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Effective and robust energy retrofitting measures for future climatic conditions—Reduced heating demand of Swedish households

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ABSTRACT

This article quantifies the energy saving potential and robustness of nine energy retrofitting measures, as well as four combinations of these, for residential building stocks of three major cities in Sweden and for five scenarios of future climatic conditions, downscaled by a regional climate model (RCM). The retrofitting measures are evaluated for five temporal resolutions of hourly, daily, monthly, annual and 20-years during the period of 1961 through 2100. The evaluation takes into account a very important uncertainty factor of future climate data, induced by different global climate models (GCMs). The application of a statistical method for assessing the retrofitting measures is being evaluated.

Results verify the consistency and reliability of the comparative assessment and confirm the possibility of assessing the retrofitting measures without the need for long-term simulations and considering climate uncertainties. Among the considered retrofitting measures, a combination of an improved thermal insulation of the building envelope with energy efficient windows is the most effective and robust retrofitting measure, while tuning the indoor set-point temperature to 20 °C can also contribute to significant energy savings.

1. Introduction

Improving the energy efficiency of buildings through retrofitting is a key part of energy saving, carbon dioxide (CO_2) reduction and climate change adaptation strategies for countries with established building stocks. Retrofitting buildings is promoted in European countries and guidelines are provided to meet the EU energy and climate change objectives by 2020 and to take forward its 2050 decarbonisation agenda [1,2]. Retrofitting usually involves a combination of techno-economic measures that are aimed at reducing the energy demand for operation of buildings and, if necessary, at improving the indoor comfort, but also at guiding building owners and tenants to use the building in an energy efficient way. There exist a variety of retrofitting measures; easy to implement measures, such as using efficient light sources, as well as comprehensive and combined measures such as upgrading the building services and envelopes.

Selection of proper retrofitting measures and assessment of their long term benefits are challenging tasks due to numerous retrofitting options and their direct and indirect impacts on the building performance. Several approaches and techniques exist for planning and assessment of retrofitting strategies, which commonly take into account availability, applicability, cost and energy efficiency of the measures, as well as building energy simulations (e.g. [3–7]). Multi-objective optimization techniques are often needed in the retrofit analysis (e.g. [8–12]), as well as methods to deal with uncertainties and risks that arise in the assessment [13–16].

Climate is the most important boundary condition for building simulations and when climate change is taken into account, uncertainties in meeting the desired performance of the retrofitted buildings increase due to inherent uncertainties of the climate models (see [17–19]). Several researchers have shown that climate change affects the energy performance of buildings (e.g. [4,18,20,21–24]), even after retrofitting buildings (e.g. [3,16,25,26]). Moreover it has been shown that climate change uncertainties, presented as different climate scenarios, can affect building simulations significantly (e.g. [4,18,20,24]). Importance of these effects vary depending on the considered time resolution;

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for example differences in the hygrothermal and energy performance of buildings due to climate uncertainties can increase on the daily or seasonal scales compared to the annual or periodical (20-year or 30-year) scales (e.g. [4,18,19,28]). Although uncertainties in model predictions of future climate are large, scientific evidences for warming of the climate system are unequivocal [27]. Climate changes will be observed on different time scales: long-term, e.g. higher average temperatures over decades and short-term, e.g. much warmer summer daily hours or much colder winter night hours. For all these reasons, both the climate change and climate uncertainties should be included in retrofit analyses.

Consideration of climate change in the retrofit analysis brings two major aspects which, in combination with multiple retrofitting options, make the assessment laborious: 1) very large sets of weather data (e.g. over 100 years on hourly resolution) and building data, and 2) important uncertainties due to future climate scenarios. Statistical methods have been proven adequate for efficient analyses of large data sets produced by building simulations (e.g. [4,26,28]). A particular statistical method has been developed previously by the authors for assessing the future performance of retrofitting measures in terms of their effectiveness and robustness on five time resolutions of hourly, daily, monthly, annual and 20-years [26]. The effectiveness is quantified as an average energy saving percentage for space heating demand over a period of time, due to retrofitting, while robustness is quantified by calculating the standard deviations of the effectiveness values among several time periods and climate scenarios. Robustness is a gauge for quantifying the variations of the effectiveness; lower variations among periods or scenarios deals with higher robustness of the retrofitting measure. The ideal case is having no variations (zero) which means an absolutely robust retrofitting measure. The method was exemplified on two selected retrofitting measures implemented on sample buildings from a building stock (city of Stockholm, Sweden), and for five different climate scenarios. Results of the analysis showed that the relative performance of the retrofitted buildings, compared to the non-retrofitted ones, does not change considerably over time, regardless the climate scenario and time resolution. It was further concluded that the relative performance of the considered retrofitting measures could be assessed by considering an arbitrary 20-year period from any climate scenario, while their future performance could be estimated based on the future performance of the reference or non-retrofitted buildings.

The present work evaluates the application and consistency of the suggested statistical method from [26] further by including a more representative portfolio of single retrofitting measures (i.e. nine measures) and four combinations of these, applied on sample buildings of three major cities in Sweden: Stockholm, Gothenburg and Lund. For all the considered measures, their effectiveness in decreasing the energy demand for space heating and their robustness against climate change and its uncertainties are studied for five temporal resolutions: hourly, daily, monthly, annual and 20 years. One of the most important uncertainty factors of future climate data in energy calculations, induced by different global climate models (GCMs) [19], is taken into account. More than verifying the consistency of the suggested statistical method, this article aims at assessing the effectiveness and robustness of the considered retrofitting measures for uncertain future climatic conditions of three cities in Sweden.

This article is divided into three major parts: Section 2 briefly describes the background knowledge about the considered building stocks, retrofitting measures (single and combined) and future climate scenarios, and also the previously developed statistical method which is used in the assessment. Results of the energy simulations and the retrofitting measures are assessed thoroughly in Section 3. Firstly, consistency of the statistical method is evaluated for the five temporal resolutions for the buildings in Stockholm and thirteen retrofitting options. Then, the possibility of relying on the relative performance of the retrofitted buildings for only one 20-year period and one climate scenario is assessed. In the second part of Section 3 the performance and robustness of the retrofitting measures are evaluated for the buildings in all three cities, by looking into five temporal resolutions. Finally section 4 describes the conclusions of this work.

2. Methods and data sets

In this section the methods and data sets which are used in this work are discussed as the following: (1) Statistical representation of the building stock; describing three building stocks which are studied in this work, (2) Energy retrofitting measures; explaining nine single retrofitting measures and four combinations of them, (3) Climate data and uncertainties; providing a deeper insight about the climate data sets which are used in this work and the considered uncertainties, (4) Modelling the energy performance of the building stock; containing more information and specific references about the building models and (5) Assessment method; describing the statistical applied statistical method in brief. For each subsection there are specific references which the readers are referred to, discussing the previous works of the authors in connection with the current article.

2.1. Statistical representation of the building stock

The residential building stocks of Stockholm, Gothenburg and Lund are represented by 153, 184 and 52 sample buildings respectively, for which statistics on the average thermal transmittance of the building envelopes (U-value), the heated floor area and the window area are shown in Fig. 1. These buildings belong to a group of 1400 buildings that have been chosen statistically to represent all residential buildings in Sweden, and characterized in an extensive field investigation [29], conducted in year 2005. This data is the major source of information for modelling and assessment of energy performance of Swedish residential building stock and has already been used in previous works by the authors, e.g. [18,30,31].

There are weighting coefficients for the sample buildings, quantifying the frequency of the sample buildings in the existing building stock. For example for Stockholm the input data consists of around 450 thousand dwellings (50 and 400 thousand dwellings for single-family dwellings (SFDs) and multi-family dwellings (MFDs) respectively) in around 62 thousand buildings (44.9 and 17.1 thousand SFD and MFD buildings respectively), corresponding to a heated floor area of around 42.9 million m^2 (7.5 and 35.4 million m^2 for SFDs and MFDs respectively). For Gothenburg the input consists of 270 thousand dwellings (for Lund: 220 thousand) of which 60 and 210 thousand for SFDs and MFDs respectively (for Lund: 56 and 9 thousand), in around 62 thousand buildings (for Lund: 65 thousand) of which 44.9 and 17.1 thousand are SFD and MFD buildings respectively (for Lund: 55 and 165 thousand). These correspond to a heated floor area of around 26.9 million m^2 (for Lund: 20.6 million m^2) divided into 8.2 and 18.7 million m^2 for SFDs and MFDs respectively (for Lund: 0.8 and 1.2 million m^2)—The number of dwellings modelled in Stockholm corresponds to 20% and 70% of the SFDs and MFDs respectively accounted in the national statistics [32] for the so-called “big Stockholm” and, in Gothenburg, to 35% and 80% of the SFDs and MFDs,respectively, of the so-called “big Gothenburg” in the same statistics. The number of dwellings is not available in the statistics for the city of Lund.

Impacts of climate change on the energy performance of the residential building stock of the considered cities as it was in year 2005, which is referred as the non-retrofitted or the reference case in this paper, have been studied previously [18,19]. The heating/cooling