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Study of energy efficient measures – a life cycle perspective

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Table of Content

1. Introduction

A central issue from a sustainability and climate perspective is how existing buildings can be refurbished in an efficient manner from a variety of perspectives. This study will focus on energy and life cycle economy. However, the assessment of a refurbishment project and its performance will needs to be based on multiple criteria such as technical function, economy, environmental issues, social issues and cultural issues.

The purpose of this study is to analyse the efficiency of different measures and opportunities to enhance the energy performance of existing buildings built before the 1940´s. The study object has been a building, that earlier was a hospital and a psychiatric ward, built in the 1930´s.

The following measures have been analysed:

- Demand controlled ventilation
- ESX-ventilation with plate heat exchanger
- Recirculation of heat from ventilated air and heat pump
- Supplementary insulation the attic
- Supplementary insulation of external walls
- Energy efficient windows
- Radiators shut off automatically when opening windows
- Solar collectors for pre-heating radiators and hot water
- Individual measuring and charging of hot water
- Recycling of heat from waste water

1.1 Method

The study has been conducted by examining a possible alternative use of an old hospital building in Malmö from the 1930´s. The alternative use has been assumed to be multi-family housing. A simulation program, VIP-Energy, has been used as a tool to carry out the energy calculation that is the base of this study. General climate data from Swedish Meteorological and Hydrological Institute (SMHI) for Malmö has been used to assess the external climate factors that affect energy usage. Examination on site has been made to assess prerequisites such as wind exposure, incident solar radiation and shadowing effects. Heating needs are based on a period of six months from October to March.

2. Analysis of energy efficient measures

2.1 Ventilation

The main task of ventilation is first and foremost to remove moisture and pollution which are produced in buildings. The Swedish building code (BBR) published by The Swedish National Board of Housing, Building and Planning have standard requirements for housing of a ventilation flow and an air change rate of at least 0.35 l/s, m^2 applicable for both an entire flat as well as a single room. If demand controlled ventilation is being used it is allowed to decrease the ventilation flow to 0.10 l/s, m^2 when no one is present in the room or flat.

According to Warfvinge and Dahlblom (2010) there is an existing praxis concerning ventilation flows that is based on earlier recommendations from The Swedish National Board of Housing, Building and Planning. Table 1 is an extract from these recommendations.

Table 1: Recommendations for ventilations flows

Type of space	**Minimum exhaust air flow rate**
Kitchen	10 l/s plus forcing
Kitchenette	15 l/s *
Bath or shower room with opening windows	10 l/s *
Bath or shower room without opening windows	10 l/s plus forcing *
Toilet	10 l/s
Cleaning room	3 l/s, m^2, dock minst 15 l/s
Laundry and drying room	10 l/s *

* If the floor area exceeds 5 m^2, the exhaust air flow rate should be increased by 1 l/s for every m^2.

If the ventilation flows from table 1 is being followed it means that the air change rate can be considerably higher in small flats in comparison to the requirements of BBR. As an example a flat of about 40 m^2 has a requirement from BBR of an air change rate of 40*0.35 = 14 l/s. Extract air in the flat would then occur in the kitchen and the bathroom with a minimum exhaust air flow rate of 10 + 10 l/s, a excess ventilation of 6 l/s. A one room apartment of about 30 m^2 with a kitchenette would have minimum requirement of 30*0.35 = 10.5 l/s, while the real air change rate according to table 1 would be 10 + 15 = 25 l/s two and a half times the minimum requirement.

There are opportunities to control the ventilation flow with sensors that measure the relative humidity and the level of carbon dioxide. The result of this, for the one room flat of 30 m^2, is that when nobody is home the actual air change rate is 30*0.10 = 3 l/s, compared to 25 l/s.

Energy calculation

After studying the drawings the building is assumed to have the following prerequisites: a total possible net floor area of 1120 m^2 and a subsidiary usable area, consisting of corridors and staircases of 250 m^2. This is equivalent to 28 two-room apartments of 40 m^2 each. The ventilated room volume is then 4521 m^3 (1370 m^2 x 3.30 m).

Calculation 1

An extract air ventilation system without any recycling of heat and without any demand control:

The air change rate then becomes for the entire building 650 l/s (28 x 20 l/s + 250 x 0.35 l/s, m^2). The energy losses due to ventilation then become 61450 kWh a year.

Calculation 2

Demand controlled ESX-ventilation with plate heat exchanger and an efficiency of 60%:

In this case the presences of people in the rooms play a significant part when assessing the energy losses due to ventilation. The following assumptions have been made:

- Weekdays 10h absence a day — 0.10 l/s, m^2
- Weekends 5h absence a day — 0.10 l/s, m^2
- 2h a day with full ventilation — 20 l/s, lgh
- Remaining time — 0.35 l/s, m^2(14 l/s, lgh)
- Staircases and corridors — 0.10 l/s, m^2

The savings compared to calculation 1 then amounts to 43 500 kWh a year, reduced by 70%.

The benefits of a plate heat exchanger in combination with ESX and demand control is 15 450 kWh a year. If there is no system for demand control

2.1.1 Extract air ventilation system with recycling of heat.

If an extract air ventilation system is used instead of an ESX system it is not possible to use a plate heat exchanger. Instead can liquid based recycling system be used, which has approximately the same efficiency as a plate heat exchanger, which means that the recycling effect is unchanged. The system allows for the exhaust air fans to be placed on the attic while the heat pump is placed in the basement. This system is quite commonly installed when refurbishing old buildings. The energy losses due to ventilation then minus recycling become 32 200 kWh a year (61 450 – 29 250 kWh), reduced by 50%.

2.2 Supplementary insulation

If supplementary insulation is conducted in a wrongful manner there is a high risk for damages due to unwanted moisture effects. In less insulated walls/roofs the temperature difference through the wall/roof becomes relatively high. If supplementary insulation is added the temperature on the outer part of the wall/roof drops, which increases the possibilities of a high relative humidity.

The benefits of supplementary insulation depend upon the amount of existing insulation. For a reduced U-value of 50% the thickness of the insulation needs to be doubled.

2.2.1 Supplementary insulation of the attic

There is currently no exact measure of the existing layer of insulation in the attic of the studied building. However an assumption can be based on the amount of insulation in similar buildings in the same area, which is 200 mm. An increased layer of insulation by 200 mm of insulation only gives a small saving effect of 3 600 kWh a year.

2.2.2 Supplementary insulation of external walls

The external walls are built with a 300 mm brick wall with plaster on both sides. The U-value is 1.17 W/m^{2}K. Supplementary insulation on the inside effect in a lower temperature in the brick wall with a higher risk of frost damage. However, due to construction of the wall this scenario is unlikely. For a supplementary insulation on the outside the facade needs to be re-plastered, which affects the external appearance of the building. Regardless if the supplementary insulation is made on the inside or the outside an additional layer of 100 mm of insulation (λ = 0,036) will decrease the U-value to 0.28 W/m^{2}K. Resulting in a decreased energy usage of 46 000 kWh a year.

2.3 Windows

The share of the energy losses due to windows is quite substantial. However, there is a large variation depending on different factors such as the number of windows, their size and U-value. Picture 1, shows a window from the studied building. The window is divided into four parts with window bars. Because the window has the highest U-value around the casing frames this types of windows are not a good solution from an energy saving viewpoint. Further the windows are single glass windows and the estimated U-value is 3.0 W/m^{2}K.

Picture 1: Existing window from the studied building

Calculation
The existing window area is about 265 m^2. This area is estimated from observations on site in addition to existing drawings.

In the first calculation the U-value is estimated to be 3.0 W/m^2K for existing windows. Additional calculation has been made on the premise that the existing windows are changed to more energy efficient ones with a U-value of 1.4 W/m^2K in alternative 1 and a U-value of 0.9 W/m^2K in alternative 2. Alternatives one are two glass windows and alternative 2 are three glass windows, the existing ones are single glass.

Existing windows: Transmission losses 62 500 kWh a year

Alternative 1: Transmission losses 29 300, reduced by 33 200 kWh

Alternative 2: Transmission losses 18 900 kWh, reduced by 43 600 kWh

Further, the window change will probably reduce the effects of cold downdraught, which will enable the radiator system to work with lower temperatures, which further increases the energy saving effect.

2.4 Radiators shut off automatically when opening windows

Under normal circumstances and functional ventilation there is no need for opening windows for airing. Airing by opening windows during the season where additional heating is needed has a major effect on the energy usage. The calculations in this chapter are all interpreted from Jensen (1999). The air flow rate is different depended upon if the airing in one sided or double sided. For double sided airing there is a need for a through flat. Air flow rate depends on the wind pressure and wind direction. After studying the drawings it is assumed that no through flats will be possible in the building, the flats will have to be placed on different sides of a corridor. Thus only one sided airing will be possible, where it is mainly the temperature difference between inside and outside that affects the air flow rate. The higher the temperature difference the higher the air flow rate.

With a temperature difference by 20 °C between outside and inside and a part open window of 0.1 m2 the air flow rate becomes 17 l/s (Jensen, 1999).

Calculation
With an inside temperature of 21 °C and a daily medium temperature outside of 2,7 °C, the air flow rate becomes 16 l/s. If this occurs every night for one flat by ten hours the increase of energy usage will be 700 kWh. Even if there is a function that shut off heating when a window is opened some energy losses are still inevitable. To completely avoid energy losses when airing may not be possible, however, a system that automatically shut off will probably affect the behaviour of the users and airing will decrease.

2.5 Solar collectors for pre-heating radiators and hot water

Vacuum based solar collectors have the highest efficiency; however plane solar collectors are more cost effective. According to manufacturers the effect is approximately 500 kWh per m^2 solar collector and year. Solar collectors have been developed technically over the latest couple of years, which have made both more efficient as well as more cost effective. However, solar collectors are still relatively expensive and it is important not to over dimension the system installed. Although, solar collectors can give additional heat to the radiator system there is variance over time. The capacity is the highest in the summer when the need is low, and vice versa in the winter when the need is high. However, for hot water there is an effect all year around.

The municipal housing company in Lund (LKF), has installed solar collectors for pre-heating hot water in one of the properties (Boo, 2005). De installed 0,05 m^2 of solar collectors per m^2 living area or 3,2 m^2 a flat. The same circumstances for a future refurbishment of the studied building would amount to the installation of 56-90 m^2 of solar collectors (28 flats of 40 m^2 each. However, Dahlenbäck (2004) states that the need can up to 3-5 $m^2$for each flat, which would mean a range from 84-180 m^2. The rental house Fullriggaren in Gävle, that in 2011 was awarded a price for facility of the year by Svesol, has 29 flats and 80 m^2 of solar collectors.

Based on the arguments above the recommendation for the studied building is 80 m^2 of solar collector for 28 flats of 40 m^2 each.

The solar collectors for the LKF property mentioned above have had a measured energy gain of 312 kWh per m^2 and year (2001-2003), which less than the planned effect of 397 kWh per m^2 and year (Boo, 2005). The installation was plane solar collectors with direction to the south and a gradient of 45 degrees. Another project in Lund with plane solar collectors has had a gradient of 33 degrees. The system was divided into two parts one with direction to the south and one with direction to the north. The one directed to south had an energy gain of 290 kWh per m^2 and year, the one to the west gave 185 kWh per $m^2$and year (2001-2003) (Boo, 2005).

According to the drawings the roof of the studied building had a gradient of 30 degrees. This gradient is relatively small and a device that increases the possible gradient of the solar collectors may be needed. Further the roof id directed to the southeast which is not optimal. With regard to the lessons learned from the above described projects the potential energy gain has been assessed to range between 300-400 kWh per m^2 of solar collectors. With a total solar collector area of 80 m^2 the total energy gain would be between 24 000-32 000 kWh a year.

2.6 Individual measuring of hot water.

Individual measuring and charging of hot water is generally profitable for the property owner. There are a number of studies that show on a significant reduced use of hot water from 15% up to 30% and sometimes up to 50%. However, there are examples where no reduced use have been observed, this is often the case when the economic incentive for saving by individual tenant is low.

Statistics from the Swedish Energy Agency shows that the use of hot water per person in a flat is 58 l per person and day, while the same figure is 42 l per person and for a single family home. Hence, the one that directly pays for their hot water, which is the case for single family home, uses less than if the use of hot water is part of the rent. Based on a reduced usage of hot water from 58 to 42 litres per person and day and 1,2 person inhabiting each apartment the energy saving will amount to 12 750 kWh a year.

2.7 Recycling of heat from waste water

Although the technology is available it is uncommon that heat is recycled from waste water. How much energy that is possible to extract from waste water can vary heavily depended on the usage of hot water and the type of heat pump. Based on a hot water usage of 58 l per person and day and an efficiency of 60% the theoretical contribution would 23 500 kWh for one year. With a hot water usage of 42 l per person and day the theoretical contribution would 17 600 kWh for one year.

3. Preliminary life cycle profit analysis

The definition of life cycle profit (LCP) is a collective assessment of investment, running and maintenance costs for an object in relation to the benefits that this object creates during its economic life span. The discounted net present value method is necessary in order to assess the consequence of the rate of return on invested capital.

$$LCP = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} - I + \frac{RV_n}{(1+r)^n}$$

I = Initial investment cost
R_t = Revenues year t
C_t = Costs year t
RV_n = Residual value after n years
r = Calculated rate of return
n = Economic life span

The role of the calculated rate of return

Because the economic life cycle assessments are often based on net present values there assessed calculated rate of return will have ha large impact on the results. A high calculated rate of return tends to favour alternatives with low initial investment cost while a low calculated rate of return has the opposite effect. Thus, it is of importance to carefully assess a suitable calculated rate of return for the analysis at hand based of internal rate of return and risk assessments with organisation that is the subject of the analysis and for different types of measures.

3.1 Life cycle profit analysis for energy efficient measures in the studied building

This analysis is based on the following prerequisites:

- All measures is assumed to have a life span of 50 years
- No residual value after 50 years

- Energy savings is the only factor affecting future revenues
- The price of energy is for 2012 assessed to be 0,75 SEK per kWh.
- The annual price change is assessed to 2%
- The calculated rate of return is set to 6%.
- The calculation is made to assess the maximum investment possible based to achieve a profit level of 6% (calculated rate of return)

The analysis is made as a preliminary calculation where the LCP is set to zero and then the maximum initial investment cost have been calculated in order to assess the framework that future investment must be within in order to be profitable (based on the above prerequisites. Thus, based on the energy gains assessed in chapter the following maximum initial investment constitutes the framework of the energy efficient measures that are proposed.

$$LCP = \sum_{t=1}^{50} \frac{R_t - C_t}{(1+6\%)^t} - I + \frac{0_n}{(1+6\%)^n}$$

$$LCP = 0 \rightarrow$$

$$\sum_{t=1}^{50} \frac{R_t - C_t}{(1+6\%)^t} = I$$

3.1.1 Ventilation

With present conditions as a starting point e.g. an extract air ventilation system without any recycling of heat and without any demand control. An investment to demand controlled ESX-ventilation with plate heat exchanger will amount to an energy saving of 43 500 kWh a year, which admit an initial investment cost (I) of maximal 696 000 SEK.

3.1.2 Supplementary insulation

Supplementary insulation of the attic enables an energy gain of 3 600 kWh a year, which admit an initial investment cost (I) of maximal 58 000 SEK. For supplementary insulation of external walls the energy gain is 46 000 kWh,

3.1.3 Windows

Alternative 1 with a U-value of 1.4 will save 33 200 kWh of energy usage and alternative 2 with a U-value 0.9 saves 43 600 kWh. This allows for a maximal initial investment (I) of 532 000 SEK for alternative 1 and 698 000 SEK for alternative 2.

3.1.4 Solar collectors

If the energy gain is assumed to be between 300-400 kWh per m² the savings in energy usage will amount to 24 000 – 32 000 kWh. This allows for an initial investment cost of 384 000 – 512 000 SEK.

3.1.5 Individual measuring and charging of hot water

Based on the possible reduced water usage from 58 to 42 litres per person and day and 1.2 persons per flat, the energy gain will amount to 12 750 kWh a year,

3.1.6 Recycling of heat from waste water

Based on a hot water usage of 58 l per person and day and a efficiency of 60% the theoretical energy gain will amount to 23 500 kWh a year. If the hot water usage can be reduced to 42 l per person and day (see 3.1.5) the energy gain will be 17 600 kWh a year. This allows for an initial investment cost (I) of 282 000 – 376 000 SEK.

4. Further studies

The forthcoming evaluation of this refurbishment project will focus on the following:

- How is a calculated rate of return to be assessed with respect to climate change and sustainability as well as profit demands on invested capital?
- How can various criteria relevant for assessing energy efficient measures be evaluated in the decision process of the real estate owner?
- How is the feasibility of energy efficient measures evaluated with respect to function, technology, financing, quality and sustainability?

The input for this work will be based on the investigation an choices made by the real estate owner in the forthcoming stages of the refurbishment project. Together with interviews with different actors various decision criteria will be identified and analysed. Further calculation of investment for various alternative solutions will be the basis for updated analysis of life economy.

5. References

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