the widespread availability of 'over the counter' air-conditioners and aggressive marketing, alternatives to counter the trend must be well supported and understood.

It should not be forgotten that in some circumstances, using technology to provide the solution will be the best available environmental and social option. Numerous French studies have highlighted the need for air conditioning in hospitals and to protect the elderly and vulnerable. Providing cooling may be as important for vulnerable people as providing warmth. This will lead to a range of policy conflicts in future as difficult to solve as the tension between fuel poverty and energy efficiency or carbon emissions reduction programmes at present. This report recognises air-conditioning is a necessary option in these circumstances but due to the complex health considerations does not make any recommendations in such cases.

This report is structured into eight chapters. Following this Introduction, chapter 2 reviews climate scenarios from UKCIP with past and future temperature changes. chapter 3 then explores the growth in the air-conditioning market and develops this by looking at how our specification of comfort and consequent behaviour will affect demand for cooling, specifically air-conditioning. Four possible scenarios are presented based upon the extent to which we wish to control our indoor environment, irrespective of external conditions. From this it is possible to create a regional, population weighted figure for cooling demand. Chapter 4 finishes with a look at the effect cooling demand could have on the UK's emission targets for Kyoto.

Solutions are then discussed: for reducing the cooling energy demand using technology options (chapter 5) and how we can change social and cultural outlook on comfort (chapter 6). These solutions are then applied to create policy options based on each Comfort Scenario (chapter 7), drawing out final conclusions and recommendations (chapter 8).

2 RISING TEMPERATURES

This chapter introduces and analyses historical temperature trends and future forecasts. Temperature is approached in a number of ways – mean temperatures, peak temperatures, and cooling degree days. This is because each building and each person responds to heat differently, depending on both long term trends as well as occasional peak events.

We review the modelling carried out by the Hadley Centre, Tyndall Centre (and others) as part of the UK Climate Impacts Programme (UKCIP) which provides a set of climate change scenarios for the 2020s, 2050s and 2080s. Property built in the 2000s will in general be expected to have a life beyond 2060, and therefore, the 2020s and 2050s scenarios will be considered.

2.1 Climate past

The much cited news from the Met Office (2004), that nine of the ten warmest years were between 1995 and 2004, has focused many minds on the delights of a long hot summer. For those living where record temperatures were set, such as 38.5°C peaks in Brogdale, Kent (Met Office 2003), during the hottest period on record, March to August 2003, it was not so delightful. More than 2000 people were reported to have died between 4 and 13 August 2003 because of the heat (Back *et al* 2005).

Despite the attempts by some scientists to refute the statistical basis for temperature trends, the underlying evidence has been shown to be correct: temperature increases on the scale currently experienced are a recent phenomenon. The global trends that have attracted this publicity are supported by data measurement for Central England mean temperatures (CET) as shown in the graph below.

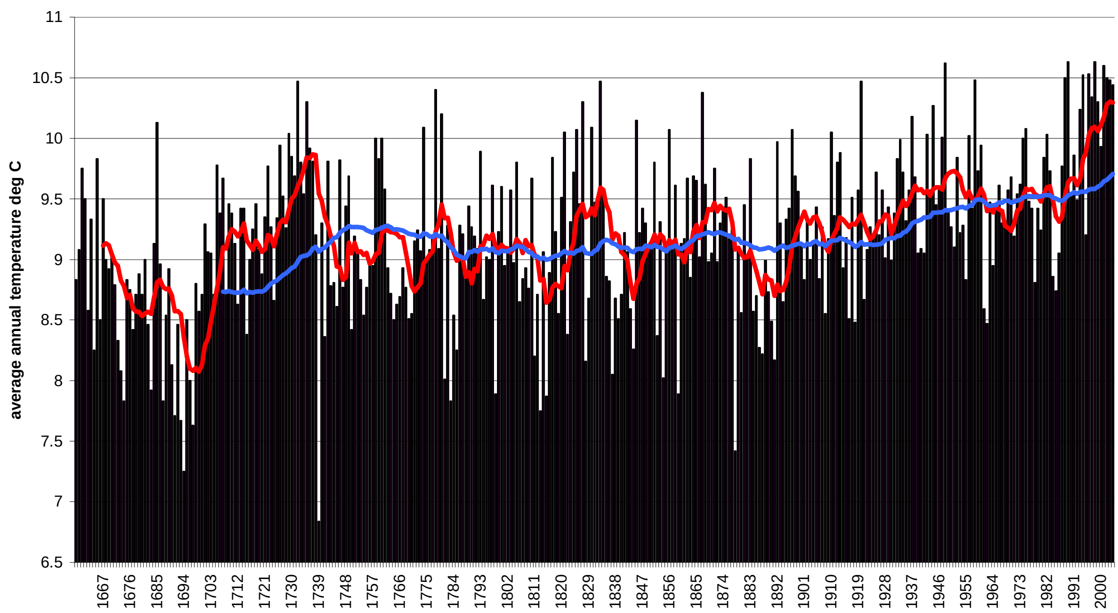


Figure 1: Mean annual Central England temperatures 1659 to 2005 (data from: Hadley Centre *et al* 2006)

Two trend lines are shown, the red, more variable one is the ten year moving average, and the blue, smoother line is the fifty year moving average. Both show the trend that has led to around a one degree rise in the average temperature over the last 300 years. From around 1940, this increase has continued to be above any previous 50 year average, with the rise currently on an upward curve.

A similar trend is seen on the global scale, with temperatures now at approximately 0.8°C higher than the end of the nineteenth century (Hadley Centre 2005).

It is important to note that although the one degree may sound insignificant, it can produce major impacts on weather patterns, which have a greater effect on people than temperature alone. In addition, average daily temperatures combine both day and night, and night time cooling is an important issue. Furthermore, an increase in average daily temperature also suggests an increase in the frequency of very high peak temperatures.

The period for which we are considering air-conditioning is very recent. The next graph allows us to compare the winter and summer temperatures over the fifty years 1956-2005.

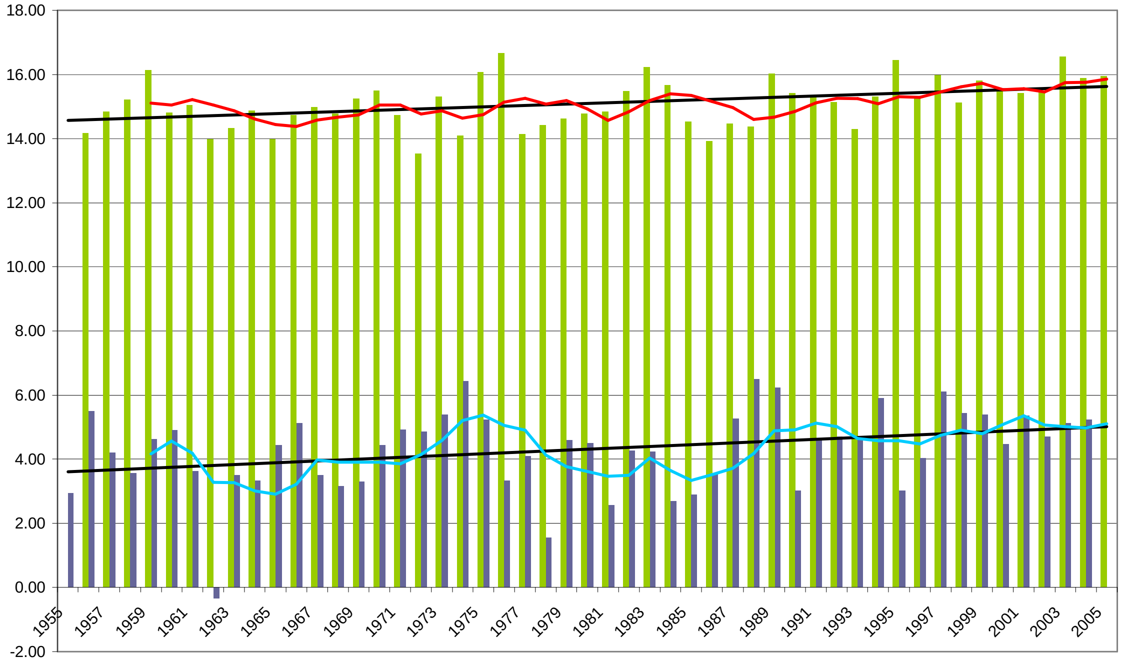


Figure 2: CET Winter and Summer temperatures and trends 1956-2005 (data from: Hadley Centre 2006)

The trend lines in Figure 2 show the linear regression (straight line) and the five year moving averages for winter (blue) and summer (red) separately. 'Winter' in this case is defined as December, January and February, and 'summer' as June, July, August and September. This may have created a slightly smoother moving average for the summer, but with the vagaries of summer being 'early' or 'late' it seemed appropriate in order to capture the hottest months, whereas the months between December and February are consistently the coldest. Note that for all the rest of the modelling in this report, summer is taken as the May, June, July period in line with UKCIP models.

The trend lines show that both summer and winter average temperatures are increasing, with winter temperatures rising faster than in the summer. This is important to recognise because it alters the balance between winter heating and summer cooling requirements. The five year moving averages demonstrate consistent increases in the last ten years as already indicated from the Met Office press releases.

The Hadley Centre interpreted the Central England measurements with particular reference to the daytime and night time temperatures:

> 'The sustained rise of about one degree Celsius in CET since about 1980 is noticeable; due more to an increase in maximum temperatures (about 1.2°C over the same period) than night minimum temperatures (about 0.7°C). 1990, 1999, 1949 and 2002 were joint warmest years on record. Temperature averaged over such a small scale as Central England has much more variability than that averaged over the entire globe and hence it is not surprising that years further back, such as 1949, were very warm.' (Hadley Centre 2005)

Night time temperatures become an important issue when considering cooling needs; many studies have considered the effect of heat-disturbed sleep on the economy and people's welfare. As we will see, studies of comfort-taking suggest that raised temperatures at night will cause more of a problem than higher temperatures during the daytime.

2.2 Climate future

The climate scenarios which underpin this research project were developed by the UK Climate Impacts Programme (UKCIP), published originally for 1998 data and updated in 2002, therefore known as the UKCIP02 model.

There is uncertainty in modelling of this nature, and in the UKCIP02 report, Hulme *et al* (2002) compares its findings with other models to gain a degree of consensus and also to assess the confidence in the findings. Generally, confidence about the UKCIP02 scenarios presented is high (although rates of change may be faster or slower and specific events may occur that distort the trends temporarily).

Scenarios have been developed for the 2020s, 2050s and 2080s. The focus of this report will be the 2020s and the 2050s, as buildings built now will be in operational use in the 2050s. For each period, the high and low emissions scenarios are also considered. Higher temperatures can be expected from higher emissions scenarios.

The synopsis of the weather effects is:

- UK climate will become warmer, especially in the summer. By 2020s annual temperatures may increase by one degree C and by up to 6 degrees in the South East by 2080s. Some models put this substantially higher based on current data input into their programmes.
- Very cold winters will become rare.
- Urban centres will be even hotter than surrounding, less built up sprawl and rural locations due to the 'heat island' effect, where more heat is generated by intensive energy use and hard surfaces absorb heat and retain heat longer due to their thermal capacities, without natural heat extraction and circulation provided by vegetation and ecological processes (Figure 3).
- Winters will become wetter and extreme rainfall events may be more frequent.
- Higher wind speeds are possible.

These scenarios do not predict sudden changes such as switching in the Gulf Stream. Such an event is too considered too unlikely in this century.

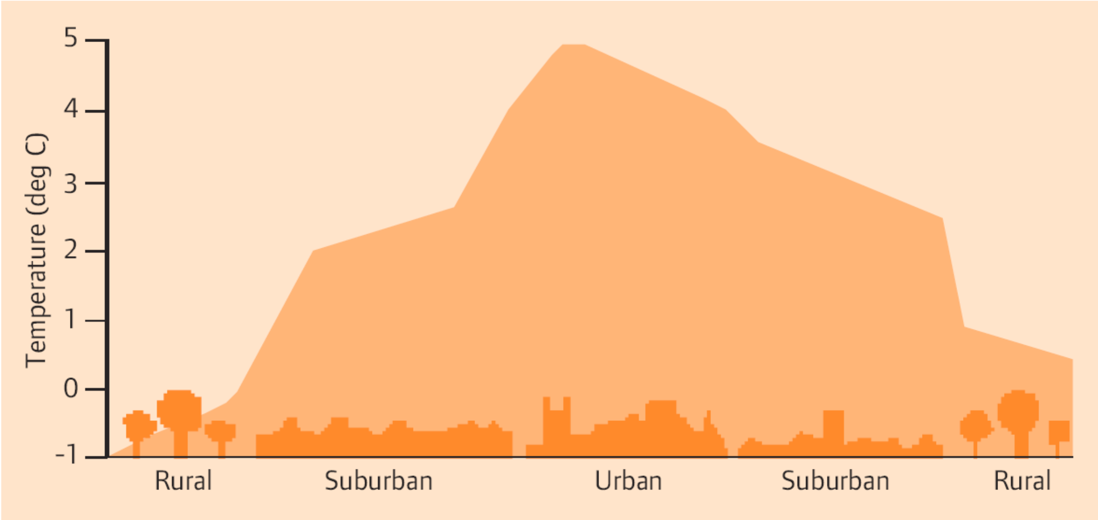


Figure 3: Urban Heat island effect (Three Regions Climate Change Group, 2005)

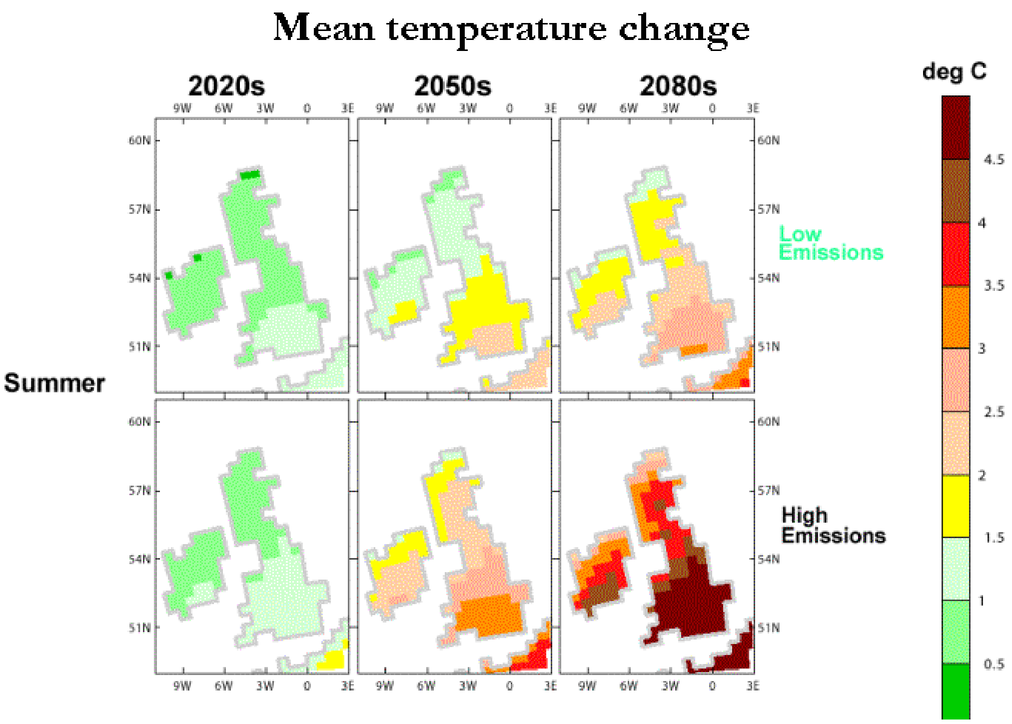


Figure 4: Mean temperature change, summer (UKCIP 2002)

2.2.1 Peak and mean temperature forecasts

In Figure 4, the scenarios under the High and Low emissions scenarios are shown for summer. These indicate one degree increase in mean temperature, above the increase in the last ten years, in the southern part of Britain by the 2020s. The temperature could then rise by up to 3.5 degrees by the 2050s and by the 2080s, this could have increased by 5 degrees on average.

What does this mean for peak temperatures, and their duration? The UKCIP scenarios measure this by counting the number of days where the daily-average temperatures exceed the baseline temperature. This baseline is defined at the 90th percentile of the 1961-1990[1] temperature data. The peak temperature therefore

[1] Section 5.3 in the UKCIP technical report.

captures the hottest remaining 10%, i.e. the average temperature of the hottest 9 days in a 90 day summer. For southern England in winter this is 11°C and in summer it is 23°C. By comparison, for Scotland these figures are 7°C and 17°C.

The scenarios show that the peak temperatures will vary around the country and with the emissions scenario. In general, the change in the 2020s is only about 1.5°C in the south, but in the 2050s it is up to 4°C. By the 2080s, temperatures increase by 4-7°C in the Southwest, and around 2°C in Scotland.

Additionally, the number of days that a region that would exceed the 1960-1990 baseline – the old 90th percentile – is calculated. Around the country, except in Northwest Scotland, the number of days exceeding the baseline changes from 9 days by definition (10% of 90 days) to about 20 by 2080. In SW England, the daily-average temperature is likely to exceed 30°C about once every ten days instead of two or three times over the summer as a whole.

Extreme temperature forecasts, however, use only the highest temperature predictions which will contain the outlying statistics errors. This creates a greater risk of incorrect results, but despite this we can be reasonably confident forecasting daytime temperatures of 42°C up to twice a week in the peak season, under the high emissions scenarios by 2080.

The movement in temperatures over the summer months in the 2020s and 2050s is summarised in Figure 5 below.

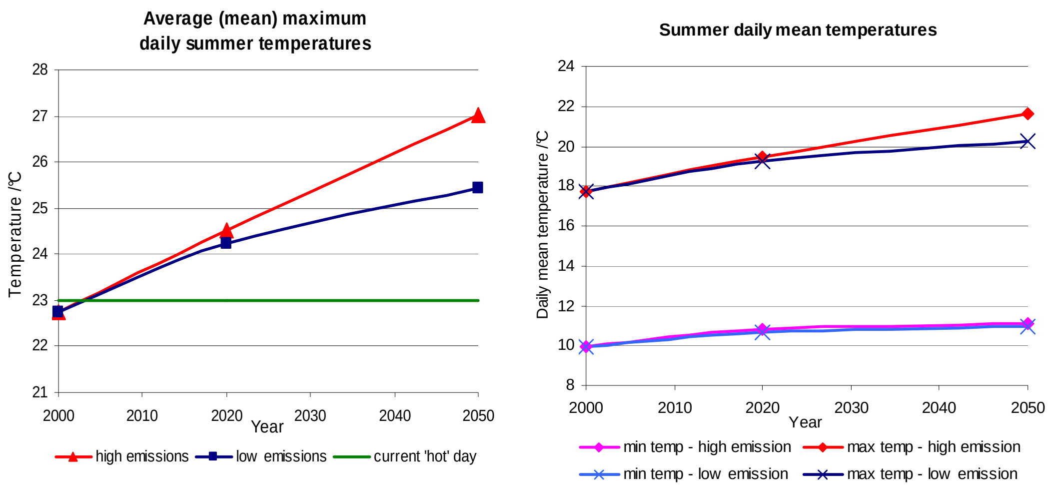


Figure 5: Summer daily temperature forecasts

2.2.2 Design Summer Years

The earlier temperatures forecast the *average* summer in 2020 and 2050. CIBSE Design Summer Years (DSY) model future 'hot' summers using hourly temperatures instead of daily means. These are created from the third hottest summer between 1976 and 1995, then scaling up the temperature based on the predicted climate changes. Hot summers are used for worst case scenarios, indicating future risks from extreme temperature which can be hidden in mean forecasts.

Figure 6 shows the historical temperature record from the 1980s and its projection in 2050. This graph is useful because we can see both peak temperatures and how long was spent at or above a particular temperature over the course of a year. Under the medium-high emissions climate scenario, it can be seen that temperatures in a hot 2050s summer will peak in the heat stress zone (T>35°C) and the time spent above 25°C has risen dramatically.

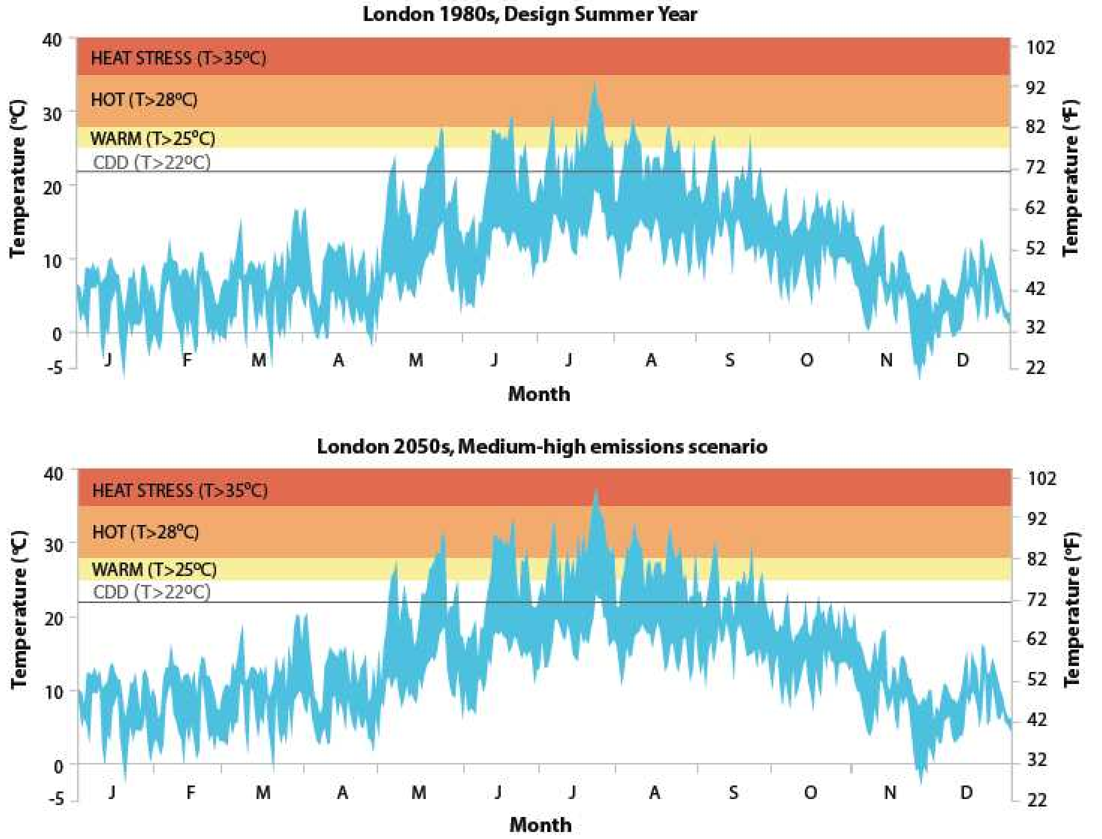


Figure 6: DSY for 1980 and 2050 (Hacker *et al* 2005)

The period above 22°C increases even more so, to include half period between July and September and also parts of in May. This directly influences the number of cooling degree days.

2.3 Heating and cooling degree day forecasts

Heating degree days (HDDs) and their counterpart cooling degree days (CDDs) measure how long temperatures exceed (either above or below, never both) a defined temperature and by how much. It is used to estimate the fuel consumption for heating or cooling over a set period.

Heating degree days are worked out by averaging a day's temperature and subtracting that from 15.5°C (which is the minimum temperature set by health and safety standards), to get the number of degrees of heating needed for the day. Then all those are summed for the year, ignoring negative values (where no heating is required).

Because it is used to estimate fuel consumption, the temperature limit should be the threshold at which the cooling, or heating system is required. Degree days measure outdoor temperatures, and must be adjusted to reflect indoor comfort levels. Therefore, although 15.5°C outdoor temperature is lower than the recommended indoor 18/21°C, after heat gains from occupants, household appliances and lighting is taken into account it becomes more realistic. Even this, however, is insufficient because buildings lose and gain the incidental heat at different rates, depending on its insulation levels and other factors.

Similarly, for cooling, the definition should take these gains into account and the target temperature for cooling the room. Accordingly, we can expect the threshold temperatures to change in different countries. The US Dept of Energy and ASHRAE define cooling degree days from 18°C, whilst both 18°C and 24°C are used in Australia.

Therefore, any definition used should allow the threshold to be reviewed periodically, and changed if necessary. As we discuss in chapter 4 there is considerable latitude in the 'ideal' temperature, and by promoting and institutionally locking in an ideal temperature we risk promoting an adverse result in cooling use.

We use the UKCIP-selected 22°C as the maximum temperature above which cooling is needed on the basis of standard building engineering practice. CDDs are then calculated in the same way HDDs, where the day's average temperature above 22 becomes the degrees of cooling that is summed for the year.

Under the UKCIP baseline conditions, between 2100 and 2300 HDDs are required in southern England (3000-4000 in Scotland). CDDs are 310-330 in southern England, 20-50 in Scotland.

The changes in the HDDs and CDDs in UKCIP scenarios for various parts of the country are shown in Table 1.

Table 1: Heating Degree day percentage point reductions (UKCIP02)

HDD	Baseline	2020s	2050s	2080s
Scotland & N Ireland	3000-4000	0-15%	0-25%	15-30%
Wales	n/a	0-15%	0-25%	15-45%
N England	n/a	0-15%	0-25%	15-40%
S England	2100-2300	0-15%	15-30%	20-45%

Cooling Degree day increases

CDD	Baseline	2020s	2050s	2080s
Scotland & N Ireland	20-50	+0-20	+0-30	+10-40
Wales	n/a	+10-30	+20-60	+20-100
N England	n/a	+0-20	+10-60	+20-80
S England	310-330	+40-60	+100-150	+100-280

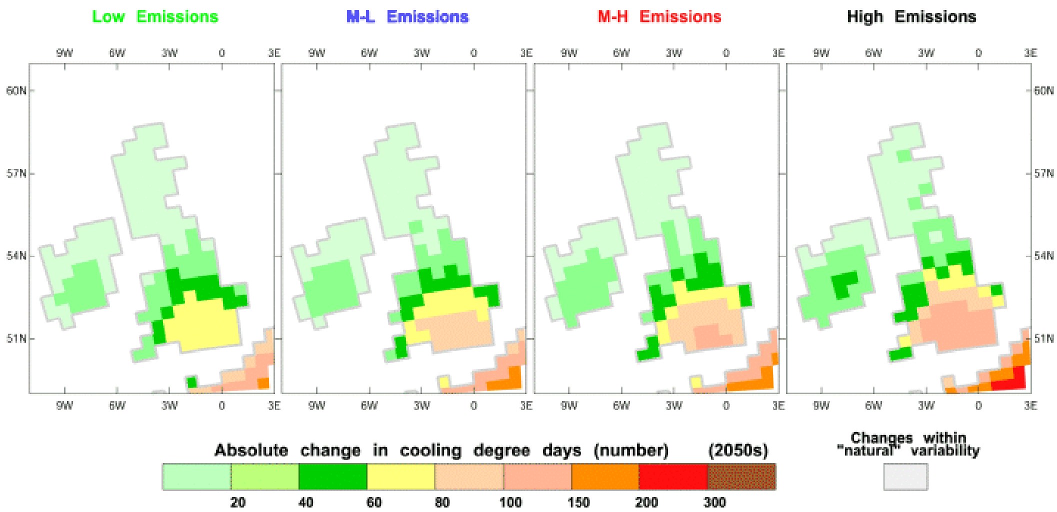


Figure 7: Change in cooling degree days for the 2050s scenarios (UKCIP02)

Changes in the 2020s are relatively slight but, even under the low emissions scenarios, the changes by the 2080s are significant. If policies want to ensure a low emissions trajectory it is important that changes are in place early.

The change in CDDs for the 2020 to 2050s shown (Figure 7) illustrate the differences between the regions. These cover changes in CDDs for the whole year, rather than just the summer season, although much of the temperature increase is experienced in the summer as discussed earlier.

One of the most important points here is that the rise in CDDs is linked to HDDs falling (Figure 8). The energy increase from cooling is, therefore, potentially offset by the lower heating requirement. Note Figure 8 only sums the heating and cooling *degree days* for each region, not the actual heating or cooling requirements, and that by definition, HDDs are counted below 15.5°C and CDDs are counted above 22°C, leaving a 6.5°C 'comfort zone'.

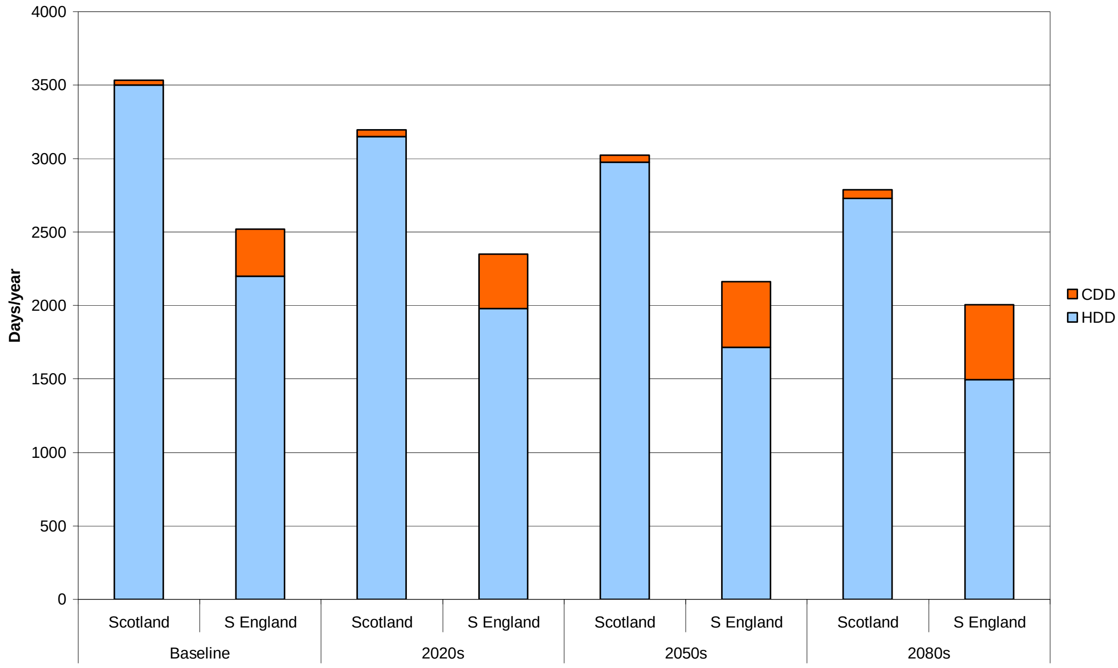


Figure 8: Heating degree days and cooling degree days for baseline and climate scenarios, Scotland and S England (UKCIP02)

On the face of it, even if there is a huge increase in the amount of air-conditioning purchased by UK householders, provided these use no more energy per cooling degree than heating does for heating degrees, the net effect should be to reduce overall consumption. The questions that follow are: (1) does cooling use no more energy than heating and (2) if yes, then by how much is consumption reduced?

The RCEP (2000) says that to minimise the risk from climate change we should be reducing our carbon emissions by 60% by 2050. Does the rise of air-conditioning threaten this longer term policy goal? The next section looks at the evidence from sales, and then we analyse scenarios for use in order to determine whether despite the net reduction in apparent need for indoor climate control, and whether in fact there is a threat to emissions from residential cooling systems.

3 RISING SALES?

Despite the apparent use of air-conditioning in every building visited by the public in general terms, such as shopping centres, cinemas, hotels, offices, the actual penetration in the built environment is reported to be quite low. Figure 9 shows the percentage of buildings with air-conditioning currently installed.

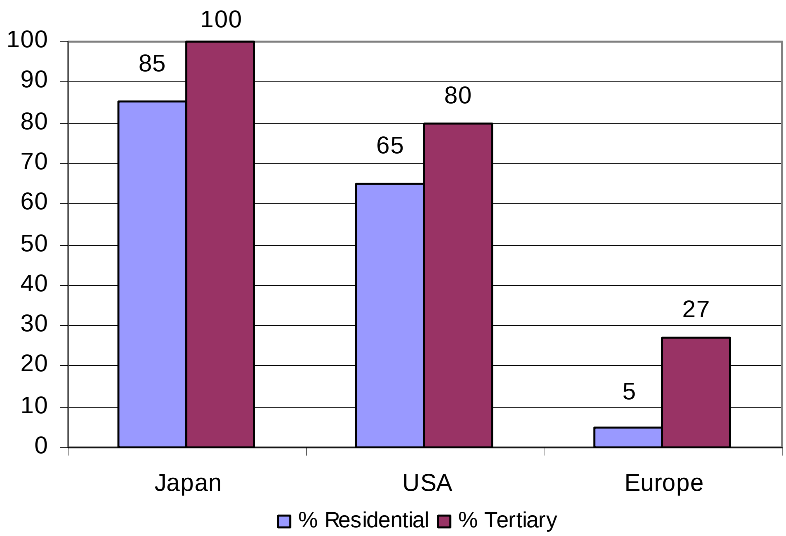


Figure 9: Global penetration of air-conditioning in buildings in 1997 (CEP, no date)

In evidence to the House of Lords Select Committee on Science and Technology (2005), representatives of the Institute of Refrigeration made the following points about the size of the market and its rate of growth:

- Approx 95% of market is commercial and 5% domestic
- Estimate ca 10 % of non-domestic floor space in the UK is air-conditioned (offices, hospitals, education establishments)
- Office installation probably 15% air-conditioned
- In dwellings, the market penetration is less than one per cent, probably less than half a per cent as a best estimate
- Very good equipment is available, equipment efficiency is generally improving steadily and has improved enormously in the last ten years
- End-users commonly either buy very cheap equipment rather than the best on the market and/or operate the equipment badly; also equipment is not maintained in an optimum fashion
- The Defra-funded Market Transformation Programme (MTP) estimates a three-fold increase in the floor area of air-conditioned buildings over a 20 year period, a 6 per cent compound growth over 20 years. Growth is expected to continue at that level.
- In the domestic sector, growth is probably rather higher in percentage terms but it is starting from a very low level.
- The non-domestic sector is adding more to the Kyoto emissions, but in the long term it is feasible that the domestic sector could change more significantly.

The Institute representatives went on to compare growth in buildings with the market for air-conditioning in cars: ten years ago the penetration in that market was probably about 10% of new cars at the luxury end of the market. In 2004 about 75% of new cars had air-conditioning. They pointed out differences in the markets' characteristics. In cars the turnover is relatively short—replacement for cars is every few years—and in the domestic situation it is quite complicated to retrofit air-conditioning (ibid.). The Institute therefore would not expect dwellings to reflect transport air-conditioning growth, but they were alert to a rising trend.

The trend for growth in air-conditioning, but unsupported by actual figures, is one of the biggest barriers to confidence in policy making. Property developers, at least in southern England, have reported that new commercial property must be air-conditioned to be let at reasonable terms (Wade *et al* 2003). However, companies that are commissioning new headquarters may specify low energy or even passive HVAC solutions to demonstrate their commitment to mitigating climate change as part of their corporate social responsibility (Pett *et al* 2004). These approaches may be awarded an imaginative name such as “super prestige design” and indicate that some specifiers and architects are aware of the problem and taking steps to be part of the solution. However, there is no guarantee yet that we know the right approaches for attaining low energy comfort in modern buildings (Dunn 2006).

An analysis of non-domestic building energy use and carbon emissions, found air-conditioning and ventilation used only 3% of energy but produced 5% of carbon dioxide emissions (Pout *et al* 2002). There was considerable variation between building end uses; commercial offices and retail space used 13.9 kWh/m^2/yr, whilst warehouses and hotel & catering establishments used 11.1 kWh/m^2/yr. This is compared with government offices (5.6 kWh/m^2/yr), whilst schools and health centres which barely register. This is equivalent to over 5% of all energy use in offices, retail and warehouses. Addressing cooling separately from refrigeration, the same report identified cost effective potential to reduce carbon emissions from cooling by 0.23 MtC by 2020. These figures, however, were produced based on 2000 data which this report updates for 2005. This is achieved by estimating the increase in energy for cooling, and the increase in floor space for each end use. Floor space data is taken from the latest available valuation data (ODPM 2006a), and compared with the 2000 valuation data used in Pout *et al*.

Non-commercial properties are assumed to use the same amount of energy for cooling per m^2. This probably understates the issue. For new commercial space (office, warehouse, retail and hotel), however, the kWh/m^2/yr figure is updated. We know from previous work that the difference in cooling demand between air-conditioned and non-air-conditioned property is typically a factor of ten (between 14 and 41 kWh/m^2 for air-conditioned offices, compared with 2 kWh/m^2 for typical non-air-conditioned) (DETR 2000 cited in Wade *et al 2003*). We assume that 80% of new commercial property is air-conditioned, based on the assertion from our property stakeholders in previous work (Pett *et al* 2004).

The results from this calculation suggest an increase in cooling energy use from 7.3 TWh/yr to 8.9 TWh/yr, an increase of 18% in five years.

3.1 Mobile air-conditioning units

In some ways, the growth of integrated, central air-conditioning may be a smaller problem then the unconstrained sales of mobile ‘air-conditioning’ units, mainly to the domestic sector. We also include cooling units in this category and this report. They are more correctly described as comfort cooling units because they do not condition the air, merely lowering the air temperature in the same way as a fan heater provides a heat source. As pointed out by BRE (Butler, pers. comm.) these cooling units are usually a ‘distress’ purchase’ – bought during a heat wave or similar – for homes and small businesses, and once bought are likely to be used whenever temperatures rise, rather than only at the previous peak which brought on the distress factor.

These units will be desirable sources of cooling in peak heat conditions, especially for elderly people at risk of heat stroke and for comfortable night-time conditions that allow people to sleep. However, we can imagine a worst case scenario where the cheapest units, without adequate thermostatic controls, are left on in a bedroom overnight, with a window open for 'cooling' breezes, and the sleeper wearily pulling a blanket over them in the comparatively chilly early hours rather than wake up sufficiently to turn the cooler off.

Similarly, although energy efficiency labels are required, for consumers there is limited guidance or instruction about best practice. This can result in very inefficient use and therefore unnecessarily high energy consumption. For example, the units need ventilating to the outside, which can lead to a scenario whereby the cooling unit is switched on, whilst hot air is being drawn in from outside, simply because the window is open too wide.

Mobile and domestic sized units are readily available in DIY and electrical stores. B&Q has a range of 14 units available on its web site[2] ranging from wall-mounted climate control units, which provide both heating and cooling that give an optimum (user defined) temperature all year round, to split units with a cooling device mounted outside, and mobile units with a hose for ventilation 'through a wall or window'. Some energy efficiency ratings are given in the product details on their website. A full range of leaflets and videos promoting best practice in fitting are also available. Because using air-conditioning is not always intuitive, producing a DVD explaining to the ordinary customer how to use a cooling unit to best effect could also maximise energy efficiency and conserve energy.

Homebase[3] provides some useful information on its smaller range of eight coolers and air-conditioners, including an explanation about the benefits and drawbacks of more energy efficient evaporative coolers. An explanation of the energy efficiency rating is supplied on an air-conditioning buyers guide. However, the hyperlink to the Buyers Guide is not prominent, and it would be easy to buy a unit online without noticing the Guide.

Rental and purchasing of air-conditioning has become more prominent due to recent heat-waves, with external temperatures over 30°C leading to substantial increases in demand. Anecdotal evidence from a well-advertised rental firm suggests that the market is not only extremely competitive for rental but also purchase, citing both plant hire in the rental market, and high street stores for sales, competing for both the domestic and small business consumer - the John Lewis Partnership, for example, offers a 2.9 kW cooling capacity unit.

Fixed windows in offices mean that calls for cooling services also increase on the basis of solar gain. The cooling-rental firm cited one week in April 2006 with more than double the number of calls received compared with the following week where external temperatures were the same, but with rain instead of sun. The glazing industry is rapidly responding to calls for thermally reflective glass as one solution, but there is lot of window area to be retrofitted even if this does prove a good solution.

3.2 Forecast growth

The MTP estimates that in the ten years from 2000 to 2010, energy use from air-conditioning and cooling will increase from 10 TWh to nearly 20 TWh under the current policy regime (MTP forthcoming). Modelling based both on a top-down and a bottom-up approach result in comparable energy predictions. The top-down method, however, forecasts further forward to 2020, when energy used by cooling is predicted to be 25 TWh. The MTP policy proposals aim to manage market development, and assume that technology will be needed to optimise thermal comfort. These types of proposals are examined in chapter 5.

[2] www.diy.com

[3] www.homebase.co.uk

The Tyndall Centre (Levermore *et al* 2004) also modelled predicting heating and cooling energy requirements in buildings. They adopted the CIBSE principle for designing buildings that withstand near-extreme temperatures in a Design Summer Year. They found that although minimum temperatures increase, they do not rise as much as maximum temperatures, so the incidence of extremely hot days increases.

> The [modelled] average comfort temperature rises significantly through the 21st century. The cooling load demand (for air-conditioning or natural ventilation) also rises significantly although the larger heating demand reduces. However, the heating demand would be met by gas heating and the cooling demand by electric air-conditioning. The electric power requires more CO_2 per kWh of consumption. So in terms of kg of CO_2 emissions for the cooling load there is an increase of up to 27% in kg of CO_2 and a 6% reduction for heating. (This is optimistic as plant efficiency, fans and pumps have not been included). By 2080 the cooling load has increased by 110% and the heating load has reduced by 25%.
>
> *(Levermore et al 2004)*

Furthermore, they examined the need for cooling compared with the need for heating. As shown previously (Figure 8), whilst cooling degree days are offset by reduced heating degree days they found that it is far outweighed by the primary energy required for each degree day of cooling being much greater than that needed for heating. This is due to the predominantly gas powered heating in the UK, which has much lower carbon emissions than predominantly electric cooling. This means that carbon emissions from reduced heating are far outweighed by the increase in emissions from cooling. The Tyndall Centre concludes that technical solutions to managing cooling energy consumption will not be enough, and suggest that further research into adaptive responses to comfort is required.

The implications of this issue are examined in the next chapter along with alternative scenarios for thermal comfort developed by the Future Comfort Programme at Lancaster University. After this, we review the alternative technical approaches and then move on to suggest alternative strategies for policy.

4 MODELLING COOLING USE AND ABUSE

How many will people actually buy air-conditioning? And how much will they use it? The rational energy user suggests the answers are 'few' and 'rarely', except on excessively hot days.

However, experience driving cars with 'climate control' suggests that air-conditioning could become the default; the technological solution will maintain the internal climate at pre-determined 'comfort' levels without user intervention. In other words, an 'always on' system might only activate when needed, but it always uses energy and the temperature limits may be too rigidly prescribed. Indeed, it has been argued (Shove 2003) that comfort is an artificial construct that has been standardised due to the interests of the air-conditioning industry.

This section examines possible user behaviour, based upon 'Comfort Scenarios' developed in Lancaster University's "Future Comforts" project, and triggers for buying and using cooling appliances. The domestic sector is the major focus since it is the highest growth area but poorly understood. These market drivers are essential to predict possible cooling energy demand and determine future policy.

4.1 Defining model Comfort Scenarios

The "Future Comforts" project (Shove and Chappells 2004) addressed both heating and cooling issues, examining the relationship between climate change, conventions of thermal comfort and the built environment. In it, Shove and Chappells describe a matrix of attitudes to thermal comfort (Table 2) and conclude that there are four possible scenarios:

I. **The comfort zone extends** – People are comfortable in a much wider range of indoor temperatures, and they expect to be colder during the winter and warmer during the summer. Seasonal fashions would be geared towards providing comfort indoors without contributing to climate change. Building designs would only need to maintain temperatures within more 'elastic' definitions of comfort so that resource consumption would be significantly reduced.

II. **Indoor climates diversify** – In this scenario, regional climate differences are positively valued through, for example, local cultural reinvention. This would massively reduce the environmental cost of comfort for a moderate climate and we can expect people to accept and adapt to rising temperatures. This scenario is less probable since standards are presently anticipated to converge globally.

III. **Standardised efficiency** – In this case conventions of comfort and clothing stabilise but far more efficient ways of providing and delivering precisely defined conditions of 'comfort' are developed, such as new forms of technology, better controls, or climatically sensitive passive design strategies.

IV. **Escalating demand** – Interpretations of comfort will develop in ways that are even more demanding than those of today. People, for one reason or another, expect to be even warmer during the winter and even cooler during the summer. The energy demand will increase as a result along with associated emissions.

Table 2: Theories of comfort (adapted from Shove and Chappells 2004)

	Theory	Concept	Temperature characteristic	Achieving comfort
Physiological	Biological heat balance	Natural climate as the threat to human productivity – a threat to be kept at bay	22°C 'thermal monotony'	More efficient air-conditioning
Adaptive	Physiological/ behavioural adaptation	Modify the external climate: mediate and transform but do not exclude	Indoor conditions 'float' with external ones and provide variety of experience	Natural ventilation exemplars and adaptive standards
Social Convention	Social and cultural experience	Mediated indoor climates; thermal needs and thermal conditions defined by socio-cultural and socio-technical worlds prevailing	From 6 to 30 °C depending on society	Promote diversity in meanings experiences and expectations

The first two Comfort Scenarios support Henderson's suggestion: air-conditioning does not become a major threat, and the level of use will be linked to the frequency of 'hot' days. In scenarios III and IV however, the assumption is that not only will air-conditioning be used all the time to maintain indoor temperatures within the range defined by cooling degree days, but it could be used to deliver unreasonably low indoor temperatures during peak heat periods.

4.2 Real life Comfort Scenarios – from USA to UK

The USA has a mature air-conditioning market. Analysing trends in the US may, therefore, indicate the direction of the UK cooling market. US energy statistics are made available by the Energy Information Administration (EIA, part of the US Federal Department of Energy) through the Residential Energy Consumption Survey (RECS). Data is analysed by census regions, split along the time zones. For comparison, moderate climates similar to the UK can be found in the western United States: Washington, Idaho, Oregon, etc. This is caused by the moderating influence of the Pacific Ocean currents in a manner similar to the westerly winds and North Atlantic Current with respect to the UK. There is no split between northern and southern states, however, and this region stretches from Alaska to Hawaii. More focussed analysis of the RECS raw data, which also includes cooling degree days, is beyond the scope of this paper.

Table 3 shows the usage changing over time for window and wall-mounted air-conditioning (split units or 'splits'). No data were available for the mobile units, which are expected to make up most of the UK market, but split units are already available in the DIY market as indicated in the previous section.

Table 3: Frequency of wall/window air-conditioning use

Year	% using window/wall air-con			
	Not at all	Few days nights	Quite a bit	All summer
1981	7.3	72.9	12.9	6.7
1982	14.8	60.5	13.5	3.9
1984	9.9	51.1	22.0	11.9
1987	8.9	54.9	17.7	9.2
1990	9.9	53.8	20.0	14.7
1993	12.5	71.0	12.3	4.3
1997	3.7	59.8	21.8	14.7

Whilst there is a general trend over time in the US to use air-conditioning more frequently (EIA, 2000), it is not immediately obvious with wall units. This is because it is overwhelmed by the trend to install central air-conditioning units (Figure 10) which cool a greater floor area and are used for significantly longer.

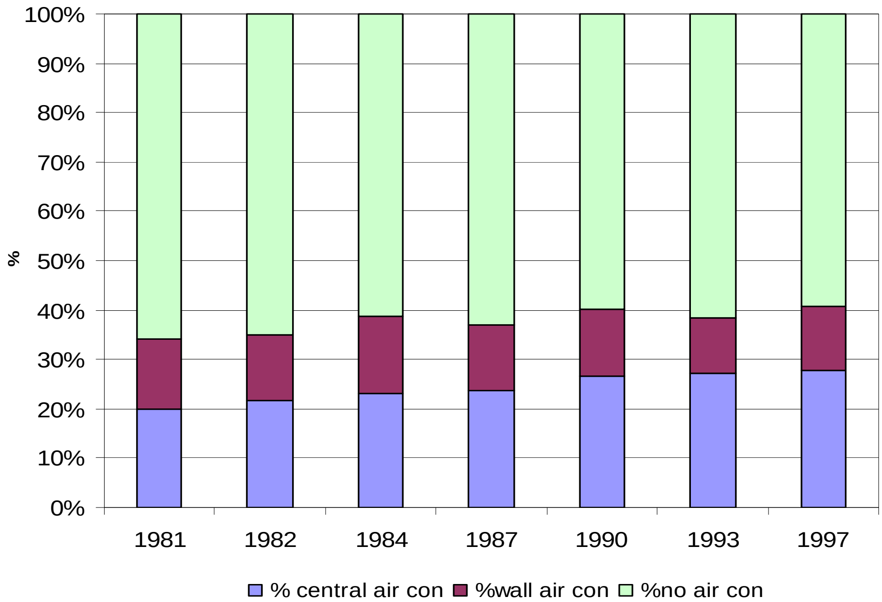


Figure 10: Ownership of air-conditioning in West USA

Without central air-conditioning expected in UK homes, we might therefore expect a more significant trend for households to use mobile/wall units with increased frequency over time. There are many factors affecting how people view air-conditioning, but because the climate has not changed significantly[4], the data lend support to the theory that people grow more accustomed to high levels of comfort and start demanding more control, i.e. Comfort Scenarios III and IV.

4.3 Non-climate drivers in UK households for cooling

In the UK, what proportion of people would choose to use air-conditioning in the home and for what temperature range? The answer would surely be influenced by:

- The ‘comfort zone’, quantifies the Comfort Scenarios by setting the mean temperature and comfortable temperature range for the

[4] NCDC time series graph shows a 0.1℃ rise in average June to August temperature from 1981 to 1997 using GHCN land surface data set in the region: Longitude: -122.0 to -117.5 Latitude: 45.1 to 33.6

population. We assume this is a normal distribution.
- The degree to which air-conditioning outside of the home (such as at work) defines individuals' personal comfort zone.
- Cost, which should include both upfront and running costs with the former being probably more critical.
- Fashion or social status, which could imply more (e.g. Comfort Scenario IV) or less (Comfort Scenario I) cooling requirement.

Four model population groups are defined to represent each influence:

A. The whole population.

B. The population who can afford air-conditioning. We have used the distribution of households paying higher rates of council tax (bands D to H), assuming they adopt air-conditioning as a lifestyle option[5].

C. Assumes that rural dwellers experience a 'fresher' temperature and are more resistant to air-conditioning than urban dwellers. The distribution of urban and suburban dwellers is taken from the English House Condition Survey 2001 regional data (ODPM 2003).

D. Assumes that people decide to use air-conditioning based on whether their work environment is air-conditioned. Air-conditioning incidence is principally high in the commercial sector, including offices, retail and leisure. The data on professional occupation is taken from the 2001 Census (ONS 2006), and uses an assessment of office quality variation by region previously developed by ACE (Wade *et al* 2003).

These groups are used to determine the population size, in South England, who will buy air-conditioning. Because the aim is to identify the scale of unconstrained growth it is assumed that a mature market exists, i.e. everyone in the group who is uncomfortable has purchased air-conditioning. It must be noted that the population groups show considerable overlap and cannot be added together – high-income, urban-dwelling office workers are not uncommon.

The groups are not adjusted over time and therefore it is assumed that the population is stable with respect to the four groups. Projecting these changes is beyond the scope of the project. Therefore, in 2020 and 2050, the total population size has not changed, people are no more affluent than now, the population mix living in urban or rural locations has not changed, and the same number of people will work in air-conditioned offices.

4.4 Creating a comprehensive demand model

The analysis so far identifies the factors that a comprehensive model must take into account:

- Outdoor temperature increases
  - How outdoor temperature rises effect indoor temperatures, based on building design
- Cooling-market
  - Unit costs
  - Competing technology
- Who will choose to buy and use air-conditioning based on population groups
  - Rate of purchase in each population group
- How long the air-conditioning is used based on Comfort Scenarios
  - Trigger temperature for switching on the unit

[5] This may be correct in the early years, but data from the USA shows that in practice there is little difference in uptake of air-conditioning between social classes (cited in Waide 2004)

- Target comfort temperature

This report models the last factor, Comfort Scenarios with rising temperatures, followed by a discussion of population groups.

4.4.1 Assessing cooling demand – outline of method used

The anticipated temperature and cooling demand increases use CDDs and extreme temperature forecasts from the UKCIP02 scenarios. These indicate that the highest temperatures will be in southern England, covering the East of England, London and South East regions. The South West and West Midlands will also be affected in later years, but for 2020 the problem will not be more than a handful of days per year. The population groups indicated above have therefore only been analysed in Southern England.

Defining Comfort Zones for each Comfort Scenario

The comfort zone is a normal distribution which specifies the comfort range of the population. Most of the population is comfortable at the average temperature whilst fewer are comfortable at the extremes. We define the normal distribution using the mean comfort temperature and the standard deviation, the temperature range within which a fixed proportion of the population is comfortable.

The modelling takes Scenario III as the baseline to set the mean comfortable temperature and temperature range. We use outdoor temperatures because this is the basis of the CDD and HDD, whilst remembering internal temperatures are higher. The mean comfortable temperature is set halfway between the HDD (15.5°C) and CDD (22°C) limit, ie 19°C. We must assume that most of the population will be out of their comfort range at the CDD or HDD limit and therefore switch on their system. For simplicity we set the CDD limit at one standard deviation, which is 84% of the population.

Comfort Scenario I specifies a much wider range of comfortable temperatures but the same comfort mean. We therefore move the first standard deviation to 26°C, an increase of 4°C from the 22°C in Scenario III, which we believe is realistic.

Comfort Scenario II has no mean temperature or range. This is because people have adapted to whatever climate changes have occurred, however unrealistic this may be.

Comfort Scenario IV demands even lower summer temperatures and therefore the mean temperature has dropped to 17°C. Since the range does not change, the 84% limit (1 SD) falls to 20°C.

Table 4: Population comfort zones

Comfort Scenario	Mean temp /°C	SD /°C
I	19	±7
II	n/a	n/a
III	19	±3
IV	17	±3

The following paragraphs quantify two methods for analysing the cooling demand. We can assume cultural lock-in of the 22°C limit and the uncomfortable population proportion changes, or move the temperature limit so it represents 84% of the population and recalculate the CDD.

Cooling demand at 22°C limit for varying population proportions

By plotting the population against the DSY (Figure 11) we can see what proportion of the population is uncomfortable at a given temperature and how long they will stay in it. Comfort Scenario III is drawn in dark blue and the population below the 22°C line is uncomfortable at any temperature above 22°C. This is the majority of the population (defined at 84%). However, in Scenario I (shown in green), a smaller proportion is uncomfortable (66%) and would need cooling. In Scenario IV (shown in red) 95% of the population demands cooling. The CDD can be adjusted accordingly to give the proportional population weighted CDD (PCDD, Figure 12).

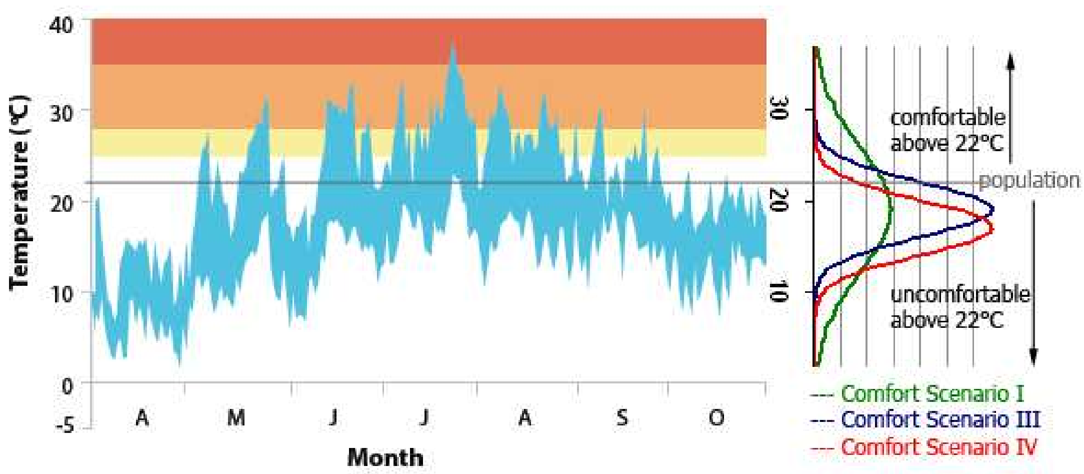


Figure 11: Population comfort zone illustrated against a DSY

Cooling demand for 84% of the population at varying temperatures

The comfortable temperature limit for 84% of the population is 26°C, 22°C and 20°C under Scenarios I, III and IV. As we have seen in section 2.3, however, the CDDs do not change linearly with temperature.

From the DSY, we estimate the CDD halve when the limit is 26°C and multiplies by 1.5 at 20°C. This is applied to 84% of the population (Figure 12).

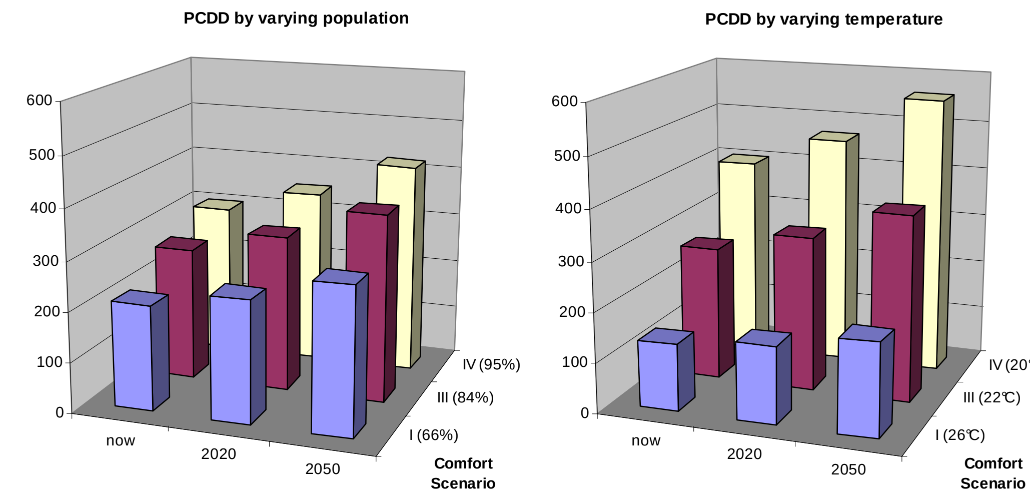
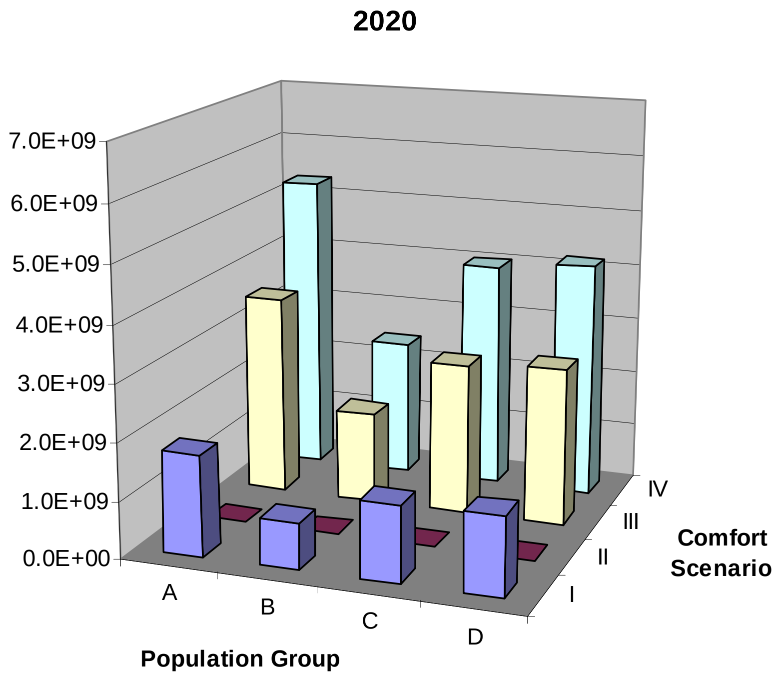


Figure 12: PCDD variation

These initial results suggest the greatest risk, and most effective method of reducing air-conditioning use arises from changing the expected temperature, rather than limiting the population demanding cooling at 22°C. However, a number of critical assumptions are made which need further research.

4.4.2 Cooling demanded by population groups adopting air-conditioning

The final air-conditioning demand indicator (Figure 13) is calculated by multiplying the PCDD by the population size of each group (section 4.3). We use the PCDD predictions created by varying the temperature CDD temperature limit.



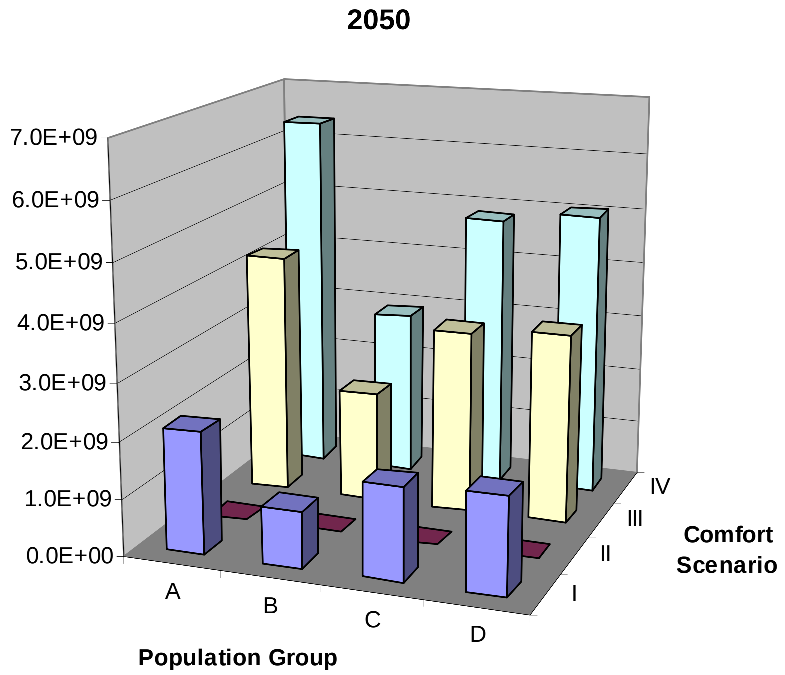


Figure 13: Final air-conditioning demand based on Comfort Scenario and population group

The baseline for air-conditioning demand is the current demand. This has not been shown because it is virtually zero. Any air-conditioning demand is therefore new demand.

As stated previously, Comfort Scenario II presents a future where everyone accepts a much wider range of temperatures, so 'cooling demand' is not a socially acceptable concept. The degree to which this is realistic under the UKCIP's High Emissions scenario in 2050 and for any scenario in 2080 is questionable. However, it does provide a comparison with the other scenarios. To achieve a low-energy solution to high temperatures in the future, proven zero-carbon emission cooling solutions need to be found and implemented at an early stage, before energy consuming solutions take hold in the market.

Acceptance of warmer temperatures and personal intervention makes a very great difference in demand in Comfort Scenario I compared to III and IV. Accepting a wider range of temperatures also makes a wider range of simpler solutions viable. This is because the aim is to reduce temperatures by a few degrees rather than exert total control over the absolute temperature.

In the last two scenarios, where air-conditioning is accepted as a way of life – provided to achieve a 'reasonable temperature for all' (III) or the 'personal comfort temperature' (IV) – cooling demand is at least twice as high as Scenario I. Controlling carbon emissions will require equipment to be at least twice as efficient or halve the carbon intensity of electricity production.

By the 2050s, when temperatures are increasing further, cooling demand will increase but by only 20%. This suggests that we may need to take action to adopt the more tolerant approach to comfort described in scenario I unless we are prepared to adopt a wholesale improvement in cooling technology. The use of electricity from fossil fuels to cool ourselves at the early stages will mean we are set for the high emissions scenarios in the UKCIP02 models, with consequent extreme temperature by the 2080s, where 42°C becomes common.

Note that the cooling demand indicator takes no account of the difference in power required to cool by 1 degree at, for example, 28°C and at 42°C. The greater the difference between external temperatures and target temperatures, the more power is required per degree cooled. The calculations also make no distinction between hot days over a period of time (a heat-wave of say, ten days at 30°C) and an isolated day of 40°C. No attempt has been made to model the night-time cooling requirement separately or distinctly from the day's, although this might be where the greatest demand for cooling will arise.

The differences between the groups are not as great as might be thought at first with Groups C and D being most similar. This is partly because the distribution of rising temperatures coincides with other factors such as urban centres and working in a commercial environment. London, for example, is almost wholly urban and has 78% of its population engaged in occupations that involve working in an office, commercial or public sector building, most of which are air-conditioned, and where exposure to air-conditioning might promote its adoption at home. If air-conditioning ownership in the western USA is assumed to be representative of the UK, then around 40% of the population will use air-conditioning. Group B represents 45% of the population and when we include the 84% population threshold, defined by the Comfort Scenario, this is reduced to 38%.

Population densities in South England are also higher than in many of the other regions. Thus, not only are the temperatures likely to rise highest in the south and east, but a majority of the population live there, and are the ones most likely to demand cooling in order to enjoy reasonable sleeping and working environments. Our indicator of affluence, based on home value (Group B), halves the cooling demand. However, the size or cost of a home is not necessarily a good indicator of whether air-conditioning will be adopted on the basis of cost; previous work has shown that many people living in social housing have a high ownership of consumer electronics.

4.5 Considering the effect of building design

Our approach can be compared with that taken by Arup in their research for UKCIP (Hacker *et al* 2005). They used heat stress criteria, illustrated in Table 5.

Table 5: Sample Thermal Discomfort measures (Hacker *et al* 2005)

Thermal discomfort	**Warm temperature threshold**	**Hot temperature threshold**
Offices, schools and living areas in homes	25°C	28°C
Bedrooms in homes	21°C	25°C
	Building has 'overheated' if it is over 'hot' temperature for more than 1% of occupied hours	
Heat Stress Risk	Indoor temperature above 35°C (for healthy adults at 50% relative humidity)	

Hacker focuses primarily on the response of different building types to climate changes. Adjusting to indoor temperatures (a 2-3°C increase), these fit well with the assumptions made in our analysis above, i.e. some people will resist using air-conditioning until it is 'hot' (28°C or above), whilst others prefer to be 'warm'. However, evidence from the US suggests that air-conditioning is set so that indoor temperatures are often *lower* in summer than in winter, which gives rise to concern.

> However, the important consideration is the overall comfort which is assessed for a naturally ventilated building by the proportion of the occupancy time that is above 25°C. … The building used in the simulation complied with the comfort criterion for 1980 but by 2025 even the heavyweight building had far exceeded the criterion. This means that natural ventilation would not provide adequate comfort and that air-conditioning should be used. Once air-conditioning has been installed the energy use in the building would effectively double. Low energy and mixed-mode air-conditioning could significantly reduce this use but it would still be above that of a naturally ventilated building.
>
> *Levermore et al*

A further reality check is provided by Levermore as shown in the box left. A warning about well insulated buildings is presented by CEPE (Jakob 2006): well insulated buildings do not cool down sufficiently at night to enable the thermal mass to dissipate the absorbed daytime heat in the way that designers might expect – which poses a particular problem in commercial buildings, where there is a security issue of allowing open windows at night. Lighter fabric buildings may be more appropriate in some design contexts. However, overshadowing by other buildings can be another factor in an urban setting. The results demonstrate how individual buildings can react to rising temperatures very differently, and that a very wide variety of factors need to be considered. It is also clear that simple, blanket advice will be inadequate and a much better understanding is needed for buildings to adapt to the forecast temperatures in the 2020s.

> With many buildings in the UK being quite old there is a strong probability that they will fail the comfort criterion by a larger margin than the example used [in the analysis]. Hence there will be a need for major refurbishment to maintain summer comfort. Buildings constructed under current Building Regulations will perform better but these are in a significant minority.
>
> *Levermore et al*

Old buildings and their (built) environment may also behave unexpectedly. Experiences of living and working in Victorian and older buildings, especially those narrow and deep from front to back, shows they allow better circulation of what cool air is available, and shading is better handled. Reexamining these building types may provide a range of solutions suitable to Comfort Scenarios I and II, but unable to provide prescribed temperatures through refurbishment measures.

4.6 Cooling demands on the UK Kyoto Target

As a result of the 1997 Kyoto Convention on Climate Change ('The Kyoto Agreement') which was ratified in 2005, the EU is committed to achieving an 8% decrease in greenhouse gas emissions from 1990 levels by the 2008-12 reporting period. The UK's share is 12.5% and the Government set a target in the UK Climate Change Programme 2000 of a 20% reduction in CO_2 emissions by 2010. That this seems increasingly unlikely to be met has led to some rewording of 'target' with 'aim' and 'aspiration'. The 2006-reviewed Climate Change Programme (DETR 2000) cited a 15-18% carbon dioxide emissions reduction from the programmes proposed. However, the Royal Commission on Environmental Pollution had previously published a detailed report indicating the need for a reduction in emissions of 60% by 2050. That course was adopted by the Government and has underpinned the Carbon Trust's work since its inception in 2001, leading to considerable research on pathways towards a low carbon future.

A number of questions arise from the previous sections. Does the rise in air-conditioning threaten our climate change target? Do the options we choose lead us into the high emissions scenario where 42 ˚C will become a reality that leads to a drastically different type of built environment if we are to live and work in it? Just how much carbon dioxide will be emitted from increased air-conditioning, and what policies or regulations are needed to adopt passive measures that would mitigate climate change?

4.6.1 Carbon dioxide emissions from earlier predictions

Commercial and domestic sector

The model of cooling demand leaves us with too many variables to make a reliable calculation of carbon dioxide impact, but some estimates that indicate the order of magnitude of the problem are calculated.

The most reliable estimates simply use the MTP forecasts of overall increase in the air-conditioning market. Using these MTP projections it is possible to predict carbon dioxide emissions, assuming all cooling is electric and electricity carbon intensity does not change from the Carbon Trust's current 0.43 kg CO_2/kWh (Table 6).

Table 6: Estimates of CO_2 emissions from MTP

Year	Energy Used /TWh	Carbon emissions /Mt CO_2e
2000	10	4.3
2010	20	8.6
2020	25	10.8

Under Kyoto, the UK must reduce emissions from 751.4 MtCO_2e to 657.5 MtCO_2e, a reduction of 93.9 MtCO_2e. Increased emissions from 2000 of 4.3 MtCO_2, therefore, do not seem large but it negates over half of the 7.7 MtCO_2 projected savings from the combined 2002 and 2006 Building Regulations (HM Govt, 2006). This is also much larger than the 0.85 MtCO_2 (0.23 MtC) of cost effective savings by 2020 calculated by Pout *et al* (section 3).

Commercial Sector

Less reliable estimates can also be derived from the predictions in section 3. If commercial cooling and climate control use is set to grow from 7.3 TWh/yr to 8.9 TWh/yr by 2011, this would increase CO_2 by 0.6 Mt. However, fact sheets from the Carbon Trust (2006) indicate that waste heat from appliances and higher staff concentrations are the main drivers of air-conditioning, and thus the number of cooling degree days is likely to exacerbate air-conditioning electricity consumption.

Research at CEPE by Aebischer *et al* (2006) indicates that for different cities, with a 2°C rise in summer and 1°C rise in winter temperatures by 2035, their net electricity use and carbon emissions for cooling and heating differ considerably. The changes are based on the commercial sector, assuming the CDDs approximately double the energy demand, and cooled floor area increases energy by 40%. This is mitigated in part by energy efficiency improvements in old and new buildings.

Figure 14 shows CO_2 varying from current levels as a function of current HDD, the CO_2 intensity of electricity in the future (either 'high' or 'low'), and what proportion of heating energy is electricity (either 'little'=10% or 'much'=50%). London is the middle series in the graph with 2904 heating degree days. CO_2 reduces if the electricity carbon content is 'low' (90% emission free) but rises otherwise.

The most important conclusion from this result is that the carbon emissions from CDD increasing outweigh the decreased heating demand. Cooling demand, therefore, must be seriously considered in future building design and policy.

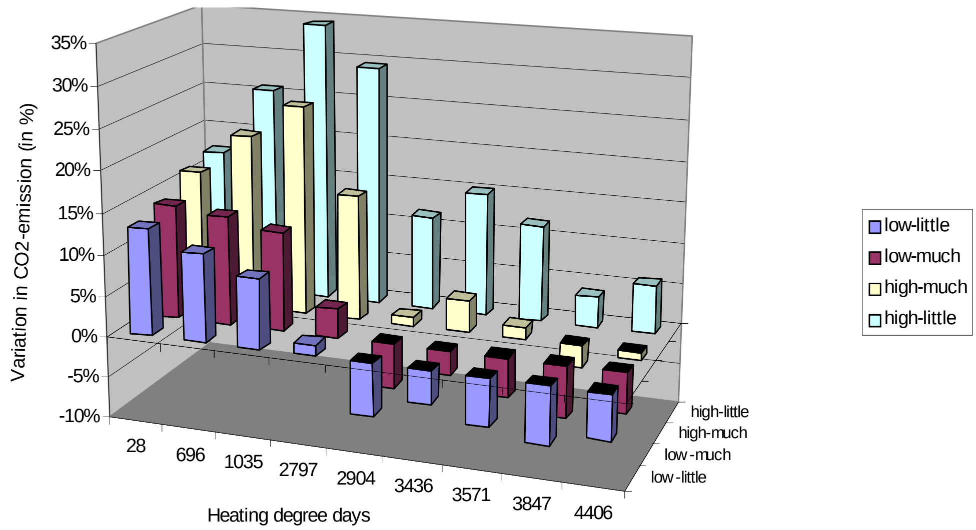


Figure 14: Percent change in relative CO_2 emission from heating and cooling due to climate change in different locations characterised by HDD (Aebischer *et al* 2006)

Domestic sector

Emissions from the residential market are the most difficult to assess, because the current market is so small that the CO_2 emissions are negligible. Whilst this means that all air-conditioning use can be described as additional CO_2 emissions, it also makes it very difficult to extrapolate current electricity use into the future. Very broad calculations are shown in Table 7.

The energy consumed is based on the air-conditioning demand calculated in section 4.4.2 and shown in Figure 13. It uses population group A as the worst case and population group B which is similar to current USA ownership. We assume the trigger temperatures vary under each Comfort Scenario. We then define each household to have three people, owning one 'C' rated (EER=2.3) 10,000 Btu single unit air-conditioner sufficient to cool a south facing 25m² living room[6]. Because the house is not occupied during the hottest period of the day, the air-conditioner is only used for 8 hours of each degree day.

Table 7: Estimated domestic air-conditioner energy use: Population group A

	Scenario I (26°C)		Scenario III (22°C)		Scenario IV (20°C)	
Year	Energy /TWh	Emissions /$MtCO_2$	Energy /TWh	Emissions /$MtCO_2$	Energy /TWh	Emissions /$MtCO_2$
2020	3.8	1.6	7.6	3.3	11.0	4.9
2050	4.6	2.0	9.1	3.9	14.0	5.9

Population Group B

	Scenario I (26°C)		Scenario III (22°C)		Scenario IV (20°C)	
Year	Energy /TWh	Emissions /$MtCO_2$	Energy /TWh	Emissions /$MtCO_2$	Energy /TWh	Emissions /$MtCO_2$
2020	1.7	0.7	3.5	1.5	5.2	2.2
2050	2.1	0.9	6.9	1.8	10.0	2.7

These figures agree in magnitude with the MTP projections and, looking across both population groups, show energy consumption varying by as much as 5.2 TWh to a maximum of 11 TWh in Comfort Scenario IV by 2020. The Building Regulations in the domestic sector are predicted to save 5.5 $MtCO_2$ (1.5 MtC). Air-conditioning carbon emissions by 2020 could negate 15% to 90% of these Building Regulations savings. Emissions from residential air-conditioning could be as high as 5.9 $MtCO_2$ in 2050.

[6] Calculated using manufacturers sizing guide http://www.delonghi.co.uk/feature_pages/air_conditioners_feature/air_conditioners_microsite.php

An EER 2.3 10,000 Btu air-conditioner uses 0.8kW.

Energy =air-conditioning demand *# hours unit is on in a degree day*energy consumption of unit/people per house

=air-conditioning demand*8*0.8/3 (in kWh)

5 SOLUTIONS FOCUSSING ON TECHNOLOGY AND DESIGN

There is already plenty of guidance relating to options for adapting to higher temperatures in a way that puts least pressure on the environment. In this chapter we give a brief overview of the measures proposed in the literature.

5.1 Passive and active cooling

There are two main approaches: using passive measures to provide the cooling without using energy, and active measures which use energy, usually electricity. Active measures which use only solar or other renewable energy sources could be classed as passive. Where active measures must be used, there is a need for the highest levels of efficiency, both in fuel use for distribution mechanisms (e.g. fans) and generating cool air, but this is not enough as good design of the layout of the system is also needed to minimise the power required to distribute the cooling.

The analysis by Arup for the UK Climate Impacts Programme (Hacker *et al* 2005) looked at adaptation measures for a variety of 'typical' buildings and explored the most appropriate measures under a range of the UKCIP02 scenarios. In their introduction they state:

> Passive measures can greatly reduce mechanical cooling needs. For homes in London, they have been shown to work well into the 2080s. For London's offices and schools, it is likely they will need to be supplemented by mechanical cooling from the 2050s onwards.
>
> This is because offices and schools have high indoor "waste heating" from people, lighting, computers and other electrical appliances. One solution is to adopt a 'mixed mode' approach in which passive cooling measures are used as far as possible but mechanical cooling systems are still provided for times of need. With careful design and system management, such buildings can provide high levels of indoor comfort while still operating in a relatively energy efficient manner.

They also comment that the standards required in London will be much stricter than those in Manchester and Edinburgh, as the temperature profiles for Manchester in the 2050s are likely to match those for London in the 1980s, and Edinburgh is unlikely to reach these types of temperatures until the 2080s.

The most successful passive measures identified were:

- Shading from the sun
- Providing controllable ventilation during the day and high levels of ventilation at night (without compromising building security)
- Using heavier-weight building materials combined with night ventilation, to enable heat to be absorbed and released into the building fabric
- Improving insulation and air-tightness so that undesirable heat-flows can be controlled.

It is vital to understand that in most cases, passive measures need to be considered at the design stage, as orientation to the sun, the lie of the land, and the local climate all play a part in passive design solutions. After that, glazing, ventilation, thermal mass, insulation and air tightness have to be considered to produce a building with optimum performance under both hot and cool temperatures. Finally, waste heat, heating and cooling systems need assessment.

However, refurbishment and design of the exterior also play a part in adapting existing buildings. In their case study of a Victorian terraced house, Hacker *et al* (2006) suggest solar shading and natural or mechanical ventilation. The addition of air-conditioning, through a chiller unit, adds significantly to the carbon emissions from the house, and far outweighs the reduction in heating requirement in winter over the course of a year in the 2020s and 2050s (approximately 16% and 20%

more respectively than Hacker *et al*'s base year of 1980s climate). For a house built to the 2002 Building Regulations specification, they suggest the same measures plus an option to increase the thermal mass of the building itself. These measures would achieve a reasonable, if warm, temperature under most scenarios, only exceeding comfort levels in the 2080s. The measures would actually reduce the overall annual carbon dioxide emissions from this house type, but if a chiller is added to provide extra cooling, a similar increase to the Victorian house is found.

For a 1960s office, Hacker *et al* recommend a series of measures: double glazing; increased fabric insulation and air tightness; solar shading; increased thermal mass in the concrete floor slabs by removing suspended ceilings; automatically controllable mechanical ventilation via an underfloor air supply system, used for nightcooling in summer; heat reclaim from exhaust air in winter, and introducing water-chilled beams for cooling when temperatures exceed 25°C. Installing these measures keeps maximum temperatures below 28°C and net carbon dioxide emissions only exceed the current levels in the 2080s.

For new buildings, design is of the essence, and a checklist of issues and measures is provided by the Three Regions Climate Change Group (2005). Their design issues cover: location; site layout; buildings; ventilation and cooling; drainage; water, outdoor spaces and connectivity. Recommendations for developers and design teams relating to temperature issues can be summarised:

- Ensure that overall layout minimises solar gain, maximises natural ventilation and vegetation.
- Design building envelope so that exterior of buildings reduces heat gain in summer, especially from roofs, possibly through green roofs or thermally reflective surfaces.
- Provide shade in outdoor spaces and for buildings themselves.

And, for ventilation specifically they recommend low carbon solutions:

- Secure ventilation systems that can be closed in high temperatures (to keep hot temperatures out) and open at night in cooler temperatures.
- Use techniques from southern Europe including light colour surface treatments, sunscreens, ventilation regulation and use of materials with high thermal mass.
- Adopt newer cooling technologies including evaporative cooling, chilled ceilings and ground cooling. The concept of trigeneration (heat, cooling and power as an extension of CHP systems currently in use) should also be explored.

Solely using air-conditioning may not even be able to provide the answer in extreme weather events. In the 2006 heatwave, some found air conditioners were not powerful enough to compete with the extremely high temperatures. The peak load also caused blackouts in London, leading to complete failure of energy using cooling options. If larger air conditioners were installed to combat this, the electricity grid would be even less able to cope, making powercuts even more likely.

An article in *Energy in Buildings and Industry* (March 2005), suggests that air-conditioning professionals "must be aware that [planned new building to 2016] will include using natural ventilation rather than leaping straight to mechanical ventilation systems […] traditional air-conditioning is always the last resort". The Chartered Institute of Building Services Engineers (CIBSE) has commissioned reports to support its professionals, and concludes that "with appropriate design it is possible to produce low-energy solutions that will provide acceptable ventilation into the 2080s" (EiBI March 2005). However, the article also proposes that EU labelling will have an impact on air-conditioning unit efficiency and that simple to control systems can improve comfort and reduce wasted energy. It points out that currently available technology can fit onto existing heating and ventilation equipment to "reduce energy saving" [sic], and one hopes they mean reduce energy consumption, by up to 40%. If this is the case, then surely this should be made compulsory straight away!

5.2 Appliance efficiency

Air-conditioning efficiency has already advanced very significantly, particularly for larger, central air-conditioning systems with complex ventilation systems. The technologies are not relevant to this analysis but rather the market conditions and policies which have driven these forward.

The three main policies to achieve this are Minimum Energy Performance standards (MEPs), labelling and financial incentives.

5.2.1 Minimum Energy Performance

A variety of different MEPs are used in different countries. Europe has favoured fleet averages that are self regulated by the manufacturers. These voluntary agreements set an energy efficiency target agreed upon between the EU and the industry body representing the manufacturers. Each manufacturer must then ensure the efficiency of all units sold when averaged meets the target. This has been applied with some success to cold appliances and washing machines. Additionally, in theory, self-regulation reduces the level of administration and the associated costs to both industry and government. However, there is no guarantee all manufacturers will participate and efficiency targets have been less ambitious compared to other countries.

The USA has set some of the most ambitious targets (IEA 2003). In addition, their targets are mandatory. Using Least Life Cycle Cost (LLCC), the US regulations minimise the overall cost of a unit, based on manufacturing, running and disposal costs. Lower running costs imply high efficiency whilst manufacturing costs ensure this does not place an unnecessary burden on manufacturers. However, this method requires thorough analysis of both technology developments and changing economics and markets.

A simpler solution is the ‘top-runner’ method adopted by Japan. This approach states simply that within a certain timeframe the fleet average must reach the efficiency of the best product currently on the market. This assumes that the market for the product functions correctly. If not, the target could be either too high if one manufacturer has a clear advantage or too low if manufacturers collude. Cultural differences have also been suggested as a reason this works in Japan but may be ineffective in Europe.

Perhaps the simplest option for a country introducing new MEPs is to adopt ‘regulatory best practice’. This approach compares other national standards and seeks to adopt the most stringent regulation provided the testing methodology reflects the national situation sufficiently. At the time Australia was developing its air-conditioning policy strategy, Taiwan had the most stringent targets for most types and sizes of air-conditioner (EnergyConsult 2002). A follow up report found that although 85% of air-conditioners would have to be withdrawn from market, the average cost would increase by only 1.5% and there would be a cost-benefit ratio between 3.0 and 10.3 (Syneca Consulting 2003). These standards were adopted in Australia and New Zealand.

With the exception of the European MEPs, only a few minimum standards have been set in the UK. Significantly however, a MEP for gas boilers was set in April 2005 as part of the new Building Regulations. Given the physical similarities between space heating and cooling, a MEP for air-conditioning might be a possibility with enough demand.

5.3 Building Regulations

The draft Building Regulations for England and Wales (ODPM 2006b) have already identified a risk of overheating and require provisions be made to "limit high internal temperatures due to excessive solar gains", referring to EST guidance CE129 (which was unavailable from the EST website at the time this research was conducted). A procedure for calculating cooling needs is provided in SAP 2005 (Standard Assessment Procedure). Air-conditioning installed in new dwellings must meet a minimum 'C' efficiency rating.

SAP is the national methodology to calculate building energy efficiency. By looking at the building fabric and the heating and lighting systems, it estimates the energy consumed and associated carbon emissions. The cooling calculations, however, are not included in the final energy statement even though they are included in the methodology.

Proposed Building (Scotland) Regulations (SBSA 2006), however, make more use of the SAP cooling calculations. The Regulations specifically state an intention to avoid a situation where a dwelling occupier installs cooling at a later date. It recommends that active cooling should not be installed unless all guidance has been taken and the SAP assessment states the "likelihood of high internal temperatures in hot weather" is "high".

Whilst the Scottish regulations could be sufficient because the UKCIP climate change scenarios predict a low risk of high temperatures, the England and Wales Regulations appear weak, especially for Southern England. New dwellings could be assessed on cooling performance alongside heating and be based on future climates. Existing dwellings, which have had no cooling performance standards, need addressing through refurbishment standards. As discussed earlier in section 5.1 passive options such as solar shading are simple alterations and could significantly reduce cooling demand.

6 CHANGING EXPECTATIONS AND PRACTICES

The options and policies discussed in the previous section offer technical solutions to reduce energy demand from cooling, but do not require people to adopt these solutions and do not address user behaviour such as demand for comfort, choosing energy efficient products and misuse of equipment. From the modelling, we have seen these are determining factors to the use and purchase of air-conditioning.

Empowering people to minimise energy consumption requires information, awareness and education. They need encouragement to consider and make decisions which save energy. Simple examples of this, such as choosing energy saving bulbs and switching lights off when the room is unoccupied – whether to save money or reduce carbon emissions – can be extended analogously to cooling.

So there is a question of: can we avoid people using it at all, particularly in this domestic end and in some office situations, where we have managed for many years without air-conditioning? However, I guess, as we become a wealthier nation people want all these things, and the market penetration in the USA of air-conditioning is very high indeed. So there is a need for some sort of market avoidance policy. I do not know how one develops that because it becomes a bit of a hair-shirt sort of philosophy, if you are not careful; nevertheless, I think it is needed. The thing that, really, I feel, is needed, is something about the way in which people operate the equipment. If I give an example of the possibility of a domestic building putting air-conditioning in; if you think about it there are probably 10 or 20 days a year when it is really hot and you want to cool that bedroom down or you feel awful going to bed. If you put in an air-conditioner for five or six hours a day for 10 days a year actually it would not have much impact on the energy consumption of the country; the problem will be that once you have got it you will probably use it 50 days a year or even 100 days a year, so it becomes an operational issue rather than an equipment efficiency issue. The same applies in the commercial sector. We see situations where, for example, a heating system will be on at the same time as an air-conditioning system is on in the same part of the building because the control system is not good enough to do it. So there are technical solutions available but it is a hearts and minds issue to make people do it properly. I think we desperately do need policies to address those sorts of issues. Minimum equipment efficiency standards, yes, we need them, and they are on the books coming out of Brussels, anyway, with labelling schemes and so on, but it is that next level which is more difficult, I am afraid.

Evidence to Select Committee from Ray Gluckman, Institute of Refrigeration

6.1 Understanding and reducing the impact of air-conditioning

Guidance is readily available and can be found on websites of many utilities companies. Consumer advice is broadly as follows:

- Purchasing
    - Ensure system is sized correctly
    - Buy the most efficient air-conditioning unit, look for SEER rating or EnergyStar label
- Maintenance
    - Clean filters monthly
    - Avoid obstructing vents
- Operation
    - Use a timer and thermostat
    - Set the temperature higher at night
    - Never set below 25°C
    - Close windows and doors

Is guidance sufficient? What policies should be in place to ensure that people carry out these actions, and how much promotion of the messages should be carried out? These types of guidance have surely to be part of an overall message to consumers on all aspects of reducing their resource use and their impact on climate change. Purchase information and labelling at the point of sale is an active influence.

6.2 Purchasing and labelling

Labels provide information to consumers that allows informed decision-making. Two types of label are used, energy ratings, such as the standard EU label, and thresholds, such as EnergyStar or Energy Saving Recommended. Whilst labels are very cost-effective (IEA 2003), they do not, however, produce the energy savings made by MEPs. Used in conjunction with MEPs they are most effective – it creates the demand for more efficient products which encourages manufacturers to make them.

Air-conditioning is already labelled under UK Statutory Instrument 2005 No. 1726, The Energy Information (Household Air-conditioners) (No. 2) Regulations 2005. It uses the standard EU Energy Efficiency Rating (EER). The EER is the ratio between the cooling output and energy input at full load and a higher figure suggests greater efficiency. However, if a system does not run at full load it will not run at maximum efficiency.

Therefore, it is important that users understand this and purchase correctly sized and appropriately designed air-conditioning. This information should be easily available and, for example, could be more prominent in the websites discussed in section 3.1. Central air-conditioners in the USA, which are designed to be left on all season, have a Seasonal Energy Efficiency Rating (SEER) label to address changes in load, similar to the SEDBUK boiler rating in the UK.

Perhaps a more effective label would be able to compare all active measures on an equal basis, giving the energy used per degree cooled per volume of room space. Combined with a method to compare maximum cooling load, customers could find the most energy efficient option more easily.

In addition to appliance labelling, all buildings will have to be labelled under the EU Energy Performance in Buildings Directive (EPBD). Again, with SAP 2005, there is a methodology in place to calculate the passive cooling potential in homes, but it is not used. It would be a simple addition to flag homes which fail to control the temperature, for example in the forthcoming Home Energy Reports. This could be particularly effective for refurbishment and enables buyers to consider additional costs from cooling, or encourage passive measures to be installed.

At a minimum, MEPs must be introduced to support the labelling. There must also be more awareness and information surrounding alternative purchases for cooling, i.e. passive and low-carbon measures, especially those which lower heating costs and therefore are particularly cost-effective and emission-reducing.

This could be supported by financial incentives, such as the VAT reductions already found for other energy efficiency products.

6.3 Operation and maintenance

Despite people living in houses for centuries, occupants often do not manage their heating system efficiently. For example, when a house is too warm in the winter occupants will often open the window rather than turn down the heating (numerous studies including EAS 2003). Active cooling is perhaps more counter-intuitive and can result in greater waste.

The easiest way to cool down in the house is to open the windows, which lets in cooler air and also creates a cooling breeze. This assumes that the air outside is cooler than the air inside. Using air-conditioning, however, it is necessary to close the windows to stop the cold escaping. The problem arises because the two cooling methods, opening windows and switching on the air-conditioning are not complementary but will cancel each other out. Therefore, it is important to provide advice to users and building managers which will be read and understood.

Section 4.2 has also shown a trend to use air-conditioners for longer and longer periods, which could outweigh any technical efficiency gains. This is a similar problem of comfort-taking to that found when installing more efficient heating. So, the same advice must be provided and the controls to do so, such as thermostats and timers to control operation coupled with information and campaigns making users aware of the extra cost of lowering the thermostat by 1°C.

Regular maintenance is also recognised as essential for air-conditioning efficiency. The EPBD requires regular maintenance for larger air-conditioning systems which can be used for larger businesses but a mandatory policy is more difficult to enforce in homes and small businesses. As well as more education, simple design changes can assist this. For example, the proposed new Scottish Building Regulations (SBSA 2006) require easy access to air-conditioning units in new dwellings so they can be serviced. Another possibility is to add a simple warning light to the appliance which blinks every month to remind the user to clean the air filter, similar to indicators found on water filters. Further options become available through regular servicing of gas boilers, if a whole house approach is taken by energy and energy service companies, to maintain all household comfort technology in one visit.

As operation and maintenance becomes increasingly complex and detailed it is essential the message is delivered in an engaging and simple manner.

6.3.1 Kuuru Bizu (Cool Biz) – Changing office behaviour in Japan

Japan has very narrowly defined cultural work attire. Men are expected to wear jackets and ties at all times, which needlessly places extra pressure on air-conditioning. Japan's climate is such that air-conditioning is found in virtually all commercial floor space (CEP no date). Cool Biz was a government-launched programme by Prime Minister Junichiro Koizumi and the environment Minister Yuriko Koike and raises air-conditioning from 25°C to 28°C in Tokyo. This is considered the overheating limit in UK. Widely reported in the media, it showed some success with respect to ensuring awareness was high. There were no penalties, however, for failing to comply and the Guardian reported success of this policy was in doubt from its launch (Johnston 31 March 2005). Final savings were also calculated by Bloomberg to be less than one tenth of a percent of total energy sales (Richard 2005).

However, it demonstrates the Government is willing to innovate, which created much of the publicity, and such policies could be adapted. Lessons can clearly be learned from cultures in hotter regions, for example, extending businesses hours into the evening and closing during the hottest part of the day. Trying to estimate savings if this approach is applied in the UK would be extremely difficult. Whilst work attire in the UK is already more casual than Japan, there is probably more willingness to relax dress even further and across the work sectors, thus enabling greater savings.

7 POLICY OPTIONS

Chapters 5 and 6 approach cooling demand from two different angles – changing our environment and changing our attitude to the environment. The two approaches intersect, and policies combining the two, such as MEPs and labelling, have proven effective. The main decision, therefore, is the point of intersection which will determine at what level CO_2 emissions are controlled.

The aim of these policy options is to reduce cooling demand as much as possible, firstly by engaging people so they re-examine their ideas about comfort. This will indicate what Comfort Scenario we can hope to achieve and what policies are needed to promote this. The most effective technical solutions can then be recommended for that Comfort Scenario.

Policies must also be revisited regularly based on the most up-to-date climate change scenarios. For example, if temperatures of 42°C occurring twice a week were predicted moving towards 2080, it is clear much stronger policies would have to be adopted to improve buildings. Deadlines for reviewing and acting on the information should be drawn up now to ensure the policies are introduced sufficiently early to be effective.

This analysis is structured around the four Comfort Scenarios, starting at the worst case, scenario IV, and moving to scenario II. Within each section, behaviour and attitudes changes are discussed to promote the Comfort Scenario and prevent it from slipping. Technology options will need to be applied in line with the Trias Energica; cooling load must be reduced using passive measures then applying increasingly aggressive active cooling measures until the desired comfort level is reached.

7.1 Scenario IV - Escalating demand

Air-conditioning offers the greatest control over the environment and is a silver bullet for achieving closely defined temperatures in a wide range of situations. This scenario would mean air-conditioning is perceived not only as a necessity, but an opportunity to provide relief against outside temperatures. The energy consumption must therefore be reduced by minimising the air-conditioning load, through passive building measures, and maximising systems' efficiency. Because demand is so high building designs must be re-examined and the highest efficiency standards set through ambitious MEPs and labelling. Maintaining and servicing cooling equipment also becomes a priority and legislation such as the EPBD Article 9 could be extended to smaller units.

Building regulations will play an important part in this; they must include cooling in SAP CO_2 calculations, including refurbishment. More attention must also be paid to the efficiency of other consumer and household appliances since they have the double effect of increasing energy use and acting as heat sources which the cooling system must work harder against.

These strict building standards will be necessary but also raise the cost of buildings, perhaps significantly. Preventing this scenario becoming reality could be a much cheaper option.

7.2 Scenario III - Standardised efficiency

Whilst air-conditioning offers very precise control, it consumes a large amount of electricity to achieve it. A stable and less demanding comfort temperature makes other low-energy technologies more viable. Such technologies may offer less control and are unable to lower temperatures by as much but still within the range of comfort.

Achieving this Comfort Scenario can be attempted through best practice usage, such as setting thermostat temperatures for cooling at 25°C. Campaigns which highlight the huge increase in energy use and its climate impacts could persuade people to raise the temperature slightly.

Greater awareness must be made of the benefits of passive thermal management technology, such as low-e glass, solar shading and thermal mass. Lower energy active measures such as night ventilation, ceiling fans, evaporative cooling and ground source heat pumps should also be encouraged through financial incentives and raising market awareness about these alternatives.

This is the easiest of the scenarios to model and regulate as the approach is consistent with the technical market at present; both CIBSE and manufacturers themselves are geared towards standard measures of 'comfort' and are focused on delivering cooling and heating to a narrowly defined range of temperatures. Policy mechanisms that work with industry to improve efficiency, such as the MTP and SAVE programmes, have been in place for some time, using labelling and voluntary agreements. The important aspect of this approach is for the UK government to select an approach (in conjunction with the EU so as not to introduce barriers to trade) which develops fast improvements in the technologies available, such as adopting the Japanese-style top-runner approach. This would not only encourage market development, but provide a challenge for the design industry, thus gaining economic benefit for the country.

7.3 Scenario I - Extending the comfort zone

Elastic comfort definitions are needed and therefore comfort solutions have been tailored to the UK's regional climate conditions. Technical solutions only need to be designed to protect the temperature from extremes e.g. taking the lower and upper limits for comfort at the 10% and 90% deciles rather than at the current standard.

Passive measures should be able to achieve this, at least for the low and medium climate scenarios. Again, these need promoting through building regulations which may need to be regionally focussed and promote cooling solutions that address the regional climate profiles. However, a review of offices', shops' and premises' statutory health and safety temperatures is also required, and this is an issue which requires further research.

Engaging the public will also be a challenging task. More innovative approaches – which carry a positive message about enjoying the climate variations and not just highlight global warming threat – may be needed to draw links between climate change and our comfort demands. This fits well with national campaigns like the Climate Change Communication Initiative and the Energy Saving Trust.

7.4 Scenario II - Diversifying indoor climates

In this scenario, the solution is to value regional climate differences since very little climate control or cooling is allowed. This requires a strong element of 'return' to non-technological solutions, and will be difficult in a country where the majority of the buildings are already built in a style that does not allow for adaptation to vernacular cooling technologies found in Mediterranean and African climates. Alternatives could include societal changes to work and education patterns, such as adopting a siesta, which has already been mooted in a light-hearted way. This would actually be easier than adapting buildings wholesale, as less investment is needed, provided there is agreement by all sectors of business and industry. Further analysis is needed as other factors are involved including child care and traffic patterns. The fashion industry could receive a boost, as a wider range of clothing would be required to fit the new acceptance of temperature ranges.

This scenario is difficult to foresee but very strict personal carbon allowances (domestic tradable quotas) may give people a strong incentive to save energy. To help the vulnerable at risk better support must be available that, for example, offers them alternative living space during peak temperatures. Individuals must also choose this scenario willingly, and we do not propose dictating how people should behave.

Policy recommendations are summarised in Figure 15. The Comfort Scenarios are placed in the four quarters defined by comfort temperature and the cultural or technical influence creating the initial attitude. Expectations and practices must be changed first from bottom up (shown in green) to achieve the desired comfort attitudes. Technical solutions can then be applied from top down (shown in blue) to match the Comfort Scenario.

For example if the policy is designed to achieve Comfort Scenario III with maximum efficiency, few cultural influences are needed except to ensure best practice of appliances installed and labelling /information to promote passive and low energy measures. The technical solutions, however, should start with the full suite of passive measures, before installing low energy active cooling options.

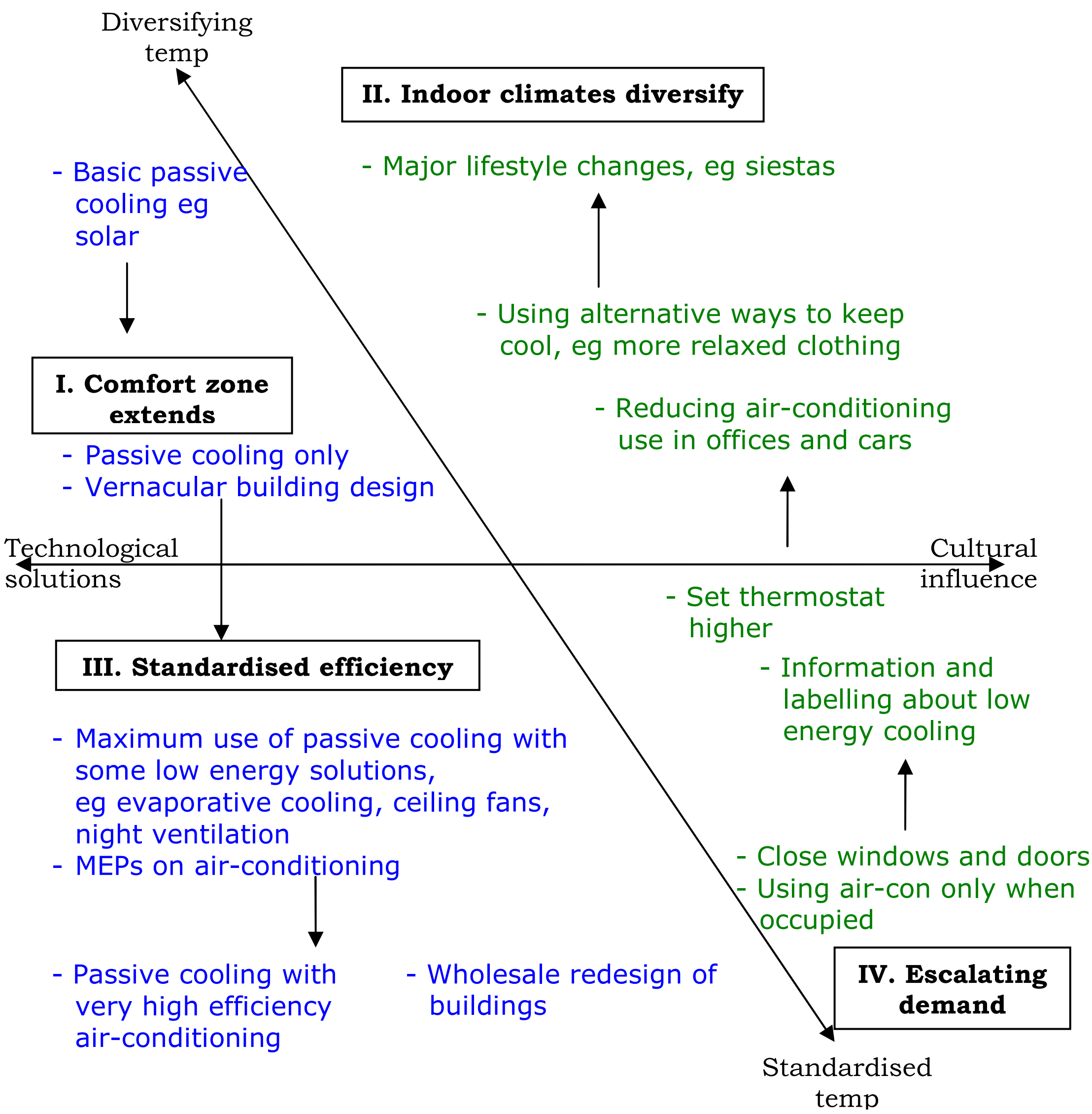


Figure 15: Schematic of scenarios, and attitude and policy responses

8 CONCLUSIONS AND RECOMMENDATIONS

This scoping report shows that cooling will be needed in future and if this is served by unconstrained use of air-conditioning then it will make a noticeable contribution to UK carbon emissions. Residential carbon emissions, starting from a current figure of almost zero could reach 5.9 $MtCO_2$ by 2050. This will be influenced by how the population responds to the climate change, which has been modelled using Comfort Scenarios. These highlight the strong effect of changing the discomfort trigger temperature in reducing cooling demand.

The model of residential cooling, however, was developed for a scoping report. Further work is needed to back up the assumptions made which will enable the policies to be more accurately quantified. Linking the model to Hacker *et al*'s building model and the EHCS could provide the clearest picture of air-conditioning demand and the extent to which this can be met using passive and low energy solutions.

Overall, it is clear that air-conditioning and cooling need a multi-disciplinary approach if they are to develop in a way that does not have a detrimental effect on UK's Kyoto and post–Kyoto strategies for minimising greenhouse gas emissions.

Indications from USA experience, manufacturer marketing and CIBSE guidance all point to Comfort Scenario III (Standardised Efficiency) as the likely reality. In this scenario, policies to minimise carbon emissions will rely strongly on better use of well established technologies. Building regulation and guidance, supported by increased awareness and information will be needed to ensure they are used.

The most pressing concern is to ensure we do not slip into Scenario IV by ensuring any air-conditioning is used strictly in line with best practice. As cooling demand increases with temperature increases, low energy and passive options must be available and take strong precedence over air-conditioning.

This requires more work to ensure buyers have the information and labels to choose low energy products, a role in which product manufacturers should have an interest. Homebuyers should be given cooling performance information by including it in Home Energy Reports. In particular, building regulations need to include refurbishment standards which take into account future cooling needs and consider a whole house approach. Old leaky buildings are a concern because the air flow allows uncontrolled heat transfer between outside and inside, precluding the use of low energy passive measures, such as ground source heat pumps, which do not have the cooling capacity of air-conditioning.

For new build cooling guidelines should become mandatory – given the very low demolition rates and long lifetimes of the average house, current homes will exist well past 2050 towards 2080 which for the south and east of England shows cooling degree days almost quadrupling. Buildings that require active cooling should have this calculated into their SAP ratings. This also creates opportunities for manufacturers of construction products. They can use this to economic and market advantage, since there will be increased scope to market their construction products not only on winter comfort but summer comfort improvements.

Cooling demand can also be reduced by entwining building regulations and planning permission more closely; building designs need to take into account the impact of their building on the surrounding pre-existing buildings. Planning should consider how a new building provides cooling and shading, as well as the performance of the building envelope itself.

MEPs for appliances are needed as soon as possible, and could be implemented using 'best regulatory practice'. Care must be taken, however, to avoid efficiency standards validating air-conditioning as a green solution. For this reason, a label encompassing all cooling measures could be useful.

Alongside traditional awareness and labelling activities, which have been extended to cover cooling demand, businesses should be encouraged to reduce the amount of air-conditioning in commercial space to prevent possible links between household and work expectations.

Whilst the immediate increase in cooling demand is likely to be modest, and limited to the southern-most counties and London, the impacts of unrestricted growth will cause the very effects that will lead to the high emissions scenario of very hot summers in the whole of the south and east of the country. The problems of communicating this to the public are manifold, not least because it reinforces the concept of the North-South divide, yet needs all regions to take a stringent approach to their emissions to contribute to the limitation of atmospheric CO_2. Indeed, the northern regions may welcome the increased winter temperatures and warmer (but not necessarily hot) summers. On such a small scale it would seem odd if, for example, the southern counties started to adopt siestas whilst the northern counties were required to maintain a nine to five work pattern.

However, better awareness of resource use and initiatives such as personal carbon trading may begin to bring a stronger message home about personal responsibility. People need to understand and agree that personal responsibility is something they can take action on, and it really does contribute to the common good. The Kyoto Protocol has shown that it is possible to get a large number of countries ostensibly talking about a difficult subject and aim for a joint target. It isn't perfect, but it is a start. Our report indicates getting individual citizens to make responsible decisions about cooling and their own comfort levels may be the next small, or slightly larger step.

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