Air conditioning demand assessment

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Contents

1 Summary

This study has examined the potential changes that could be seen in electricity demand for cooling in the Electricity North West Region by 2030. Utilising the RESNET Scenario Tool, it has been possible to assess potential cooling demand in 2030, in both domestic and commercial sectors, taking account of different penetration levels for air conditioning and using different assumptions for how temperatures may change as a result of climate change. In addition, the drivers for air conditioning uptake and how cooling demand may vary within the commercial sector have been reviewed. Key findings from the study include:

- Although the level of actual warming by 2030, and subsequent increases in summer high temperatures, resulting from climate change are uncertain, the evidence that they will increase is clear. Coupled with higher uptake rates for cooling systems, which could be driven in part by the increasing temperatures, the results here show that this will have impact on electricity demand and potentially the electricity distribution network.

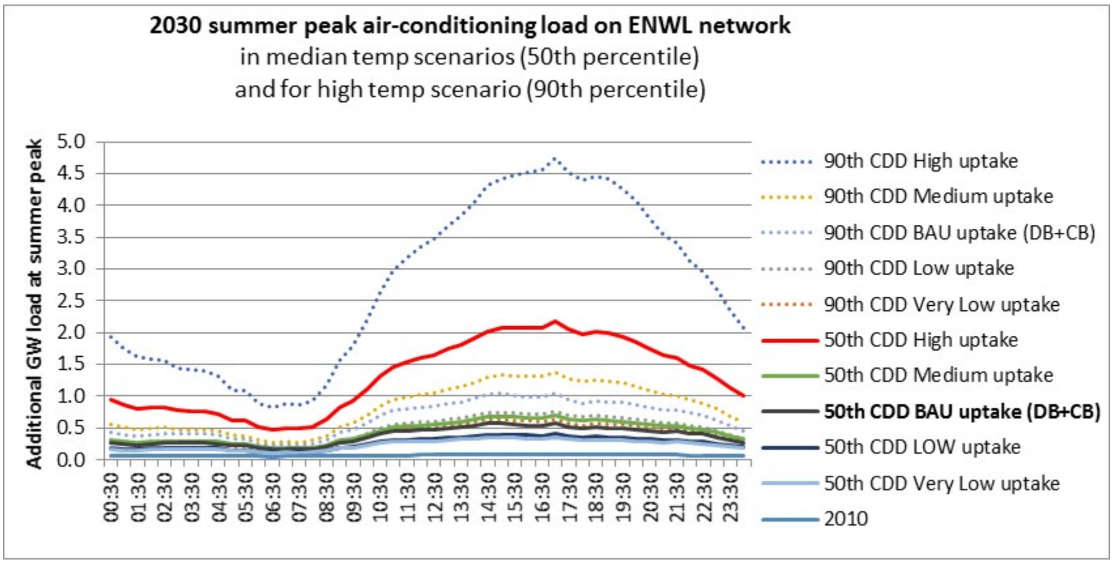
- In the scenario tool used for the analysis, the impact of increases in the number of cooling degree days (CDDs) is similar to the impact of increasing penetration rates when looking at the domestic sector (e.g. doubling one, or the other, increases annual energy demand by 50%). However, current low levels of domestic air conditioning systems mean that penetration rates need to increase considerably before there is any major impact. While increases in temperatures up to 2030 may be inevitable, an increase in penetration rates for air conditioning in the domestic sector is not.

- If growth in the domestic air conditioning uptake rate were to be similar to that seen in the USA or Australia (Domestic Level B), one of the lower penetration rates used in the analysis, the peak summer day electricity demand from domestic air conditioning would be more than double current peak day commercial cooling demand. If 30% of households in the ENWL region have air conditioning by 2030 then the peak demand due to air conditioning on the hottest day is estimated to be as high as 3 GW (at 6pm).

- If the percentage of commercial space that was actively air conditioned in the ENWL region were to increase from just below 10% to just below 30% (Level B) by 2030 then the scenario tool estimates that total annual air conditioning electricity demand could increase by over 150% and peak day air conditioning demand could be nearly 8.5 times higher than the 2010 baseline.

- As can be seen on the figure below, the 90th percentile temperature scenario used in the analysis, combined with the high air conditioning uptake scenarios leads to over 4.5 additional GW load during the summer peak across the ENWL region. By contrast the 50th percentile temperature scenario combined with low levels of air conditioning uptake leads to less than 0.5 GW additional load during the summer peak. The 50th percentile temperature scenario combined with what ENWL have selected as the 'Business As Usual' uptake rates, leads to additional load of just over 0.5GW during the summer peak. However, it should be noted that the temperature data used does not necessarily reflect the potential future extremes of summer temperature.
  It should also be noted that the analysis assumes that the relationship between CDDs and electricity demand is linear, i.e. that additional units are used as temperature increases, if this were not the case the difference

between the results for the 50th and 90th percentile CDD results would not be as large.



- The difference between the average commercial demand profile for cooling (both daily and seasonal) and the profiles of specific types of commercial customer at a substation level may have a significant impact on actual electricity demand for cooling.

- Given the moderate temperatures in the UK compared to areas where there is very high penetration of air conditioning, the relationship with extreme heat events, income and social norms may underpin any rapid changes in air conditioning penetration.

- There is scope to reduce the adoption and use of air conditioning by influencing building design (passive measures and layout), introducing variable price electricity tariffs and encouraging behavioural responses to keeping cool (e.g. adopting cooler attire for the workplace).

- A lack of UK data on air conditioning uptake and use makes understanding trends in the sector challenging – there is considerable scope for better data collection.

2 Acronyms

AC	Air conditioning
BRE	Building Research Establishment
CDD	Cooling Degree Days
CIBSE	Chartered Institute of Building Services Engineers
COP	Coefficient of performance
DPP	Dynamic Peak Pricing
DSYs	Design Summer Years
ENWL	Electricity North West Limited
EPW	Energyplus weather file
HVAC	Heating, ventilation and air conditioning
NCM	National Calculation Methodology
PCMs	Phase change materials
TRYs	Test Reference Years
WG	Weather Generator

3 Scope of work

The aim of the Resilient Electricity Networks for Great Britain (RESNET) project was to explore the potential impact of three concurrent challenges to the resilience of the electricity network brought about as a result of climate change: changes in the supply mix as a result of efforts to decarbonise generation; shifts from non-electricity energy demand to the electricity network; and changes in the weather as the mean climate alters over the course of the next 40 years. One aspect of the project, the RESNET scenario tool, was built to explore how daily electricity demand on peak winter and summer days may change over time. The tool enables a user to make various assumptions with respect to changes in the future electricity demand of existing electricity end-uses together with the uptake of new technologies that require electricity, in particular heat pumps, electric vehicles and air conditioning in domestic properties. Crucially, the impact of temperature on demand is incorporated into the model. This is a central factor behind peak day demand and is also expected to change with a changing climate. In the tool, demand is disaggregated across the 17 National Grid Study Zones, each attributed to one of 3 weather regions. For the RESNET project the tool was used to develop a plausible high future diurnal electricity demand scenario up to 2050, to test the resilience of the transmission network. One of the key issues that this highlighted was the potential for air conditioning demand in the summer to increase dramatically.

For this project, commissioned by Electricity North West (ENWL), the tool was adapted to examine the area covered by ENWL for a period up to 2030, assessing the potential demand from air conditioning. For this work a number of scenarios with differing penetration rates for air conditioning in both domestic and commercial sectors were explored. The purpose is to assist ENWL in the process of developing summer peak scenarios, and to inform future analysis by Distribution Network Operator companies (DNOs), National Grid and wider industry/ stakeholders.

4 Air conditioning drivers review

There is limited data on air conditioning uptake and use in the UK and various studies agree that this is a key challenge in understanding the current and potential future implications of energy demand for cooling. In this review we identify existing sources and trends and explore drivers for these. This section is arranged under the following topics:

- Current size of the air conditioning market
- Penetration levels
- Rapid uptake of air conditioning internationally
- Role of temperature
- Occupant use of air conditioning units
- Overheating, building standards and efforts to reduce energy demand
- The role of social norms as a driver of demand for air conditioning
- Smart homes and lifestyle marketing air conditioning

4.1 Current size of the air conditioning market

Globally, the air conditioning market was reported to be worth US$ 97.7 in 2013. Within this, the UK air conditioning market had sales of $1 billion in 2013 (with sales growing by 22% over 2013). In their report summary, The Building Services Research and Information Association (BSRIA) explain that the UK market is strongly linked to commercial trends and heavily driven by levels of construction in the London area[1]. Publically available information on market reports offer an indication of the value for the sector but these are at an aggregated sales (£) level and therefore do not offer a detailed breakdown of numbers or types of systems and customers (i.e. types of commercial customer and domestic customers). In addition, they don't offer insight on the levels of sales related to replacing exiting systems versus systems being installed for the first time. The challenges of identifying baseline and trend data in the sector is underlined by results from AMA Research which reported that the UK Ventilation and Air Conditioning market had experienced growth of 4% during 2014, following a static period during 2010-2012 and refer to the market having 'stabilised' in 2013 (compared to the 22% growth reported by BSRIA in the air conditioning market alone). AMA Research expects the air conditioning and ventilation market to increase by 10% on 2015 levels by 2019[2] (air conditioning accounts for over half of this market). Increases in income combined with expected decreases in the cost of air conditioning units are thought to underpin expansion of the sector globally (e.g. Euromonitor expect global unit prices for air conditioners to reduce by 5% over the period 2013-2018[3]).

4.2 Penetration levels

The penetration of air conditioning appliances in UK households is thought to be fairly low, with Euromonitor reporting this to be 1.5% in 2010 increasing to 1.6% in 2015, with replenishment cycles 12 years for room air conditioners and 7 years for split air conditioners. DECC's *Energy Consumption in the UK* data set does not include data on domestic air conditioning ownership (it does include information on washing machines etc). The numbers of households reported to be installed with an

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[1] BSRIA, 2015, World Air Conditioning market grows thanks to hot spots, available at ww.bsria.co.uk/news/article/world-air-conditioning-market-grows-thanks-to-hot-spots

[2] AMA Research, 2015, Ventilation and Air Conditioning Market report, available at www.amaresearch.co.uk/Ventilation_Air_Conditioning_15.html.

[3] Euromonitor, 2014, Why will Air Conditioner prices be cheaper in the future? cited in RESNET Technical report.

air conditioning system of some form range from 1%[4] to 3%[5]. A reply to a Parliamentary question on the subject of domestic air conditioning penetration in the UK indicated that in 2010 approximately 3% of households had some type of air conditioning in 2010[6]. In the analysis presented here, we scale this national level based on temperature which results in a 2010 baseline penetration level for the ENWL region of 1.2% (see section 4 for further details).

The Carbon Trust expects that 40% of commercial floor space will be air-conditioned by 2020 compared to 10% at the end of 1994 [7]. Annual energy demand in the UK by major end uses is reported in Energy Consumption in the UK, including electricity consumption for cooling and ventilation in the commercial sector. In this analysis we have applied assumptions about the disaggregated demand for each of these components, determined a UK penetration level of air conditioning and scaled this to the ENWL region based on temperature and the amount of commercial space. This gives a 2010 baseline penetration level of 9.94% in the commercial sector (see section 4 for a full description of this process).

4.3 Rapid uptake of air conditioning internationally

Rapid uptake and high penetration levels in the USA and Australia are often cited as evidence of the potential for the UK air conditioning landscape to undergo rapid change. Although the climates in these nations are both varied within the nation and different to the UK, they offer useful context as the domestic adoption rates show significant increases that cannot be explained by changes in temperature alone. In the USA, from 1960 to 2009 there was an increase from 12% to 83% penetration[8,9]. In Australia air-conditioning penetration rose from 32.5% to 74% between 1994 and 2014[10].

In the USA context, a number of studies have explored the range of factors that led to such increases in air conditioning uptake. Factors identified have included, rising incomes, falling prices of air conditioning systems, post war changes in mortgage arrangements which were permitted to include the cost of installing air conditioning, the post war building boom and house builders adopting standard approaches to design to reduce cost rather than customising homes to suit local climates. The availability of air conditioning systems also facilitated the building of increasingly tall structures that are challenging to cool through natural ventilation alone and so air conditioning became a necessary part of many large cities[11,12, 13,14, 15]. In Australia,

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[4] Frontier economics, Irbaris and Ecofys, *Economics of Climate Resilience Building and Infrastructure Theme: Overheating in Residential Housing - Annexes*, 2013, p. 16 <http://randd.defra.gov.uk/Document.aspx?Document=10666_CA0401-rep-housingreportannexesfinal.pdf>.

[5] *Ibid*, p.19

[6] Hansard, 2005, p. 7 June 2005, Column 459W <http://www.publications.parliament.uk/pa/cm200506/cmhansrd/vo050607/text/50607w05.htm#50607w05.html_spnew6>.

[7] The Carbon Trust, 2012, Air Conditioning, Maximising comfort, minimising energy consumption.

[8] U.S. Department of Energy, Energy Information Administration, 2009 Residential Energy Consumption Survey, https://www.eia.gov/consumption/residential/data/2009/

[9] Cox, S., 2013, Losing Our Cool: Uncomfortable Truths About Our Air-Conditioned World and Finding New Ways to Get Through the Summer. The New Press.

[10] Australian Bureau of Statistics, 2014, Energy Use and Conservation, www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4602.0.55.001Mar%202014?OpenDocument

[11] Ackermann, M. A., 2002, Cool Comfort: America's Romance with Air Conditioning. Washington, DC: Smithsonian Institution Press.

[12] Biddle, J., 2008, Explaining the spread of residential air conditioning, 1955–1980, Explorations in Economic History, 45(4), 402–423.

[13] Cooper, G., 1998, Air-conditioning America:Engineers and the Controlled Environment,1900–1960.

similar drivers have been identified including falling prices and rising household incomes as well as enhancements to new homes (e.g. air conditioning being offered as a standard product to try to differentiate in the promotion of new homes) and changes to building stock such as taller and deeper buildings limiting potential for passive measures such as tree cover [16].

4.4 Role of temperature

Longterm increases in average temperatures under climate change are often the driving rationale for examining potential increases in air conditioning uptake and use. However, shorter term temperature spikes (i.e. heat waves) have been found to be an important driver in air conditioning purchase. During the 2003 heat wave B&Q reported that their sales of air conditioning units were 176% higher than during the same week in the previous year[17]. The Urban Heat Island effect during the 2003 heat wave led to an increase in night time temperatures of between 5-10°C in Manchester again potentially driving an increase in demand for mechanical cooling[18]. Based on heat waves in 1995 and 1996, BSRIA argue that significant increases in domestic sales could occur if high temperatures were experienced over three consecutive years combined with a substantial marketing campaign by air conditioning manufacturers[19]. In their analysis of the risks of overheating in homes in the UK, Frontier Economics[20] argue that there is currently little risk of significant overheating and therefore, there is not likely to be a short term increase in purchase of air conditioning. They state that people will be 'reactive' and only when hot summers begin to occur each year will a significant change in demand be seen.

In a US study, Sailor and Pavlova found a strong correlation between cooling degree days (CDD) and central systems, however window units demonstrated a much more scattered pattern demonstrating that the relationship between temperature and air conditioning use is complex. Their analysis found that taking an arbitrary increase in CDD of 20% had the effect of increasing air conditioning electricity consumption by 20-60% allowing for both additional use and additional penetration. However, they identified that the level of air conditioning uptake was a much more important in determining the overall energy demand than external temperatures.

Although some increase is air conditioning uptake and demand is to be expected particularly in the absence of more widely communicated, understood and adopted

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Baltimore, MD: Johns Hopkins University Press.

[14] Shove, E., Walker, G., & Brown, S., 2013, Transnational transitions: the diffusion and integration of mechanical cooling. *Urban Studies*, 0042098013500084.

[15] Sailor, D. J., & Pavlova, A. A., 2003, Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. *Energy*, *28*(9), 941-951.

[16] Strengers, Y., 2010, Air-conditioning Australian households: The impact of dynamic peak pricing. *Energy policy*, *38*(11), 7312-7322.

[17] Darby, S. and White, R., 2005, Background document C for the 40% House report, University of Oxford, available at http://www.eci.ox.ac.uk/research/energy/downloads/40house/background_doc_c.pdf

[18] Capon and Oakley, 2012, cited in Frontier economics, Irbaris & Ecofys, 2013. The Economics of Climate Resilience Buildings and Infrastructure Theme: Overheating in Residential Housing (CA0401), http://randd.defra.gov.uk/Document.aspx?Document=10664_CA0401-rep-housingreport-final.pdf.

[19] Frontier economics, Irbaris & Ecofys, 2013. The Economics of Climate Resilience Buildings and Infrastructure Theme: Overheating in Residential Housing (CA0401), http://randd.defra.gov.uk/Document.aspx?Document=10664_CA0401-rep-housingreport-final.pdf. This view was given in personal communications with the consultants producing the DEFRA report from BSRIA representatives.

[20] *ibid.*

passive strategies to deal with heat, Derby and White[21] state that significant growth in air conditioning uptake is not inevitable even when considering increases in long term temperature. They stress that southern European households show a much less steep curve of air conditioning ownership in relation to temperature than other nations (such as Australia and USA) and argue that this is due to the dominance of architectural styles and materials utilising high thermal mass, tree shading, shutters, blinds and verandas. They report of experience in Lyon in France where daytime temperatures of 40°C were reached for around a month during the summer of 2003. While residents did report being uncomfortable, the experience did not lead to a significant increase in air conditioning purchase. Although penetration of residential air conditioning in France did increase steadily from approximately 0.5% in 2000 to 5% in 2010[22], the 2003 heat wave did not lead to a spike in uptake levels.

4.5 Occupant use of air conditioning units

4.5.1 Domestic

In addition to the lack of data on penetration of air conditioning technology, there is also little understanding of the actual use of air conditioning systems once installed. Strengers explains the lack of information on residential cooling in stark terms, noting that 'virtually nothing is known about how households use air conditioners'[23]. Pathan et al[24] offer a very relevant empirical study in terms of monitoring actual use of air conditioning units. Their study was small (13 households in the South East of England) and covered just 4 continuous weeks in summer 2004. However, it offers a rare insight based on actual use and expressed reasons for this use. The study found that temperatures at which users switched on their units were 24-25 °C on average with typical running times of 5 hours during the day and 7 hours during the night. They found that users tended to turn the units on 'when they felt hot' rather than trying to maintain a specific indoor temperature. The average measured value at the point of switch on in the study across the 13 households was 24.2 °C. The temperatures that users set their remote controls at varied from 18 to 25.5°C. The average measured maintained temperature was 22.3°C for the period of the study. The period for switch on varied from a couple of hours to more than 12. Generally very high satisfaction was reported from respondents with fixed units but those (2) with portable units did not feel that they could sufficiently cool their rooms. Respondents with a unit in their bedrooms all reported improved sleep. From this small study there are clear indications that the patterns of use may vary fairly dramatically across users and further research is needed to explore the relationship between external temperatures, internal temperatures and air conditioning use.

How the same physical environment is experienced can vary greatly between individuals in terms of their level of comfort. In addition, comfort has also been found to relate to the degree of control that occupants have and the presence of mechanical heating and cooling. Occupants in naturally heated or cooled buildings have been found to accept a wider range of temperatures. By contrast those in

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[21] Darby, S. and White, R., 2005, Background document C for the 40% House report, University of Oxford, available at http://www.eci.ox.ac.uk/research/energy/downloads/40house/background_doc_c.pdf

[22] Lapillonne, B., Sebi, C., and Mairet, N., 2012, The challenges, dynamics, and activities in the building sector and its energy demand in France, Report from the Entranze project, http://www.entranze.eu/files/downloads/D2_1/D2_1_Short_country_summary_report_-final-France.pdf

[23] Strengers, Y., 2010, Air-conditioning Australian households: The impact of dynamic peak pricing. *Energy policy*, *38*(11), 7312-7322. (p7313)

[24] Pathan, A., Young, A., & Oreszczyn, T., 2008, UK Domestic air conditioning: A study of occupant use and energy efficiency, Proceedings of: Air Conditioning and the Low Carbon Cooling Challenge. Network for Comfort and Energy Use in Buildings: London, UK

environments with climate control are found to report being uncomfortable outside a much narrower range [25,26,27]. At a certain point of temperature behavioural responses such as removing clothes may no longer have an effect, for example it has been suggested that after 28 degrees people may not be able to further adjust their clothing to achieve a comfortable state. The discomfort that people experience in this context is amplified if the there is no control over internal temperatures or if the controls provided are not effective [28].

In a study of the impact of Dynamic Peak Pricing (DPP) in Australia where 10-40 times the off peak electricity price is charged during short periods in order to reduce peak demand (which is predominantly due to residential air conditioning demand), occupants were found to adopt a range of alternative cooling strategies during peak times. These included operating fans, changing their clothes or going to the beach whilst others simply turned their air conditioning off and made no further adjustments. However, there was discussion by some occupants that they would not respond to the price change in really hot conditions. This could pose a challenge where conditions of the most extreme heat (where the DPP might be most relied upon in order to reduce demand) might be the very time when people choose just to pay the higher rate. The study criticised demand managers for recommending pre-cooling of homes on days were peak prices were to be applied as potentially constructing demand for air conditioning and failing to fully engage with alternative behavioural responses. In terms of future research, in addition to understanding the use of air conditioning systems, there is a need to further understand how occupants achieve 'coolth' to avoid legitimising the expansion of air conditioning as the only response to increases in external temperatures[29].

4.5.2 Commercial

In 2006, The Chartered Institution of Building Services Engineers (CIBSE) recommended a summer operative temperature, i.e. the temperature people experience in a building, of 22-24°C [30]. The Carbon Trust recommends that cooling doesn't not start until internal temperatures reach 24°C [31]. The internal temperature is determined by external temperature, solar gains, internal gains from people or equipment and the building fabric, generally external temperatures of less than 24°C can lead to internal temperatures of that level.

Lekeridou et al[32] explored the potential for air conditioned offices in the UK to increase their summer set point (the temperature to which an office is cooled to).

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[25] Brager, G.S., de Dear, R.J., 2003. Historical and cultural influences on comfort expectations. In: Cole, R., Lorch, R (Eds.), Buildings, Culture and Environment: Informing Local and Global Practices. Blackwell Publishing, Oxford, UK, pp. 177–201.

[26] Chappells, H., Shove, E., 2004. Comfort: a review of philosophies and paradigms

[27] Strengers, Y., 2010, Air-conditioning Australian households: The impact of dynamic peak pricing. *Energy policy*, *38*(11), 7312-7322.

[28] Roaf, S., Crichton, D., and Nicol, F., 2009, Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide, 2nd Edition, cited in Frontier economics, Irbaris & Ecofys, 2013, The Economics of Climate Resilience Buildings and Infrastructure Theme: Overheating in Residential Housing (CA0401), http://randd.defra.gov.uk/Document.aspx?Document=10664_CA0401-rep-housingreport-final.pdf.

[29] Strengers, Y., 2010, Air-conditioning Australian households: The impact of dynamic peak pricing. Energy policy, 38(11), 7312-7322.

[30] CIBSE Guide A. Environmental Design. London: Chartered Institution of Building Services Engineering; 2006

[31] Carbon Trust, 2007, Air conditioning – maximising comfort, minimising energy consumption. CTG 005 (Technology Guide).

[32] Lakeridou, M., Ucci, M. and Marmot, A., 2014. Imposing limits on summer set-points in UK air-conditioned offices: A survey of facility managers. *Energy Policy*, *75*, pp.354-368.

They drew on modelling work by the British Council of Offices which found that temperatures of 24°C plus or minus 2 degrees could be maintained without necessarily negatively affecting comfort or productivity (although they note that their models do not take account of expectations and habits). They also drew on the Japanese Government's *CoolBiz* campaign where a minimum set point on 28 °C and wearing more casual, cooler clothing was advocated with support from the Prime Minister. In 2015, polo and aloha shirts were the latest inclusion as the campaign seeks to redefine appropriate work wear[33]. Noting the lack of data on set points in UK offices, they undertook a survey of facility managers and found that over 60% reported a summer set point of less than or equal to 22°C. The air conditioning part of their survey was completed by 91 respondents. They found that offices with a summer set point of greater than or equal to 24°C were mostly occupied by public organisations. They recommend that the public sector could lead the way on introducing minimum summer set points given their already higher starting point and higher expressed enthusiasm for minimum standards. They identified the need for further research on occupant expectations and productivity and the perceptions of senior managers. In 2011, a survey of 1200 British Workers reported that the majority of respondents found their offices too cold over summer[34]. However, in the Lakeridou et al survey of facilities managers, the most common summer complaint received from occupants was that they were too hot.

4.6 Overheating, building standards and efforts to reduce energy demand

The Department for Communities and Local Government (DCLG)[35] commissioned a review of the risks of overheating in UK homes. The review identified overheating as a significant health problem which accounts for around 2000 accelerated deaths annually. Without adaptation to achieve better cooling (including mechanical, behavioural and passive measures) it is estimated that this could increase to 5000 by 2080 due to climate change. The unintended consequence of high insulation and air tightness standards in both new builds and retrofitted houses may be an increase in overheating risk. In addition, the increase in ambient temperature under climate change may impact upon the effectiveness of natural ventilation in reducing the risk of overheating as external air may be too warm to serve this function and the difference between day and night temperatures may not be significant enough for effective night purge approaches. The study recommended passive measures such as wider use of shading and shutters. It also identified a relationship between dwelling construction age and the risk of overheating, with small top floor flats in 1960s dwellings at high risk whereas concrete ground floors were found to have a significant cooling effect. It has also been found that more recently built dwellings may also suffer from overheating risk. This is due to a focus on thermal efficiency to reduce energy consumption in the design. However, the review does stress that this overheating concern is primarily based on modelling studies and there is very limited empirical evidence available on this topic.

Another potential area of unintended consequences from energy efficiency measures arises in relation to heat pumps. There is evidence from a Danish study that households that have adopted heat pumps, promoted on the basis of energy efficiency, have (in a minority of cases) used their pumps to deliver air conditioning,

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[33] see http://www.japantoday.com/category/national/view/cool-biz-fashion-season-begins-across-japan
[34] See http://www.express.co.uk/news/uk/265645/Cool-it-you-ve-got-air-con-rage
[35] AECOM, 2012, Investigation into overheating in homes, Literature review, Department for Communities and Local Government, Stationery Office.

leading to some concerns that adoption of the technology could lead to an unexpected increase in cooling demand[36].

Building regulations have been criticised for focussing on climate change mitigation (i.e. improving thermal efficiency and reducing energy consumption) without adequate consideration of adaptive requirements and capacity under higher temperatures due to climate change[37]. Part L of the current Building Regulations stipulates that new dwellings should have appropriate measures included to limit the impact of heat gains on summer indoor temperatures. This requirement is applied irrespective of the inclusion of mechanical cooling systems and is designed to reduce need for and installed capacity of mechanical systems. SAP 2012 allows designers to check that their designs do not result in excessive gains[38]. Designers are also encouraged to consider the impact of future climate change on their designs but this is a not a requirement.

In addition to measures to reduce demand for cooling through building design, there are also measures in place to encourage improvements in the efficiency of air conditioning systems on the market and those in situ. Air conditioning units up to 12kW are included in the EU Eco Design and Energy Labelling Schemes in order to give consumers information about efficiency when making purchase choices and drive efficiency innovation in the industry. Commercial buildings with systems over 12kW have to have their air conditioning systems inspected. This requirement is designed to improve the efficiency and reduce the energy consumption of the system the inspections and must be conducted not more than 5 years apart[39].

4.7 The role of social norms as a driver of air conditioning uptake and use patterns

Various studies have examined the complexities of the drivers for air conditioning uptake and use, stressing the importance of social norms and changes in practices. Shove et al[40] are critical of much of the work on air conditioning penetration which assumes that in hotter climates as soon as residents can afford air conditioning, they will adopt it. They instead call for a wider consideration of the co-evolution of social norms and the infrastructure in which living and working occurs. In their in-depth UK study of how cooling has become ‘normal’ in different settings, they considered a hospital, two office settings and seven hotels. They drew on range of forms of data to explore how air conditioning is becoming standard, expected or indeed ‘needed’ - for example their review of Manchester hotel rooms on laterooms.com in January 2012 showed that 40% came with air conditioning with 100% saturation at the more luxury

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[36] Gram-Hanssen, K., Christensen, T.H. Petersen, E.P., 2011, Heat pumps and user practices – energy reductions or increased comfort? Paper presented at Sustainable development of energy , water and environment systems conference, Dubrovnik, Croatia.

[37] Frontier economics, Irbaris & Ecofys, 2013. The Economics of Climate Resilience Buildings and Infrastructure Theme: Overheating in Residential Housing (CA0401), http://randd.defra.gov.uk/Document.aspx?Document=10664_CA0401-rep-housingreport-final.pdf.

[38] Building Regulations Part L: Conservation of Fuel and Power, available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/516016/BR_PDF_AD__L1A__2013_with_2016_amendments.pdf

[39] DCLG, 2012, A guide to improving the energy efficiency of our buildings, A guide to air conditioning inspections for buildings, available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/51121/A_guide_to_air_conditioning_inspections_for_buildings.pdf

[40] Shove, E., Walker, G., & Brown, S., 2013, Transnational transitions: the diffusion and integration of mechanical cooling. *Urban Studies*, 0042098013500084.

end of the market. In the office case studies air conditioning were justified in terms of noise from open windows, intensification of space usage and the special demands of computers and server rooms. Uptake and use in hotels and offices were driven by global companies looking to standardise their operations. In the hospital case study, drivers were slightly different. Intensification of space was an issue but requirements of clinical performance and global developments in medical technologies were also found to be driving demand for air conditioning. It was found that the number of room air conditioners had increased from under 20 in 2002, to over 100 in 2009 (as well as having a centralised HVAC system in some buildings)[41]. High levels of insulation, combined with heat being produced by a range of specifically medical (e.g. monitoring) and non medical (e.g. drinks coolers, lighting and computing equipment) electrical equipment had led to some occupants feeling ill and fainting in areas of the building where there wasn't air conditioning. The proliferation of these electrical devices was found to be driving cooling demand where it had not existed before.

In Australia, the role of air conditioners as a status symbol and the emergence of 'pre-cooling' where homes are cooled before the arrival of guests have also been identified as potential emerging trends which could lead to increased uptake and use. There is potential for much more rapid diffusion of air conditioning if social norms around what it means to be a 'good host' in terms of providing cool spaces[42] come to require mechanical cooling.

Across domestic and work settings, as new practices or understandings of the 'proper' way to do things emerge there is the potential for air conditioning to become embedded within expected infrastructure. Researchers in this area of *practices* or social norms call on policy makers not to look at air conditioning in isolation but at the specific processes and practices of which air conditioning has become a part. This could relate to the cooling of drugs or the increasing amount of bedside technology which has become part of modern hospital care, the establishment of 'appropriate' clothing for offices, the intensification of the use of office space, new norms about what being a 'good host' means etc. The implications of these changes in practices for internal temperatures, occupant comfort and related energy demand for air conditioning requires further exploration and must consider the co-evolution of uptake and use patterns.

4.8 Smart homes and lifestyle marketing of air conditioning

In considering the development of social norms and practices around air conditioning, the role of marketing and product innovation in the air conditioning sector is also worth considering in examining how penetration patterns in the UK may develop. For example in South Korea, marketing campaigns linked watching the 2012 Summer Olympics from London in a cool and comfortable space, using celebrities from the athletics world to promote their air conditioning products.

In reviewing the prospects for global growth in air conditioning, Euromonitor, 2015[43] identify the innovations in *smart technology* for air conditioners as one of the key innovations that will drive growth in the UK market. Internet connectivity, smart phone compatibility and sensors to monitor ambient temperature as well as human movement are thought to be key elements of such a smart system. In line with

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[41] Walker, G., Shove, E., & Brown, S., 2014. How does air conditioning become 'needed'? A case study of routes, rationales and dynamics. *Energy Research & Social Science*, *4*, 1-9

[42] Strengers, Y., 2010, Air-conditioning Australian households: The impact of dynamic peak pricing. *Energy policy*, *38*(11), 7312-7322.

[43] Euromonitor, 2015, Increasing household income and technology advances to fuel growth in air conditioners, cited in RESNET Technical Report.

emerging practices identified in the previous section, Daikin Industries Ltd have introduced smart phone controls to allow pre-cooling before residents arrive home. MIdea Group and Xiaomi Inc co-launched their smart air conditioner that can also be linked to a Xiaomi wrist band to automatically adjust the air conditioner in response to physiological readings. The system can also be set for energy saving features such as turning off when a window is open or when the wristband wearer falls asleep.

Fig 1. Smart air conditioning unit and wrist bandsXiaomi.com[44]

Such product innovation gives an insight into how air conditioning manufacturers may seek to position the technology in order to increase sales in the UK. If the numbers of ‘smart homes’ do increase in the UK, the potential for additional energy demands to be built into the infrastructure need to be carefully monitored in order to anticipate expansion of air conditioning demand.

4.9 Implications of the review

From the review it is clear that there is evidence of a number of factors influencing air conditioning adoption and use. Factors such as disposable income, affordability of air conditioning systems and increases in average temperatures may all have a role to play in driving future demand. However, particularly given the moderate temperatures in much of the UK compared to nations with high air conditioning penetration, it is important to consider the role of heat waves, unintended consequences of building regulations and changes in social norms at home and at work that could drive a level of uptake that at first sight seems at odds with the external temperatures experienced. It is also important to consider how other adaptation measures may counteract the effects of rising temperatures, in particular the opportunities presented through the use of green infrastructure to provide a cooling effect in urban areas through evapotranspiration and shading.[45,47] Increasing the coverage of green space within urban areas through, for example, green roofs and planting trees along roads can reduce the surface temperatures compared to

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[44] from http://xiaomi-mi.com/news-and-actions/smart-air-conditioning-the-brainchild-of-xiaomi-and-midea/

[45] Gill, S., E., Climate Change and urban greenspace (Doctoral Dissertation)The University of Manchester 2006 available at: http://www.greeninfrastructurenw.co.uk/resources/Susannah_PhD_Thesis_full_final.pdf

baseline conditions, presenting an opportunity to moderate summer temperatures and air conditioning demand through spatial planning. [46,46]

The review highlights the need for collection of much more robust data on both air conditioning uptake and patterns of use in the commercial and domestic sector. This could be pursued in the form of specific studies for the ENWL area or through lobbying central government to collect more air conditioning specific data. A potential option would be to add domestic air conditioning appliance ownership to DECC's Energy Consumption in the UK collection process.

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[46] Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, *95*, 1-66. DOI:doi:10.1016/j.progress.2013.08.001. Publication link: 5dbb4d89-f1f2-4449-8aa9-a2e6496ed6db

5 Explanation of scenario air conditioning penetration levels

5.1 Developing the domestic penetration level scenarios for 2030

From reviewing the literature on commercial and domestic uptake of air conditioning, the following potential penetration rates for the domestic and commercial sectors in 2030 for the ENWL region have been developed and are used as scenarios in the analysis. There are 4 levels of penetration scenarios for domestic air conditioning uptake and 3 for commercial. The rationale and context for each of these levels is explained below. For this analysis a penetration rate for 2030 is assumed but it should be noted that in reality the pathway to this point could vary substantially from a smooth trajectory to sudden increases depending on the drivers of uptake.

5.1.1 Domestic Level A

This is a fairly low level growth scenario that draws on market data trends for consumer appliance ownership. The Euromonitor data for 2010-2015 shows a slight increase in the percentage of households owning a split or room air-conditioning unit over the period from 1.5% to 1.6%[47]. This relates to a 1.3% growth in the penetration rate over the period. Applying this trend to the 2010 baseline of 1.2% penetration results in penetration of 1.6% for the ENWL region by 2030.

It is important to consider a lower end penetration rate in the scenarios, as the data on trends in adoption is currently not robust enough to have a confident view of the increase in domestic penetration. Euromonitor International only started collecting data on UK ownership of air conditioning appliances in 2009 and data is not currently collected on domestic air conditioning penetration in Government data sets such as DECC's *Energy Consumption in the UK*.

5.1.2 Domestic Level B

For the second level of adoption, historic trends for two international cases which now have high penetration of air conditioning are considered. Adoption rates in USA and Australia, show significant increase in levels of domestic air-conditioning that are not *only* a response to rising temperatures. In the USA, from 1960 to 2001 there was an increase from 12% to 81% penetration[48,49,50]. This implies an annual growth rate in the penetration level of 4.8%. In Australia data from 1994 and 2014 indicate that air-conditioning penetration has risen from 32.5% to 74% over this period[51]. This implies an annual growth in the penetration level of 4.2%. For the Level B scenario an annual growth in the penetration level of 4.5% is assumed as a mid range value from these examples. This leads to the penetration by 2030 being 2.9%.

Taking an annual growth in penetration level from the USA or Australian case where there is now high penetration still leads to fairly modest penetration as the UK starts from such a low level. So, whilst these annual growth rates led to substantial shifts in

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[47] Euromonitor International 2016, Consumer Appliances in the United Kingdom, cited in the RESNET Technical Report

[48] This increases to 83% by 2009 - we assume that the penetration is stagnating from 2001 and consider the growth in the penetration rate to this point.

[49] U.S. Department of Energy, Energy Information Administration, 2001 Residential Energy Consumption Survey, https://www.eia.gov/consumption/residential/data/2001/

[50] Cox, S., 2013. Losing Our Cool: Uncomfortable Truths About Our Air-Conditioned World (and Finding New Ways to Get Through the Summer. The New Press.

[51] Australian Bureau of Statistics, 2014, Energy Use and Conservation, www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4602.0.55.001Mar%202014?OpenDocument

the level of penetration in USA and Australia, the UK levels would remain comparatively low over the 20 year period of the study. Clearly the climates in the countries are substantially different to the UK, however the growth in penetration levels from these nations are explored on the basis of economic and cultural similarities.

5.1.3 Domestic Level C

Various sources identify the potential for fairly rapid uptake of air conditioning. This could be due to a series of 'stress' events where air conditioners are purchased during unusually hot weather, a combination of increases in disposable income and reducing prices for air conditioning units and changes in social norms around expected levels of cooling and inclusion of air conditioning within new builds.

Levels C and D allow exploration of the potential implications of a more rapid uptake of air conditioning in the domestic sector.

National Grid's Gone Green Scenario builds on DECC's Pathways Analysis[52], in adopting a 33% penetration for air conditioning by 2051 (in line with DECC's Level 3) [53]. Starting from the 1.2 % 2010 baseline, penetration of 33% in the ENWL region by 2050 implies annual growth in the penetration rate of 8.64%. Applying this rate from 2010 to 2030, results in ENWL region penetration reaching 6.3% by 2030. For the Level C scenario, the 6.3% penetration level by 2030 is adopted. This scenario could arise from an increase in disposable income, reductions in the price of air conditioning units and increasing inclusion of air conditioning in new homes (potentially as part of the growth of 'smart homes').

5.1.4 Domestic Level D

In DECC's Level 2 in their pathways analysis, a 67% penetration by 2050 is assumed. National Grid previously used this level for their Consumer Power Scenario but reduced it to 60% following feedback from stakeholders that this was too high[54]. In order to explore a high penetration scenario in the analysis, the 60% penetration level is assumed to have occurred in the ENWL region by 2050. Taking a mid point (rather than applying a growth rate), the penetration by 2030 is 30.6% (this implies a 17.6% annual growth rate).

This scenario could arise from the combination of an increase in disposable incomes and reduction in unit prices combined with a series of heat waves, where householders respond by purchasing air conditioning units to such an extent that cool indoor environments become increasingly expected in terms of social norms. This high level of adoption is used to explore potential stresses in the system.

5.2 Developing the commercial penetration level scenarios for 2030

5.2.1 Commercial Level A

Although data is collected on sales (£) in the air conditioning market there is not a good data set covering the penetration of air conditioning in terms of floor space.

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[52] Department for Energy and Climate Change, 2010, 2050 Pathways Analysis, www.gov.uk/government/publications/2050-pathways-analysis

[53] Personal communication between Tyndall Centre, Electricity North West and National Grid.

[54] Personal communication between Tyndall Centre, Electricity North West and National Grid.

DECC's Energy Consumption in the UK (ECUK) data indicates the number of air conditioning appliances owned within the services sector[55]. The ECUK data has floor space data for the services sector from 2000-2012, using this data and the number of appliances owned, a figure for number of units per square meter is calculated and used as a proxy for considering the trend in penetration in the commercial sector. The average annual growth rate for this proxy is 3% between 2000 and 2012. Applying this 3% annual increase in penetration to the 9.94% 2010 baseline level for the ENWL region, penetration by 2030 is 18.0%. This lowest level in the scenarios analysed in this report could arise due to slow growth in construction and commercial space renovation. This level of penetration would see the ENWL region remain below the 2010 baseline UK penetration rate of 24% in 2030.

5.2.2 Commercial Level B

The Carbon Trust expects that 40% of commercial floor space will be air-conditioned by 2020 compared to 10% at the end of 1994 [56]. This forecast implies an annual growth in the penetration level of 5.48%.

Applying the 5.48% growth in penetration level to the 2010 baseline of 9.94% out to 2030, results in 28.9% penetration by 2030 in the ENWL region. This scenario could arise with strong performance in the construction sector and preference for mechanical rather than passive cooling in new builds and renovations.

5.2.3 Commercial Level C

The Level C scenario draws on the work of Walker et al on how air-conditioning becomes 'expected' and 'needed'[57]. They identify the various socio-technical conditions which shape technology adoption and use (looking beyond external temperatures and disposable income). From this perspective, air-conditioning could become a standard and expected part of the practices of the commercial sector. These practices could then spread through the various business sectors and adoption of air conditioning could be unrelated to local temperatures in the UK – e.g. offices across the UK are all fitted with air-conditioning as standard. To explore this standardisation of air conditioning penetration across the UK, in the Level C scenario, the ENWL region reaches the same penetration rate as the whole of the UK. Extrapolating from the Carbon Trust's projection that by 2020, 40% of UK commercial floor space will be air conditioned, a level of 68.2% penetration is reached by 2030. However, it is still assumed that the actual use of air-conditioning is still related to local temperatures. This implies an annual growth in the penetration level of 10.1% in the commercial sector.

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[55] Chapter 5, Services Data Tables, www.gov.uk/government/statistics/energy-consumption-in-the-uk

[56] The Carbon Trust, 2012, Air Conditioning, Maximising comfort, minimising energy consumption.

[57] Walker, G., Shove, E. and Brown, S., 2014, How does air conditioning become 'needed'? A case study of routes, rationales and dynamics. *Energy Research & Social Science*, *4*, pp.1-9.

5.3 Summary of air conditioning penetration levels and brief rationale

	ENWL region air con penetration	**Number of households with a/c**	**Rationale**
Domestic base (2010)	1.2%	24,221	As in RESNET Scenario Tool - assumed that temperature in ENWL region means that adoption is lower than UK average. (UK average based on Frontier Economics report and a Parliamentary Question, ENWL region level scaled based on temperature).
Domestic Level A (DA) (2030)	1.6%	35,994	Euromonitor data trend from 2010-2015 on domestic air conditioning appliance ownership. Modest growth offers exploration of a level below the international uptake rates in countries with high penetration.
Domestic Level B (DB) (2030)	2.9%	65,239	Penetration levels for USA and Australia used to determine a mid range penetration growth rate of 4.5%. Applying this annual rate to the penetration level results in penetration of 2.9% in 2030. Note that the penetration remains low compared to USA and Australia due to low starting point of 1.2%.
Domestic Level C (DC) (2030)	6.3%	141,726	Assuming 33% penetration by 2050 in line with DECC Level 3 and National Grid Gone Green scenario. Growth rate calculated from 2010-2050 based on 33% penetration. This rate then applied to 2030. Growth rate approach rather than straight line is in line with National Grid information by email.
Domestic Level D (DD) (2030)	30.6%	688, 381	Assuming 60% penetration by 2050 in line with stakeholder feedback on high uptake scenario in 'Consumer Power' in the National Grid Future Energy Scenarios. 2030 penetration taken as a mid point between the 2010 baseline and 2050 penetration. Allows exploration of high levels of penetration for example, as a response to a series of heat waves.
	ENWL region air con penetration	**m^2 with a/c**	**Rationale**
Commercial base (2010)	9.94%	2,305,312	As in RESNET Scenario Tool based on ECUK data and scaled for ENWL region temperature.
Commercial Level A (CA) (2030)	18.0%	4,505,260	Trend taken from available ECUK data 2000-2012 based on proxy of air conditioning appliances per m^2 in the services sector.
Commercial Level B (CB) (2030)	28.9%	7,233,445	Takes the Carbon Trust forecast of 40% air-conditioning by 2020 to determine a growth rate in the penetration level of 5.48% pa. Applied out to 2030 from the ENWL region baseline.
Commercial Level C (CC) (2030)	68.2%	17,069,929	Adopts extrapolated Carbon Trust level for the UK in 2030 (68.19%). Based on insights from Walker et al, assumes spread of social practices in commercial sector mean that ENWL region has the UK average penetration (but actual use of air-conditioning when installed is related to local temperature). For this level of penetration in 2030, the annual growth in the penetration rate would be 10.11%.

6 RESNET Scenario Tool – determining baseline and 2030 demand

This work has examined the potential changes that could be seen in electricity demand for cooling in the ENWL region. Utilising the RESNET Scenario Tool, it has been possible to assess potential cooling demand in 2030, in both Domestic and Commercial sectors, taking account of different penetration levels for air conditioning and using different assumptions for how temperatures may change as a result of climate change.

6.1 Domestic Cooling Electricity Demand

6.1.1 Annual Demand

As discussed previously there is limited data available on the use of air conditioning (a/c) in GB and the electricity consumption associated with it in the domestic sector, therefore assumptions are necessary to enable annual air conditioning demand in GB to be estimated in the baseline year 2010. The numbers of households reported to be installed with an a/c system of some form range from 1%[58] to 3%[59]. For the 2010 baseline in the Scenario Tool, the number of houses with air conditioning selected is based on Hansard[60] which details a reply to a question on air conditioning made by Elliot Morley (then a Minister of State in the Department of Environment, Food, and Rural Affairs), which stated that by 2010 there was an expectation that 0.7million homes would have air conditioning. Given that this value lies within the 1-3% range quoted by other sources, this figure was used for the baseline value. The number of GB homes with a/c was disaggregated down to different regions using an approach that took account of temperatures in each region and numbers of households. For the ENWL region this gives a baseline penetration rate of 1.2%.[61]

To calculate demand, the Scenario Tool assumes a relationship between cooling demand, temperature (represented by cooling degree days (CDDs), and a value of demand per CDD per household. There is no consideration of the size of individual air conditioning units and how much cooling they can supply – in essence it is assumed that cooling demand can continue to increase with temperature with no limit. The possibility of imposing an upper limit was considered but given that the option exists to add new a/c units to meet additional cooling demand, it was decided to not follow that route to enable the exploration of plausible worst case demand scenarios. The annual demand is calculated using the following formula:

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[58] Frontier economics, Irbaris and Ecofys, *Economics of Climate Resilience Building and Infrastructure Theme: Overheating in Residential Housing - Annexes*, 2013, p. 16 http://randd.defra.gov.uk/Document.aspx?Document=10666_CA0401-rep-housingreportannexesfinal.pdf.

[59] *Ibid*, p.19

[60] Hansard, 2005, p. 7 June 2005, Column 459W www.publications.parliament.uk/pa/cm200506/cmhansrd/vo050607/text/50607w05.htm#50607w05.html_spnew6.

[61] In the RESNET Scenario Tool, Great Britain was divided into 3 weather zones in order to study the impacts of temperature on demand. The cooling degree day values were calculated for 2010 in each zone based on a baseline of 22°C for domestic properties. The relative numbers of cooling degree days for each zone were then used to disaggregate the total number of GB houses with a/c to each area. The ENW region corresponds to one of the zones (based on Manchester weather data) chosen and the proportion of homes assumed to have air conditioning installed in this zone has also been applied to the ENW area. Degree days provide a means of recording the variation of external temperature from a baseline temperature (22°C). For the 2010 baseline the CDDs were calculated using an approach called the Meteorological Office equations that use daily minimum and maximum temperatures. The Meteorological Office equations can be found in CIBSE, *Degree-Days: Theory and Application*, 2006.

Formula 1

$$E(ac)_{annual} = \frac{C \times H(ac) \ \times CDD_{annual}}{\epsilon_{annual}}$$

Where
$E(ac)_{annual}$ = the annual energy demand (unknown)

$H(ac)$= the number of households with air conditioning (calculated using the 1.2% penetration for 2010 discussed above and the number of households in the ENWL region)

CDD_{annual} = the annual number of cooling degree days (Calculated using 2010 weather data for Manchester[62], a baseline temperature of 22^0C[63], and the Meteorological Office Equations)

ϵ_{annual} = the annual average CoP for the a/c systems (see below),

C = a constant that is the cooling demand/CDD/household[64]

In the model the value of ϵ_{ac} is treated as temperature dependent, i.e. as the temperature increases the performance of the a/c system is assumed to decrease in efficiency as it has to work harder to cool the air. This relationship was assumed to be linear and is described in Formula 2. For the annual demand an average CoP was calculated by assuming a daily average number of CDDs (e.g. total divided by 365). For the peak day the actual number of CDDs was used.

Formula 2

$$CoP = mCDD + b$$

Where
b = the value of the CoP when the number of CDDs is zero (e.g. at 22^0C)[65].

m = the relationship between CDD and CoP when CDD>0 (with *b* known this could then be calculated).

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[62] From www.wunderground.com

[63] This is the value used in the UK Climate Projections. See e.g. http://ukclimateprojections.metoffice.gov.uk/22715

[64] To calculate C and a subsequent value for 2010 annual demand for domestic a/c, estimates of domestic a/c demand in London from A.R. Day, P.G. Jones and G.G. Maidment, 'Forecasting Future Cooling Demand in London', *Energy and Buildings*, 41.9 (2009), 942–48 http://dx.doi.org/10.1016/j.enbuild.2009.04.001 was used. This work suggested that with an annual CDD level of 110, and 300000 properties with air conditioning, the demand for a/c would be 280GWh giving a value of Y demand/CDD/household which could be used in the RESNET Scenario Tool.

[65] This was calculated based on the relationship between temperature and CoP detailed in M N Izham and T M I Mahlia, 'Effect of Ambient Temperature and Relative Hunidity on COP of a Split Room Air Conditioner', *Journal of Energy and Environment*, 2.1 (2010), 35–38. The % variation in these values of CoP at different temperatures from a value at 26^0C was calculated. For the scenario tool the value of *b*, the CoP at 22^0C (0 CDDs), was then calculated assuming the same % variation from 26^0C as in the Izham work, and a starting CoP at 26^0C.

6.1.2 Daily demand and diurnal load profile

Using the annual demand derived from Formula 1 the daily demand is calculated using the same approach as above with the number of CDDs for the peak day[66] replacing the annual number of CDDs e.g.

Formula 3

$$E(ac)_{peak\ day} = \frac{C \times H(ac) \quad \times CDD_{peak\ day}}{\epsilon_{peak\ day}}$$

$E(ac)_{peak\ day}$ = the peak day energy demand

H(ac)= the number of households with air conditioning (as in annual demand)
$CDD_{peak\ day}$ = the number of cooling degree days on the peak day for the Manchester region[67].

$\epsilon_{peak\ day}$ = the CoP for the a/c systems derived from Formula 2 using the CDD on that day.

C = a constant that is the cooling demand/CDD/household (as from calculation of annual demand)

In order to distribute the total peak day electricity demand for domestic air conditioning across the day, a modelled peak day profile for a house with central air conditioning in the US[68] was used, due to lack of evidence in the UK. This was used to calculate the variation of half hourly values from the average half hourly value (if load was evenly distributed). Using this, alongside the total peak day demand, the diurnal load profile was derived, with peak demand at around 6pm and lowest demand around 6.30am. The shape of the demand across the peak day has remained fixed in all the scenarios, with changes only to the magnitude of demand.

6.2 Commercial

6.2.1 Annual demand

Annual energy demand in the UK by major end uses is reported by DECC's annual report, Energy Consumption in the UK[69] (ECUK). ECUK reports annual electricity consumption for cooling and ventilation by the commercial sector[70]. Three components of this could be distinguished (which taken together are referred to as air conditioning) – ventilation, dehumidification, and cooling – and the average energy use per square metre per annum of each identified[71]. With total energy usage

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[66] In the scenario tool the summer 'peak day' is the day when the number of CDDs is greatest.

[67] Calculated from weather data from 20th July 2010 for Manchester (the day of peak electricity demand during the summer (from National Grid data), and the meteorological office equations.

[68] K Hamachi LaCommare and others, *Investigation of Residential Central Air Conditioning Load Shapes in NEMS*, 2002, p. 9 http://escholarship.org/uc/item/4mr0f0m2.pdf. The modelling assumed one load shape for the US, i.e. no regional differences.

[69] Department of Energy and Climate Change, *Sub-National Total Final Energy Consumption in the United Kingdom: 2005-2011*, 2013 https://www.gov.uk/government/statistical-data-sets/total-final-energy-consumption-at-regional-and-local-authority-level-2005-to-2010.

[70] This includes: commercial offices; communication and transport; education; Government; health; hotel and catering; other; retail; sport and leisure; and warehouses.

[71] This follows Ivan Scrase, *White Collar CO2: Energy Consumption in the Service Sector*, The Association of Energy Conservation, 2000, p. 9. This details these components and the energy use per square metre associated with each for different office types. The average energy usage (based on a

for cooling and ventilation known for 2010 (from ECUK) and with the assumed energy demand per square metre for each component, it was possible to calculate the total amount of mechanically air conditioned space associated with these figures. This worked out as 24% of the total commercial space[72].

The amount of commercial air conditioned space in each weather zone in the RESNET Scenario Tool was based on work[73] that detailed the distribution of air conditioned properties by region. The result was that 14.72% of the total air conditioned space was allocated to the ENWL region, which when compared to total commercial space, gives a penetration rate of 9.94%.

In the Scenario Tool it was assumed that electricity demand for ventilation was spread evenly throughout the year and was not temperature dependent[74]. Dehumidification and cooling were seen as closely linked and were treated together[75] (referred to as cooling in the following). For cooling, two components of demand were used in the scenario tool: a baseline demand that arose even when CDDs were zero[76]; and a temperature dependent component that varied with CDDs. The formula used to calculate this temperature dependent component had the same format as for the domestic sector

Formula 4

$$E(cool)_{annual} = \frac{C \times m(ac) \quad \times CDD_{annual}}{\epsilon_{annual}}$$

$E(cool)_{annual}$ = Total energy demand for the temperature dependent component of cooling

C = a constant for cooling demand/CDD/m^2

$m(ac)$ = the total amount of space that is actively air conditioned (as discussed above)

CDD_{annual} = the annual number of CDDs (from a baseline temperature of 18^{0}C[77] and calculated as for domestic CDDs)

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naturally ventilated open plan office, and a standard air conditioned office) are: ventilation (no mechanical a/c) – 8kWh/m^2/annum; ventilation (a/c office) – 60kWh/m^2/annum; dehumidification (a/c office) – 18kWh/m^2/annum; cooling (a/c/ office) 31kwh/m^2/annum.

[72] This compares with figures from Carbon Trust, 'Air Conditioning', 2011 http://dx.doi.org/10.1007/SpringerReference_7849. This suggests that in 1994 10% of commercial space was air conditioned and by 2020 it is expected that 40% would be air conditioned.

[73] Gavin Neil Dunn, 'Air Conditioning in 32 UK Office Buildings: Measured Energy and Carbon Performance' Thesis? Presented to the University of Wales, Cardiff, 2005), p. 125 http://orca.cf.ac.uk/55391/1/U201402.pdf.

[74] Based on additional modelling work (Hill, pers comms, January 2016). Although the usage of ventilation may vary with occupancy patterns without any additional evidence to support this the assumption that it is evenly spread through the year was used.

[75] *Ibid*.

[76] *Ibid.* This value of the baseline demand was 25kWh per square metre of air conditioned space. While a baseline load is found empirically when examining both building energy simulations of cooling demand and variations in national electricity demand, the reason for it is unclear but could reflect the wide variety of purpose for which air conditioning is used in the commercial sector (e.g. cooling servers, food storage warehouses, offices etc.).

[77] As Christenson 'Climate Warming Impact on Degree-Days and Building Energy Demand in Switzerland', *Energy Conversion and Management*, 47 (2006), 671–86 http://dx.doi.org/10.1016/j.enconman.2005.06.009>. notes, 18.3^{0}C is the standard baseline used by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)

ϵ_{annual} = the average annual CoP for cooling systems (calculation method detailed above)

Given that the total demand from ventilation and the baseline cooling load can be calculated from the demand per square metre per annum, and the total air conditioning demand for 2010 is known from ECUK it was then possible to calculate a value for C.

6.2.2 Daily demand and diurnal load profile

As mentioned above, the demand associated with ventilation was assumed to be evenly spread throughout the year, hence the peak daily demand is the total demand divided by 365. It is also assumed to be evenly spread through the day. The baseline a/c demand is treated as seasonal – i.e. that it comes about through use in Spring and Summer – so the daily demand is the annual total divided by 183. Again it is assumed that this is evenly spread through the day[78].

The demand from temperature dependent component of air conditioning on the peak day was calculated as annual demand but with peak day CDDs substituting for annual CDDs, and the CoP for the peak day being used – as with the Domestic sector.

The load profile was derived from work published by the Building Research Establishment (BRE) for DECC[79] which provided half hourly load profiles on the peak demand days for 2006 in the period January-March (Q1), April-June (Q2), July-September (Q3), and October-December (Q4). This detailed the half-hourly load profile on those peak demand days for the commercial sector by end use (with air conditioning as one component), and this was used as a basis on which to distribute the daily total demand to each half hour in the peak day[80]. For 2010 it was assumed that the pattern of demand remained the same as for 2006 so the load profile could be calculated once the daily demand was known. In assessing demand in 2030, the shape of the profile was again assumed to remain the same and, as with domestic, the peak day taken as the one with the highest number of CDDs.

6.3 Calculating future demand

In calculating the values for energy demand for air conditioning in the domestic and commercial sector in 2030 there are a number of key inputs. Some of these inputs are varied across scenarios while others remain the same in all scenarios. The Table below details these.

Input	Fixed or variable	Comment
Total number of households in 2010	Fixed	
Number of households with a/c/ in ENWL region in 2010	Fixed	

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[78] Again there was no evidence to suggest how this might vary, hence the assumption that it is evenly spread.

[79] C H Pout, F Mackenzie and E Olloqui, *Final Report : The Impact of Changing Energy Use Patterns in Buildings on Peak Electricity Demand in the UK*, 2008, p. 26 Figure 20. The Building Research Establishement for the Department of Energy and Climate Change, UK.

[80] It was not possible to get the data underpinning the figures. Therefore, it was necessary to read off values by eye.

Total number of households in 2030	Fixed	
Total number of households with a/c in 2030	Variable (different penetration rates)	Different penetration rates detailed in section 5.3
Coefficient of performance for a/c systems	Fixed	Across all scenarios it is assumed that the efficiency of the a/c systems improves by an average of 1% per annum due to innovation and development in the technology. However, given that the performance is also dependent on temperature this may be negated somewhat by increasing temperatures.
Total m^2 of commercial space in ENWL region in 2010	Fixed	
Total m^2 of commercial space in ENWL region in 2030	Fixed	
Total m^2 of commercial space that is actively air conditioned in 2010	Fixed	
Total m^2 of commercial space that is actively air conditioned in 2030	Variable (different penetration rates)	See section 5.3
Annual number of CDDs in 2030	Variable (between mid, 50th percentile, and high, 90th percentile) but fixed across different penetration rates within these two categories.	Although the number of CDDs is different between the Domestic and Commercial Scenarios they are based on the same temperature data and the difference arise from having differing baseline temperatures.
Peak Day number of CDDs in 2030	See above	See above. As explained earlier the 2030 'peak day' is the day with the highest number of CDDs within the weather data set used.
Cooling demand/CDD/household actively air conditioned	Fixed	For the domestic sector the Scenario Tool assumes that this value declines by 1% per annum but it is fixed across the scenarios
Cooling demand/CDD/commercial m^2 actively air conditioned	Fixed	

The annual and peak day air conditioning demand for 2030 is calculated as is 2010 demand with the formulae outlined in Sections 5.2 and 5.1 above, but with the new 2030 inputs.

The two different levels for CDDs – Mid and High – are used to highlight the uncertainty around the level of temperature rises that will be seen as a result of climate change. The cooling degree days (CDDs) for Manchester under a high emission scenario of climate change for 2030 are estimated using the temperature data from the PROMETHEUS project[81]. The PROMETHEUS project developed probabilistic (10th, 33rd, 50th, 66th and 90th) future weather files from the UKCP09 weather generator on an hourly resolution. The Mid CDD relates to the 50th percentile temperature data and the High CDD to the 90th. Therefore, the probability of the Mid CDDs occurring is higher, however, it is important to consider both to reflect both the possibilities for extreme weather and the uncertainty involved in discerning future weather. The high emissions scenario is used as, in comparison with current emissions trajectories, that most closely represents the course that is being followed (and even this underestimates emissions that have already occurred, further justifying the use of the High CDD approach alongside the Mid CDDs). It should be noted that by selecting the 90th percentile, potential extreme hot temperatures are not captured. For further information on this see appendix A.

6.4 Limitations of the approach

As in clear throughout the report, the main limitation of the approach is that it is based on very little actual data. The paucity of information around air conditioning has presented a real challenge in developing the Scenario Tool. As further information becomes available it would be possible to refine the approach, however, it represents the best working model that was possible. Consideration was given for this analysis to recalculate a 2015 baseline and examine an interim period of 2022. However, given the various uncertainties it was agreed that this would not give any additional insight.

There are a number of specific issues that can impact on the results.

6.4.1 Domestic Sector

- For domestic it has been assumed that all cooling demand is directly related to temperature, unlike in the Commercial sector where directly temperature related demand is only one component. The impact of this shows in the results with a higher proportion of the annual demand seen on the peak day for the Domestic sector. In real use it is possible that the Domestic sector may also be complex.
- Related to use of air conditioning is the question of baseline temperatures to define cooling degree days. In the model a baseline of 22^{0}C is used for the domestic sector. The baseline temperature has a significant effect. If we assume a value for annual demand from a/c, then having a baseline temperature of 22^{0}C as opposed to 18^{0}C means that there are fewer days when the baseline is exceeded, and therefore, the demand on those days when a/c is used is higher. Hence, the demand on the peak day will be higher with a higher baseline temperature. For commercial a/c it was assumed that operation would occur at lower temperatures than in the

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[81] Centre for Energy and the Environment. PROMETHEUS [Internet]. Exeter: University of Exeter; [cited 2015 Apr 1]. Available from: http://emps.exeter.ac.uk/research/energy-environment/cee/research/prometheus/

domestic case so a baseline of 18⁰C was used. Again, more understanding of how air conditioning is used in practice would provide useful evidence to back up the baseline figures.
- As mentioned previously, the Scenario Tool does not consider individual a/c units and the limits on cooling and subsequent electricity demand that would exist for each unit. This could mean that the model over estimates cooling demand at higher temperatures (although this is less likely to be an issue when considering up to 2030). Hill and Wood are currently investigating this relationship.

6.4.2 Commercial Sector

- Electricity consumption is reported as ventilation and cooling. To ascertain temperature dependent elements breaking this down further is necessary and introduces uncertainties.

The use of air conditioning in the commercial sector appears to be complex, with an understanding of numerous components (e.g. ventilation, baseline air conditioning, temperature dependent air conditioning) required to ensure that the model was consistent with empirical data, in particular to actual electricity demand in 2010.[82] Again greater understanding of how the different elements respond to temperature and how they are used in different situations across the commercial sector would enable the model to be refined to take account of this. The consideration of different types of commercial property as opposed to a simple m^2 commercial space, as in Section 6 offers one approach to refining the tool.

6.5 Results

For detailed results please see the excel sheets provided.

The figures below indicate the changes in annual electricity demand for cooling in the domestic and commercial sectors in the ENWL region under our range of penetration scenarios and under high and mid CDD levels. The load profile for peak summer day air conditioning demand under high and mid CDDs is also given for both the domestic and commercial sectors.

6.5.1 Domestic

Although the level of actual warming by 2030, and subsequent increases in summer high temperatures, resulting from climate change are uncertain: the evidence that they will increase is clear. Coupled with higher uptake rates for cooling systems, which could be driven in part by the increasing temperatures, the results here show that this will have a significant impact on demand and could have an impact on the electricity network. In the scenario tool used for the analysis, the impact of increases in the number of cooling degree days (CDDs) is similar to the impact of increasing penetration rates when looking at the domestic sector (e.g. doubling one, or the other, increases annual energy demand by 50%). However, current low levels of domestic air conditioning systems mean that penetration rates need to increase considerably before there is any major impact.

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[82] In addition to checking the output from the scenario tool against the National Grid data for the peak day (20th July 2010), it was also checked against other days (using the appropriate CDD value) to ensure that it gave expected outputs.

While increases in temperatures up to 2030 may be inevitable, the increase in penetration rates for air conditioning in the domestic sector is not. If the rate of domestic air conditioning uptake were to be similar to that seen in the USA or Australia (Domestic Level B), one of the lower penetration rates used in the analysis, the peak summer day electricity demand from domestic air conditioning would be more than double current peak day commercial cooling demand. If 30% of households have air conditioning by 2030 then the peak summer day air conditioning demand could be as high as 3 GW (at 6pm).

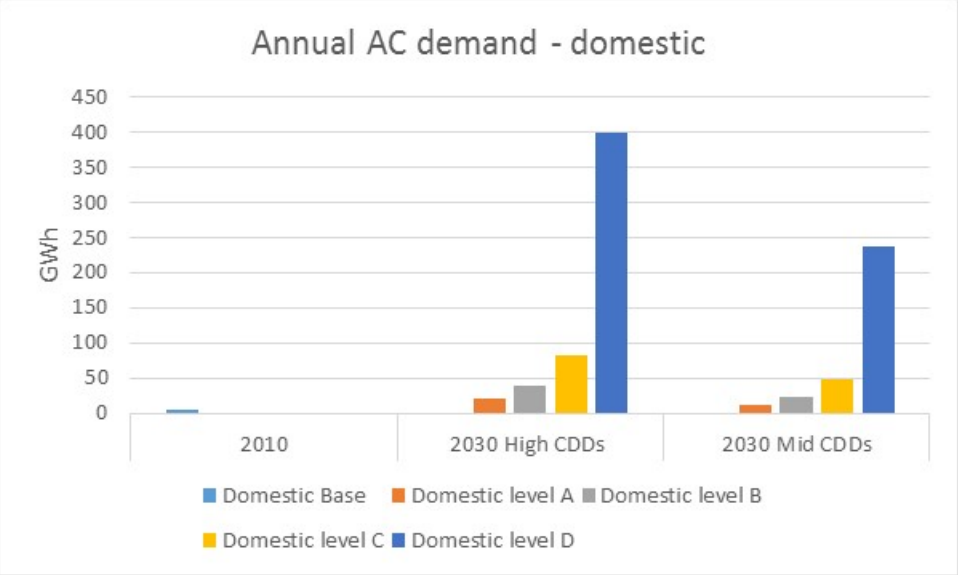

Figure 1 Annual AC demand - domestic

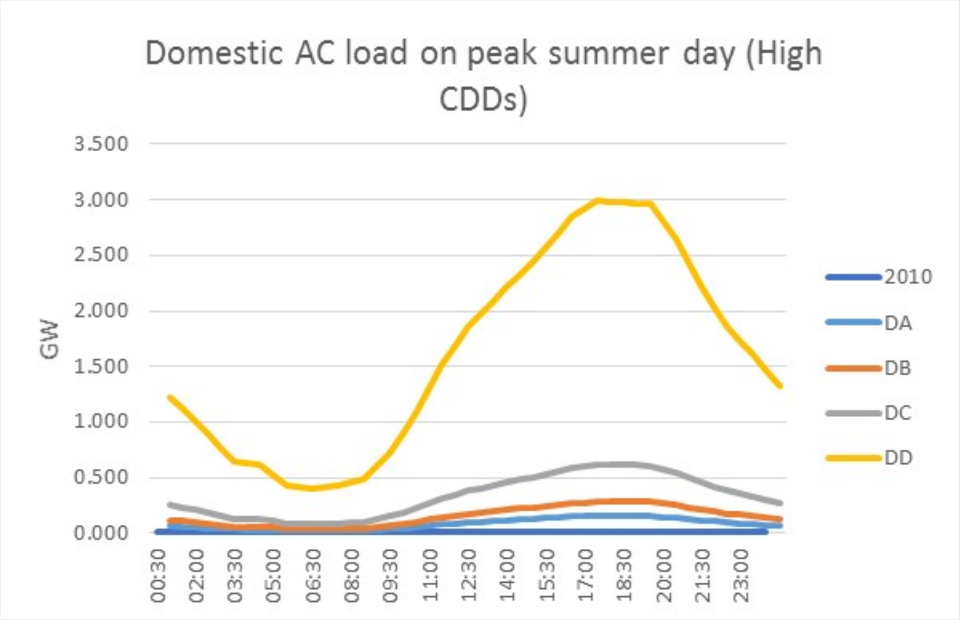

Figure 2 Domestic AC load on peak summer day (High CDDs)

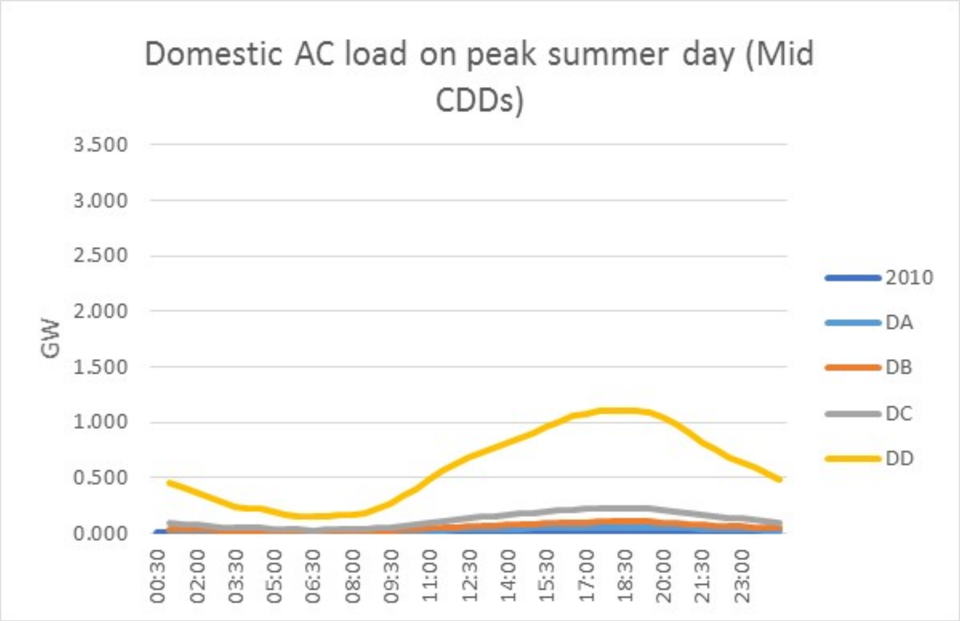

Figure 3 Domestic AC load on peak summer day (Mid CDDs)

6.5.2 Commercial

There is better understanding of air conditioning uptake in the Commercial sector as it is a more established technology in the UK. Coupling expected increases in uptake with potential rises in temperature show that demand could increase considerably. Following estimates from the Carbon Trust (as set out in Commercial Level B), the % of commercial space that was actively air conditioned would increase from just below 10% to just below 30% by 2030 and, under the high CDD scenario, the total annual electricity demand for a/c could increase by over 150% and peak day air conditioning demand could be nearly 8.5 times higher than the 2010 baseline.

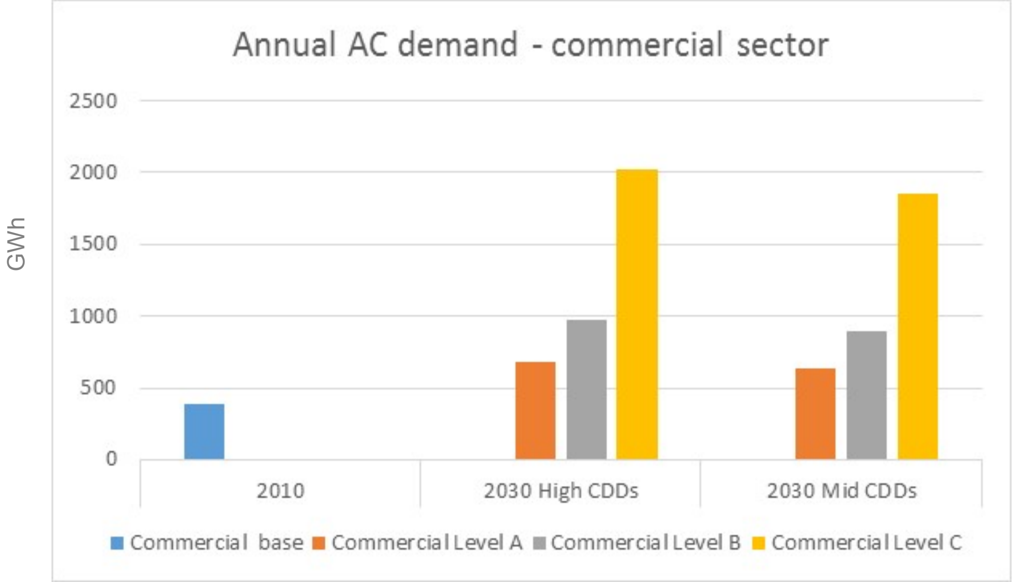

Figure 4 Annual AC demand - commercial sector

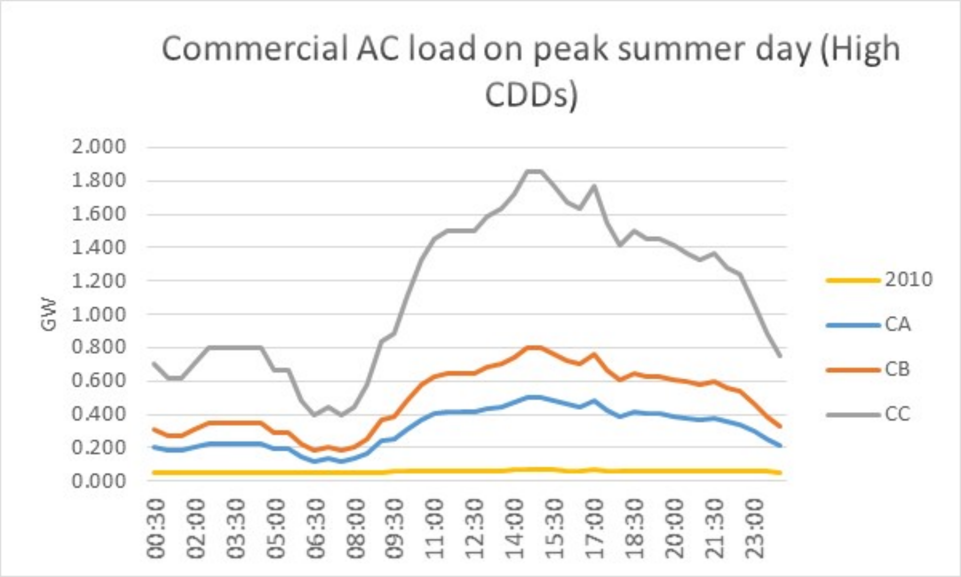

Figure 5 Commercial AC load on peak summer day (High CDDs)

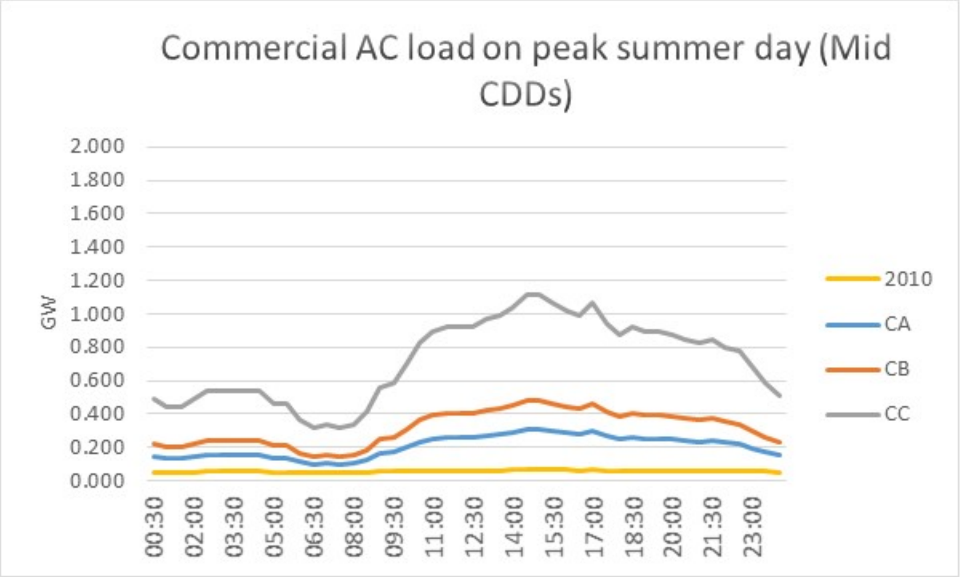

Figure 6 Commercial AC load on peak summer day (Mid CDDs)

6.5.3 Combined figures

Figure 7 below combines domestic and commercial values to demonstrate the potential demand of both. For both high CDD (90th percentile) and mid CDD (50th percentile) is assumes 5 combined scenarios:

- Very Low – combines the values from Domestic A and Commercial A
- Low – combines Domestic B and Commercial A
- BAU uptake – the assumption here is that the uptake scenarios of Domestic B and Commercial B constitute an expected, business as usual, scenario as selected by ENWL
- Medium – combines Domestic C and Commercial B
- High – combines Domestic D and Commercial C

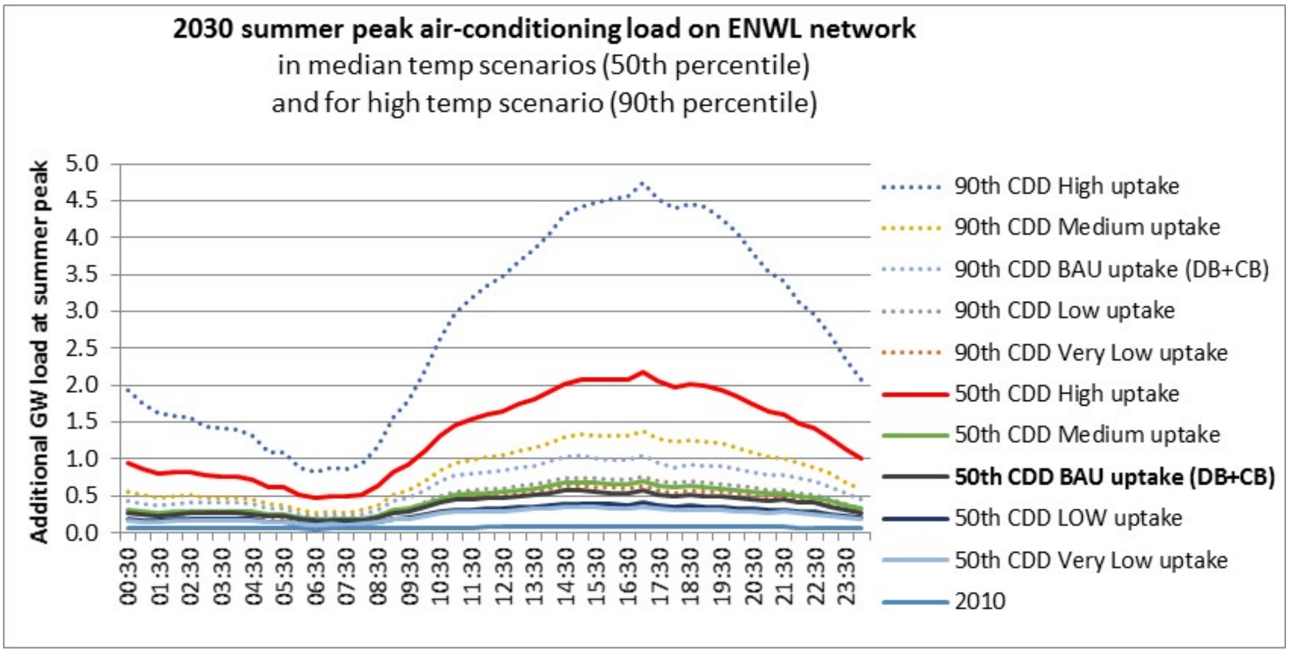

Figure 7 2030 summer peak air-conditioning load on ENWL network

All of these scenarios represent possible futures, dependent on the various conditions outlined in the report. They offer a clear starting point for further discussions about the potential impact that air conditioning could have on the ENWL network and more widely.

7 Profiling of electrical cooling demand for different types of commercial users

The patterns of cooling demand in commercial properties across a day that have been provided in this report are based on an aggregate of all types of commercial buildings from Pout et al[83]. This section outlines how different building types may differ from this aggregated 'average commercial building' profile. This is important to recognise when considering the demands at a sub-station level as the numbers of commercial properties per sub-station are likely to be small and the types of commercial property will vary between sub-stations. The aggregate demand profile for each substation will be dependent on the numbers and types of commercial property being supplied, and the difference between this and the 'average' commercial property could make a significant impact on actual electricity demand. This section firstly discusses the different drivers for cooling demand in commercial buildings and secondly outlines the additional components of electricity demand associated with HVAC that are temperature independent that also need to be considered. It then provides an overview of the methodology used to estimate the cooling profiles for different building types, presents the indicative results and discusses how these profiles could change in the future. It should be noted that industrial process cooling and refrigeration were not included in the analysis.

7.1 Factors affecting cooling demand in buildings

Electrical demand for cooling in a building depends on many interrelated factors. The primary impacts are occupancy patterns, external temperature (and therefore also coefficient of performance (COP) of cooling plant), and solar gain. In addition, specific activities within buildings require controlled temperatures, while others generate heat quite intensively.

7.2 Related components of cooling demand in buildings

Electricity usage in commercial buildings is submetered only to the extent that all HVAC energy usage is combined into one data stream. The overall HVAC data stream includes the electricity demand for fans and pumps for movement of air and central heating water which is independent of external temperature, as well as energy specifically used for cooling. This latter includes air conditioning compressors and condensers, and individually installed "cassette" or "split" systems with their associated air handling units that cool the air being circulated and are affected by external temperature, and also building integrated systems such as chilled ceilings. In order to differentiate cooling demand (and thus demand that could be affected by future climate change) from other elements of HVAC demand, it is assumed that the cooling demand is, in many types of building, the difference between winter and summer HVAC demands. The other components of HVAC electricity demand we assume will already have been taken into account in ENWL's existing demand projections.

7.3 Estimating load profiles for different building functions

Where possible, empirical data from existing buildings of different use-types (extracting cooling demand from HVAC demand as above) have been used as an indicator of what demand patterns may be expected of the sector. However, in other

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[83] Pout, C.H., Mackenzie, F., and Olloqui, E., 2008, *Final Report : The Impact of Changing Energy Use Patterns in Buildings on Peak Electricity Demand in the UK*.

cases, it has been necessary to create estimated profiles, which indicate the pattern of demand across a day rather than the size of demand *per se*. In these cases, the potential pattern of electricity demand for cooling has been based on expected occupancy and activity patterns, and specific control requirements for each building type. These estimate profiles have been established on the basis of BRE's National Calculation Methodology[84] (NCM) activity database which is widely used in prediction of operational energy demands. Although the NCM's intended purpose is for regulatory compliance modelling, and its use for any other purpose has been widely criticised, it is, nonetheless, the best source that is available, and the source to which professional building service engineers have directed the authors when consulted. In some cases Building Services Managers have been informally interviewed to ground truth these assumptions and amendments have been made to the profile accordingly.

In addition to the impacts of occupancy on the pattern of demand across the day, the variation of temperature during a day on the cooling equipment's COP and the impact on demand due to solar gain throughout the day was needed. The effects on COP were calculated from weather data files[85,86] and, where appropriate, the impact on demand due to solar gain has been estimated from basic physics. Figure 8 illustrates the overall results of this analysis, to give the following profiles for hourly variation of electrical cooling demand in July, when the demand peaks. The detailed methodology used for each of the profiles is found in the following sections.

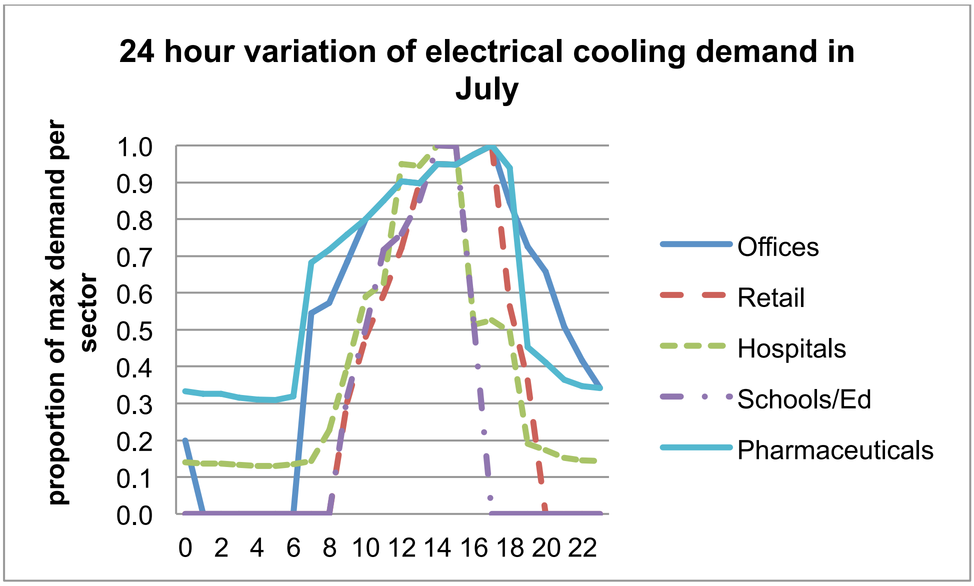

Figure 8 Hourly variation of electrical cooling demand for different commercial user types in July

7.3.1 Offices

The office cooling demand profile here is based on the HVAC demand profile from data from office buildings. In accordance with Pout et al's profile for commercial buildings used in the analysis provided for ENWL, the data used demonstrates that offices show a more extensive period of daily cooling than would have been predicted directly from application of activity figures from the NCM. It is apparent that cooling is pre-programmed to cover expected needs rather than simply as being used responsively when overheating occurs. Thus offices are cooled from before

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[84] BRE (2010) National Calculation Methodology, The Building Research Establishment, Watford, UK.
[85] EPW weather files for Aughton, Lancashire, *https://energyplus.net/weather*
[86] COP=(Tevap)/((Tcond-Tevap)*2) where Tevap = temperature at evaporator, and Tcond = temperature at condenser; Levermore G, 2000, *Building Energy Management Systems: Applications to Low Energy HVAC and Natural Ventilation Control,* 2nd Edition, E&FN Spon, Taylor & Francis, London

occupants arrive until after they leave, with residual cooling continuing through the evening. This gives a broader, lower profile, with less of a peak than might have been expected from application of a responsive mode of operation.

7.3.2 Retail

For retail buildings, no representative empirical data was found and so the profile is developed using the NCM. The NCM identifies a later rise in occupancy levels in retail premises than in offices. Following the pattern of application of a pre-programmed, wider, lower cooling profile observed in the empirical data from offices, the profile for retail cooling demand offered in Figure 2 has also been widened and flattened to some extent. This reaches peak values at lunchtime which are maintained through the afternoon in response to the combined effects of solar gain and occupancy related heat gain.

While the NCM does not indicate occupancy extending beyond 5pm for retail premises, it has been recognised that many non-food retail premises remain open into the early evening, and the profile has therefore been extended accordingly. It is not, however, expected that the few large non-food retail premises with opening hours late into the evening will be requiring significant active (conditioned) cooling at that time due to relatively low occupancy, and therefore low occupancy related gains, so that ventilation will largely suffice, taking advantage of outdoor temperatures falling through the evening.

Supermarkets have some of the highest energy demands, and the longest opening hours. However, supermarket retail floors are not expected to require any cooling in addition to the cooling effect of refrigerated cabinets. Little activity is expected in offices, store rooms, and other parts of supermarket buildings, and therefore little or no cooling demand is predicted.

7.3.3 Hospitals

The profile included in Figure 2 is based on empirical data of current cooling use in a typical 1980s Cheshire “nucleus design” hospital, where most of the cooling is passive, using opening windows for managed ventilative cooling. However, key clinical areas, including operating theatres, intensive care and scanning suites are cooled with a plateau between 12 noon and 3pm, and an overnight setback load of approximately 30% between 6 or 7pm and 9am, Monday to Friday, with some cooling required on Saturday mornings. This is switched off between November and March. The centralised IT suite requires constant cooling. The IT cooling system requires 20-25% of the total cooling capacity. Additionally “cassette” or “split” coolers are being installed in some consulting rooms, and if funds are available, these might be retrofitted more widely. This would increase the load observed further.

Over the past 5 years, a noticeable increase has been observed in the number of hours for which overheating thresholds have been breached in this case study building. It is anticipated that newly built hospitals would have mechanical cooling throughout. Loads from newly built hospitals are likely to follow occupancy and use patterns dependent on the services provided by the hospital. Occupancy regimes in hospitals range widely between outpatients consultation areas, wards, and circulation and service areas. Accident and Emergency areas are expected to require conditioning all the time. Daytime peaks in outpatient consultation areas and due to visiting hours in wards are likely to occur.
A newly built hospital might therefore have a higher base load than indicated by the profile in Figure 2, which reflects the usage in the Cheshire 1980s hospital.

7.3.4 Schools and other educational establishments

The cooling demand profile for schools and colleges starts by taking a profile of occupancy for schools from the NCM. As for offices and retail, the cooling demand profile is assumed to lag behind this a little. The predominant requirement for cooling in schools is in IT suites[87], due to the high level of internal gains from the computers. Only a slight drop in cooling demand is therefore predicted over the lunch break, assuming many computers will remain in use for students to work on at this time, although doors are more likely to be left open. A maximum demand is seen in the early afternoon, when the impacts of occupancy related heat gains and solar gain accumulate.

Term breaks have not been included in the hourly estimates (Figure 2), as they will not affect peak demands, except for the normal closure period over the summer which covers the whole month of August, and has been shown in the monthly variation in demand (Fig 3). Term breaks in further and higher educational establishments may be longer, but some occupancy will persist through these in most buildings, although this is likely to be at a lower level, and so not cause a demand for cooling. Specific requirements of laboratory spaces have not been considered here: they will represent a very small part of the institutional load.

7.3.5 Manufacturing and warehousing

No profiles have been established for manufacturing and warehousing except for within the pharmaceuticals chain. Whilst the processes and energy demands involved vary considerably, in general, in both manufacturing and warehousing, little or no cooling is required, other than that provided by ventilation.

Refrigeration for food processing and warehousing has been excluded from these estimates, as refrigeration is generally regarded as “process energy demand” rather than “building related energy demand”, and we assume that this element of demand will already be captured in ENWL’s existing demand projections and effects from climate change are likely to be minimal beyond the variation in COP.

7.3.6 Pharmaceutical industry

It is understood from personal communication with Building Services Engineers that ventilative cooling (i.e. circulating air into and around a building without cooling it) is usually sufficient in warehousing and factory buildings, with the exception of those in the pharmaceuticals industry, where mechanical cooling may be necessary. Thus, a baseline for pharmaceutical demand has been applied, at a low level overnight, but increased to respond to occupancy related gain during occupied hours. The profile is thus predominantly dependent on the variation of COP with external temperature.

7.4 Seasonal variation of demand

Demand varies seasonally, due to the need for cooling of air for ventilation in relation to external temperature, and to the variation of the COP of cooling equipment with the temperature of air surrounding the condenser; and also with holiday periods. Figure 9 is offered to indicate seasonally varying demand.

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[87] CIBSE TM36, 2005

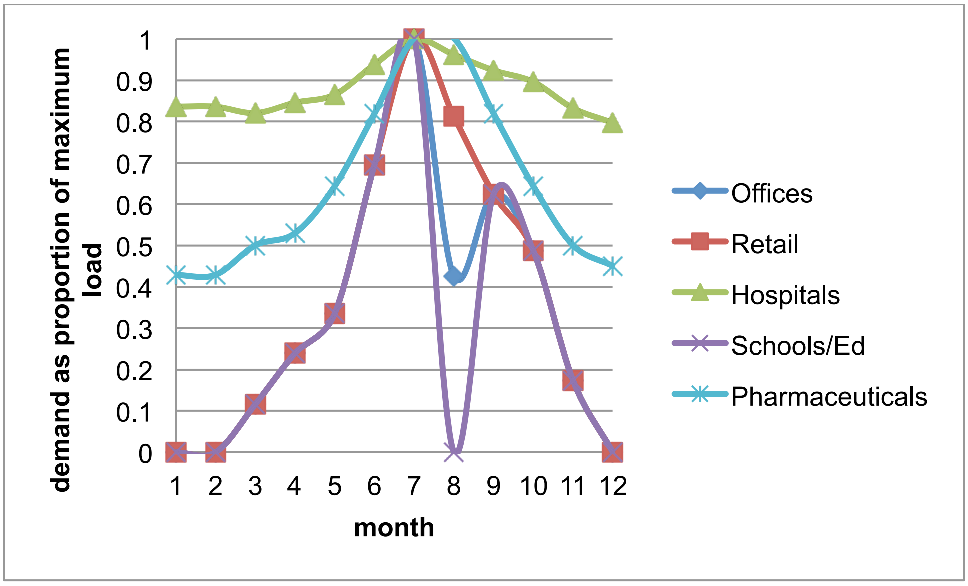

Figure 9 Seasonal variation of peak demand for cooling

It is assumed that, apart from educational establishments and offices, where August shows a significant dip in cooling demand due to holiday taking, holiday periods will even out. For offices, retail and schools, these profiles are based on the variation of HVAC seen in office energy data.

7.5 Factors likely to drive changes in these profiles for commercial end-users in the North West of England, including some passive and low energy solutions available

An increase in ambient temperature due to climate change will push the demand for cooling up due both to the higher temperature of air drawn in for ventilation, and the decrease in coefficient of performance of air conditioning units which results from the increased temperature of the air surrounding their condensers (in air handling units on the roof). Although continuing incremental improvements may be expected in the performances of the different components of cooling units, there is no indication of the likely scale of these, and it is thus impossible to estimate to what extent these may compensate for the increases in cooling demand that will otherwise be seen due to increase in ambient temperature.

Internal electric loads have already been decreased in most buildings in the drive for efficiency. As newer technologies for lighting and IT equipment are developed and installed, their increased efficiency will reduce the level of internal gains, and the resultant contribution to overheating. Detailed modelling would be required to determine the level of decrease of internal gains from electrical loads that would lead to an increase in the external temperature which would trigger the use of air conditioning by a degree.

Application of passive and low energy solutions to buildings has the potential to reduce the likelihood to overheat. One focus for passive solutions is on the reduction of solar gain. Such solutions include shading of south-facing windows, either from above or by installation of brise-soleil. A second focus is on improvement of the use of ventilation for cooling, possibly by the use of passive stack systems, and/or using air drawn through underground ducting, where it is cooled by the cooler ground as in the Building Research Establishment Headquarters in Watford, and the Cooperative Headquarters in Manchester. One low energy solution that should be considered more widely is the use of thermal mass within the building to absorb heat at peak times, and the cooling of this overnight. Even if this requires some use of fans for night time ventilation, this would result in demand shifting, and peak shaving. However, in many cases, the passive stack effect (driven by buoyancy of warmer air) may be used instead of mechanical ventilation. One specific form of thermal mass that may be applied is the use of phase change materials (PCMs). Systems already developed for retrofitting PCMs into buildings for this purpose (Monodraught) require the use of fans, although it is noted that it is probably impracticable to install sufficient quantity of PCM to fully mitigate overheating in any setting. The take-up of such passive and low energy solutions is hard to predict, but promotion of these could decrease the demands for electricity for cooling and, specifically, decrease the intensity of peak demands for electricity for cooling.

8 Appendix A: Cooling degree days for Manchester for use in the ENWL Scenarios

The cooling degree days (CDDs) for Manchester have been used as an indicator of climate change in the ENWL region. The CDDs under a high emission scenario of climate change for 2030 are estimated using the temperature datasets generated by the PROMETHEUS project[88]. The PROMETHEUS project developed probabilistic (10th, 33rd, 50th, 66th and 90th percentiles) future weather files premised on three emission scenarios of climate change from the United Kingdom Climate Impacts Program (UKCP09) Weather Generator[89]. The Weather Generator (WG) within the UKCP09 is able to output daily and hourly weather data on a 5 km grid over the UK in 30 year time slices in decadal steps from 2020s up to 2080s. The percentiles are defined (according to the mean air temperature) as likelihood of a certain amount of climate change such as unlikely to be less than the 10% value, unlikely to be greater than the 90% value, a central estimate (50%) of the magnitude of change and estimates in between (33% and 66%). The Weather Generator provides 1000s of simulated yearly weather datasets that are consistent with the future climate under different emission scenarios, as such the volume of data is too high for building energy simulation tools, which generally use far fewer weather years to estimate energy demand and overheating in buildings. The Prometheus project, however, provides future weather datasets that are suitable for building performance analysis.

A building's response for heating or cooling to the external weather conditions is analysed over a 'standard' year. The Chartered Institute of Building Services Engineers (CIBSE)[90] provided 'standard' weather years, as the Test Reference Years (TRYs) and Design Summer Years (DSYs), for use in building design – TRYs are used for energy analysis and DSYs are used for overheating analysis. The weather years are based on past observations (1983-2004) and these are available for 14 locations in the UK. TRY is composed of the 'most' average months from 1983 to 2004 based on the cumulative distribution functions (CDFs) of daily mean values of dry bulb temperature[91] (DryT)[92]. In other words TRY comprises 12 separate average months from the 22 years of data and is appropriate for energy performance calculations. The creation of DSY was based on daily mean DryT for April to September (inclusive) calculated for each year from 1983-2004. Then the year with the third hottest April to September DryT was selected as DSY which gives a near extreme year to examine how buildings might perform under near extreme conditions (over heating risk assessments)[93]. These 'standard' weather years can also be used to explore the impacts of future climate on a building's heating and cooling demand.

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[88] Centre for Energy and the Environment. PROMETHEUS Exeter: University of Exeter Available from: http://emps.exeter.ac.uk/research/energy-environment/cee/research/prometheus/

[89] Centre for Energy and the Environment PROMETHEUS and Eames M, Kershaw T, Coley D. On the creation of future probabilistic design weather years from UKCP09. Build Serv Eng Res Technol 2011 Oct 20 (2):127–42. Available from: http://bse.sagepub.com/content/32/2/127.abstract

[90] CIBSE - Chartered Institution of Building Services Engineers [Internet]. [cited 2015 Jun 1]. Available from: http://www.cibse.org/

[91] Daily mean values were determined from the hourly values of the parameters for all months in the years 1983-2004.

[92] Levermore GJ, Parkinson JB. Analyses and algorithms for new Test Reference Years and Design Summer Years for the UK. Build Serv Eng Res Technol 2006 Nov 1 27(4):311–25. Available from: http://bse.sagepub.com/cgi/doi/10.1177/0143624406071037

[93] Levermore GJ, Parkinson JB. Analyses and algorithms for new Test Reference Years and Design Summer Years for the UK. Build Serv Eng Res Technogy 2006 ;27(4):311–25. Available from: http://bse.sagepub.com/cgi/doi/10.1177/0143624406071037 and Eames, Kershaw et al (2011)

The PROMETHEUS project building on CIBSE's approach to generating TRY and DRYs sampled the UKCP09 weather generator output of 100 sets (100 realisations) for every 30 year time period. The weather data includes natural variability as well as the effects of climate change and is spatially resolved to a 5x5km grid of the UK. The 100 sets of 30 year period results in an hourly time series of 3000 equi-probable future weather years[94]. For the analysis in this report, only the DSY is required. For the DSY each 30 year period (for the period April- September) is ranked in ascending order and the 90th percentile or 4th warmest year was selected. [95]. The end result of this process is to generate a set of 100 DSYs, one from each of the 30-year samples. To create probabilistic weather years, the mean monthly temperature (average of mean daily temperatures over the month) is then ordered ranked from lowest to highest. The weather data associated with the 50th and 90th percentile of this monthly order is then selected from Prometheus' datasets for this work. By using this method, a 90th percentile DSY gives a near extreme weather year having 90th percentile of natural variability with a near extreme climate signal[96].

The hourly temperature (DryT) from the selected weather files were converted to CDDs for commercial and domestic based on the CIBSE guidelines[97] and using the Meteorological Office equations; daily maximum (θmax) and minimum (θmin) temperatures together with baseline temperature (θb). The formula used is based on four possible relationships between the base temperature and diurnal temperature variation as shown below:

- base temperature exceeds the maximum daily temperature, $\theta b > \theta max$
- maximum temperature exceeds base temperature by less than the base temperature exceeds the minimum temperature, $(\theta max - \theta b) < (\theta b - \theta min)$
- maximum temperature exceeds base temperature by more than the base temperature exceeds the minimum temperature, $(\theta max - \theta b) > (\theta b - \theta min)$
- minimum temperature exceeds base temperature, degree-days are zero[98]

It is assumed that for CDDs when the external temperature exceeds the baseline temperature air conditioning systems will be used – this is different to the set point temperature discussed in Section 2. Depending on the building fabric, orientation and internal gains the internal temperature of buildings will differ for any given external temperature – the baseline temperature here represents the external temp at which UK buildings on the whole would internally use cooling. The baseline temperature used in cooling degree day calculations[99] are 22°C for domestic and 18°C for commercial.

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[94] Eames M, Kershaw T, Coley D., 2011, and Levermore G.J., Parkinson J.B., Analyses and algorithms for new Test Reference Years and Design Summer Years for the UK. Build Serv Eng Res Technogy 2006 ;27(4):311–25. Available from: http://bse.sagepub.com/cgi/doi/10.1177/0143624406071037

[95] For an explanation of how the 'most average' months are estimated see Eames, Kershaw et al (2011) and Mylona A. The use of UKCP09 to produce weather files for building simulation Building Services Engineering Research and Technology. Sage journals; 2012. p. 51–62. Available from: http://bse.sagepub.com/content/33/1/51.refs

[96] Eames M, Kershaw T, Coley D., 2011, and Levermore G.J., Parkinson J.B., Analyses and algorithms for new Test Reference Years and Design Summer Years for the UK. Build Serv Eng Res Technogy 2006 ;27(4):311–25.

[97] Day, T., 2006, Degree-days: theory and application. London: CIBSE, p106.

[98] Day, T., 2006, Degree-days: theory and application. London

[99] *ibid*

Using CIBSE's guidelines, CDDs were estimated for each day of the combinations selected such as 2030 DSY 50th percentile. The CDDs estimated for each day of the year is then ranked in ascending order and the day with highest CDD is used for this analysis. The table below shows the highest CDD estimated during the year, the maximum temperature during the CDD and highest temperature during the entire year. The analysis suggests that highest CDD may not necessarily arise on the same day when the maximum temperature occurs.

Highest temperatures and CDDs estimated using DSY methodology

	Highest domestic CDD	**Highest commercial CDD**	**Highest temperature on the CDD**	**Highest temperature across the year**
2030 DSY 50th percentile	2.3	5.3	29.2	29.2
2030 DSY 90th percentile	5.7	9.7	30.9	32.3

In meteorological estimates the current climate or base period is calculated over 30 year period as it is long enough to filter out any inter-annual variation or anomalies, but also short enough to be able to show longer climatic trends. Hence the UKCP09 uses current climate period or base which is calculated from 1 January 1961 to 31 December 1990.[100] Consequently, to avoid the anomalies or rare extreme events CDDs from a single year such as 2010 are not appropriate to be used as comparators with climate projections.

The CDDs for domestic and commercial in the 2030s on a DSY basis under high emissions scenario is compared to CIBSE base period (1983-2004) for the period April to September and are shown in Figure 10 to Figure 15. The base period in the figures are labelled as a 'representative' year (1900) to avoid confusion with actual data from the base period. This is estimated based on the DSY methodology of selecting the fourth hottest April to September period within the years 1983 to 2004.

The historic observations suggest extreme maximum temperatures generally occur in July or August for 2 or 3 hours after midday. For example, on 3 August 1990 a temperature of 34.5 °C was recorded at Knutsford, Cheshire, and in the heat wave in July 2006 34.3 °C was observed at Crosby, Merseyside on the 19th.[101] As the DSY methodology selects fourth hottest summer, the representative base year is not the maximum recorded to avoid the rare extreme weather event. Similarly the future projections, also estimate the fourth hottest April to September to represent the 90th percentile (unlikely to be greater than the given temperature or CDD). Hence the DSY temperatures and CDDs used in this analysis should be taken as an indicative extreme condition under high emissions scenario of climate change.

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[100] CIBSE in their DSY and TRY method uses a different climate period (1983-2004) as the base.

[101] Met Office. North West England & Isle of Man: climate [Internet]. 2016 [cited 2016 May 12]. Available from: http://www.metoffice.gov.uk/climate/uk/regional-climates/nw

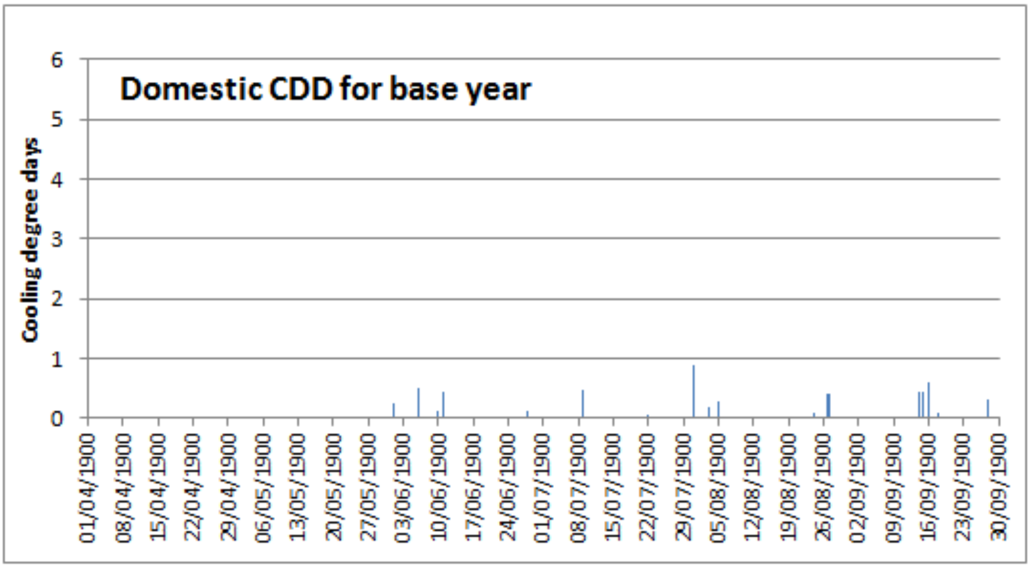

Figure 10 Domestic CDD for base year

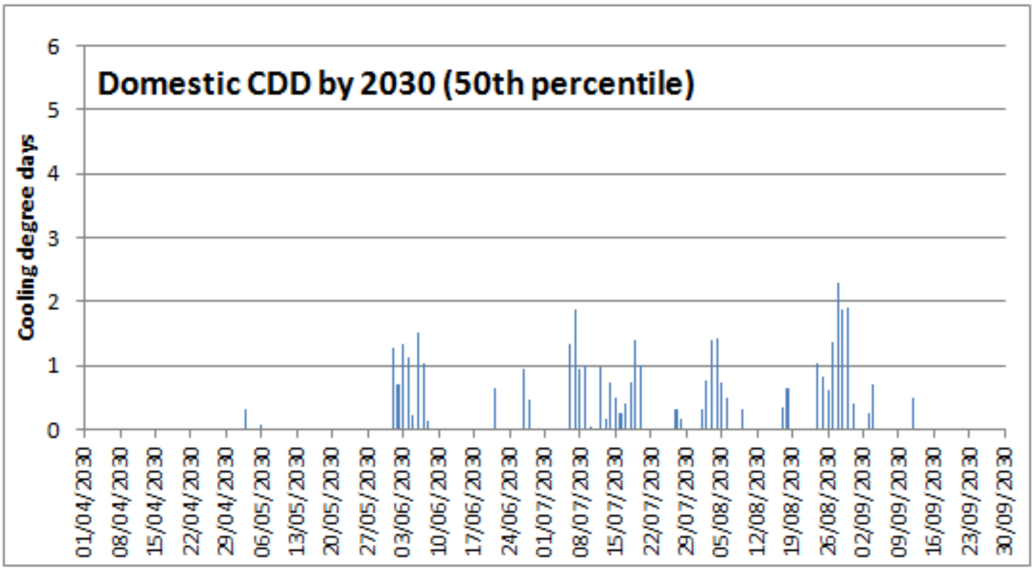

Figure 11 Domestic CDD by 2030 (50th percentile)

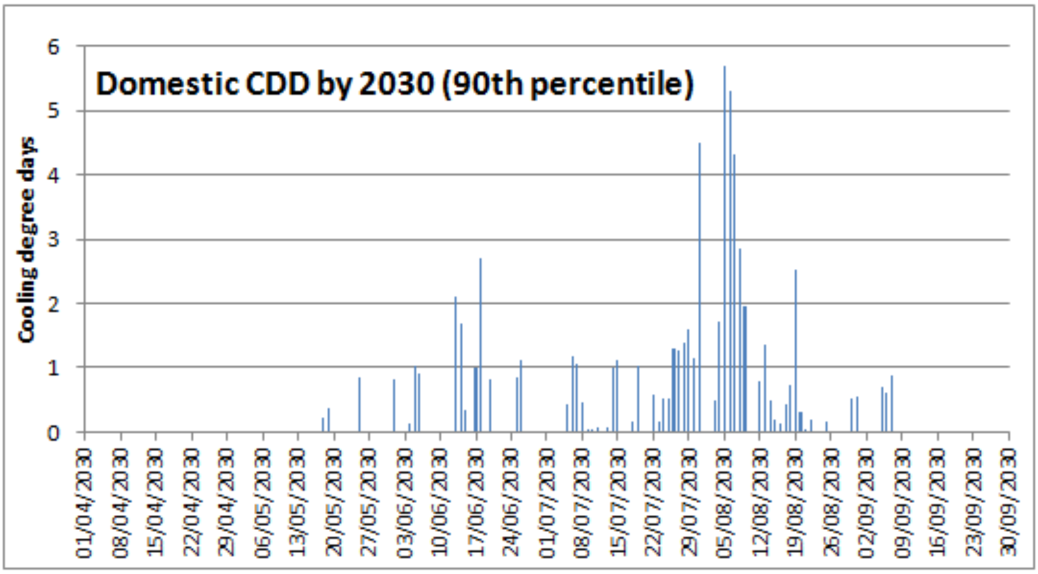

Figure 12 Domestic CDD by 2030 (90th percentile)

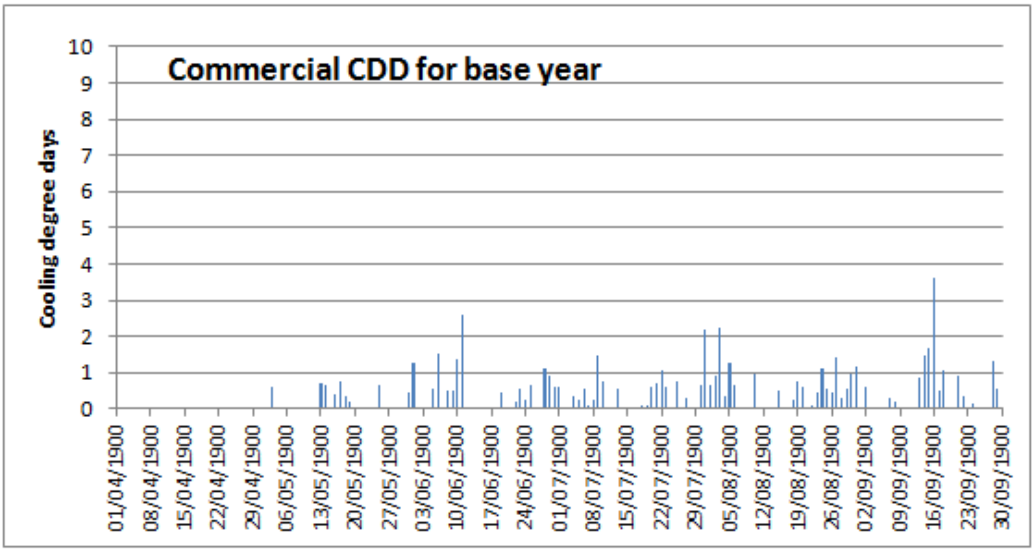

Figure 13 Commercial CDD for base year

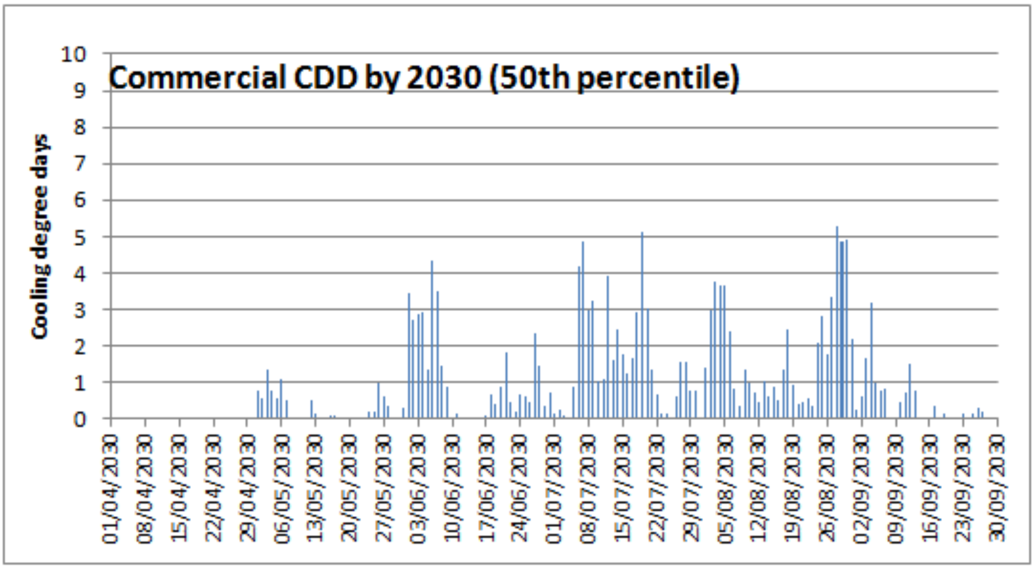

Figure 14 Commercial CDD by 2030 (50th percentile)

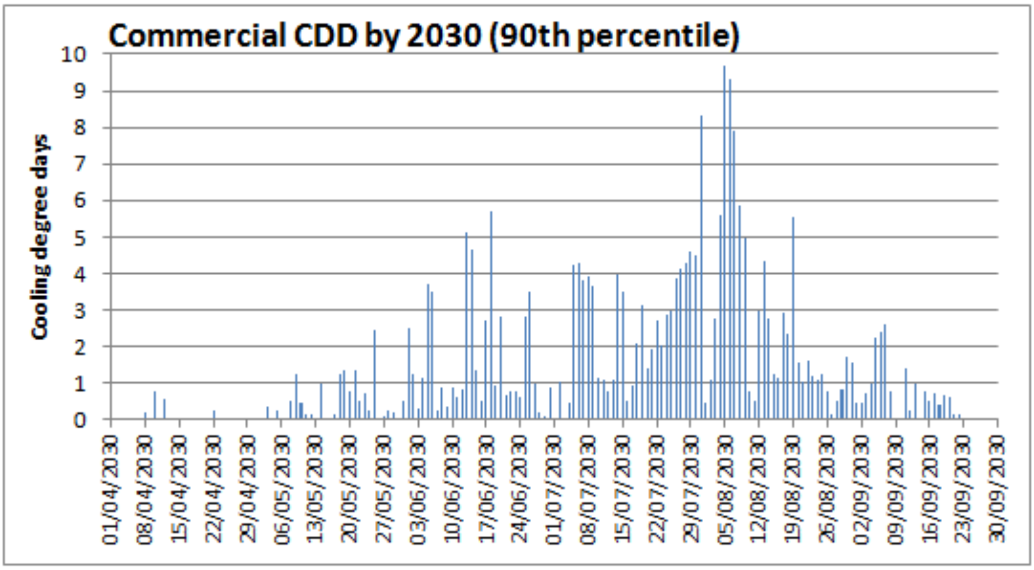

Figure 15 Commercial CDD by 2030 (90th percentile)

Figure 10 to Figure 12 show that the annual number of domestic CDDs by 2030 will be unlikely to be more than 61 (i.e. the 90th percentile) compared to 18 during the base period. Similarly, for commercial CDDs. Figure 13 to Figure 15 show that by 2030 the annual number of commercial CDDs will be unlikely to be more than 146 (i.e. the 90th percentile) compared to 88 during the base period.

UKCP09 summary projections

The estimation of extreme events under climate change in the future is challenging because of the smaller number of observational records of such events. The statistical limitation on estimating the extremes from the climate models requires the user to approximate uncertainties and confidence limits. Consequently the future projections of temperature rise due to climate change under high emissions scenario is explained in terms of both mean and maximum temperatures utilising a probabilistic approach. The UKCP09 climate projections are probabilistic recognising that there is no single answer or in this temperature and therefore a range of possible outcomes are provided. Hence the probability of temperature rise is explained as being less than or greater than a certain value using the cumulative distribution function (CDF).[102] The UKCP09 projections are provided for seven 30-year overlapping time periods 2020s (2010-2039) to 2080s (2070-2099) compared to baseline period (1961-1990). The UKCP09 datasets shows that daily maximum temperature during summer has increased by 1.63ºC and the annual CDD have increased by 12.8 between 1961 and 2006 in the Northwest region. The mean summer temperature rise for three probabilities (10%, 50% and 90%) under high emissions scenario for 2020s and 2050s are shown in the table below.[103]

Mean summer temperature rise under high emissions scenario climate change for Northwest region [104]

Time period	Change at 10% probability in ºC	Change at 50% probability in ºC	Change at 90% probability in ºC
2020s (2010-2039)	0.6	1.5	2.5
2050s (2040-2069)	1.5	3.0	4.7

The extreme temperatures from observed trends (1960-2004) for the Northwest are described using return years, which is the estimated average frequency of occurrence, and is shown in Figure 16. Hence the hottest day under a ten year return period was 30ºC whereas hottest night for same return period was 17.5ºC.

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[102] Jenkins G, Murphy J, Sexton D, Lowe J, Office M, Centre H. UK Climate Projections : Briefing report. 2010.

[103] Jones P, Jones P, Harpham C, Harpham C, Kilsby C, Kilsby C, et al. Projections of future daily climate for the UK from the Weather Generator [Internet]. Weather. Newcastle; 2009. Available from: http://ukclimateprojections.defra.gov.uk

[104] Unfortunately this dataset does not include data for the 2030s but the 2020s and 2050s are shown here to indicate relative change.

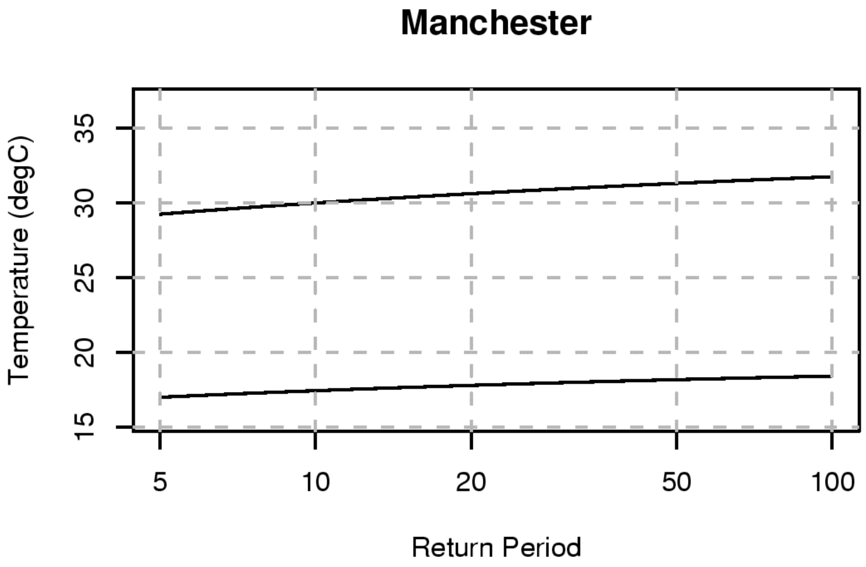

Figure 16: Summer hottest day and hottest night return level for Manchester (°C) from the observed trends 1960-2004 [105]

To explore what climate change may mean for the return periods of different hottest days, we can infer values using UKCP09 projections. Using the UKCP09 climate projections, change in temperature for the warmest day in Northwest region is estimated under a high emissions scenario (shown in Figure 17). The cumulative distribution function (CDF) for the temperature change is shown for three time periods 2020s, 2030s and 2040s. From Figure 17, the change in temperature for 2030s (2020-2049) is very unlikely (10%) to be less than -1ºC and very likely (90%) to be less than 7ºC. Alternatively, there is a 90% probability (very likely) that temperature change will exceed about -1ºC and a 10% probability (very unlikely) that the temperature change will exceed about 7ºC.

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[105] Brown S, Boorman P, Buonomo E, Burke E, Caesar J, Clark R, et al. A climatology of extremes for the UK. A baseline for UKCP09 [Internet]. Exeter; 2008. Available from: http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87918&filetype=pdf

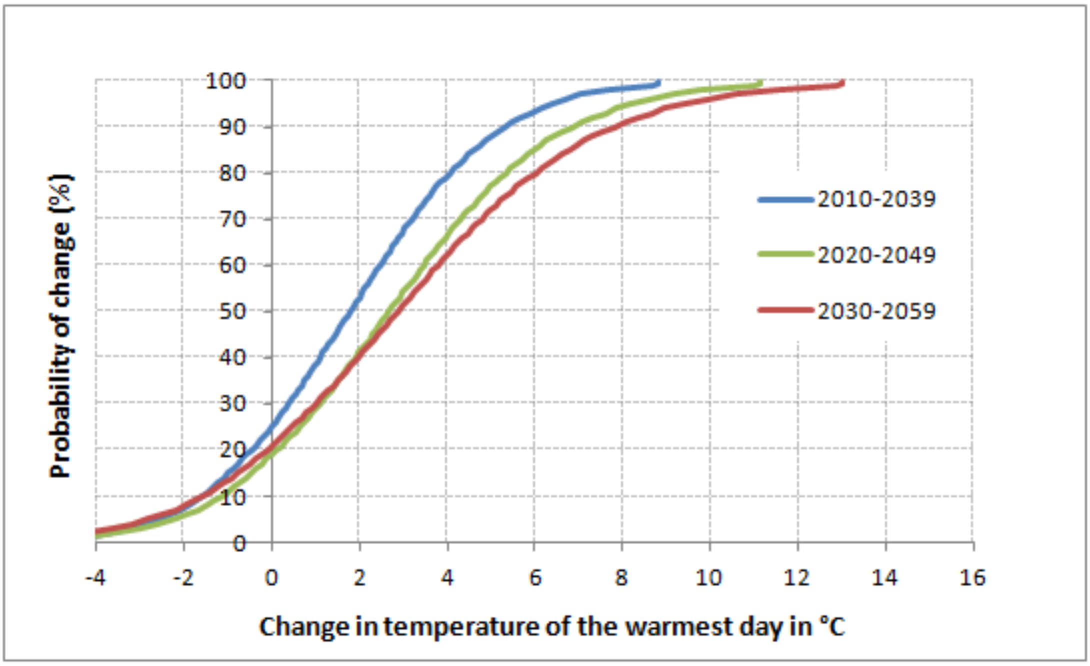

Figure 17: Change in temperature of the warmest day for Northwest region (°C) under a high emissions scenario[106]

Taking the 2020-2049 CDF, it is unlikely that the temperature of the warmest day will increase by more than 7ºC. Therefore it is unlikely that the maximum temperature during the warmest day by 2030 would be greater than 37ºC based on a 10 year return period (i.e. occurring once every 10 years). The warmest day thus estimated (37ºC) is 2.5ºC higher than the maximum temperature previously recorded (at Knutsford in 1990). The UKCP09 estimates are much higher than the maximum temperature used within the DSY methodology from the PROMETHEUS project (31.3ºC) as shown in Table 1. This consideration of maximum temperatures, using the data from UKCP09 for extreme temperature suggests that the PROMETHEUS project’s summer extreme temperature using DSY methodology may not adequately capture near-extreme weather conditions. Hence, the CDDs used in the analysis presented in this report (which are based on the PROMETHEUS project), should be read as average conditions of maximum temperature rather than extremes.

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[106] Murphy, J.M., Booth, B.,, Collins M, Harris, G.R., Sexton, D.M.H., Webb, M.J., A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. Philos Trans A Math Phys Eng Sci [Internet]. 2007;365(1857):1993–2028. Available from: http://rsta.royalsocietypublishing.org/content/roypta/365/1857/1993.full.pdf