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Assessment of renovation measures for a dwelling area – Impacts on energy efficiency and building certification

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A R T I C L E I N F O

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A B S T R A C T

The European Union has an ambitious plan to reduce energy use and emissions by the year 2030. The building and real estate sectors have a great potential to help reduce emissions by energy efficiency. However, different energy sources and environmental standards affect the decision making of these major renovations in the existing stock. This study investigates how different renovation strategies affect the energy rating of a selected Building Environmental Assessment Tool and analyses the consequences in terms of greenhouse gas emissions for the local district heating system. Both building energy simulations and energy systems cost optimization were used to determine the energy use and local emissions. The results of different renovation scenarios were used to evaluate the rating in the selected tool and the impact in the district heating local emissions. The used methodology illustrates how energy efficient renovation impacts on the district heating system's local emissions. However, a bias towards resource classification within the Swedish Building Environmental Tool, Miljöbyggnad, needs to be addressed in order to assess the impact of local emissions.

1. Introduction

The European Union (EU) energy efficiency communication [1] has set a goal for reductions in energy use in buildings of approximately 30% and in Greenhouse gas (GHG) emissions of 40% by 2030 compared to 1990. Buildings are responsible for 40% of the total energy use and 36% of total GHG emissions within the EU [2]. In Sweden, large reductions in CO_2 emissions from the building and real estate sectors have been made, accounting for only 15% of the total national GHG emissions. This is because both electricity and district heating (DH) in Sweden mainly come from renewable energy sources and nuclear power, in which is not the case in other EU countries [3]. Due to the low-carbon energy sources in Sweden, the building and real estate sector is a forerunner when it comes to decreasing GHG emissions within the EU, but still there is great interest in Sweden in improving energy efficiency.

According to the European Commission [4] 80% of the population will be living in already existing buildings by the year 2030. According to Botta [5], this is because more buildings are being renovated than there are new ones being built in Europe and North America. This trend is noticeable in the EU where the growth rates of the residential sector are just around 1% [6]. In Sweden, around one third of the total housing stock was built in the period 1965–1975 in the so-called Million Homes Program (Miljonprogrammet). The program was characterized by a highly rationalized use of materials as well of a high degree of experimentation, which in turn led to the culmination of roughly one million dwellings (in - at the time-a country of 8 million inhabitants) making this one of the most ambitious housing programs of its era [7]. After roughly 40 years after its culmination, and with the new EU energy directives in sight, the way that these dwellings use energy is a challenge in rethinking. Most of these buildings were finished before the 1973-74 global oil crisis in an era when an unlimited supply of cheap energy was assumed [8].

Shortages in oil during the first oil crisis and the threat of a shortage of energy due to the dependency on imports also gave an opening for a big development of district heating systems in Sweden. Most of the buildings built during the Million Homes Program were connected to a district heating system; in fact roughly 90% of Sweden's multifamily buildings are connected to DH systems. In

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230 of Sweden's 270 municipalities there is a DH plant, covering approx. 50% of the national heating demand [9]. The first oil crisis and the dependency on fossil fuels also sparked the concern about the impacts of our activities, in particular regarding the limits to growth. Public awareness of environmental impacts led to the development of Building Environmental Assessment Tools (BEAT) during the 1990s. Two of the most used and known tools are LEED [10] and BREEAM [11]. In the late 1990s there was a need to develop a tool for the particular Swedish conditions, mainly because it was found that different tools define environmental performance differently making it difficult to make comparisons [12]. According to Glaumann et al. [13], a dialogue between different actors in the Swedish building sector led to the development of a BEAT that would be building oriented, easy to use and implement, available for as many stakeholders and buildings as possible and based on both national and international experience. It was important for the tool developers to tackle the limitations of other BEATs (such as LEED and BREEAM). The development of the Swedish BEAT resulted in what is now called Miljöbyggnad('Environmental building') which is the most used BEAT in Sweden [14]. Miljöbyggnad is based on Swedish building praxis and governmental regulations. The main goal is to have a simple and effective certification system. It focuses on three areas; 'Energy use', 'Indoor climate' and 'Materials and chemicals' and can be implemented both in renovation projects and for new construction [15]. The system design has been guided by simplicity and by using existing regulations such as energy declarations, mandatory ventilation control etc. In order to tackle the limitations of other BEATs one of the main goals of the development of Miljöbyggnad was to keep the cost of implementation as low as possible, as the different indicators are intended to affect the whole rating of the building, leading to a holistic approach and tackling the so called "points chasing". Miljöbyggnad on the other side aims to assess every aspect in their own and gives the aspects an equal weight, so it is not possible to compare it to LEED and BREEAM [12]. When it comes to energy sources, LEED and BREEAM have a completely different approach as Miljöbyggnad has due to the fact that LEED is intended originally to be used in the US and BREEAM in the UK [16].

Buildings and DHS are interactive systems. When there are changes in one of the components it will have an overall impact in the other system. Both systems are linked dynamically and the demand for heat is closely linked to several factors such as weather and user behavior. When it comes to studies of the district heating system, buildings are usually referred to as a "load" without taking into consideration that buildings change over time due to refurbishment and more energy efficient appliances and equipment. Similarly, when energy efficient refurbishment scenarios are analyzed, usually it is taken into consideration an energy source which is more or less static without considering that energy carriers have a rapid development and in some cases, as in district heating, they vary on demand and price due to other aspects such as availability and storage. When it comes to environmental impacts there is abundant literature when BEAT is applied to energy efficient renovation with a simplification of the energy system. At the same time studies of energy systems often focus on energy use (often MWh) or in some cases CO_2 equivalents, without considering any other environmental impacts. In a previous work by Lidberg et al. [17] an interactive methodology between Building Energy Simulation (BES) and Energy systems simulation was proposed in order to determine how minor refurbishment measures would affect the local energy system. The aim of this study is to.

1. Investigate how different dwelling renovation strategies affect the energy rating in a Swedish Building Environmental Assessment Tool (BEAT) (Miljöbyggnad 2.1)
2. Analyse the consequences in terms of CO_2 emissions from the district heating system
3. Discuss implications of Miljöbyggnad in relation to these results

2. Methodology

The methodology is proposed to determine how different refurbishment scenarios could affect the local GHG emissions and the rating in the selected BEAT. The methodology is adapted from Lidberg et al. [17] (using a new DH system simulation tool and adding a BEAT). In the first step the Construction and Calibration of IDA-ICE (Indoor Climate and Energy simulation Tool) Pilot building model, data is collected to calibrate the proposed model. Then in the second step, Simulation of renovation scenarios in IDA-ICE, the proposed renovation strategies are simulated based on the validated model and the results are scaled up to mirror similar changes in the whole area. These results are filled in the third step, Simulations of DH system with MODEST (an energy system optimization model developed by the Department of Mechanical Engineering - Linköping University: Model for Optimization of Dynamic Energy Systems with Time dependent components and boundary conditions (GHG Emissions) [18]. The output of this simulation is finally analyzed to assess the impact of the scenarios on local GHG emissions. At the same time the results for the building energy performance are used to assess the selected building with a BEAT giving a building environmental rating that is used to analyze the overall result (Fig. 1)

2.1. Construction and calibration of IDA-ICE pilot building model

The selected case study building is a three story residential building located in the municipality of Borlänge, Sweden (250 km Northwest of Stockholm). The building is located in an area called "Tjärna Ängar", built within the years 1969–1971 during what was known as the Million Homes Program.

The selected building was simulated using IDA-ICE, software to simulate indoor climate and energy consumption in buildings. To make an accurate simulation a calibration was obtained based on the monitored heat demand of the building provided by the operator. It should be noticed that the monitored heat demand is one of the supplied energy loads in the building energy balance. Another important heat load is the utilized solar irradiation. The latter is difficult to estimate. Thus the calibration was based on data from the period November 2014–February 2015 when solar irradiation has a negligible contribution to the heating demand in Sweden [19].

To monitor the building, heating demand temperature loggers were placed in both the supply and return of the hydronic system of the building as the district heating substation is located in another building. The indoor temperature was measured using a temperature logger in the exhaust ventilation duct. Water flow was measured with a logger located in the district heating substation as was the outdoor temperature. Data was logged on an hourly basis under the measured period. The heat demand was calculated using a regression known as the "energy demand signature" [20]. This method is useful to integrate field measured data into Building Energy Simulations (BES); the regression shows results that are robust and increase the accuracy of such models. The results of the regression were compared with the building model in order to adjust the input parameters [21] (Table 1).

2.2. Simulation of renovation scenarios in IDA-ICE

In order to determine the influence of different energy efficient refurbishment scenarios, four scenarios were simulated. The first