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Measured and predicted energy use and indoor climate before and after a major renovation of an apartment building in Sweden

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ABSTRACT

This article presents a case study of a renovated Swedish apartment building with a common design built in 1961. The aim is to present numerical predictions, validation and evaluation of energy use and indoor climate for the building before and after renovation. Comprehensive field measurements were carried out before and after the renovation to be used as input data in the building energy simulation tool IDA ICE and for validation of model results. Indoor temperature is predicted with maximum standard deviation of 0.4 °C during winter. Annual heat demand is in good agreement with measurements. The building had an annual climate normalized district heat demand of 99.0 MWh before renovation and 55.4 MWh after, resulting in a 44% reduction. A slight under-prediction of the saving potential is noted, since the indoor air temperature has increased after the renovation. The results also show that assumptions of user behavior have significant impact on the energy-saving potential, and that choice of renovation measures, such as level of insulation, and efficiency of the ventilation heat recovery system need careful consideration. Choice of system boundaries also has a major effect on climate and resource impact from selected renovation measures.

1. Introduction

Residential buildings represent about 23% of the total energy use in the European Union [1]. Improving energy efficiency in the older part of our housing stock has become central to reducing energy use in the building sector overall. Space heating remains the largest share of energy use in buildings, representing between 60 and 80% of total energy use in regions with cold climate [2]. Renovation of buildings can significantly reduce space heating demand, and studies have shown great potential for energy saving by improving the thermal quality of the climate envelope [3–5], and installing ventilation heat recovery systems [4,5]. Changes in buildings not only impact building energy use, but also have a significant effect on surrounding energy systems, resource use and climate impact [6]. The Energy Performance of Buildings Directive (EBPD) recognizes that when buildings are in need of major renovation, opportunities for reducing energy use emerge [7]. The EBPD defines major renovations as renovations where the costs for renovating the climate envelope and technical building installations comprise more than 25% of the value of the building, or when more than 25% of the climate envelope is changed.

Around 35% of Swedish apartments are located in buildings constructed between 1961 and 75 [8], a record-breaking period for residential construction in Sweden. In 2003, the Swedish National Board of Housing, Building and Planning performed an extensive investigation of the Swedish housing stock and concluded that the rate of renovation needed to increase threefold within the next 15–20 years, mainly in multifamily buildings from this period [8]. It is estimated that around 75% of these buildings are in need of some sort of renovation [9]. The importance of improving energy efficiency when renovations are performed was recognized in the Swedish Budget Bill for 2017, where 105 million EUR is budgeted for renovation and improvement of energy efficiency in multifamily buildings [10].

Several major renovation projects in similar climatic conditions as the case presented in this study have been reported in the most recent years. In order to compare the results from this study nine other projects are presented, see Table 1. All renovations included thermal improvements of the building envelope and installation of a heat recovery system. Control systems, such as demand controlled ventilation, was implemented in three of the nine cases. Substantial thermal improvements were made in project Brogården and Katjas gata and significant energy savings were achieved.

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Table 1
Results from renovations and performed renovation measures in contrasting studies.

Location	Project name	Building envelope	Heat recovery	Control system	Solar collectors	Solar (PV)	Energy use (kWh/m²·year)[a]		Reduction	Ref
							Before	After		
Allingsås, Sweden	Brogården	X	X				177	58	67%	[11]
Gothenburg, Sweden	Gårdsten	X	X	X	X		263	145	45%	[11]
Gothenburg, Sweden	Katjas gata	X	X				178	52	71%	[11]
Linköping, Sweden	Magistratshagen	X	X				131	80	39%	[12]
Halmstad, Sweden	Maratonvägen	X	X				145	92	37%	[13,14]
Hvalso, Denmark	Traneparken	X	X	X			139	96	31%	[15]
Roskilde, Denmark	Sems Have	X	X			X	156	51	67%	[13,14]
Kapfenberg, Austria	Kapfenberg	X	X	X		X	146	46	68%	[13,14]
Vilnius, Estonia	Project I-464	X	X				212	132	38%	[16]

[a] Including domestic hot water.

Significant energy use reductions were also seen in the renovations where solar installations have been implemented.

Building energy simulation (BES) is a powerful tool for predicting the effects from renovation or other energy measures, and is widely used in the planning phase of renovation or new construction. However, previous research indicates that there is a lack of post-occupancy evaluation of building energy performance [17]. Several authors have also indicated a gap between predicted and measured energy use in both newly constructed and renovated buildings [17–21]. It is widely agreed that user behavior and occupancy is one reason for differences in expected, modelled or calculated and actual performance of buildings [21–25]. Dar et al. shows that different user behavior can cause a deviation of up to 12% from predicted energy use [21]. De Wilde argues that uncertainties in the design stage is another reason for a performance gap [17]. This study both evaluates the technical aspects of a major renovation and takes into consideration the realistic conditions under which the building is used by an extensive empirical validation of a BES model.

This article presents a case study of a major renovation of an apartment building in Sweden. The aim of this study is to present numerical predictions, validation and evaluation of energy use and indoor climate for the studied building before and after renovation, and to analyze how different choices of renovation strategies, user behavior and the efficiency of the ventilation heat recovery system impact energy performance. Comprehensive field measurements have been performed in the building and reference apartments during occupancy before and after the renovation and are used as input data in a BES model and for validation of modelled results. Resource and climate impacts are analyzed based on energy use-related CO_2 emissions and primary energy use.

2. Case description and methodological approach

The building was modelled in IDA ICE version 4.6.2 using field measurements and other available information about the building, such as blueprints. IDA ICE is a general simulation framework released in 1998 [26] that offers detailed dynamic simulation for building energy use, heating loads and indoor climate. Energy needed for domestic hot water is excluded from the simulations, and any reference to energy performance or heat demand therefore refers to thermal energy needed for space heating, unless otherwise stated.

2.1. Case description

The studied building is an apartment building with district heating located in southeastern Sweden, owned by a municipal company. It was constructed in 1961 and underwent major renovation in 2014. The building has five stories that hold twelve apartments. The original construction was light weight concrete (LWC) and the building was ventilated with an exhaust air system. The windows were non-gas filled, clear glass 3-pane and 2-pane windows. The building was in need of renovation primarily since interior surfaces were worn, and kitchen and bathrooms were in need of an upgrade. Previous studies also indicate that obsolescence in installations is the primary reason for renovation, rather than failure in durability or environmental reasons [27]. There was also a desire to reduce energy use in the building and hence thermal properties of the building were improved, see Table 1. *U*-values are calculated from thermal conductivity of materials and their thickness, in accordance with ISO standard 6946 [28]. Information in original blueprints was used. The predefined values for thermal bridges in IDA ICE were used and all were set to “typical.” IDA ICE then assigns loss factors in W/K/meter joint or perimeter. Loss factors vary between 0.03–0.05 W/K m for connections between internal walls and slabs and external elements (roof, external walls and external slab), as well as around windows and doors. External walls in connection to external elements have loss factors varying between 0.08–0.14 W/K m. Exact values can be found in IDA ICE version 4.6.2.

Insulation was added to the entire façade, new well-insulated windows were installed and the attic was insulated. The mean *U*-value was calculated as the sum of each segment’s transmission losses divided by the total external area. The mean *U*-value was reduced from 0.54 to 0.29 W/m^2 K. The exhaust ventilation system was replaced with a mechanical supply and exhaust ventilation system with heat recovery. Fig. 1 shows a comparison of the heat balance of the unrenovated and renovated building modelled with the validated building model and normalized climate data.

Both transmission losses and ventilation losses have been significantly reduced. There is a slight increase in transmission losses through the floor and other losses (such as infiltration) in the renovated building, since the indoor temperature is higher after the renovation. Although the new windows reduce the heat losses, they also give smaller solar heat gains, due to the lower solar gain factor; 16 MWh compared to 24.4 MWh. The internal heat gains from appliances are the same before and after renovation, but a larger share is useful heat gains, free heating, before the building was renovated.

2.2. Field measurements

Field measurements were performed in two occupied reference apartments, one renovated and one unrenovated. The reference apartments were similar in size and located in the same part of the building, see Fig. 2. The tenant in the unrenovated apartment did not move back in after the renovation was performed and the new resident was uninterested in participating in the study. Hence another reference apartment was used after the renovation.