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Primary energy implications of different design strategies for an apartment building

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ABSTRACT

In this study, we explored the effects of different design strategies on final and primary energy use for production and operation of a newly constructed apartment building. We analysed alternatives of the building "As built" as well as to energy efficiency levels of the Swedish building code and passive house criteria. Our approach is based on achieving improved versions of the building alternatives from combination of design strategies giving the lowest space heating and cooling demand and primary energy use, respectively. We found that the combination of design strategies resulting in the improved building alternatives varies depending on the approach. The improved building alternatives gave up to 19–34% reduction in operation primary energy use compared to the initial alternatives. The share of production primary energy use of the improved building alternatives was 39–54% of the total primary energy use for production, space heating, space cooling and ventilation over 50-year lifespan, compared to 31–42% for the initial alternatives. This study emphasises the importance of incorporating appropriate design strategies to reduce primary energy use for building operation and suggests that combining such strategies with careful choice of building frame materials could result in significant primary energy savings in the built environment.

1. Introduction

The share of fuel use was about 97% of the global primary energy use in 2012 with fossil fuels making up over 80% and accounting for about 66% of the total greenhouse gas (GHG) emissions [1]. Despite a significant increase in the renewable energy share in the European Union (EU-28) from 6% in 2001 to 10% in 2011, still about 75% of the total primary energy use in the EU-28 came from fossil fuels in 2011 [2], whiles in Sweden fossil fuels accounted for about 36% of the primary energy use in 2011 [3].

Buildings are key to a sustainable future because their designs, construction and operation are significant contributors to energy-related sustainability challenges. Reducing energy use in buildings can play one of the most important roles in solving these challenges [4]. In 2010, the building sector's final energy use amounted to about 32% of the global final energy use and over 30% of related CO_2 emissions [5]. In the EU-28, buildings accounted for about 38% of the total final energy use [2] while the Swedish residential and service sectors' share of the total final energy use was also about 38% with buildings accounting for about 90% of the final energy use in these sectors and about 60% of this energy use was for space heating and hot water supply in 2011 [3].

Building envelopes affect the space heating and cooling demands as well as the comfort levels in buildings. Energy loss through building envelope elements could be significant. The thermal properties of different building envelope elements in new and renovated buildings have improved over the years but the *u*-values of windows are still relatively high compared to those of walls and roofs. Therefore, windows can be a source of large energy losses during the use phase of buildings, reaching between 40% and 60% of the total energy loss [6,7]. Nevertheless, windows could also contribute to reduced energy use in buildings if they are carefully selected and properly incorporated in building envelopes to take advantage of the building's local climate. The construction and design of low energy buildings have focused on reducing space heating demand, especially for cold climate regions. However, with improved thermal performance and warming climate, energy efficient buildings are becoming more prone to overheating and increasing cooling demand. This is confirmed by several studies which have evaluated the design and performance of such buildings in different climate contexts [8–10].

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Different studies have shown the significance of the influence of window sizes and orientation on the energy balance of buildings in different climates. Persson et al. [11] studied the influence of different window sizes and orientations on the final energy use of a low-energy terrace house in Sweden. They performed simulations of the building with decreased window areas on the south façade and increased window areas on the north façade and investigated the influence on the final energy use to maintain a comfortable indoor temperature. Their results showed that the effect of varying the window areas facing the south façade was more significant for the space cooling demand of the building than for the space heating demand. Hassouneh et al. [12] considered the effects of eight different glazing types on the heating demand of an apartment building in Amman by using a self-developed simulation software based on ASHRAE tables. They varied the orientation and size of the windows to determine their influence on the thermal balance of the building. They found that with different types of energy efficient windows, there is a wide range of flexibility in the choice of glazed area and orientation. They concluded that for the analysed apartment building, certain combinations of glazing types and orientations were more energy efficient than others. Jaber and Ajib [13] analysed the performance of a single, two different types of double (low and high) and a triple glazed windows on the annual space heating and cooling demands of a building in three different cities: Amman, Aqaba and Berlin. They varied the windows' *u*-values, orientation and size, and found that the space heating demand of the building was more sensitive to window type and size than the space cooling demand. Yaşar and Kalfa [14] investigated the influence of different types of double glazed windows with a tinted, clear reflective, low-emissivity or smart glass on the energy demand and economy of two different apartment building types in Turkey. They concluded that double glazed windows with smart and low-emissivity glazing were the most energy- and cost-efficient option. Gugliermetti and Bisegna [15] studied the energy savings possibility of the potential use of fully reversible double glazed windows with an absorbing and clear glass on either side. They considered several configurations of the windows in different Italian climate locations as well as different strategies to control the risk of overheating. They concluded that though reversible windows could lead to energy savings, for Mediterranean climates they may also be linked to winter overheating due to excessive solar gains and that appropriate strategies may be required to control the overheating risks. Grynning et al. [6] proposed three rating methods for the assessment of the energy performance of different window configurations. They applied the proposed ratings to analyse the energy performance of windows installed in a Norwegian office building by varying the *u*-values and solar heat gain coefficients of the windows. They showed that the extent of energy saving potentials depends on the rating method but reducing the window *u*-value from 1.2 to 0.8 W/m^{2}K resulted in 5–15% reduction of space heating and cooling demands depending on the corresponding solar heat gain coefficient. Poirazis et al. [16] performed energy balance simulations of glazed office buildings in Sweden. They analysed the impacts of varying the ratio of window area to external wall area by 30%, 60% and 100%, glazing type and size among others on the operation energy use of the buildings. They found that highly glazed office buildings could result in higher space heating and cooling demands, compared to buildings with conventional façade elements. The above studies have focused mainly on the effect of different window types, sizes and orientations on the space heating and cooling demands of individual buildings or their variations with identical energy performance.

Few studies have compared the influence of window sizes and orientations on the final and primary energy use for space heating and cooling of buildings with varied energy efficiency levels. Leskovar and Premrov [17,18] studied the influence of glazing size on the architectural design and energy efficiency of timber-frame buildings with different external wall configurations and varying thermal transmittances. The focus of their studies was to analyse the effect of glazing size on the space heating and cooling demands of the studied buildings and to identify the optimum glazing size on the southern façade. However, they did not consider the primary energy implications and possible effect of the production energy of the different external wall configurations of the studied buildings.

Various design strategies may be adopted to achieve lower operation energy use. In Nordic climate, with low outdoor temperatures and limited solar radiation during the cold season, design strategies that reduce solar gains during the summer season and allow as much solar gains as possible in the winter season may be beneficial. Hence, the size, type and orientation of windows may influence the space heating and cooling demands of buildings in such a climate.

The choice of window types and sizes may also have implications for the production energy use of buildings and hence the optimisation of the life cycle energy use. Different quantities of building materials are required to construct buildings with varied sizes of window openings and thermal performance of the envelope elements. Hence, both the energy use for production and operation need to be considered to optimize different design strategies of buildings aiming at a minimised life cycle energy use. However, studies that have analysed the energy implications, especially primary energy implications of incorporating different design strategies in buildings from a life cycle perspective are lacking.

In this study we analyse the final and primary energy implications for an apartment building with three different energy efficiency levels considering (i) the proportion of window areas on the different façades; (ii) the orientation of the largest window areas of the building alternatives; and (iii) the thermal transmittance (*u*-values) and solar transmittance (*g*-values) of the windows. We also consider the effect of different heat supply systems and the trade-offs between the primary energy for operation and production as a result of the varying proportions of envelope elements in the building alternatives.

2. Studied building

The studied building is a 6-storey concrete frame structure with 24 apartments, comprising 1–3 rooms with a total heated floor area of 1686 m^2. It was completed and occupied in early 2014 with a calculated final energy use per square meter heated area of 71.6 kWh/m^2 year, including space heating, tap water heating and electricity for ventilation. The studied building "As built" was designed and built with a lower annual specific final energy use than required in the Swedish building code of 2012 (BBR 2012) [19], but higher than that for the Swedish passive house criteria of 2012 (Passive 2012) [20]. The foundation of the building consists of layers of 200 mm crushed stone, 300 mm cellplast insulation and a 100 mm ground floor concrete slab. The external walls consist of 100 mm and 230 mm concrete on the outside and inside respectively, with a 100 mm layer of cellplast insulation material between them. The internal walls are of two types, namely load bearing and non-load bearing. The load bearing internal walls are made of 200 mm thick concrete, whiles the non-load bearing walls comprise of two layers of 30 mm thick gyproc plasterboards with steel studs spaced at 600 mm and air gaps of 95–145 mm between them. The intermediate floors are 250 mm concrete slabs whiles the ceiling floor is made up of 250 mm concrete slab and 500 mm loose fill rock wool insulation with wooden trusses and a roof covering over layers of asphalt-impregnated felt and plywood. The