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Impact of climate change on the design of energy efficient residential building envelopes

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ABSTRACT

Climate change has been shown to significantly alter the heating and cooling needed to maintain thermal comfort within a home. However, limited studies have investigated the impact on the design philosophy associated with achieving an energy efficient building envelope with the onset of climate change. Applying robust future TMY for 2070 the change in heating and cooling demand has been studied in this paper for various combinations of external and internal wall insulation, roof insulation, reflective foil, thermally reflective roofs and different floor coverings. A building thermal model was used for the mild temperate climate of Adelaide, Australia, which requires both heating and cooling, but is dominated by heating. Climate change was found to increase and shift this demand to cooling dominated. It was determined that with climate change, heating becomes significantly less important in better insulated buildings and therefore measures which reduce cooling load are more critical. It is concluded that in this climate zone, climate change design approaches need to dramatically change to focus on cooling, contrary to present strategies.

1. Introduction

The analysis of the heating and cooling energy demand based on the building envelope is typically considered ignoring climate change. The energy efficiency of a building is likely to be affected with climate change over its useful life. The impact of climate change on building energy demand was first studied in the 1990s [1–4]. Some of these studies used the degree-day method to analyse the changes of energy demand of buildings in the future [1,2]. Being based on temperature, this approach does not capture all the weather impacts on building energy efficiency. Therefore, some other studies [3,4] used building energy simulation tools to evaluate the impact of climate change on energy demands in buildings. Building thermal simulation models such as DOE-2 and AccuRate apply the Typical Meteorological Year (TMY) weather data to simulate the heating and cooling energy loads of the building hour by hour. Varying the weather year to consider the impact of climate change to building models has been the preferred analysis to study the impact of climate change across a variety of climatic regions [5,6].

Aguiar et al. [7] simulated the hourly energy consumption of Portuguese buildings between 2070 and 2099 in three different location categories in the country: south, centre and north. They used monthly and daily time series from the HadCM3 and HadRM models. Two models were issued by the Climate Impact LINK Project on behalf of the Hadley Centre and the UK Meteorological Office. It was found that the heating thermal load decreased for all three locations while the cooling thermal load increased. They described that annual heating thermal load decreased between 34% and 60% from north to south while the cooling load had a massive increase of 130–525% from north to the centre. As a result, they concluded that the overall annual energy requirements for space conditioning will be increased by the end of the twenty first century.

A study by Radhi [8] on residential buildings in Al-Ain city in the United Emirates assumed a 1.6–2.9 °C increase in annual average temperature by 2050 and then 2.3–5.9 °C by 2100 considering climate data from the Environmental Agency of Abu Dhabi. This study revealed that when the ambient air-temperature is increased by 5.9 °C, the cooling demand in homes will be raised considerably by 23.5%. Therefore, as expected global warming will affect the energy use pattern in buildings in the United Emirates as well as other cities around the world.

Another study [9] on the residential building stock in a cold climate of Stockholm, Sweden used different climate scenarios

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derived from Global Climate Models (GCMs) and Regional Climate Models (RCMs), and varying future emission scenarios (A1B, A2 and B) and considering different initial conditions. This study concluded that heating energy requirements will decrease by around 25–30% during 2081–2100 compared to 2011. On the other hand, the cooling demand will increase in the future. However this increase will be small, and can be dealt with through natural ventilation.

There are also studies on impact of climate change on non-residential buildings in the literature. Berger et al. [10] simulated nine sample office buildings in Vienna, Austria to find out the impact of climate change on cooling and heating energy demand in these buildings. Results showed that there is a large increase in cooling demand. However, heating requirements will be decreased.

Studying the impact of climate change is very much dependant on the quality of the predicted climate data applied to the building model. Wang et al. [11] analysed the behaviour of the modern detached brick veneer residential house in five different cities in Australia under three emission scenarios from 1990 to 2100. They chose five cities from different climate conditions ranging from cool temperature to hot and dry. Cities included Alice Springs, Darwin, Hobart, Melbourne and Sydney. The future climate was simulated with the morphing approach using nine General Circulation Models (GCMs) based on three emission scenarios including A1B, A1FI and 550 ppm. They represent the medium emissions, high emissions and the emissions under policy influences, respectively. The building simulation model AccuRate was used in this study to calculate the annual heating and cooling energy requirements of the house, measured in stars. This has been assessed under the IEA BESTEST method, known as an inter-programme comparison where a candidate programme is compared with results from a set of reference programmes. AccuRate was found to compare well against eight reference programmes from Europe and the USA including TRNSYS, DOE 2 and BLAST [12]. Results from AccuRate are shown in a star rating which ranges from 0 to 10, where 10 defines a fully passive house [11]. Current buildings in Australia are built to a 6 star requirement. At first, authors simulated the selected house design achieving 2, 5 and 7 stars energy efficiency, by varying insulation and other energy efficiency measures, representing the range of efficiency of homes in Australia.

The results of total annual energy requirements of 5 star homes in five different cities under three emission scenarios and nine climate models shows that for a hot humid climate location like Darwin where cooling is dominant the total heating and cooling energy requirement increases steadily over time. Similar results have been seen for the hot and dry summer climate (Alice Springs), and heating and cooling balanced temperature climate (Sydney). There was an increase of 227 MJ/m^2 by 2050 and 540 MJ/m^2 by 2100 for Darwin under A1FI scenario. Similarly, there was an increase of 80 MJ/m^2 by 2050 and 305 MJ/m^2 by 2100 for Alice Springs. However, a smaller increase from 49 MJ/m^2 in 2050 to 170 MJ/m^2 in 2100 was reported for Sydney. In other words, in Alice Springs total annual heating and cooling energy will be increased by 33%, 66% and 85% by 2050 and 109%, 212% and 279% by 2100 for a house with 2, 5 and 7 stars, respectively. In addition, total annual heating and cooling energy requirements will be increased in Sydney to 144%, 350% and 434% by 2100 for a house with 2, 5 and 7 stars, respectively.

For a city like Melbourne, where heating is dominant, the results showed an initial reduction in total heating and cooling energy requirement and then an increase. Under the A1FI scenario, first there was a reduction of 29 MJ/m^2 by 2050 and it continues until 2065 and reaches a maximum reduction of 33 MJ/m^2. Then there is a change and reduction of 20 MJ/m^2 by 2100. It was also found that absolute changes in energy requirements were less for higher star rated homes.

Collectively, these studies present climate change scenarios and the impact on heating and cooling demand due to the building envelope. However, limited research has investigated the impact of climate change on thermal performance of building design parameters. Gaterell and McEvoy [13] assessed the sensitivity of different insulation measures to selected climate scenarios including low and high emission scenarios in the UK. They analysed changes in space heating savings while using different insulation measures for two years of 2003 and 2050. The insulation measures adapted in this study included loft insulation, curtains/insulated shutters, double glazing and cavity wall insulation. Results showed that for both low and high emission scenarios, changes in savings (kWh) in space heating and cooling were found. It was concluded that savings from double glazing was the most sensitive insulation measure to climate change in relation to heating, but the least sensitive in relation to cooling. Therefore, climate change can change the relative importance of different energy saving measures.

Investigating the impact of climate change on a number of energy efficiency measures would provide new knowledge to the design of energy efficient building envelopes subject to climate change. Unlike previous studies, the research presented in this paper investigates the impact applied to a large combination of design options related to wall/roof insulation, roof colour, foil insulation, window glazing and floor type. Furthermore, a detailed description is provided of the climate data set that is used, which is often not provided in previous studies. The climate change impact is more acute in mixed climate zones requiring both heating and cooling, and therefore this study helps to demonstrate which design features are the most sensitive to climate change.

2. Methodology

Fig. 1 presents the methodology used in this work. Being the most common design, a brick veneer house in Adelaide was selected. The house has a typical plan of an Australian dwelling. The goal of the study was to assess the effects of different building design variables on heating and cooling energy demand in the building. A number of design parameters which predominantly influence this energy demand were investigated. For each variable the main options typically used in buildings were applied. Using the software tool, AccuRate, the annual energy needed to maintain thermal comfort was determined for each configuration. This demand was specified in terms of star rating of the design. This was investigated for each scenario considering current TMY data and future TMY data, which considers climate change. Each combination of variables and options was investigated. Therefore, unlike previous research, where only one variable was changed while other variables were kept constant, the entire population of design options were investigated. Consequently in this study, general trends of the impact of each variable could be identified, and furthermore, the optimum design could be determined.

3. House model description

A conventional residential brick veneer house in Adelaide, Australia was selected for the purpose of this study. The house has one floor with living area of 204.5 m^2. It has a garage with area 35.5 m^2, 4 bedrooms, 2 bathrooms and 1 kitchen. Fig. 2 presents the plan of the house.

According to the Australian bureau of Meteorology, the monthly average ambient air temperature for Adelaide airport between 1981 and 2010 is shown in Fig. 3. Adelaide is defined as a mild temperate climate with long mild winters and short hot summers, requiring both heating and cooling.