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A statistical method for assessing retrofitting measures of buildings and ranking their robustness against climate change

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ABSTRACT

Evaluating the usefulness and the reliability of retrofitted buildings for future climate can be a challenging task, while different scenarios and uncertainties exist both for retrofitting buildings and future climate. This paper presents a method to assess and quantify the relative robustness of retrofitting measures on long term, while climate variations in different time scales, extreme conditions and uncertainties of climate change are considered. The applicability of the method is examined by comparing two energy retrofitting measures for the existing residential building stock of Stockholm, whose energy performance is numerically simulated during 1961–2100 for five climate scenarios. The considered climate uncertainties are due to downscaling climate data from five different global climate models. The relative robustness of the retrofitting measures are evaluated in five time scales; hourly, daily, monthly, annual and 20-year period.

The presented method facilitates the assessment and ranking of retrofitting measures, using few numbers. It also generates an overall view about the relative performance of retrofitting measures in different time scales.

1. Introduction

Retrofitting buildings is promoted in many countries, especially in Europe where extensive financial resources are allocated by the European Union (EU) for studying and practicing it, with the intension of facing climate change (mitigation and adaptation) and the economic recession [1]. Guidelines have been provided on retrofitting existing buildings to meet the EU energy and climate change objectives by 2020 and to take forward its 2050 decarbonisation agenda [2]. Usually retrofitting buildings is a big investment with long term goals, therefore it is important to consider the adaptability of retrofitted buildings to future climate.

According to the fourth assessment report of the Intergovernmental Panel on Climate Change [3], which is also confirmed by the fifth assessment report (AR5) [4], climate changes induce increase in temperature, climate variability and extreme events. Most of the future climate scenarios point to more frequent and extreme conditions in Europe, which make buildings and the built environment more vulnerable. Climate change affects the performance of buildings both on long and short terms; most likely there will be less heating demand in the heating dominated regions of Europe, however there can be stronger and more often extreme conditions, such as seasonal hot/cold waves, which results in violating the comfort limits and challenging the design capacity of energy systems. Not preparing for the future changes increases risks, costs and the severity of damages, which can badly influence the living conditions and the economy. Sustainability of the built environment depends on its adaptation to future climate. Retrofitting measures are kind of adaption measures which can reduce the risks of climate extremes and disasters, regardless of the degree of certainty around future changes [5]. Retrofitted buildings should provide the desired energy performance and indoor comfort, not only for current climatic conditions, but also for future climate with its long and short term changes.

With the help of dynamic climate models it is possible to assess the future performance of buildings using different weather data sets. Availability of numerical models, which can simulate climate for the spatial resolutions down to 5 × 5 km, brings its advantages

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and challenges in the impact assessment of climate change. One of the main advantages is using the weather data sets which represent climate variations in different time scales. Therefore instead of applying a range of changes to the current weather data sets and keeping the same trend of variations (usually referred as morphed data), it is possible to consider the varying nature of climate (and its uncertainties) and to study the impacts of changes in different time scales. Some of the main challenges in the impact assessment of climate change are the long time periods to be considered, while the impacts of climate variations and uncertainties can be visible in different time scales [6–8]. Moreover, the importance of climate uncertainties in the building simulations differs depending on the considered time scale [7,8]. Combining climate uncertainties with the existence of several building types and retrofitting strategies, makes the assessment more challenging due to the increased amount of data and the coherent uncertainties.

Uncertainties in retrofitting buildings can be related to financial risks, CO_2 mitigation and energy saving strategies, such as uncertainties in material/component properties, control/HVAC systems and user behaviour [9,10]. Energy modelling of the retrofitted buildings and their uncertainties have been studied in different works; Hillebrand et al. have compared 64 combinations of the most common refurbishment measures, taking into account the uncertainty of future energy prices and pointed out the necessity of having a multi-criteria evaluation of retrofitting measures [11]. According to Booth et al. [12,13], overestimating the energy savings from retrofit measures can induce significant financial risks. A study by Daly et al. [14] for the cooling dominated climate of Australia, using the morphed weather files, has shown that future climate does not affect the retrofitting strategies for commercial office buildings as much as e.g. changes to the building construction and usage. Uncertainties of the climate data and their importance in building simulations have been considered in some works, e.g. [8,15–17]. Impact assessment of climate change on the future performance of different classes of buildings [15], or different retrofitting measures [18], helps in estimating the usefulness of the applied techniques. Moreover, it can help in avoiding unnecessary changes/retrofitting, which will not help in having better buildings for future.

Assessing the energy efficiency of retrofitting measures is mostly a multi optimization problem which can complicate the decision making procedure. Several methods and approaches have been tested to increase the computational efficiency of large-scale retrofit analysis such as decomposing the building energy models into discrete components [19,20]. However, in most of the cases few buildings have been considered with several retrofit options or other affecting uncertainties, such as economy uncertainty. Asadi et al. use multi-objective optimization models to assist stakeholders in evaluating retrofitting strategies and minimizing the energy use in a cost effective manner [21]. Murry et al. [22] have used static modelling, using degree-days simulation technique and genetic algorithms, to suggest the optimal retrofitting measures. Norisa et al. have provided a protocol for selecting retrofits based on predicted energy and indoor environment quality, while retrofit cost and initial apartment conditions are also taken into account [23]. Booth et al. propose a framework to quantify the risks and to handle uncertainties, combining statistical calibration and probabilistic sensitivity analysis [12,13]. Heo et al. employ a Bayesian approach to calibrate uncertain parameters in energy simulations, considering parameter uncertainty in the energy simulation model, discrepancy between the model and the true behaviour of the building, and observation errors [24].

The current paper proposes a method to assess and quantify the relative robustness and the effectiveness of retrofitting measures on long term, while climate variations in different time scales, extreme conditions and climate uncertainties are considered. The proposed method calculates the relative difference (RD) of the retrofitted building compared to the non-retrofitted (reference). Then it investigates the robustness of the retrofitting measure by quantifying variations of RDs among different time scales and different climate scenarios. The method is based on calculating average and standard deviations in five temporal resolutions: hourly, daily, monthly, annual and 20-year periods. Applicability of the method is exemplified by assessing the energy performance of the residential building stock in Stockholm while two retrofitting measures are applied. The heating demand of the retrofitted buildings is explored thoroughly by showing the calculation results in several tables. Although the number of tables increases due to considering five time scales and two retrofitting measures, at the end it is shown that the method enables comparing different retrofitting measures with few numbers. This work evaluates only a heating dominated region of Europe, however the method may well work worldwide for distinct climates.

2. Climate data

The climate data used in this work are the results of the Rossby Centre regional climate model, RCA3, for the city of Stockholm in Sweden. The city is located on the south-central east coast of Sweden with humid continental climate, quite warm summers and cold winters. According to measurements, the annual temperature has increased for about 1 °C during 1991–2010 compared to 1961–1990 (www.smhi.se).

On a global scale, global climate models (GCMs) are used to simulate the climatic conditions [25]. GCMs have a rather coarse spatial resolution (often 100–300 km), which is not suitable for building simulations. Regional climate models (RCMs) are used to downscale results from the GCMs dynamically, achieving a higher spatial resolution over a specific region. RCMs have the advantage of generating physically consistent data sets across different variables and have a better representation of topography and meso-scale processes, compared to statistical downscaling [6,7,26].

Using the numerically simulated climate data in the building simulations introduces different uncertainties. It has been shown that the most important uncertainty factor concerns the changes in the large-scale circulation determined by the GCM [6,7,27]. In this paper, climate data from RCA3, downscaling five GCMs to 50 km horizontal resolution are used: (1) ECHAM5, (2) CCSM3, (3) CNRM, (4) HadCM3 and (5) IPSL (for details see Ref. [26]). Different GCMs result in different climate conditions and different energy performance of the building stock, as has been discussed thoroughly in previous works, e.g. [6,8,17,27].

3. Energy model of the building stock

The residential building stock of Stockholm is represented by 153 buildings, which have been chosen statistically in an extensive field investigation (so-called BETSI programme [28]), conducted by the Swedish National Board of Housing, Building and Planning (Boverket) in year 2005. The aim of BETSI programme was to describe the status of the entire Swedish building stock in terms of energy use, technology status, indoor air quality, damages and maintenance. In all 1400 residential buildings were chosen as representative of all Swedish buildings, corresponding to 300 categories that combine building design and age, and are distributed among 30 different locations. The 153 buildings modelled in this work are those (of the 1400) that were located in Stockholm.

The energy performance of the building stock is modelled as a lumped system in Simulink toolbox of Matlab, where each building is represented as one zone, and incorporates hourly-based calculations of energy balance in the zone [29,30]. The energy