Assessing the impacts of climate change on the German building stock

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Abstract

This study investigates the impacts of future climate uncertainties in the new generation of future climate data sets according to AR5(5th assessment report of IPCC) on simulating the energy performance of buildings by studying the building stock in Germany (Potsdam). This work is based on two data bases, namely 'Tabula web tool- European building' and 'EPISCOP'. Software IDA ICE was used to make comprehensive energy simulation of buildings. Four different climate models and two representative concentration pathways (RCP 4.5 and RCP 8.5) were used in the assessment. Simulations run for three 30-year periods between 2010 to 2099. Effects of uncertainties induced by RCPs are thoroughly investigated for long time period.

Through the comparison of energy simulation results, it is found that due to climate change, heating demand will decrease, however, cooling demand will increase. According to the results, for the second 30-year period, the heating demand decreases by 7% and cooling demand increases by 16%, compared to the first 30-year period. By comparing the distribution of the data sets, it is also found that the uncertainty caused by the climate model has an estimated impact on the future heating (cooling) demand greater than the uncertainty caused by the time period. The change in heating demand due to climate change and uncertainty is relatively low and very large for cooling demand.

Introduction

Climate change is widely known as a primary problem on the planet. According to the intergovernmental Panel on Climate Change (IPCC, 2018), between 1970-

2004, the emission of greenhouse gas increase about 70% (IPCC, 2007). The building industry accounts for 30% of global annual greenhouse gas emissions and 40% of total energy consumption (Bernstein et al., n.d.). Furthermore, between 1971 and 2004, carbon emissions from commercial buildings were estimated to have increased by 2.5% per year, and residential buildings by 1.7% per year (Isaac & van Vuuren, 2009). IPCC 2018 issued a report about global warming of 1.5°C, exceeding 1.5°C, will greatly increase the risk of drought, floods, heat and poverty for hundreds of millions of people (IPCC, 2018).

(Shen, 2017 et al., n.d.) carried out a study of four cities in the U.S by integrated on global climate data (GCM). The study result shows that the annual energy consumption change of residential buildings during the year of 2040-2069 is expected to be -1.64% to 14.07% under scenario A2 (carbon emission defined by IPCC). The study also indicate that the increasing peak electricity consumption during the cooling season will put more pressure on the future power grid. (Rey-Hernández et al., 2018) study the long-term effects of climate change which they module zero energy and carbon dioxide buildings through energy efficiency and renewable energy. The results show that in 2050 and 2080, cooling demand will increase significantly, while space heating demand will decline. (Cao, Li, Wang, Xiong, & Meng, 2017) investigated, under climate change the energy-saving design in different climate zone in China under climate change and found that both increasing, range from 0.2 °C to 0.7 °C and decade of heating demand. (Pérez-Andreu et al., 2018) predicted the impact of climate change on the

heating and cooling energy needs of residential buildings in the Mediterranean climate in 2050 and 2100 by using two GCMs. Studies have shown that demand for heating energy is significantly reduced and The literature review reveals broad predictions of changes in building energy demand under predicted future weather conditions due to different building types, locations, building models and climate models used. The uncertainty of predicted regional climate change comes from many factors. One is an external forcing scenario, such as an emissions scenario, that changes greenhouse gas and aerosol concentrations. Another factor relates to changes in large-scale circulation as determined by GCM. It depends on the formulation of the model and the internal variability. Different RCMs can respond differently to mandatory conditions. The handling of these uncertainties can be obtained when considering multiple models, forcing scenarios, and simulations. When the results do not change much in different models and scenarios, they can be considered an indication of robustness or an indication of useful degree of certainty. The purpose of this study is to better understand the trend of future building energy use from a macro perspective by predicting the future hourly energy consumption data from four different climate models. Dealing with large data sets and considering uncertainties requires appropriate statistical methods (Nik, 2016) (Nik, 2010).

Methodology

This section provides an overview of the climate model and the information obtained from the Tabula database and uses it for future hot and cold energy calculations. For all calculations, hourly weather data

demand for refrigeration energy is increasing. They also pointed out that insulation and penetration have the greatest impact on total energy demand.

sets for 8 climate scenarios have been used for three 30-year periods 2010-2040, 2040-2070 and 2070-2100.

1) Weather data sets

The future weather database is a synthesized version of RCA4 (Samuelsson et al. 2015), the fourth generation RCM of the Rossby Centre at Swedish Meteorological Hydrological Institute, with a spatial resolution of 12.5km and a time resolution as low as 15 minutes. RCA4 has reduced scale of four GCMs: CNRM-CM5, ICHEC-EC-EARTH, IPSL-CM5A-MR and MPI-ESM-LR. All GCMs are enforced by two representative concentration paths (RCP), RCP4.5 and RCP8.5. More details about synthesizing the weather data sets are available in (Nik, 2016) and (Nik, 2010). RCPs are the four greenhouse gas concentration trajectories used by the IPCC in the 2014 Fifth Assessment Report (AR5) (van Vuuren et al., 2011). Compared with the beginning of the 21st century (average 1986-2005), the average global warming of RCP4.5 between 2046 and 2065 averaged 1.4 °C, possibly ranging from 0.9 to 2.0 °C. The temperature increase for 2081-2100 is 1.8 °C with possible range around 1.1-2.6 °C. The values for RCP8.5 is 2.0 °C during the period 2046-2065 with possible range around 1.4-2.6 °C. 3.7 °C during the period 2081-2100 with possible range around 2.6-4.8 °C (Giorgetta et al., 2013). Figure 1 and 2 shows the mean temperature distribution of Germany (Potsdam) used for further simulation.

Figure 1 mean temperature distribution of Germany (Potsdam).

2) Building models: Tabula and IDA ICE models
Tabula web tool has been introduced to this study. Tabula webtool which developed residential building for 13 European countries. For Germany, the building stock is divided into 6 different building types, mainly sorted by age, which are single family houses types 1-3 (SFH1-3) and multifamily houses types 1-3 (MFH 1-3) (see Table 1). Tabula mainly focus on energy consumption of heating and hot tap water, cooling, lighting and air conditioning are not considered. It should be noted that Tabula does not provide the geometry information of buildings; the building model

Figure 2 mean temperature distribution of Germany (Potsdam).

were made mainly according to the floor area and window area. Numerical simulation was carried out by IDA ICE. Six building model were made separately for simulation. First step: set up reference cases according to Tabula. Second step: Further simulation in IDA ICE for future climate scenarios. Third step: Sum up result according to the numbers of buildings. Fourth step: Result analysis was carried out by MATLAB and Excel visual basic (Ballarini et al., 2014)

Table 1 Germany building stock statistical status sorted by building type (IWU, 2012)

	Building type	Erection period
"Single Family Houses"	SFH 1	until 1978
(<= 2 apartments)	SFH 2	1979 - 1994
	SFH 3	1995 - 2009
"Multi Family Houses "	MFH 1	until 1978
(>=3 apartments)	MFH 2	1979 - 1994
	MFH 3	1995 - 2009
number of apartments	livings space in 1000 m ²	reference area in 1000 m ²
12450000	1285000	1413500
3160000	372000	409200
2980000	365000	401500
14820000	965000	1061500
3910000	268000	294800
2110000	160000	176000
39430000	3415000	3756500

Result and Discussion

The heating demand from IDA ICE simulation result showed from the first 30-years period (2011-2040) to (2041-2070) decreased by 7%, followed by 16% decreasing from the second 30-years period (2041-2070) to (2071-2100). Table 2 shows the variation of the last 30-year period (2071-2100) total heating demand from 4 climate model with two different RCP. As It is clearly to see that from table 1 and table 2 that heating demand in RCP 8.5 is lower than RCP 4.5 and the uncertain is relatively low, for cooling demand RC8.5 is higher than RCP 4.5. One of the reasons is due to the increased outdoor dry-bulb temperature

Table 1 Potsdam building heating demand in KWh

Climate files	CNRM-rcp4.5	CNRM-rcp8.5	ICHEC-rcp4.5	ICHEC-rcp8.5
Heating demand	1.34E+9	1.27E+9	1.45E+9	1.29E+9
IPSL-rcp4.5	IPSL-rcp8.5	MPI-rcp4.5	MPI-rcp8.5	
1.22E+9	1.19E+9	1.28E+9	1.20E+9	

Table 2 Potsdam building cooling demand in KWh

Climate files	CNRM-rcp4.5	CNRM-rcp8.5	ICHEC-rcp4.5	ICHEC-rcp8.5
Cooling demand	2.14E+9	2.45E+9	1.52E+9	1.95E+9
IPSL-rcp4.5	IPSL-rcp8.5	MPI-rcp4.5	MPI-rcp8.5	
1.64E+9	1.89E+9	1.96E+9	3.36E+9	

Figure 3 and Figure 4 shows the heating variation of 4 climate models and cumulative value for cooling demand.

As we can see the variation of heating(cooling) demand, indicate that the uncertainty for heating demand is relatively low, but for cooling demand is relatively high. The cooling demand differences between RCP 4.5 to RCP 8.5 during 2070-2100 is 86%

caused by climate change, the use of cooling energy in buildings has increased significantly see Figure 1. Another reason of the increased cooling demand and decreased heating demand is due to RCP 8.5 have the highest and rapidly increased greenhouse gas concertation. RCP 8.5 which is the extreme condition of greenhouse gas emission, in this scenario, by 2100, annual emissions have stabilized at less than 3 billion

tons of carbon compared to 2000 is about 800 million tons. The concentration of carbon dioxide in the atmosphere accelerated in 2100 and reached 950 ppm and continued to increase for another 100 years.

Figure 3 Total heating and cooling demand (KWh) 2010-2100

Figure 4 Total heating and cooling demand (KWh) 2010-2100

for CNRM, 72% for ICHEC, 64% for IPSL and 75% for MPI. Uncertainty is related to differences in spatial resolution, global climate models (GCM), co2 emission scenarios and initial conditions. For more detail about the uncertainty the reader referred to (Nik,

2016)(Nik, 2010). Also, Figure 3 and 4 shows that the cooling demand is relatively smaller than heating demands. According to the weather file, period 2041-2070 the weather is moving towards to a more moderate trend which indicate heating may not require in the future. Since the changes of more heating energy to cooling energy, so the electricity consumption during summer may become greater, which means it will put more pressure on the electricity power plant. Nonetheless, Tabula only sorted German building type into only residential building house without considering the office building. For office building the heating(cooling) demand may have differences between the residential building. For example (Shen, 2017) studied the impacts of the climate change on 4 US cities' energy use by using downscaled hourly future weather data find out, the heating and cooling energy of the office building changes differently from the residential building. For office buildings, because office buildings are more dominated by internal loads rather than climate.

The focus of this study is to predict the total heating

and cooling demand under the future climate condition which have limited consideration of nowadays building conditions. According to the weather file, period 2041-2070 the weather is moving towards to a more moderate trend which indicate heating may not require in the future. Since the changes of more heating energy to cooling energy, so the electricity consumption during summer may become greater. Nonetheless, Tabula only sorted the German building type into only residential building house without considering the office building. (Shen, 2017) studied the impacts of the climate change on 4 US cities' energy use by using downscaled hourly future weather data find out, the current four cities have the closer heating and cooling energy consumption than residential buildings. The heating and cooling energy of the office building changes differently from the residential building. For office buildings, because office buildings are more dominated by internal loads rather than climate. The weather data used in this study was Potsdam only which may have less accurate to reflect the whole German weather condition.

Conclusion

In this study the impacts of climate change on the energy using trend in Germany (Potsdam) are evaluated and assessed. The general results show that under 4 different climate scenarios Potsdam buildings are going to undergo the rise cooling demand, along with the decreased heating demand. To be better demonstrate the impact of climate change on residential buildings, we conducted building energy simulations with the help of future hourly weather data. The model was built and simulated using IDA ICE. The results show that from 2011-2040 to 2041-2070, the heating demand fell by 7%, and cooling demand increased by 16%. From the second 30 years 2041-2070 to 2071-2100, heating demand fell by 12%, cooling demand increased by 7%. The result indicated that more electricity demand and there can be more pressure to the power station. Nonetheless, the uncertainty for future climate simulation is mainly due to spatial resolution, global climate model, CO2 emission scenario and initial conditions. Lack of

occupant information, occupant behavior is another intricate factor influences the building energy performance. The occupancy was assumed to be 1 person per 20m²

This study provides a list of possible future trends in building energy consumption in Potsdam, Germany, giving a reference for choosing building materials and options for cooling and heating in the future. More research studies of different types of buildings detailing the future in their respective climate zones, providing more accurate energy use information for each type of building, and provide proper guidelines for energy use and building designers.

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