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EFFECTS OF NEARLY ZERO ENERGY BUILDING RENOVATION ON THE THERMAL COMFORT IN A SWEDISH MULTI-APARTMENT BUILDING

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ABSTRACT

A considerable share of the existing building stock in Europe is expected to last for at least the next 30 years and has low energy performance. These buildings have high space heating demand and give low thermal comfort for the occupants. This study investigates the effects of nearly zero energy building (NZEB) renovation on the thermal comfort levels in a typical Swedish multi-apartment building in Växjö, Sweden. Dynamic simulation is performed to assess the thermal comfort levels in the building before and after implementing the energy efficiency measures (EEMs). The percentage of discomfort hours for three representative apartments before and after renovation are modelled with the building's existing heating, ventilation, and air conditioning (HVAC) system, without active cooling device. The building before the notional renovation had final energy use of 133 kWh/m^2 year for space heating, domestic hot water (DHW) and facility electricity. The results show a significant reduction in the hours of discomfort after the NZEB renovation during winter period, demonstrating the effectiveness of the thermal envelope improvements in enhancing the building's thermal comfort during the heating season. On the contrary, during the summer period, the situation dramatically changes after the NZEB renovation, with the operative temperatures exceeding the 26°C threshold in 60%, 97% and 99% of the occupancy hours for the months of June, July and August, respectively. Notwithstanding summer overheating, the total percentage of discomfort hours for the whole year decreased by 61% when the EEMs were modelled for the studied building. This study suggests the need to integrate thermal comfort improvement strategies such as, installation of external shading devices and cooling devices, when renovating buildings to the NZEB standard.

Keywords: Thermal comfort; renovation; residential buildings; multi-apartment buildings; temperate climate; NZEB; indoor climate; overheating

INTRODUCTION

The global climate is undergoing accelerated changes, evidenced by a 0.99°C increase in global surface temperatures compared to the years 1850-1900 [1]. This rise can be attributed primarily to the elevated levels of greenhouse gases (GHGs) in the

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Earth's atmosphere. If no substantial reductions are made in high carbon intensity systems and current trends persist, this may result in a profound impact on the physical and human geography of the world. In line with the goals of the Paris Agreement, which aims to limit global temperature rise below 1.5°C [2], the recent European Green Deal has set a target of reducing GHGs emissions by at least 55% by 2030 [3]. Being responsible for 40% of final energy consumption, 36% of associated CO_2 emissions and 55% of electricity consumption [4], the building and service sector is considered a key factor in achieving the climate targets.

Current policies and building energy regulations in Europe are driving towards nearly zero-energy buildings (NZEBs). As global temperatures rise, heating energy demand of buildings will decrease and cooling demand is projected to increase [5]. Consequently, it becomes crucial to investigate the energy and indoor thermal comfort performances of NZEBs to identify the frequency of overheating and thereby address these incidents. Jones et al. [6] monitored indoor temperatures in identical NZEBs in the UK. They found that these buildings became uncomfortably warm and were at risk of overheating during the summer months. Also, the study shows that most of the renovation projects in cold climate countries focus mainly on heat-saving measures and ignore the cooling demand. Thus it is vital to analyze the effects of implementing heat-saving measures on the energy and indoor thermal comfort of NZEB.

The aim of this paper is to evaluate both the indoor environment and energy use of a retrofitted multi-family building in Southern Sweden. The building is renovated to achieve the energy use level of NZEBs. Energy balance simulations are done in order to investigate how the performance of the indoor environment of the retrofitted building compared to the reference case. Investigation of the annual space heating demand change is also included in this study.

METHODS

This study begins with modelling different energy efficiency measures (EEMs) to an existing multi-apartment building, to assess the impact on the building's energy consumption and indoor environment performance after achieving NZEB standards.

Case study building

The building chosen for this study is a typical multi-apartment building with a concrete frame. This type of multi-apartment dwelling constitutes a considerable portion of the current residential building stock in Sweden and other European nations [7]. The studied building was constructed in 1965 and is situated in the Alabastern neighborhood of Växjö municipality, Sweden (latitude: 56° 88' N, longitude: 14° 81' E). The three-story building contains 12 apartment units and has an overall heated area and ventilated volume of 1223 m^2 and 3173 m^3, respectively. An image of the analyzed multi-apartment dwelling is shown in Fig. 1. The building's outer construction and technical systems are in their initial state as no significant retrofitting had been done.

Fig.1. The case study concrete-frame building analyzed in this study.

NZEB renovation

Different passive and active EEMs were applied to the multi-apartment building in order to reach the NZEB energy use level. In Sweden, the specific energy requirement of the NZEB level is between 35-65 kWh/m^2 year for multi-apartment buildings with non-electric heating systems [8]. The specific energy requirements include final energy use for heating, comfort cooling, domestic hot water production (DHW) and for building facility electricity [9]. Prior to the NZEB renovation, the baseline building used 133 kWh/m^2 of energy annually for space heating, domestic hot water (DHW), and facility electricity.

For the NZEB renovation, different types of thermal insulation materials for the exterior walls, roof and ground floors were considered based on common practices and market availability. 500 mm of Glass wool insulation (λ=0.04 W/m K) was added to the roof and exterior walls. Same thickness of expanded polystyrene (EPS) insulation was added to the ground floor element. The existing windows were replaced with triple-pane windows filled with argon gas. The overall U-Value of glazing is 0.8 W/m^2 K with a g-value of 40%. The old doors were replaced with ones containing layers of aluminum, wood and light insulation material, with an overall U-value of 1.1 W/m^2 K. Furthermore, the conventional water taps were replaced with efficient water taps based on best available technology.

The active EEMs applied in NZEB renovation consisted of installation of heat recovery ventilation (VHR) unit along with PV-panels. A centralized air handling unit (AHU) with a counter flow heat exchanger for heat recovery is assumed to replace the old ventilation system. The heat recovery efficiency and supply air temperature are 85.3% and 18.0 °C, respectively [10]. The fan static pressure of the supply air and the exhaust air are assumed to be 471 and 507 Pa, respectively [10].

Energy and indoor environment simulation

A multi-zone model of the case study building was developed using IDA ICE simulation tool [11], to analyze the energy use and indoor thermal performances. IDA ICE stands as a pioneering and reliable software solution designed for comprehensive year-round, dynamic multi-zone simulations. Its primary purpose is to analyze the thermal indoor climate and assess the energy usage across entire buildings. IDA ICE employs cutting-edge physical models that align with the latest research findings and best available models, demonstrating a strong correlation between computed results and real-world measured data. This versatile tool caters to a worldwide audience while accommodating localized needs, including language support and compliance with regional requirements such as climate data, standards, specialized systems, unique reporting, and product/material data. The accuracy and reliability of IDA ICE have been demonstrated through numerous projects and studies, with validation against actual measurements [12-17]. The integrated ESBO plant model was utilized to simulate solar-based renewable energy systems.

Meteonorm software (Meteonorm, 2019) provided the weather data for the city of Växjö in 2019, which was used in the analysis. The percentage of hours of discomfort is defined as the percentage of hours with indoor temperatures outside the thermal comfort range. Discomfort hours are the hours with indoor temperatures lower or higher than the thermal comfort range. According to the Swedish National Board of Housing, Building and Planning (Boverket), the thermal comfort range is between 18 ∘ C–26 ∘ C [18]. The percentages were calculated for 3 representative apartments from each floor, for the pre and post retrofit cases of the building. The windows opening control are assumed to remain always closed during the simulations.

RESULTS AND DISCUSSIONS

Fig.2. shows the final energy use before and after renovation. Before implementing the EEMs, the case study building had an annual total final energy consumption of 133 kWh/m^2 for space heating, domestic hot water (DHW), and facility electricity. Space heating used the most energy, averaging 103.6 kWh/m^2 per year and constituted roughly 78% of the total final energy use. Energy use for DHW accounted for 19 % of total energy use yielding an annual 25 kWh/m^2. About 4.3 kWh/m^2 per year (about 3%) was used by the facility to power common spaces and the pumps and fans in the HVAC systems. Fig. 2 shows that NZEB energy use level is more than achieved when applying the active and passive EEMs, which reduced the building's annual energy use to 43 kWh/m^2.

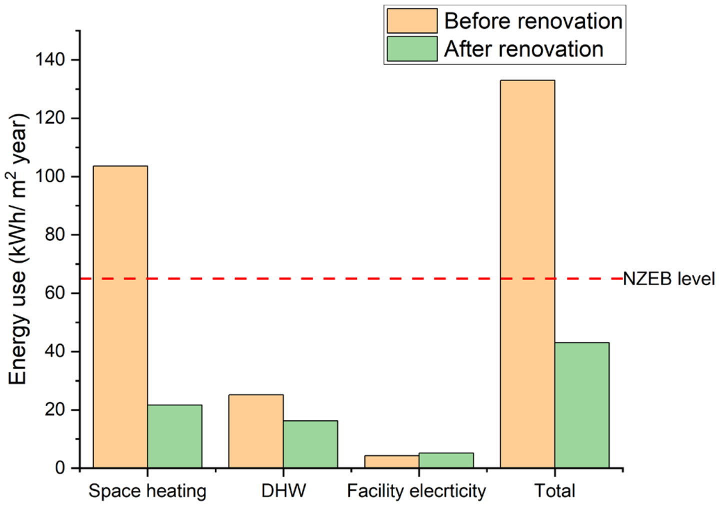

Fig. 2. Annual space heating, DWH and facility electricity before and after NZEB renovation.

Figs. 3 shows boxplots representing the statistical distribution of the indoor temperatures for 3 representative apartments from each floor for the coldest (February) and warmest (August) months.

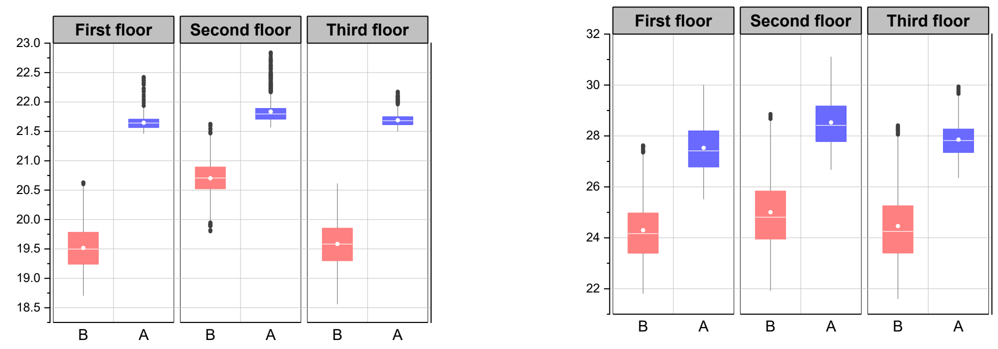

Fig.3. Boxplots of the indoor and outdoor temperature of three representative apartments before (B) and after (A) renovation during, February (Left) and August (right).

The median, lower and upper quartile along with the range of the data is represented in the figures. In the winter, the results indicates that the indoor temperature variation is reduced in the apartments after renovation compared to before renovation. This is because of the added insulation and improved windows and doors. Also, NZEB renovation prevented in winter low temperatures in the sample apartments. Much more comfortable temperatures could be reached in the winter period thanks to the renovation. For the hotter period, high indoor temperatures are recorded both before and after renovation. The renovation reduced significantly the temperature fluctuations occurred before renovation. However, the building envelope improvements resulted in high indoor temperatures after renovation. This indicates that the building is not properly ventilated resulting in low heat dissipation to the outside. The highest indoor temperature is 30.2 ∘ C and occurred in the representative apartment located on the second floor. Figure 4 Show the average percentage of discomfort hours for the three representative apartments.

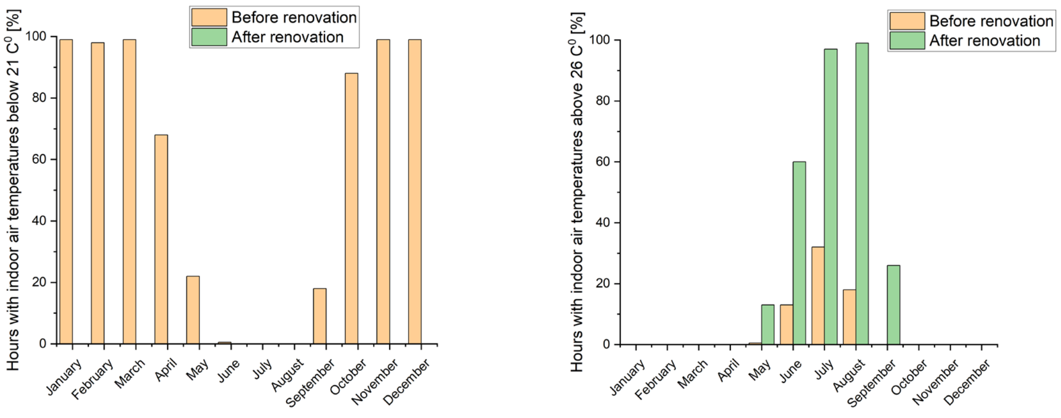

Fig.4. the average percentage of hours below 21C^{o} (left), and exceeding 26C^{o} (right).

The figure shows significant reduction in the hours of discomfort after the retrofit throughout winter months indicating the effectiveness of the thermal envelope improvements in enhancing the thermal comfort of the apartments. Also, it is vital to note that these thermal comfort levels are achieved while maintaining the existing HVAC systems and district heating. Furthermore, the profile of the indoor temperature for the three representative apartments indicates a lowered temperature fluctuations during February month where the temperatures of the apartment were maintained around 21 ∘ C compared to 19 ∘ C before renovation levels. Before renovation, the minimum values recorded in the apartments were close to 18 ∘ C while after renovation the minimum values were maintained at 21 ∘ C. This shows the influence of thermal envelope improvements on thermal comfort. On the other hand, during the summer period, the situation dramatically changes after renovation where the operative temperature is above 26°C in 60%, 97% and 99% of the occupancy hours for the June, July and August months. This shows the importance of further augmenting the NZEB renovation with the installation of external shading devices and cooling devices. Despite overheating in summer,, entailing the total percentage of discomfort hours for the whole year decreases by 61% after NZEB renovation.

CONCLUSION

This study showed significant reductions in final energy use along with improvements in the thermal comfort conditions when a typical Swedish multi-apartment building is notionally renovated to the NZEB level. The retrofitted building achieved a total specific energy use of 43 kWh/m^2 year, representing a 68 % reduction in the building's initial final energy use. Furthermore, the yearly total percentage of discomfort hours of the building reduced by 61% when the EEMs were modelled for the building. However, increasing the insulation level of the building's envelope resulted in high indoor air temperatures during summer months. In summary, this study showed the importance of analysing the effects of buildings' refurbishment despite being always positive- on the thermal comfort.

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