Building Heating Consumptions under Present and Future Climate Scenarios

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ABSTRACT: *This paper presents the analyses of climate by examining the influence of weather patterns and climate change on heating demands of large building portfolios. It investigates 12 years of historic weather data and the corresponding heating consumptions of corporate and office buildings owned and managed by Hull City Council in the UK in order to establish the correlation between heating consumptions and weather patterns. Further, the established heating consumptions trend is compared against different climate change scenarios reported in literature. In addition, the most relevant climate projection scenario is identified and discussed. The methodology presented in this paper is valuable in demonstrating climate influenced heating consumptions for large organisations, which in turn can be used for monitoring and managing energy consumptions and CO2 emissions. The research is based on a two year collaborative externally funded research project.*
Keywords: weather, climate change, space heating, carbon emissions.

INTRODUCTION

The significant challenge facing the UK is meeting the Government carbon reduction targets set out in its Carbon Plan 2011 by reducing emissions by 80% by 2050 relative to 1990 baseline [1]. As parts of carbon reduction commitment programme both public and private organisations with large building portfolios are required to report their CO2 emissions. They are the first obligatory group to make notable reduction in CO2 emissions to deliver the nation's 2050 vision. Large organisations may share common features such as holding a broad building portfolio at various locations with a constant changing estate. It is these variables, which increase the complexity of managing CO2 emissions together with formulating strategies for emissions management and reductions.

Almost half (46%) of the energy consumed in the UK is to provide heat, in which around three quarters is used by households and in commercial and public buildings [2]. For the commercial and public sector, space heating is the dominant issue for a climate like UK, which is responsible for 45% of its energy consumption in 2011 according to the latest national statistic [3].

AIMS & OBJECTIVES

The scope of this research is to analyse the extent of the heat energy consumption during heating season, which includes space heating and hot water (together referenced as heating requirement in the following context). The research also aims to establish a methodology for analysing climate effects on buildings' heating consumptions. The research therefore aims to illustrate how monitoring and forecasting the heating consumptions and demands at estate level may be used by large organisations to manage and more importantly plan forward their CO2 emissions more accurately.

METHODOLOGY

The research was carried out in Hull (53°45′N 0°20′W), East Pennines, in the UK using the building portfolio of Hull City Council. The council owns and operates 304 buildings with various building types. The methodology followed in this research is:

1) Identifying the energy consumption for heating of the analysed building portfolio.
2) Identifying the heating season weather data.
3) Baseline two sets of data from 2000, generating their ratio trends from 2000-2012 respectively.
4) Comparing the heating consumptions ratio trend with weather data ratio trend.
5) Comparing the heating consumptions ratio trends with the climate change scenarios.

BUILDING PORTFOLIO

The building portfolio of Hull City Council (HCC) sits in the service sector, mainly schools (33%), corporate buildings (22%), offices (16%) and others (29%) such as car parking, depots, parks etc. The main source of energy is gas accounting for 58% of the total energy consumption, while electricity and oil accounts for 40% and 2% of the total consumption respectively. The data used in this research are extracted from several databases, archived from 1999 onwards offering detailed information on issues such building name, building type, internal layout, building characteristics, location, age, refurbishment and retrofit programmes, building services, renewable sources of energy, energy bills and other relevant information. A comprehensive and detailed database was created to record the above information for the buildings analysed in the research.

The entire building portfolio was analysed to investigate the influence of weather on building heating consumptions during the heating season as defined in the following section. For the research reported in this paper, buildings which may have specific occupancy patterns in the heating season are however excluded. Examples include school buildings which have 6 week holidays (Christmas, Easter and half term) during the heating season, where the corresponding heating consumptions may not reflect the weather influence holistically. The results reported in this paper are based on the analyses carried out on corporate and office buildings only.

CLIMATE

The climate of Hull is categorized as a temperate maritime climate which is dominated by the passage of mid-latitude depressions [4]. The city's annual average temperature is 10°C, with a long and humid winter. The heating season for Hull is calculated as October to May, and this is based on the methodology of Heating Degree Days (HDD) published by the Chartered Institution of Building Services Engineers (CIBSE) [5]. Because of the significance of the winter influence (8 month), Hull City Council has a special policy that there should be no air conditioning in public buildings except buildings with special use e.g. museums and art galleries.

For building energy simulations, in the UK, test reference years (TRYs) for different locations published by CIBSE are widely used (figure 1). There are 14 locations available for the country, which are based upon historic observations of weather typically from 1983-2004 [6]. The location limitation may cause substantial differences if the studied location has a different weather compared to the regional representative. For City of Hull, figure 1 shows that Leeds is the recommended representative for East Pennines. Although Leeds and Hull share similar latitude of 54°N, Hull is a port city directly exposed to the North Sea while Leeds is an inland city with an altitude of 63m above sea level. To overcome this discrepancy, the research analysed several local weather stations to identify one to represent closely the actual climatic condition of Hull.

Figure 1: Map of the Areas of Influence of the 14 Weather Stations with the Weather Stations Marked as a Square [6]

Climatic data from 7 local weather stations were analysed. These include; Bridlington, Leconfield, Hull, Norman by Hall, Humberside Airport, Cleethorpes and Donna Nook as shown in Figure 2. Several criteria applied in the analysis for the selection of the most appropriate weather station for Hull. These include completeness of data, reliability, frequency and accuracy. One specific criterion applied was that the weather station should have established no later than 1995 and that there should be no planning for closure of the station in future. As no single weather station deemed to be a true representative of the climate in Hull for the so called heating season, further analysis suggested that a more accurate scenario may be constructed by taking the average of climatic data for 3 weather stations namely Leconfield, Notman by Hall and Cleethorpes.

Figure 2: Approached Weather Stations around Hull [7]

Heating Consumptions under Historic and Present Weather Conditions

Figure 3 shows the 12-year ratio trends for the heating consumptions of Hull City Council's corporate and office buildings together with the annual average temperature in the heating seasons. For ease of comparison, the average temperature line has been mirrored meaning that a rise in the average temperature line is actually a temperature drop resulting in a potential increase in heating consumptions.

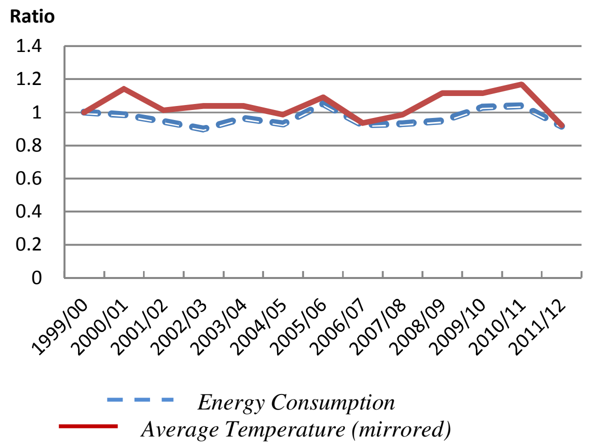


Figure 3: Ratio Trends of Heating Consumptions and Average Temperature during Heating Season for Hull City Council's Corporate & Office Buildings 2000-2012

The horizontal axis is the 12 year timescale from 2000 to 2012 with the base year established at the year of 2000 (hence ratio considered as 1). The vertical axis shows the ratios of heating consumptions and the average heating season temperature compared to the base year data of 2000.

There are two main conclusions which may be drawn from the analysis results of which are shown in figure 3. Firstly, the temperature trend in the heating season has a direct influence on the whole estate's corresponding heating consumptions. Secondly, the fluctuations in the consumption pattern seem to be more moderate compared with changes in the annual average temperature pattern. During the 12 year trial experiment, there are 3 years in which there are not direct correlation between the energy consumption and average temperature. In other words, there are cases for which there is an increase in heating demand when the heating season seems to be milder. It should be noted that there are usually other parameters which may influence the trends in heating demands of large building portfolios. These include programmes of relocation, buying and selling properties, refurbishment, conversion and retrofitting which are usually exercised by large organisations such as city councils.

One interesting point worth mentioning is that the UK Government introduced the notion of Display Energy Certificate (DEC) for all public buildings over 1,000m^2 floor area in 2004, which was enforced from 1st October 2008. It can be observed that although the year 2008 experienced a much colder winter than 2007, the space heating consumptions of these two years' are nearly the same. Because there are no records showing significant changing estate of the council, this could be the impact of introducing new energy legislation, as it contributes to raising people's energy awareness. The research showed a similar pattern in other buildings of the Councils, e.g. in Schools where energy awareness and good housekeeping resulted in tangible energy savings.

Heating under Future Climate Change Scenarios

The Intergovernmental Panel on Climate Change (IPCC) issued its first Special Report on Emission Scenarios in 2000. Its latest report, Fourth Assessment Report Climate Change issued in 2007, concludes that 'for the next two decades, a warming of about 0.2°C per decade is projected' [8]. At the regional level, the UK government established UK Climate Impacts Programme (UKCIP) in 1997, which coordinates and influences research into adapting to climate change. Its first publication UKCIP02 scenarios (figure 4), projected four different scenarios for climate change over the 21st century based on four different scenarios for greenhouse gas emissions: low, medium-low, medium-high and high emissions, over three time scales: 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) [9].

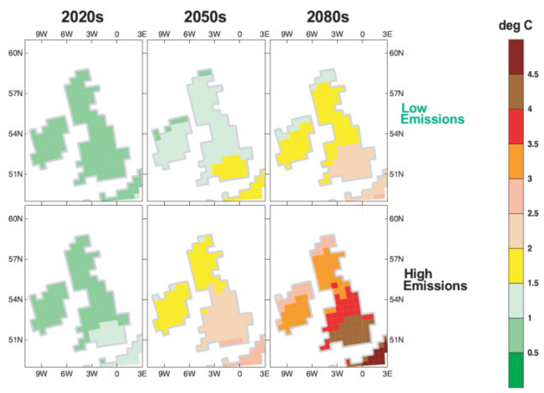


Figure 4 UKCIP02 Scenarios - Changes in Average Annual Temperature for the 2020s, 2050s and 2080s for the Low Emissions and High Emissions Scenarios [9].

The UKCIP02 scenarios provide mean monthly values of climate variables on a 50m x 50m grid. The four green house gas emissions scenarios used are ranging from a low-energy use sustainable future, to an intensive fossil fuel use future, and produce a complete set of climate data for each scenario [10].

The UK Climate Impacts Programme in its latest publication i.e. KCIP09 scenarios (figure 5), has projected the changes in temperature and precipitation across the UK for the medium emissions scenario for the 2080s with 10, 50 & 90% probability levels. Details of the scenarios are available from the UKCIP website [10].

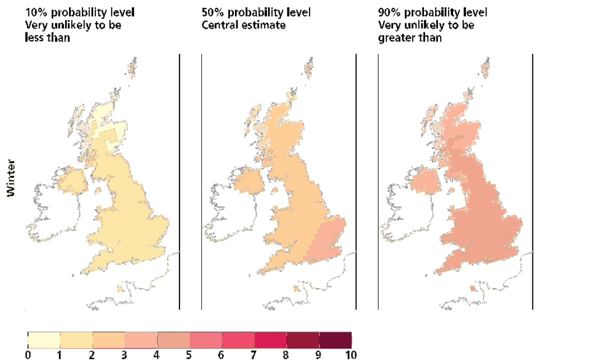
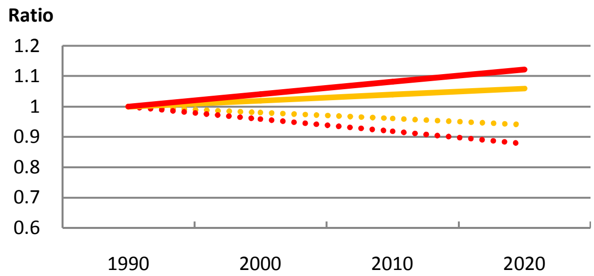


Figure 5 UKCIP09 Scenarios - Changes in Winter Mean Temperature for the 2080s under a Medium Emissions Scenario [10].

From figures 4 and 5 it can be seen that the projected future scenarios are rather too general to be used for the identification of accurate future localised climate changes. The research carried out at Exeter University through the Prometheus project aimed at downscaling climate model information to create new weather reference data for the period 2010 to 2080 using hourly climatic data [11]. Prometheus project has published a series of future weather files for 45 locations in the UK under different emission scenarios (figure 6). Hull is among the locations for which future climatic data is produced.

Figure 6 Locations of Future Weather Files Available from Prometheus Project [11].

The Prometheus project has produced 5 different scenarios for 10%, 33%, 50%, 66% and 90% increased emissions. Figure 7 illustrates the different climate change scenarios for Hull extracted from the Prometheus project for two selected scenarios being 10% and 33% increased emissions. The main observation is that the projected heating season temperatures for Hull will increase steadily compared with the base year of 1990 under both emission scenarios. Generally, the higher emission level is, the less heating demand is predicted due to increased external air temperature as a result of global warming.



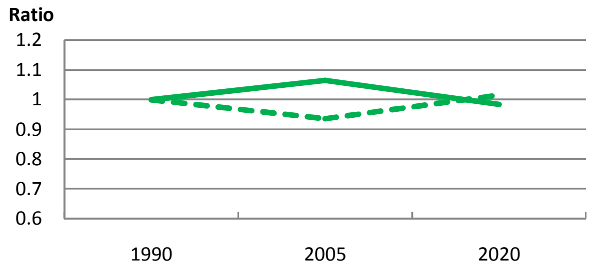
Hull Average Heating Season Temperature Prediction under 33% Emissions
Hull Corresponding Heating Prediction under 33% Emissions
Hull Average Heating Season Temperature Prediction under 10% Emissions
Hull Corresponding Heating Prediction under 10% Emissions

Figure 7: Hull Average Heating Season Temperature and Corresponding Heating Consumption Predictions under different emissions scenarios, 1990-2020 (Figure Generated from Publications from Prometheus project [11])

Table 1: Hull Monthly Average Temperature Projection (Meteonorm Version 7.0)

Month	1990	2005	2020
Jan	0.2	4.7	1.2
Feb	3.6	5.4	4.6
Mar	6.6	7.1	7.6
Apr	7.7	8.9	8.7
May	10.6	11.7	11.7
Jun	13.1	14.9	14.3
Jul	16.2	16.5	17.4
Aug	15.9	17.1	17.1
Sep	13.8	14.7	14.9
Oct	10.2	11.1	11.2
Nov	6.3	7.3	7.3
Dec	3.2	4.9	4.2

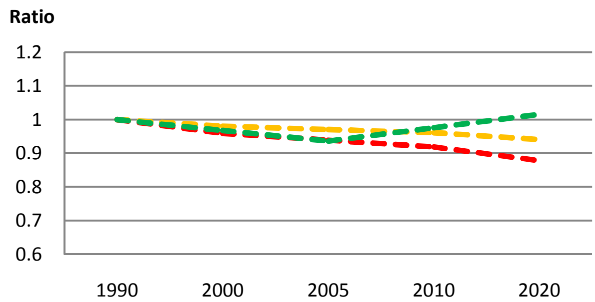
For analysing the possible future energy demands of building portfolio of Hull City Council, we also used Meteonorm – a software designed for predicting future climate scenarios [12]. Table 1 depicts the monthly average temperatures predicted by Meteonorm for Hull for 1990, 2005, and 2020. It can be seen that monthly temperatures in 2005 are higher than the corresponding values for 1990. In contract, Hull may have a colder winter in 2020 compared with 2005.



Hull Average Heating Season Temperature Prediction
Hull Corresponding Heating requirement Prediction

Figure 8: Hull Average Heating Season Temperature and Corresponding Heating demand Predictions 1990-2020 (Figure generated from Meteonorm Version 7.0)

Figure 8 depicts the predictions for average heating season temperatures in Hull together with predicted heating demands of buildings as projected by Meteonorm.



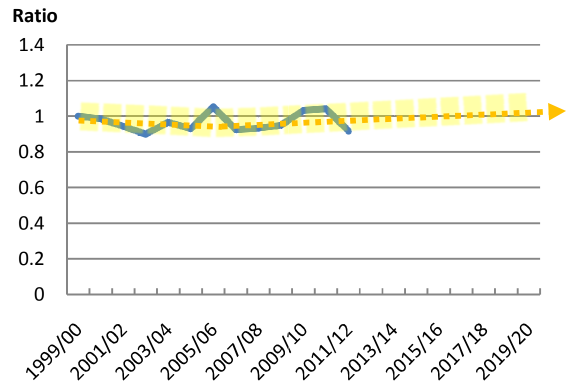
Prometheus Space Heating Prediction under 33% Emissions
Prometheus Space Heating Prediction under 10% Emissions
Meteonorm Space Heating Prediction 1990-2020

Figure 9: Prometheus and Meteonorm Projections for Hull Space Heating under Different Climate Change Scenarios, 1990-2020

Figure 9 shows the different climate change scenario projections from Prometheus and Meteonorm in terms of heating demands for Hull buildings. While Prometheus project predicts a continuous rise in Hull average heating season temperatures in future resulting in reductions in annual heating requirements, Meteonorm on the other hand predicts that the temperatures in winter of 2020 may for example be lower than those in 2005 resulting in increased heating consumptions if compared with 2005.

DISCUSSIONS

Figure 10 shows the comparison of the actual heating consumptions of Hull City Council's corporate and office buildings (2000 to 2012) with Meteonorm's heating predictions. The Meteonorm's prediction is projected into future up to 2020. It can be seen that although the actual energy consumptions fluctuate through the 12 years trial period, for most of years they closely follow the prediction line by Meteonorm with a deviation of the order of ± 1% (the yellow band). There are two extreme values among the 12 years data falling outside the yellow band representing heating consumptions for 2002/03 and 2005/06.



Energy Consumption *Meteonorm Prediction*

Figure 10: Energy consumption for Space Heating & Hot Water during heating season of Hull City Council's Corporate Buildings and Meteonorm Space Heating Prediction for Hull Buildings under Climate Change Scenario, 2000-2020

From the analysis carried out, it appears that Meteonorm's projections may more closely represent the actual heating consumptions of Hull City Council buildings compared with predictions by Prometheus.

As it is usually difficult and time consuming for large organisations to monitor or model the energy consumption of their entire building stock in future, the methodology proposed in this paper can prove to be a useful tool to help such organisations to accurately predict the heating demands of their building portfolio with a view to formulate strategies for energy conservation and reduced CO2 emissions.

CONCLUSIONS

This research attempts to establish a correlation between weather and future climatic changes with heating consumptions of large building portfolios owned and managed by large organisations. The large building portfolio of Hull City Council in the UK containing corporate and office buildings was used to establish such a correlation. Conclusions drawn from the research include;

1) Heating season temperature fluctuations have direct impacts on the heating consumptions of the entire building estate, where cold winter leads to more heating and warmer winter for less.
2) For Hull City Council portfolio, the range in the fluctuations of the heating demands is narrower compared with the range in the relative corresponding external air temperatures during the heating season.
3) In order to establish a close correlation between climate and energy performance, it may be necessary to analyse different methodologies and tools to establish a procedure to accurately represent the local conditions and the characteristics of the building portfolio.
4) It is always advisable to use localised weather stations' data to accurately represent the boundary conditions within which the buildings exchange energy with their immediate surroundings.
5) Modelling perditions should be compared against historic and actual data for fine tuning of the methodologies and procedures to be developed for predicting future trends in weather and corresponding energy consumptions.

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REFERENCES

1. Department of Climate Change (DECC), (2011). Carbon Plan Executive Summary. [Online], Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47614/3751-carbon-plan-executive-summary-dec-2011.pdf [5th May 2013].
2. Department of Climate Change DECC, (2012). The Future of Heating: A Strategic Framework for Low Carbon Heat in the UK. [Online], Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48574/4805-future-heating-strategic-framework.pdf [5th May 2013].
3. DECC, (2012). Energy consumption in the UK. Chapter 1: overall factsheet, [Online], Available: https://www.gov.uk/government/publications/energy-consumption-in-the-uk/ [23 April 2013].
4. Dennis Wheeler & Julian Mayes, (2nd edition, 2005). Regional Climates of the British Isles. Taylor & Francis.
5. Chartered Institution of Building Services Engineers (CIBSE), (2006). Degree-Days: Theory and Application TM41:2006.
6. M. Eames, T. Kershaw and D. Coley, (2012). The appropriate spatial resolution of future weather files for building simulation. Journal of Building Performance Simulation Vol.5, No. 6, November 2012, 347-358, Taylor & Francis
7. After East Riding Map, Available:http://www.uksuperweb.co.uk/images/map_eastriding.gif [10th May 2013].
8. Intergovernmental Panel on Climate Change, (2007) IPCC Fourth Assessment Report: Climate Change 2007.
9. Hulme, M., Jenkins, G.J., Lu,X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, (2002). Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report.
10. UK Climate Impacts Programme (UKCIP), (2002) UKCIP02 Scenarios. Available: http://www.ukcip.org.uk [10th May 2013].
11. Prometheus project, 2011, Centre for Energy and the Environment, University of Exeter. Available: http://emps.exeter.ac.uk/research/energy-environment/cee/projects/prometheus/downloads/ [30th April 2013].
12. Meteonorm, (2012). Meteonorm Software V7. Available: http://meteonorm.com/ [10th May 2013].