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Energy use and overheating risk of Swedish multi-storey residential buildings under different climate scenarios

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ABSTRACT

In this study, the extent to which different climate scenarios influence overheating risk, energy use and peak loads for space conditioning of district heated multi-storey buildings in Sweden are explored. Furthermore, the effectiveness of different overheating control measures and the implications of different electricity supply options for space cooling and ventilation are investigated. The analysis is based on buildings with different architectural and energy efficiency configurations including a prefab concrete-frame, a massive timber-frame and a light timber-frame building. Thermal performance of the buildings under low and high Representative Concentration Pathway climate scenarios for 2050–2059 and 2090–2099 are analysed and compared to that under historical climate of 1961–1990 and recent climate of 1996–2005. The study is based on a bottom-up methodology and includes detailed hour-by-hour energy balance and systems analyses. The results show significant changes in the buildings' thermal performance under the future climate scenarios, relative to the historical and recent climates. Heating demand decreased significantly while cooling demand and overheating risk increased considerably with the future climate scenarios, for all buildings. In contrast to the cooling demand, the relative changes in heating demand of the buildings under the future climate scenarios are somewhat similar. The changes in the space conditioning demands and overheating risk vary for the buildings. Overheating risk was found to be slightly higher for the massive-frame building and slightly lower for the light-frame building.

1. Introduction

Global climate change due to increasing atmospheric concentration of GHGs (greenhouse gases) present significant risk to environmental, infrastructural and economic systems [1,2,3,4]. The IPCC (Intergovernmental Panel on Climate Change) fifth assessment report reiterated that changes in the global climate system are occurring in all geographical regions [2]. Global surface temperatures have increased by 0.65–1.06 °C in the last century and are further projected to increase by 2.6–4.8 °C by 2100, compared to 1986–2005 levels [2]. Changes in the global climate system are likely to result in disruptions in weather patterns and this may have implications for building performance.

Production and operation of buildings contribute substantially to climate change through GHGs emissions, and climate change may have significant effects on buildings, as climate related parameters influence thermal performance of buildings [5]. Profiles and scale of buildings' energy use may change as a result of climate change [6]. Both effective mitigation and adaptation strategies are essential to minimise the potential impacts, risks and costs that may be associated with climate change for buildings [7]. Potential climate mitigation measures for buildings may aim at reducing GHG emissions while adaptation measures may aim at ensuring comfortable indoor conditions and resilient performance of buildings.

In Sweden, the latest climate projections suggest mean annual temperature increase of up to 5.5 °C by 2100, compared to 1961–1990 levels, with warmer winters and summers [8]. This may influence patterns of energy use and indoor environmental performance of buildings. The risk of overheating in buildings is increasingly expected to rise under projected climate change scenarios [9]. Different definitions of overheating are found in literature (e.g. Refs. [10-13]). Generally, overheating describes indoor temperature conditions that present heat stress and discomfort to building users, and may affect well-being, productivity and mental concentration. The SNBHW (Swedish National Board of Health and

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Welfare) reported general guidelines for comfortable indoor climate and suggests that indoor air temperatures in residential buildings should not exceed 24 and 26 °C during winter and summer, respectively [14]. The CIBSE (Chartered Institution of Building Services Engineers) guide on overheating is increasingly cited and suggests that a building is overheated if indoor temperature exceeds 28 °C in living areas or 26 °C in bedrooms for more than 1% of the occupied time within a year [11]. There has been growing interest in understanding the implications of climate change for thermal performance and overheating of buildings [15-19]. The European Union's energy performance of buildings directive highlighted the need to focus on strategies to avoid overheating and to ensure improved thermal performance of buildings [20]. Overheating risk in buildings is influenced by several factors including a building's design, glazing ratio, energy efficiency level and surrounding climate [12,21].

Studies in different countries (e.g. Refs. [5,22-29]) observed significant changes in building space conditioning energy use, with the dominance of cooling increasing and the dominance of heating decreasing under anticipated climate conditions. However, the overall effect of the projected climate scenarios varies for different locations and building typologies. In several studies (e.g. Refs. [5,24,26,28]) potential temperature increases are used as proxy to investigate the effects of climate change on building energy use. Frank et al. [24] evaluated the implications of climate change for different building configurations in Zurich, considering mean annual air temperature increases ranging from 1 to 4.4 °C. The results showed that the energy efficiency level of building has significant impact on the thermal performance of buildings under climate change. Olonscheck et al. [26] investigated the space conditioning energy use for German building stock in the context of future climate change, considering how annual temperature increase between 1 and 3 °C influenced cooling and heating degree days. They noted that such temperature changes may result in up to 78% decrease in heating demand and up to 59% increase in cooling demand compared to the current TMY (typical meteorological year). In addition to temperature variations, climate change may also result in changes in key parameters affecting building thermal performance including wind speed, solar radiation and relative humidity. A comprehensive analysis of the effects of climate change on buildings performance may consider all significant building energy sensitive climate variables.

Some detailed studies have considered a range of climate variables and different building types in exploring the effects of climate change on buildings. Wang and Chen [30] considered future changes in ambient temperature, solar radiation, wind speed and relative humidity in a comprehensive hour-by-hour analysis of the effects of climate change on heating and cooling demands of different types of buildings in 15 US cities. They found that heating demand decreased while cooling demand increased but the overall effect varies significantly for different type and location of buildings. The study showed that passive cooling of buildings may not be effective in some US cities under long-term climate change projections. Wang et al. [31] explored the implications of plausible climate scenarios for building performance in different climate zones in Australia. They considered projected future ambient temperature, solar radiation and relative humidity at hourly timestep and analysed a standard and an energy efficient versions of a case-study house. They found the net energy for space conditioning, including heating and cooling, to increase by 112–250% by 2100 compared to present levels, for the standard house located in a climate with balanced cooling and heating. The increase in the net space conditioning energy use was found to be smaller for the very energy efficient house in absolute term, but proportionally more significant. Xu et al. [32] conducted a comprehensive assessment of climate change impacts on different building configurations in California. The authors found that cooling demand for buildings is increased by 50% and 25% over the next century, under the worst and most likely climate change scenarios, respectively. A study of climate change implications for buildings in Los Angeles by Haung et al. [33] estimated average space cooling final energy use to increase by 31% and 42% by 2100, for residential and commercial buildings, respectively. The corresponding average space heating decreases were reported to be 62% and 24%, respectively. Berger et al. [34] analysed the energy performance of buildings with varying energy efficiency levels under the context of the current and projected future climate conditions for Vienna, Austria. They found that while future heating demand is reduced slightly, future cooling demand is typically increased significantly. Karimpour et al. [35] studied the performance of different building envelope and design options for the climate of Adelaide, Australia and reported that climate change shifts the space conditioning load, making cooling more dominant than heating in the year 2070. Asimakopoulos et al. [36] assessed the potential energy demand of the building stock in Greece under different projected climate scenarios. They found that heating demand is reduced by up to 50% while cooling demand is increased by up to 250% by 2100, compared to the current TMY.

Much of current literature on climate change effects on buildings has focused on potential changes in overall annual space conditioning energy use. Fewer studies have considered how peak energy demand of buildings may be altered under the future climate scenarios (e.g. Refs. [6,37,38]). In a study of buildings in the Eastern Interconnection of the US, Dirks et al. [6] found that peak energy demand increases more significantly compared to the overall annual building energy use under future climate scenarios. Changes in peak demand should be considered as it serves as a basis for appropriate dimensioning of heating and cooling systems. Some studies have explored the risk of buildings overheating under future climate conditions, and investigated strategies to minimise overheating ([15,17,24,39,40]).

While a growing number of studies have been reported on the implications of climate change for energy performance of buildings (e.g. Refs. [5,32,34]), very few detailed analyses have been reported for the Swedish context. The impact of climate change on thermal performance of buildings may vary depending on geographic location and climate condition [6,32,34]. Nik and Kalagasidis [41] explored long-term annual space conditioning final energy use and indoor air temperatures for existing Swedish buildings in Stockholm. They considered different future climate change scenarios and investigated the feasibility of different ventilation strategies for the buildings. The authors found that the buildings mean indoor temperatures and cooling demands increased variably depending on the climate scenario while space heating demand decreased by about 30%, by 2100 compared to the baseline of 2011. Kalagasidis et al. [42] analysed a simplified test building for future climate projections for the Swedish city of Gothenburg and estimated space heating demand to decrease by 30% while space cooling demand increase by 47% by 2100, compared to 1991–2000 levels. Furthermore, a study in the Swedish context investigated the robustness of building retrofit measures under different climate change scenarios using a statistical approach [43] while another study explored long-term data for building performance analysis with regard to climate change [44]. In another study, a general overview of hygrothermal effects and design criteria for Swedish buildings under future climate projections were presented [45].

Still, the Swedish studies reported, like most international studies, are based on the SRES (Special Report on Emissions Scenarios) climate projections [46]. Further, the studies considered limited configurations of buildings and adaptation strategies. Since