Effects of global warming for building energy demand in China

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Abstract

The impact of global warming on building energy demand in China was investigated by means of whole building energy analysis model and hourly weather data. Four standard multi-story office-building models, representative of four typical climate locations were constructed. For the time period 2050–2100, the climatic temperature scenario models for four typical cities was used that foresees a 2.7-4.2 °C rise in mean annual air temperature relative to the period 1961–1990 normal temperature and is thereby roughly in line with the climate change predictions made by the Intergovernmental Panel on Climate Change (IPCC). The simulation results show that the annual cooling energy demand for office buildings with internal heat gains of 20–30 W/m2 will increase by 26-58% while the heating energy demand will fall by 17-52% for the period 2050–2100. This study has also shown that the typical meteorological year (TMY) currently in use by building designers and HVAC engineers in China will lead increasingly to an overestimation of heating energy demand. Similarly, the use of TMY to compute cooling power and cooling energy consumption is likely to result in a progressive underestimation of the future demand. The future building energy demand is set to become a crucial design issue.

Keywords: Global warming, Heating energy, Cooling energy, TMY, Temperature scenarios, Typical office building model

1 Introduction

The relationship between energy and climate is one of the hot issues concerned by all nations in the world. On one hand, the exploitation and utilization of energy affects climate. On the other hand, climate change also affects the energy uses. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) predicts the most likely increment in surface temperature of 1.8–4.0 °C by the end of the 21 century, and growth scope of 0.3–6.4 °C [1]. Moreover, a wide band of uncertainty exists regarding the amount of warming. Recent research results from climate research institution in China suggest that averaged warming in China by the multi-model ensemble is in surface temperature of 1.9–5.5 °C by the end of the 21 century, a growth scope of 0.7–9.2 °C [1, 2]. Climatic parameters represent important boundary conditions for building design and the transient behaviour of the building envelope through its service life. Energy demand in buildings depends significantly on external boundary conditions, particularly on ambient temperature.

The impact of global warming on the energy consumption of a country for space heating and cooling depends on the current and future regional climate, the required thermal comfort inside buildings and technical building features such as thermal insulation quality. In previous studies for the USA [2-4] and, more recently, for Greece 5] and Switzerland [6], climate change was found to have significant implications on energy consumption in buildings. Several methods have been proposed to estimate building energy demand from monthly temperature data. Thom [7] related US-HDD to the monthly average temperature and standard deviation of monthly temperature from its long-term average. His equation was later modified by Ref. [8]. Other methods first construct hourly weather data from monthly temperatures and then calculate degree-days from standard degree-day equations [9-12] use the Swiss standard for HDD and CDD to calculate the Swiss building energy demand. Unfortunately, all the above studies employed definitions of degree-days. Degree-day methods are simple procedures, only efficient procedures for constant heat gain in buildings, but for the most buildings, especially for commercial buildings, these estimations aren't accurate due to the fact that the internal temperature, thermal gains and building properties aren't relatively constant [14]. In all above studies, the building models were the old structures. In this paper, four standard office building models entirely meeting the requirement [15] are constructed. To our knowledge, no corresponding study has, so far, been attempted to adopt whole building energy analysis method for standard office buildings in China.

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2 Methodology

2.1 CLIMATE

The meteorological parameters in the paper are based on measured date (1971–2003) at 270 stations. Improvements were made in meteorological dates. The climatic conditions looked at here are for the assessment of the performance of the building and associated HVAC systems. EnergyPlus, a computer program is used to measure the performance over a complete year at regular intervals up to one per hour. According to the requirement of criterion, the statistics year for outdoor air parameters is close to 30 years whereas building services engineers use a single year for simulation modelling. It is therefore important that the year chosen is representative of the weather over a number of years. Such a year is commonly called a typical meteorological year (TMY). The method used to select a TMY differs between countries; however, the objective is the same; to construct a set of 12 months that is representative of the past years (say 30 years). This means that a TMY is unlikely to include extremes and therefore, while suitable for the prediction of energy consumption it is unsuitable for the purpose of assessing the performance of buildings under more onerous conditions. The latter requires a year that contains periods when temperatures are higher than average.

Weather data for four cities representative of four typical climatic conditions in China were chosen for this study. Hourly weather data during the period from 1971 to 2003 were analysed. Meteorological dates show typical meteorological year for the four typical cites according to the last 30-year weather data (1971–2003).

2.2 TEMPERATURE SCENARIOS

The irreducible uncertainties associated with the future global socio-economic development [13] make any projections of future climate change inherently difficult. As a result, the aim of this study was not to determine the “most likely” trajectory for future building energy demand in China but rather to mark out the range of possible futures. For this purpose, Model for the Assessment of Greenhouse gas Induced Climate Change (MAGICC) that drives a spatial Global and Regional Climate SCENario GENerator (SCENGEN) were first compiled. MAGICC has been the primary model used by IPCC to produce projections of future global-mean temperature and sea level rise. The climate model in MAGICC is an upwelling-diffusion energy-balance model that produces global- and hemispheric-mean output. All scenarios were based on simulation results from so-called coupled Atmosphere–Ocean General Circulation Models (AO-GCM). AO-GCM is the most sophisticated tools currently available to project possible changes in global climate. In SCENGEN, the globe is discretized such that temperature, rainfall etc. are computed on a global grid. The horizontal grid point distance is in the order of five degrees. To use MAGICC / SCENGEN program for the climate warming, two main steps were considered: (i) Running MAGICC, Emissions Scenarios and Model Parameters in MAGICC are edited and (ii) Running SCENGEN and setting up analysis, model, region and variable.

In the first step, running MAGICC, the following emissions scenarios will be used: P50 for the Reference case and WRE350 for the Policy case. P50 is the median of the SRES emissions scenarios. WRE350 is the same as P50 except for CO2 emissions, which are modified to follow the WRE350 concentration profile.

In the second step, on ‘region’ window, the four typical cities can be selected from a range of ‘hard-wired’ regions. The latitude/longitude domain will be shown numerically on the right. After setting up other parameters, the result shows the four cities change (Table 5) in annual-mean temperature for the 30-year interval centred on 2080 (for the P50 emissions scenario, and ‘best guess’ climate model parameters in MAGICC) averaged over all 17 AO-GCM in the SCENGEN model data base. The changes correspond to a global-mean warming of 2.4 °C, and the patterns include the effects of aerosols according to the aerosol selection made in MAGICC.

TABLE 1 The four cities change in annual-mean temperature for the 30-year interval centred on 2080

City	Harbin	Beijing	Shanghai	Guangzhou
Longitude (deg)	126.77E	116.47E	121.45E	113.33E
Latitude(deg)	45.75N	39.8N	31.40N	23.17N
Elevation (m)	142.3	31.3	5.5	41.0
Change (deg C)	4.2	4.1	3.7	2.7

2.3 STANDARD OFFICE BUILDING MODEL

The built stock in China consists of some 5 hundreds million good-sized buildings. According to the standard, four 80 m long, 25 m wide and 35 m tall heavyweight multi-story building (Figure1) was modelled for the study presented in this paper.

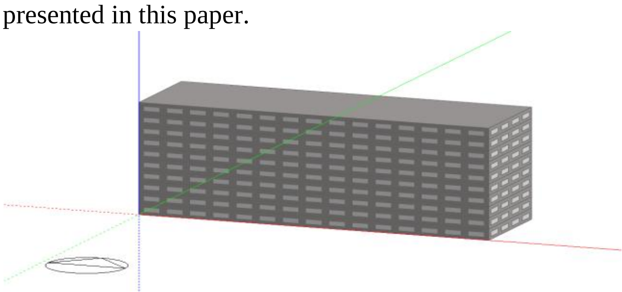

FIGURE 1 Model of the standard multi-story office building

The four standard building models meet the requirement of energy-saving building completely. The thermal insulation levels used to represent the four cities building code framework are given in Table 2.

The internal sensible heat gains considered are set out in Table 3. The per-capita area of use for the different type rooms is listed in Table 4.

TABLE 2 Thermal values of building components (shape factor<0.3, window wall area ratio=0.3) (W/(m^2 K)) [Design standard, 2005]

City	Uroof	Uouterwall	Uwindow
Harbin	0.35	0.45	2.8
Beijing	0.55	0.6	3.0
Shanghai	0.7	1.0	3.5
Guangzhou	0.9	1.5	4.7

TABLE 3 Internal heat gains for the different type rooms (W/m2) [Design standard, 2005]

Room sort	General	High	Meeting	Corridor	Other
Illumination power	11	18	11	5	11
Electrical equipment power	13	20	5	0	5

TABLE 4 The per-capita area of use for the different type rooms (m2/person) [Design standard, 2005]

Room sort	General	High	Meeting	Corridor	Other
per-capita area of use	4	8	2.5	50	20

The air conditioning systems were assumed to adopt the primary air and fan-coil systems that are used to design office buildings in China. The cold and heat source adopt the electric screw chiller and gas-fired boiler. The volume of primary air was designed for main space at $30m^3$ / (h·p).

2.4. SIMULATION MODEL AND ASSUMPTIONS

The EnergyPlus program is a collection of many program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. The core of the simulation is a model of the building that is based on fundamental heat balance principles. It is based on the assumptions that the air in the thermal zone, by default, has a uniform temperature, the temperature of each surface is uniform, the long- and short-wave irradiation is uniform, the surface irradiation is diffusive and the heat conduction through the surfaces is one-dimensional. The formulae of the solution scheme starting with a heat balance on the zone are follows:

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{zl}} \dot{Q}_i + \sum_{i=1}^{N_{surface}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_{\inf} C_p (T_{zi} - T_z) + \dot{m}_{\inf} C_p (T_{si} - T_z) + \dot{Q}_{sys}, \quad (1)$$

where N is the number of convective internal loads, $\dot{Q}_i$, $h_i A_i \; T_{si} - T_z$ is the convective heat transfer from zone surfaces at temperature T_{si} ,while $\dot{m}_{inf} C_p \; T_\infty - T_z$ is the heat transfer due to ventilation with the outside air, $\dot{m}_{inf} C_p \; T_{zi} - T_z$ is the heat transfer due to inter zone air mixing, and $\dot{Q}_{sys}$ is the system output. The capacitance Cz takes into account the contribution of the zone air as well as that of thermal masses, which are assumed to be in equilibrium with the zone air.

If the air capacitance is neglected, the steady state system output must be:

$$-\dot{Q}_{sys} = \sum_{i=1}^{N_{zl}} \dot{Q}_i + \sum_{i=1}^{N_{surface}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_{\inf} C_p (T_{zi} - T_z) + \dot{m}_{\inf} C_p (T_{si} - T_z). \quad (2)$$

The multi-story office building was partitioned into three non-conditioned thermal zones, a zone representing the first floor, a zone representing the roof and a zone representing each single office. In order to cancel out the effects of system intermittency on the energy demand, a continuous operating schedule of the conditioning system was considered in all cases, assuming a heating set point of 18 °C and a cooling set point of 26 °C.

2.5 SIMULATION OF CURRENT AND FUTURE BUILDING ENERGY DEMAND

The simulation of current building energy demand was actualized according to the TMY and standard building model established above, but simulation of future energy demand needs adding the temperature scenarios. As stated above, the limitations imposed by the annual-mean temperature scenarios forced us to base all our calculations for the season energy demand. However, the associated loss in accuracy appeared is tolerable. We were more interested in assessing long term changes and trends than precisely predicting individual monthly energy demand values. In this paper, a whole building energy analysis method was developed, comprising the following two steps.

In the first step, the building model was established in EnergyPlus. Through programming software, we can transform the XSL file into IDF file, thus the TMY weather data can be used for weather data in EnergyPlus. It was executed for the simulation of current building energy demand to explore the difference of four cities energy demand. In the second step, the future energy demand was simulated. Based on the first step, the temperature scenarios must be added to forecast the change of the future energy demand.

3 Results

3.1 IMPACT ON HEATING AND COOLING ENERGY DEMAND

The energy demand for heating decreased significantly in Harbin, Beijing, Shanghai and Guangzhou in 2080 (Figure 3). Figure 3 includes result of simulation for heating in 2007 and 2080. In the four cities, the heating energy demand is very different in 2007. Harbin is most, while Guangzhou is least. For 2008, a 17% heating energy reduction was determined for Harbin (+4.2°C temperature rise), 28% drop for Beijing (+4.1°C temperature rise), 34% drop for Shanghai (+3.7°C temperature rise) and 52% drop for Guangzhou (+2.7°C temperature rise). The cooling energy demand in 2007 and 2008 is shown in Figure 2. It can be seen that the cooling energy demand rose at all locations, with the largest rates of increase occurring in Beijing and Harbin. The increase in cooling energy demand for climate scenario (+4.2°C temperature rise) is 45% for Harbin, 58% rise for Beijing (+4.1°C temperature rise), 34% rise for Shanghai (+3.7°C temperature rise) and 26% rise for Guangzhou +2.7°C temperature rise).

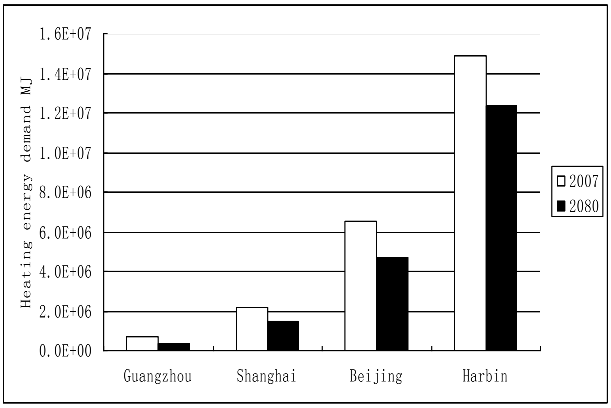

FIGURE 2 Annual cooling energy demand for four typical cities in 2007 and 2080

3.2 IMPACT ON BUILDING DESIGN

Today, building designers in China use the TMY for the building design. The TMY was chosen from 30 years monthly meteorological data provided by the Weather Bureau in China. A comparison between the heating and cooling energy demand in 2007 and 2080 is presented in Figure 2 and Figure 3. It can be seen that the difference of current and future TMY, which are based on measurements in the periods 1973–2003 and temperature scenarios, increasingly overestimated the heating energy demand and underestimated the cooling energy demand. This will affect building designer for future building design.

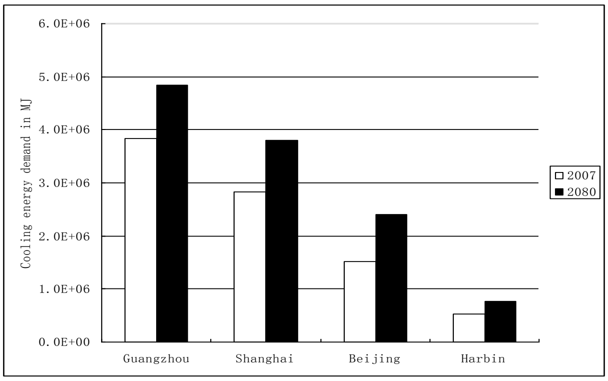

FIGURE 3 Annual heating energy demand for our typical cities in 2007 and 2080

4 Conclusions

The impact of climate change on energy demand for heating and cooling was investigated in this study. Application of the whole building energy analysis method with four standard multi-story office building models, representative of four typical climate locations revealed a significant relative heating energy demand decrease and cooling energy demand increase, over the period 2007–2080.This relative decrease, between 17% and 52% depending on building location, was most pronounced at colder regions like Harbin. On the other hand, the cooling relative increase, between 26% and 58% depending on building location, was highest at the hottest site, Guangzhou. The four standard building models meet the requirement of energy-efficiency. The change in energy demand is more obvious if the thermal insulation level in building is worse.

Buildings in China have a long lifespan of about 50–100 years. This study has also shown that the TMY currently in use by building designers and HVAC engineers in China will lead increasingly to an overestimation of heating energy demand. Similarly, the use of TMY data to compute cooling power and cooling energy consumption is likely to result in a progressive underestimation of the future demand. It, therefore, seems obvious that continuous updating of weather data for building design is needed. The presented paper aims to initiate a discussion of this issue.

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