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Warming impact on energy use of HVAC system in buildings of different thermal qualities and in different climates

Mohamad Kharseh [a,*], Lobna Altorkmany [b], Mohammed Al-Khawaj [a], Ferri Hassani [c]

[a] Qatar University, Mechanical & Industrial Engineering Department, Doha, Qatar
[b] Luleå University of Technology, Department of Engineering Sciences, Lulea, Sweden
[c] McGill University, Department of Mining Metals and Materials Engineering, Canada

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ABSTRACT

In order to combat climate change, energy use in the building must be further reduced. Heating ventilation and air conditioning (HVAC) systems in residential buildings account for considerable fraction of global energy consumption. The potential contribution the domestic sector can make in reducing energy consumption is recognized worldwide.

The driving energy of HVACs depends on the thermal quality of the building envelope (TQBE) and outside temperature. Definitely, building regulations are changing with the time toward reduce the thermal loads of buildings. However, most of the existing residential buildings were built to lower TQBE. For instant, 72% of residential dwellings in the 15-EU were built before 1972.

To investigate the impact of warming on driving energy of HVACs of a residential building a computer model was developed. Three climate categories/cities were considered, i.e. Stockholm (cold), Istanbul (mild), and Doha (hot). In each city, two buildings were modeled: one was assumed to be built according to the current local buildings regulations (standard TQBE), while the anther was built to lower TQBE. The simulations were run for present and future (in 2050) outdoor designing conditions.

The calculations show that the impact of the warming on annual driving energy of HVACs (reduction or increase) depends very much on the climate category and on the TQBE. Based on the climate and TQBE, the change in annual HVACs energy varies from −7.4% (in cold climate) to 12.7% (in hot climate). In mild climate, it was shown that the warming does not have significant impact on annual HVACs energy. Improving the TQBE can mitigate the impact of the warming.

1. Introduction

Greenhouse gas (GHG) concentrations in the atmosphere will continue to increase unless the global fossil-energy consumption decreases considerably. Observation of climate change is providing clearer evidence that climate change is response to human activities [1]. Increase atmosphere concentration of GHG increases Earth's average temperature [2–4]. Although extensive uncertainties exist in future, set of warming scenarios to make projections of future temperature was developed. Traditionally, warming scenarios help to evaluate the change in air temperature. Fig. 1 shows the projected changes in global average temperature under different GHG emissions scenarios [5].

It is worth mention that the warming rate is not constant over the world. As shown in Fig. 2 [6], regional manifestations of future climate projections vary substantially, with stronger warming over higher latitudes and land areas.

Heating ventilation and air conditioning (HVAC) systems of buildings account for 33% of the global greenhouse gas emissions [7]. Due to the ever growing demand for better thermal comfort in winter and summer, energy consumptions in buildings is projected to be higher in future [8]. Therefore, there is a growing concern about reducing energy use in buildings and its consequences for the environment. The thermal load (heating plus cooling) of a building strongly depends on outdoor design conditions. Differently, the indoor set temperature has a significant impact on the thermal load [9]. Several studies have reported a change in energy consumption of HVACs as a result of increasing outdoor temperature [8,10–13]. Another important factor that plays an important role in determination of the thermal load of a building is the

* Corresponding author. Address: Qatar University, P.O. Box 2713, Al Dafna Area, Jamaa Street, Doha, Qatar. Tel.: +974 33576314.
E-mail address: Kharseh@qu.edu.qa (M. Kharseh).

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Nomenclature

$COP_{c,i}$	coefficient of performance of ACHP working as cooling machine
$COP_{h,i}$	coefficient of performance of ASHP working as heating machine
E	annual driving energy of the HVAC system (kW h)
$Q_{c,f}$	future cooling load (kW h)
$Q_{c,p}$	present cooling load (kW h)
$Q_{h,f}$	future heating load (kW h)
$Q_{h,p}$	present heating load (kW h)
TQBE	thermal quality of building envelope
Δq_c	the relative increase in the cooling load (%)
Δq_h	the relative reduction in heating load (%)

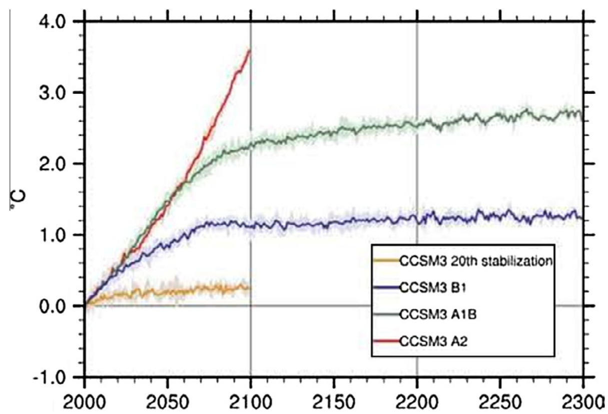

Fig. 1. Time series of globally averaged surface air, from [5].

building stock, to be exact thermal quality of the building envelope (TQBE). The TQBE mainly depends on: (1) insulation level of the exterior wall, ceiling, and floor; (2) thermal properties of windows; (3) air tightness of the envelope; (4) the cooler of external shell; and (5) thermal mass of the external shell. Tremendous publications have investigated the impact of different improvements of the TQBE on the heating and cooling load of the buildings [14–21]. Given that, the optimum insolation thickness of the exterior walls depends on the orientation of the wall itself [22]. Although building regulations are changing with the time toward reduce the thermal loads of buildings, the energy use of HVACs worldwide is still higher than those are imposed under current building regulations [13]. For instance, the maximum permitted heating load for new residential buildings in Germany under the 1995 regulations was 65–100 kW h/m^2/year, while the actual average-heating requirement of existing buildings is about 220 kW h/m^2/year [23]. The difference must have been because the majority of existing buildings were built to lower TQBE standards (i.e. before 1995). The same story occurs for whole Europe. Of the 150 million residential dwellings in the 15 EU Member States, approximately 72% were built before 1972 and hence for lower TQBE than those are imposed under current building regulations [13,16].

Definitely, increasing prevailing air temperature leads to less heating load and more cooling load. However, the reduction in heating and increase in cooling depends very much on the prevailing local weather conditions and TQBE. In another word, based on the climate conditions and the TQBE, the reduction in heating might outweigh the increase in cooling requirement, or vice versa.

The overall objective of the present study, therefore, was to find out how warming affects the heating and cooling load, and the driving energy of HVACs of residential buildings. Furthermore, to what extant improving the TQBE can mitigate the impact of the warming on energy use of HVACs.

2. Methodology

Three different climate classifications were considered in present study. A city within each of the climate was selected. These were Stockholm (cold), Istanbul (mild), and Doha (hot). Two buildings of different TQBE in each city were modeled. Indeed, the TQBE differs in each city in response to the local building regulations. The different levels of TQBE were: (A) comply with the current standards of TQBE imposed under current building regulations of each city, (B) lower TQBE than the standards. Among the different scenarios that predict the future warning (see Fig. 1), the A1B scenario (a medium-emission scenario) was considered. Present and future weather data were obtained from Meteonorm [24]. Buildings typically have a long life span, lasting for 50 years or more. Therefore, the future simulations were carried out in year 2050. Based on A1B scenario, by 2050 the mean annual air temperature will increase by 1.3 °C in Stockholm, 1.8 °C in Istanbul, and 0.9 °C in Doha.

Hour-by-hour energy simulations were conducted for each considered climate zone and each level of the TQBE. The changes in the heating load, cooling load and driving energy of HVACs as a result of warming were calculated. A comparison between the present and future energy consumption was made to show how warming impact on the building could be mitigate.

2.1. Case study

A residential house stand-alone was chosen as case study. The house has a floor area of 144 m^2 and consists of four identical

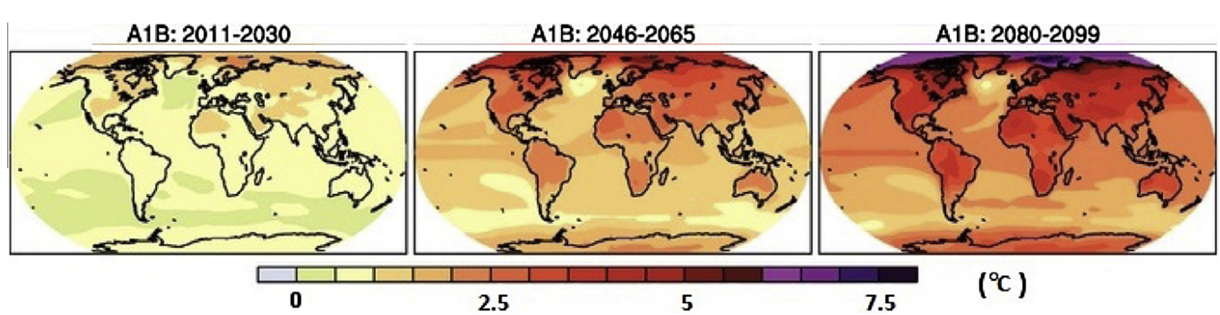

Fig. 2. Projected changes in global average temperatures for three different periods. Changes in temperatures are relative to 1961–1990 averages [6].