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Achieved Energy and Climate Goals in Project Ålidhem: An Evaluation of a Refurbishment of 21 Swedish multifamily Buildings

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Abstract

In Umeå, situated in the north part of Sweden, the largest refurbishment project undertaken by the public housing company in Umeå was completed in 2014. The project had ambitious goals to decrease the bought energy use for domestic hot water, building electricity and space heating, by 50 %. In order to achieve this, a variety of energy conservation measures were implemented in 21 multifamily buildings during the four-year project. This paper describes the used evaluation approaches and the achieved energy and climate goals. Finally, it offers some reflections that are hoped to be useful in similar projects.

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Keywords: Building refurbishment; Measurements; Energy performance

1. Introduction

In many European countries, the building stock increased at a fast pace during the years 1950-1975 [1]. In the case of Sweden, the construction rate was at its highest during the years 1965 to 1975. During this period, the Swedish government set the goal to build one million apartments in ten years, to remedy the acute housing shortage in Sweden [2]. Most of these buildings are now in need of renovation [3] and there is, amongst others, a possibility of introducing energy conservation measures (ECMs) in the renovation process. However, the renovation of this aging building stock is not always a straightforward one, since in addition to energy efficiency targets, the property owner also often needs to consider economic, social and architectural issues. Social sustainability in the renovation of buildings has received increased attention in recent years in Sweden [4]. Mangold concluded in his thesis [5] that subsequent rent increases from renovation projects in economically disadvantaged areas risks aggravating economic inequities. Thus, social sustainable renovation can be presumed to be dependent on keeping the rent increase at a manageable level for the tenants. The rent increase is in turn dependent on good decisions made by the property holder during the planning stage of a renovation project. If ECMs should be implemented, it is important to have a good knowledge of the expected energy savings.

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There exists in the literature a fairly large amount of examples of actual outcomes from individual case studies in renovation projects e.g. [3] and [6]. However, studies that show how well such results agree with results on a building

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aggregated level (multiple buildings) are less common. Therefore, in this study we would like to present results and experiences from a large refurbishment project undertaken by the municipal public housing company in Umeå. During this four-year long refurbishment project, a variety of ECMs were implemented in 21 multifamily buildings. The renovation was done in a stepwise manner, where in the first phase two case study buildings were evaluated and the results had a significant role in decision making in the remaining full scale project. This paper details the taken ECMs and the projects achieved energy and climate goals, both on building level as well as in total. In addition, the paper offers some reflections of the used evaluation approach which is hoped to be usable in similar projects.

2. Project area and measured data

The project area is shown in Fig.1 and includes 21 multifamily buildings, (buildings with common outer walls have been counted as one building). The buildings were built during the years 1970-1971 and initial measurements indicated a high average specific energy use as well as a low indoor comfort in the area. Therefore, a number of ECMs was decided to be included in the refurbishment. In order to decide suitable and cost-effective ECMs for the project a test-building, referred to as Building 1 was initially evaluated. The evaluation of energy savings (building level) was done through a comparison with a similar building, Building 2 in which no measures were undertaken at the time (a comparison possible through very high building similarities). Building 1 and Building 2 can be seen marked in Fig. 1.

Fig. 1.(a) 3D model of one block of buildings in the project area including case study buildings, Building 1 and Building 2, Fig.1.(b) 3D model of the second block of buildings in project area. Both models were created with the help of Google Earth [7].

The initial energy saving target in the project, (all buildings in Fig 1), was to decrease the supplied energy use of domestic hot water, building electricity and space heating per floor area, (referred to as EUI indicator), by 50 %. In order to evaluate this goal, the buildings energy use pre and post renovation had to be collected as well as degree day data. This was done through the local energy company and the Swedish Meteorological and Hydrological Institute (degree day data). The collected energy data consisted of supplied district heat (DH) for space heating and domestic hot water preparation, supplied electricity (property and household electricity) as well as exported and produced solar electricity. The resolution of this data was monthly.

The same categories of data were collected for Building 1 and Building 2. In addition, the indoor climate was monitored, in these buildings, with on-site measurements of the outdoor and indoor air temperatures as well as the supply temperature from the air-handling units to the apartments. Controlled air-supply velocities were also spot measured with a thermal velocity probe. In addition, a survey was conducted to collect data on user perception of the indoor climate. The supplied DH for space heating was monitored in Building 1 and Building 2, in three parts: combined heat to the radiators and air-handling units, sub metering of the supplied heat to the air-handling units and heat for domestic hot water circulation.

3. Description of buildings before renovation

The buildings have a concrete ground slab incorporating a crawl space in the center for inspection of media pipes. The loadbearing frame is made of concrete and the gables and apartment dividing transverse walls are used as loadbearing structure. The original gable walls were made of (from the outside to inside) 12 cm half stone brick, 10 cm mineral wool and 15 cm concrete. The long side outer walls were made of (from the outside to inside) 12 cm half stone brick, 1.2 cm asphalt board, wooden skeleton, 10 cm mineral wool, vapor barrier and 1.3 cm gypsum board. The roof construction consisted of a flat roof type, enclosing a 14 cm concrete attic floor insulated with 25 cm sawdust. The windows where of a two-pane construction and the buildings had mechanical exhaust and supply ventilation system, without heat recovery. The number of floors varies between 2 to 4 in the area.

Six buildings had previously been renovated in the late 80's with heat recovery ventilation (heat pumps and cross plate heat exchangers) as well as upgraded with exterior storm windows (three buildings, incl. Building 2). This reduced the heat loss through the windows on average by approximately 6 % according to onsite measurements by Högberg et.al [8] at the time. The reduction in annual DH-demand due to the installation of heat pumps in two buildings was about 25-26% [8]. The same reduction for the cross plate heat exchanger was about and 12%. This lower performance was explained by frost protection issues (stopped working when the outdoor temperature decreased below -8 °C).

4. ECMs implemented in Building 1

Building 1 was not included in the renovation in the 80's thus the refurbishment in this study was done from the original condition. During the refurbishment process the walls were additionally insulated with mineral wool, 2.8 cm (gables) and 9.0 cm (long side). The insulation was mounted from the inside, (to preserve the original exterior wall, demands made by the city architect). In the process a new vapor barrier was installed at a depth of 4.5 cm (long side). The original flat roof construction was converted to an almost double-pitched roof, incorporating a heated room for placement of an air handling unit with heat recovery. The heat recovery exchanger was of type enthalpy wheel, with a design thermal efficiency of 85%. In the process the old insulating sawdust on the attic was replaced by 50 cm loose-filled mineral wool. The two pane windows (estimated U-value 2.2 $WK^{-1}m^{-2}$) were replaced with tripled glazed windows with a design U-value of 1.1 $WK^{-1}m^{-2}$. New radiators and water pipes together with a system for individual water metering for billing were also installed. Lastly, 121 m^2 photovoltaic panels of two types; CIGS thin film (67m^2) and multi crystalline silicon (54m^2) was installed on the pitched roof.

4.1 Technical evaluation of taken ECMs in Building 1

The achieved energy efficiency is often in demand, but the definition is not always a given. Depending on the approach, a number of different perspectives can be chosen; the energy efficiency of the building and its technical systems, (i.e. neglecting household electricity and domestic hot water), the building's total energy use, minus produced solar electricity or according to the Swedish building regulations, EUI indicator. Therefore, in this study results from all of these perspectives will be presented. The annual degree day corrected energy savings were determined to be 44.4%, (from 160.9 kWh/m^2a to 89.5 kWh/m^2a), in the case of the first perspective and 44.4%, (from 205.8 kWh/m^2a to 114.4 kWh/m^2a), in the second perspective and lastly 42.1%, (from 177.7 kWh/m^2a to 102.8 kWh/m^2a), decrease in the EUI indicator. Thus, the relative savings were, in this case fairly similar between the three different ways of assessing building energy performance. It can be noticed that the savings became fairly close to the set target of a 50% reduction in the EUI indicator.

Some evaluations have also been done for Building 1 on component level. The change in thermal performance of the building envelope of Building 1 due to the above described ECMs was determined from regression analysis of energy and temperature data to be in the order of 23-26% [9]. Similarly, in [6] it was reported that the controlled airflow was almost doubled in the renovation (from 0.26 $l/s/m^2$ to 0.49 $l/s/m^2$). The supplied DH to the air handling unit was about 90% lower than that of Building 2, with negligible differences in supplied air-flow temperatures (ca. 19 °C).

4.2 Utilization of experiences from Building 1 in the rest of the project.

Poor economic returns were revealed for some ECMs in the renovation of Building 1. Firstly, since the implemented exterior wall insulation was mounted from the inside, an alternative accommodation had to be provided for the tenants during the renovation. This was fairly difficult and would have been increasingly difficult performed in a large scale. Secondly, the cost for the implementation including; new interior walls, realignment of radiators and hot water pipes, in combination with fairly low energy savings (assessed with a calibrated simulation tool [10].) resulted in a decision not to move forward with this ECM in the project. As a consequence, new radiators and water pipes together with a system for individual water metering for billing were also cancelled.

It was further found that constant hot water was supplied to the bathroom radiators, creating excess indoor temperatures summertime. Lastly, the heat-loss through the 75 m^2, heated ventilation room, was fairly significant. Thus, some minor adjustments were made regarding the size of the ventilation room and steering of the radiator system in the rest of the project. The size of the ventilation room decreased to a 33 m^2 in average, (21 buildings), and the bathroom radiators were set to be controlled based on the outdoor temperature. With the experiences from renovation of Building 1, the next building to be refurbished within the project was Building 2. It can be seen from Fig. 1 that Building 2 is largely sheltered from the sun by surrounding buildings and therefore solar panels was assessed not to be suitable in this case. With this slightly downsized package of ECMs the degree day adjusted EUI indicator decreased from 195.2 kWh/m^2a to 131.2 kWh/m^2a, which corresponds to a relative savings of ca. 33% for Building 2. Thus, from the results from the case study buildings relative savings between 33% and 42.1% in the EUI indicator was expected for the entire renovation project.

4.3 Evaluation of taken ECMs in Building 1 with respect to indoor climate

In addition to energy savings an improvement in indoor climate was desired. The user's perception of the indoor climate was assessed with questionnaires. The used questionnaire was similar to the one developed in a Nordic collaboration project by Fossdal et.al. [11]. The questionnaire addressed key-indoor climate indicators such as thermal comfort, sound (noise), daylight and air-quality. These questions were complimented with two questions addressing the user satisfaction with the apartment as a whole and lighting in public areas. The number of respondents was 55%, (11 out of 20), before the renovations and 30%, (6 out of 20), after the renovations. The results from the survey in Fig. 2 are presented in percentage form. The percentage values represents the share of the respondents who answered "satisfied" or "very satisfied" of the total number of respondents. It can be seen in Fig. 2 that most of the studied parameters changed in a positive direction due to the renovations and that the parameter which received the lowest percentage of satisfied responses was the thermal comfort.

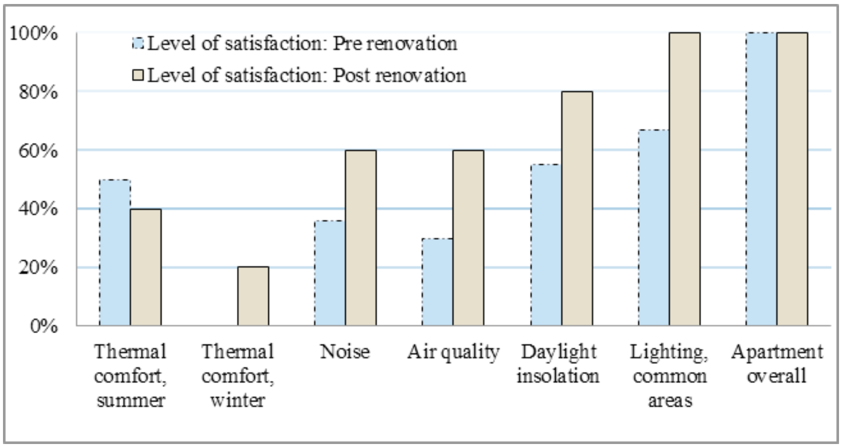

Fig. 2. Summary of results of an indoor climate survey conducted before and after the renovation of Building 1 and Building 2.

The reason for the reported low scores on thermal comfort could not be explained with the indoor temperature data since these were in line with recommended values by the Swedish National Board of Health and Welfare [12]. The daily average of the indoor temperature data seldom ranged outside 20-25 °C during the studied year post renovation (2015-06 to 2016-06. However, low supply air temperatures from the air handling unit in Building 2, were periodically recorded during the heating season, down to 15 °C. This would have created cold supply air diffusers in the apartments, which most likely had a significant impact on the thermal comfort results in Fig.2.

The relatively high proportion satisfied with the air-quality can be explained by an increased fresh air supply in the buildings after the renovation. Measurements made in Building 1 on the supply air velocity, before renovation revealed a low airflow rate of 0.26 $l/s/m^2$ on average during the heating season. After renovations the measured airflow rates were 0.49 $l/s/m^2$ in Building 1 and 0.37 $l/s/m^2$ in Building 2. Thus, both ventilation systems surpassed the recommended threshold value of 0.35 $l/s/m^2$, fresh air supply, stipulated in Swedish buildings regulation standard [13]. The increase in the proportion satisfied with daylight insolation and noise-level is assumed to be a consequence from the window upgrades, but this was not confirmed by empirical data. Somewhat interesting was the fact that the residents were either satisfied or very satisfied with the apartment overall, both before and after renovation. This is harder to analyze, since factor depends on many parameters such as the level of the rent, neighbors, closeness to city etc.

5. Total energy and CO_2 savings, (21 buildings).

The renovations proceeded at full scale with installation of the set of ECMs that were taken in Building 2. In addition, a total area of 2655 m^2 solar panels, (67m^2 of type CIGS thin film, the rest of type multi crystalline silicon), was distributed over the roofs based on conditions of solar insolation. Due to current regulations, the solar electricity production could only be utilized as property electricity [13]. The demand for property electricity was lower than the annual production during the analysed year, post renovation. As a consequence only, 58%, of the total produced solar electricity could be utilized (the rest was exported to the grid). During this period the total produced solar electricity from the system was measured to 317.81 MWh, corresponding to 6.5 kWh/m^2. According to Swedish building regulations only the proportion of produced solar electricity utilized within the building has an effect on the buildings energy performance, quantified with the Swedish EUI indicator. In Fig. 3 the degree day adjusted EUI indicator is presented for all 21 buildings, pre and post renovation, along with categories of energy use, of which put together defines the EUI indicator.

It can be seen that the average EUI indicator in the area during a typical meteorological year was determined to 125.3 kWh / m^2, post renovation and 200.3 kWh / m^2 pre-renovation. This corresponds to an annual improvement in EUI indicator of 37.4 % and a reduction of 213.4 ton CO_2. The latter result was based on a local district heat emission factor of 57 (g CO_2-e/kWh) and 82 (g CO_2-e/kWh) for electricity usage, assuming Nordic electricity mix [14]. These savings were in good agreement with the expected savings, based on the results from the evaluations of Building 1 and Building 2.

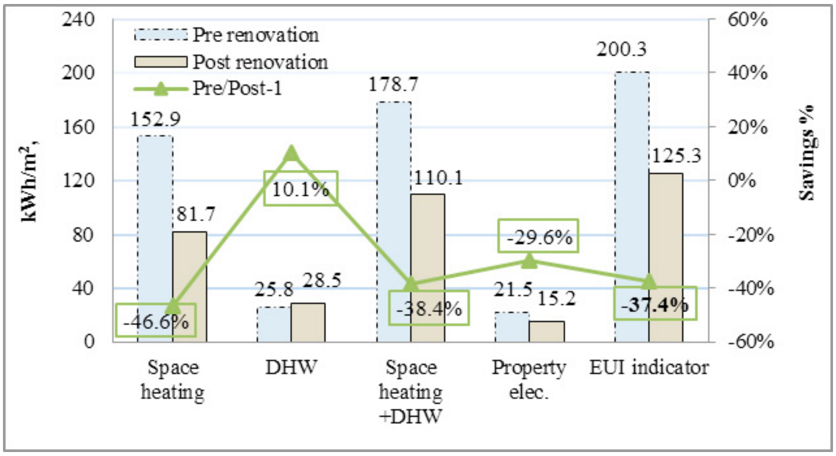

Fig. 3. Degree day corrected, measured energy use of 21 multifamily buildings refurbished in the project Sustainable Ålidhem. Data are from 2007-01 to 2008-12 (Baseline data) and 2015-06 to 2016-06 (post renovation).

Most of the taken measures affect the thermal performance of the buildings which is reflected in Fig. 3, where it can be seen that the space heating demand almost halved. The decrease of property electricity in Fig. 3 is mainly due to the installed photovoltaic system which was in full operation during the analysed year, post renovation. In Fig. 3, it can further be seen a slight increase of hot water use, post renovation. This was somewhat surprising since energy efficient water taps were installed in the buildings. However, the increase is not unreasonable since the use of hot water is mostly dependent on the users and due to the long period between the pre and post renovation performance data the users have likely changed between these periods.

6. Conclusions

A large effort has been made in this study to quantify actual energy savings on individual building level as well as on multiple building level. The results indicate that if the buildings have similar constructions the results from a small sample, (two buildings in this case), can give very good predictions of energy savings of the entire building population to be renovated. Hence, pilot studies can be very powerful if the results are considered in the decision making process in subsequent similar renovations. In this project, ECMs with poor economic returns were revealed in the first renovation of Building 1 and therefore could be avoided in subsequent renovations. This is a prerequisite for cost effective and by extension, social sustainable renovation. Although some measures in project Ålidhem were partly subsidized with government grants, the rent increase, due to the renovation was less than 10% which must be considered as fairly moderate and successful. Finally, from a project quality improvement point of view, pilot studies and subsequent large scale evaluations based on measured data enable assessment both during the renovation project (formative) as well as summative at the end. Results from the latter can be used in the next project, e.g. to adjust the calculations in the design phase to previous measured outcomes instead of the typical approach of utilizing standardized input data from guidelines, which often is not updated frequently.

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