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Impact study of the climate change on the energy performance of the building stock in Stockholm considering four climate uncertainties

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A R T I C L E I N F O

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A B S T R A C T

This work describes the research conducted in order to assess possible changes and uncertainties in future energy performance of the residential building stock in Stockholm. The investigation is performed on a sample of 153 existing and statistically selected buildings and covers the period of 1961–2100. Four uncertainty factors of the climate have been considered: global climate models, regional climate models, emissions scenarios and initial conditions; thereby, 12 different scenarios have been created. Energy performance of the building stock is studied by looking at the overall heating and cooling demand and the indoor temperature. Three cooling strategies of the building stock were evaluated: natural, natural and mechanical (hybrid mode) and only mechanical. To decrease the number of simulations, a method for sampling the climate data has been developed and tested against Sobol quasi-random sampling method.

Results of the investigation show that for all the climate scenarios the future heating demand will decrease at the end of the studied period, i.e. around 30 kWh/m^2 (30%) lower than before 2011, while the cooling demand will increase. Results for the heating demand can differ for about 30% between the scenarios and even more for the cooling demand. Since the current and future cooling demands are rather low, the natural cooling can be the safe choice for mitigating overheating. Uncertainties of the climate data can affect the energy simulation results, but it is possible to rank them and introduce margins to the design based on the importance of the uncertainty factor.

1. Introduction

Reducing the current energy demand and emissions of the greenhouse gases is one of the important missions of the building sector in Europe. Meanwhile the intended improvements in energy performance of the buildings should not be jeopardized by the future climate changes. The fourth assessment report of the Intergovernmental Panel on Climate Change [1] projects an increase in global mean surface temperature of 1.1–6.4 °C over the period 1990–2100 together with an increase in climate variability and extreme events [2]. The Swedish residential sector uses 21% of the overall energy use in the country, which is 5% less than the average values in the European Union [3]. This energy is mainly consumed for heating since in most cases there is no need of using cooling systems in the Swedish residential buildings. Mild Swedish summers with their short warm periods do not create larger comfort problems, i.e. overheating. The buildings are commonly and rather effectively cooled down by the means of ventilation with the fresh outdoor air. Nevertheless there are concerns about the future performance of buildings and the global warming, such as changes in heating and cooling demands in the future. To estimate these changes the present status of the building stock should be assessed and the future conditions should be analysed using at least one of the future climate scenarios.

Global climate models (GCMs) have been developed for simulating the climate conditions. GCMs have a rather coarse spatial resolution (often 100–300 km), which is not suitable for building simulations. Also due to recognized biases, direct use of GCM output in impact assessment may not be recommended [4,5]. The two common approaches for downscaling GCMs to a more appropriate scale involve statistical or dynamical techniques [4]. Some researchers have considered the future energy demands using the statistically downscaled climate data, e.g. [6–8]. A widely used approach in impact modelling is using RCM to downscale the GCM data dynamically (e.g. [9]). In this paper climate data from a regional climate model (RCM) have been used.

Since the future climate data are results of the numerical climate models, several scenarios for the future climate are possible.

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Basically, any different GCM, RCM, emissions scenario or initial condition can represent a new scenario [10,11]. Meanwhile it is important to remember that no single climate model can be considered as the most probable [12,13]. It means working with the future climate introduces different uncertainties to the analysis which is important to be aware of when doing the impact analysis. Uncertainties of the climate data and their importance in building simulations have been considered in some works, e.g. [14–19]. In this work four uncertainty factors of the climate data are considered which have been induced by the selection of GCMs, RCMs, emissions scenarios and initial conditions.

Different impact studies have been performed in the building sector and with the focus on the future energy demand for heating and cooling of buildings [7,14–16,20] as well as on the variations and extremes in indoor temperature [21]. Climate change adaptation of buildings and their thermal comfort have been a research subject, e.g. [14,22–27]. For example Ren et al. have concluded that in the heating dominated parts of Australia it is more cost-effective to improve the energy efficiency of the building envelop but to use high energy efficient air-conditioning equipment and appliances, while in the cooling dominated regions, all measures are cost-effective [23]. In a study of cooling loads of the residential sector in subtropical Hong Kong under different emissions scenarios, Wong et al. recommend raising the indoor temperature as the best mitigation potential for adaptation since it can be applied to both the existing and new buildings without extra cost [28]. Lomas et al. have studied naturally ventilated buildings in the UK and have found the advanced natural ventilation as a sustainable solution for mitigation of overheating in buildings in the future climate [29].

Impact studies can be performed on real or sample buildings, or more often on typical or archetype buildings [14–16,19,24]. In this work impact analysis of the climate change on the energy performance of the residential building stock in Stockholm, represented by sample buildings, is performed while effects of the four uncertainty factors of the climate data on energy simulations are considered. The description of the building stock is obtained from a large field survey [30]. Energy simulations were done by a dynamic building energy simulation programme developed in Simulink/Matlab, for the period of 1961–2100 and on hourly basis. Energy performance of the buildings is assessed by comparing heating/cooling demands and indoor temperature variations under different climate scenarios. Importance of the climate uncertainties is measured by looking into deviations in the results due to those uncertainties. Because a rather large sample of buildings is considered, namely 153, the comparisons are made mainly by looking into the probability distribution functions of the above-mentioned performance indicators and during the periods of 20 years. In the case of using data from different climate models, it is recommended to consider relatively long periods, i.e. decades, as the natural variability in the climate system is large and makes the short term comparisons unreliable [10].

When adaptation of buildings to the future climate is discussed a very first impression is the need for more powerful cooling systems. To check if there is such a need, the indoor temperature of the building stock of Stockholm is calculated for three different cooling strategies: (1) *natural cooling*, i.e. when the indoor temperature is more than 24 °C and the outdoor temperature is less than 24 °C windows will be opened, (2) hybrid *cooling*, where the natural cooling is used whenever the indoor temperature is above 24 °C and the outdoor temperature is below 24 °C; but if the indoor and outdoor temperature are above 26 °C windows will be closed and a mechanical cooling system will work , and (3) *mechanical cooling*: windows are closed and the only cooling system is mechanical which keeps the indoor temperature below 26 °C. Note that the selected temperatures for cooling are tentative and estimated for the purpose of the analysis, because cooling of residential buildings in Sweden is not covered by building regulations. When calculating the mechanical cooling loads only the sensible load is considered. Cooling systems in the residential buildings in Stockholm are rare and therefore it is difficult to get the data on the installed cooling power. For the purpose of this analysis, the cooling power of the mechanical cooling system is limited to a value equal to the maximum heating power.

2. Climate data

Climate modelling is pursued by means of models of varying complexity ranging from simple energy-balance models to complex three-dimensional coupled global models. On a global scale, global climate models (GCMs) are used. GCMs consist of individual model components describing the atmosphere and the ocean. They also describe the atmosphere–ocean interactions as well as with the land surface, snow and sea-ice and some aspects of the biosphere [31]. Regional climate models (RCMs) are used to downscale results from the GCMs dynamically, to achieve a higher spatial resolution over a specific region. RCMs have the advantage of generating physically consistent data sets across different variables [10,32]. Compared to statistical downscaling, RCMs have a better representation of topography and mesoscale processes [33]. The climate data used in this work are mainly results of the Rossby Centre regional climate model, RCA3, for the city of Stockholm in Sweden.

Using the numerically simulated climate data in the building models introduces different uncertainties to the simulations. The uncertainties of projected regional climate change arise from a number of factors. In this paper four of these factors are considered. The first one concerns the changes in the large-scale circulation determined by the GCM. The second uncertainty factor is the result of downscaling a GCM using different RCMs. The third factor is the external forcing scenarios like the emissions scenario, which changes the greenhouse gas and aerosol concentrations. Different RCMs can respond differently to the forcing conditions [31]. The fourth uncertainty is the result of having different initial conditions in the climate model.

The RCM climate data have been synthesized by coding in Matlab before being used in the energy simulations [17]. For example climate parameters were synchronized and short-wave components of the solar radiation were calculated based on a method developed by Taesler and Andersson [34].

2.1. Global climate models

Data from five different RCA3 simulations are compared in this section. RCA3 has been downscaling GCM results to 50 km horizontal resolution [10]. The GCMs are: (1) ECHAM5: a coupled atmosphere–ocean GCM developed at the Max-Planck Institute for Meteorology in Hamburg, Germany, (2) CCSM3: The Community Climate System Model by the National Centre of Atmospheric Research (NCAR), USA, (3) CNRM: the third version of the ocean-atmosphere model initially developed at CERFACS, Toulouse, France, (4) HadCM3: Hadley Centre Coupled Model, by the Hadley Centre in the United Kingdom, (5) IPSL: The coupled model by the Institut Pierre Simon Laplace des Sciences de l'Environnement Global, IPSL Global Climate Modelling Group, Paris, France (for details see [10]).

Different GCMs result in different climate conditions. To illustrate this, probability distributions of the annual mean temperature in Stockholm are plotted in Fig. 1, based on the calculations of five different GCMS. The two 20-year periods are presented: 1980–2000 and 2081–2100. Also mean values and standard deviations