Energy efficient measures when retrofitting the existing building stock

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Table of content

1. Introduction

The Swedish parliament has set targets for reduced energy use. For the building sector this means that the use of energy in buildings should be reduced by half (base year 1995) until 2050. In 1995 the average energy use in buildings in Sweden were 140 kWh/m^2, for heating, and 125 kWh/m^2, for electricity, (IVA 2012), subsequently this figures should, in 2050, be between 60-70 kWh/m^2 for all buildings. This is quite a challenge since these figures are currently below the demand for newly produced housing in Sweden and the existing building is stock very far from the mark. IVA (2012) put forward the following measures that need to be taken in order to fulfill set energy targets in 2050:

- The rate of energy efficient measurer in retrofitting needs to increase.
- All real estate owners needs to have long-term strategies and targets for the retrofitting their buildings.
- The competence and knowledge needs to be strengthened.
- The building codes when retrofitting buildings needs to be strengthened.
- The future role of heating supplies needs to be discussed.
- Consideration concerning preservation and financing needs to be resolved.

As the above list shows that the achievement of reaching set energy targets in 2050 poses a real societal challenge. In particular, this challenge needs to be met by real estate owners. This study will reflect over energy efficient measures in retrofitting mainly from the perspective of the real estate owner. The study has been carried out in cooperation with a public real estate owner, Malmö Stadsfastigheter, in connection with a larger EU-project "Cool Bricks".

The main purpose of this study has been to investigate:

- How is the feasibility of energy efficient measures can be evaluated with respect to various perspectives, mainly life cycle economy and energy savings?
- 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?

The study consists of a literature review and a study of potential energy efficient measures in a building about to be retrofitted.

2. Decision making processes in energy efficient retrofitting

In order to aid real estate owners and managers in their decision-making process when evaluating energy efficient measures in for instance the retrofitting of a building, there is a need for tools and guidelines to aid the process of making informed decisions (Ludvig 2013). However, the main challenge when managing energy targets in retrofitting is seldom the development of technical solutions; rather it is a matter of convincing stakeholders, within and outside the organization, and creating commitment and understanding for problems concerning energy efficient measures (Ludvig 2013). The pedagogical challenge is apparent though it is necessary to evaluate a vast number of criteria in the evaluations, for example (IEA 2011):

- Annual heating profile for water and/or space heating, and annual cooling profile.
- Relative timing of thermal and electric loads.
- Space constraints.
- Emission regulations.
- Utility prices for electricity, and availability and prices of other fuels.
- Initial cost and the cost of financing.
- The seasonal efficiency of the equipment.
- Complexity of installation and operation.
- Reputation of the manufacturer.
- Architect/engineer/builder/installer's knowledge of available technologies and models.

Ludvig (2013) identifies four roles within the decision-making process in energy efficient retrofitting. The *strategist* is often an expert within the organization who is the promoter of the measures to be taken. The *doer* is the one who can get things done. The *economist* is the one who controls the cash flow and understands the financial issues. Finally, there is the *reflective one* who asks the difficult questions. In playing their roles they can form a friction free and committed team when implementing a strategy towards achieving set energy targets, internal as well as external. However, the main role is often played by the expert who possess the expertise in energy efficiency that legitimize the engagement to implement energy targets in real estate management (Ludvig 2013), and the success is often depended upon personal characteristics and attributes.

A central role in the decision-making process is often played by middle managers, where the success in promoting an agenda for energy efficient measures often depend on how well they understand and make use of contextual factors, such as history, knowledge, context-specific rules, language and terminology (Ludvig et al. 2013). When promoting, for instance energy efficient retrofitting, middle managers may need to engage in activities to make sense of the proposed measures to others (see figure 1).

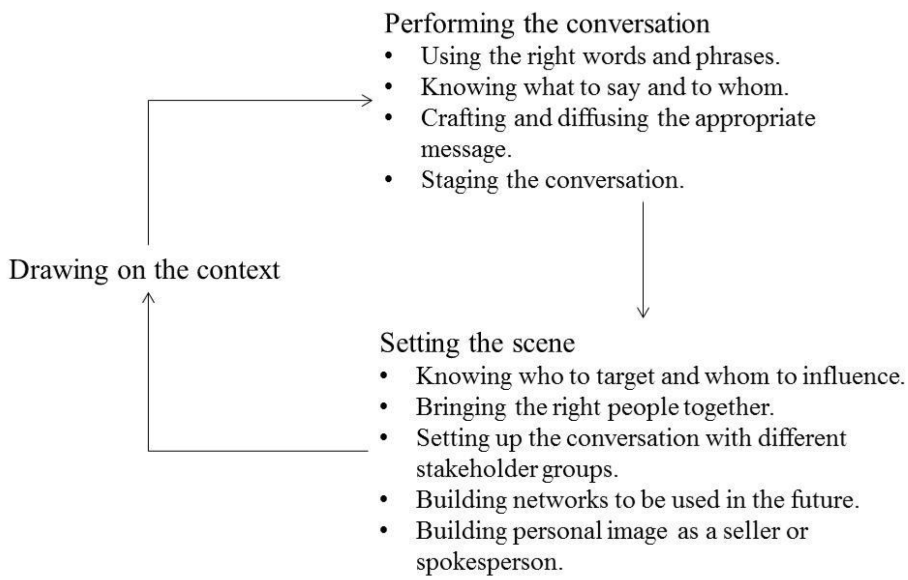


Figure 1. Activities in middle-management to promote proposed measures, for instance energy efficient retrofitting (source Ludvig et al. 2013)

Empirical results from Ludvig et al. (2013) showed that managing the process of achieving energy targets was primarily a matter of influencing stakeholders and making them committed. Considerations in the decision-making process was rarely about strategies and technical issues, rather it was about who to engage in the process and when.

One commonly used tool is life cycle cost (LCC) or life cycle profit (LCP) analysis, which may facilitate the communication regarding the long-term perspective of building performance (Ludvig 2013), in light of proposed energy targets. Further, Ludvig (2013) propose that analysis of life cycle economy can serve as a pedagogical and rhetorical tool for understanding the life cycle perspective of a building. The definition of life cycle cost (LCC) is a collective assessment of investment, running and maintenance costs for an object 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.

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

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

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. Also here 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

Mata et al. (2010) made a study based on the Swedish housing stock, where they evaluated both the energy saving and life cycle profit for 12 defined measures:

1. Change of U-factor of cellar/basement.
2. Change of U-factor of facades.
3. Change of U-factor of attics/roofs
4. Replacement of windows.
5. Upgrade of ventilation system with heat recovery for single-family dwellings.
6. Upgrade of ventilations system with heat recovery for multi-family dwellings.
7. 50% reduction of power for lighting.
8. 50% reduction of power for appliances.
9. Reduction of power used for the production of hot water to 0.80 W/m2, for single-family dwellings.
10. Reduction of power used for the production of hot water to 1.10 W/m2, for multi-family dwellings.
11. Change of electrical power to hydro pumps.
12. Use thermostats to reduce indoor air temperature to 20°C.

The results showed that after reducing indoor temperature upgrading the ventilation system with heat recovery systems had the highest energy saving potential, closely followed by improving the U-factor in cellar/basement and facades (Mata et al. 2010). However, when adding the profit factor based on a life cycle economy analysis (with a calculated rate of return of 4%) the results were rather different. Only three measures were evaluated to be profitable (Mata et al. 2010).

- 50% reduction of power for lighting.
- 50% reduction of power for appliances.
- Use thermostats to reduce indoor air temperature to 20°C.

All of these measures have the thing in common that they have low initial investment costs in relation to the energy saving potential. A part from reducing indoor temperature, investing in heat recovery systems showed the best relation between profit and energy saving potential. The measure that was worst from a life-cycle profit perspective was improving the U-value in the facades where the total cost was 0.23€ per saved kWh and year, in comparison in reducing indoor temperature that gave a profit of 0.06€ per saved kWh and year (Mata et al. 2010).

IEA (2011) identified barriers for reducing energy usage. One is cost effectiveness, in line with the reasoning above. Connected to this are first and foremost high costs for initial investment, which makes energy savings often non-profitable. The basis can be a technical uncertainty where new and potentially more cost effective measures are not used and thus do not get a sufficient market share. However, this response is rational due to even higher cost if something goes wrong. The lack of specialized knowledge could be a reason why this uncertainty exists. Another barrier is fiscal and has to with problems of financing energy saving measures. Policies for helping real estate owners to finance energy saving measures could be one way to decrease the fiscal uncertainty. Further, there are regulatory barriers, which may lead to uncertainty when it comes to how regulation in energy usage will develop.

To decrease uncertainty and thus enable a rational decision-making process requires knowledge on a variety of levels. This process can be divided into several steps when it comes to retrofitting the existing building stock in general, and for energy saving measures in particular (Crosbie et al. 2011), where the input is a need for a new retrofitted building design and the output is a retrofit strategy within given constraints:

1. Identify and model design alternatives.
2. Conduct building assessments.
3. Check design compliance.
4. Conduct trade off.

In the case of energy efficient measures step one must consist of a careful analysis of the buildings current energy performance. Crosbie et al. (2011) suggest that this is done by creating a building information model (BIM). In this model the performance and consequences of various energy saving measures can be carefully analyzed before a decision is made of how to proceed. Xing et al. (2011) suggests that there is an evolution towards the ultimate goal of zero carbon retrofitting. First is to retrofit the fabrics of the building such as better insulation. However, this is not sufficient. The next step is to install better equipment for example more effective HVAC systems. These two measures are in the control of the real estate owner, but to take the final step towards zero carbon retrofitting Xing et al. (2011) argues that there is also a need to address the supply of energy.

3. Technical considerations in energy efficient retrofitting

3.1 The case of Sege Park, Malmö (building 8)

This study is to analyse the efficiency of different measures and opportunities to enhance the energy performance of an existing building 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.

3.2 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.

3.3 Analysis of energy efficient measures

3.3.1 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, an 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.
- 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, flat
- Remaining time 0.35 l/s, m^2(14 l/s, flat)
- 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

3.3.2 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%.

3.3.3 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.

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.

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.

3.3.4 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^2,K 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^2,K in alternative 1 and a U-value of 0.9 W/m^2,K 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.

3.3.5 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.

3.3.6 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, in comparison to another project, in Lund, with plane solar collectors and a gradient 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 is 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.

3.3.7 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

3.3.8 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

3.4 Life cycle profit – an investment cost 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

3.4.1 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 the following maximum initial investment constitutes the framework of the energy efficient measures that are proposed. In essence this means that the more cost efficient a measure is during the life cycle the higher the initial investment can be in order to be obtain the set rate of return.

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

$$LCP = 0 \rightarrow$$

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

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.

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, which allows for a maximum investment of 736 000 SEK.

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.

Solar collectors
If the energy gain is assumed to be between 300-400 kWh per square meter 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.

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, which allows for an initial investment cost of 204 000 SEK.

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

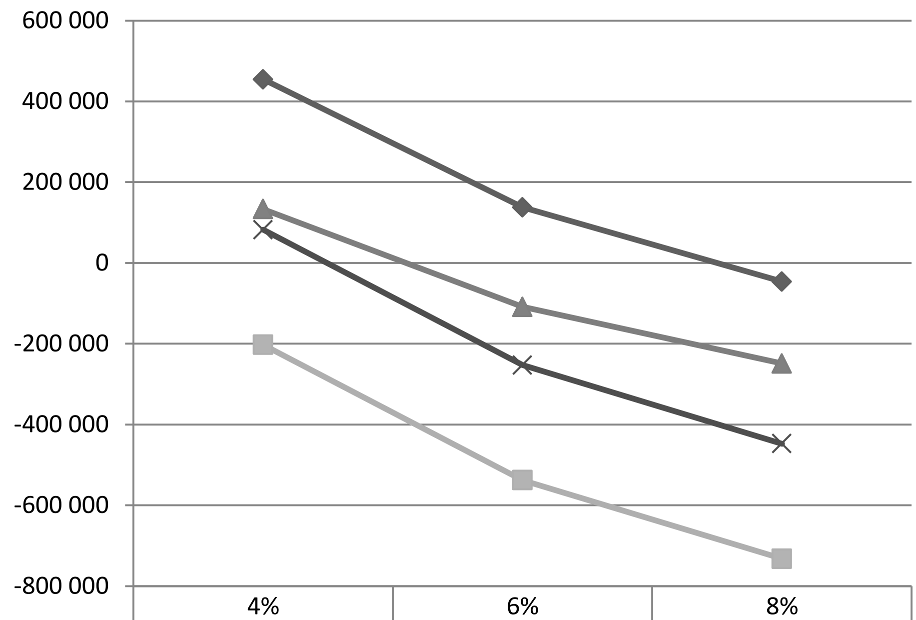
Table 2 Summary of results

	Energy savings (kWh/year)	Investment potential (SEK)
Ventilation	43 500	696 000
Supplementary insulation (attic)	3 600	58 000
Supplementary insulation (outer walls)	46 000	736 000
Windows (U-value 1.4)	33 200	532 000
Windows (U-value 0.9)	43 600	698 000
Solar collectors	24 000	384 000
Individual measuring and charging	12 750	204 000
Recycling of heat from waste water	17 600	282 000

3.4.2 Sensitivity analysis

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.

If a assessed investment cost is added in relation to a variation in a chosen calculated rate of return for the four measures with the highest energy potential the result is that a retrofitting of the ventilation is the most cost efficient and supplementary insulation to facades the least (see figure 2). It is also evident that the chosen rate of return has a large effect on the results. None of the measures were profitable at a rate of return of 8%, which is fairly normal for most teal estate companies.



	4%	6%	8%
Ventilation	454 438	137 452	-46 447
Supplementary insulation (facades)	-202 567	-537 770	-732 238
Windows U=1.4	133 104	-108 826	-249 181
Wndows U=0.9	82 142	-253 061	-447 529

Figure 2 Life cycle profits in relation to different rates of return

3.5 Analysis of existing method for supplementary insulation of facades

This section is based on existing studies concerning various technical solutions for supplementary insulation. Walls are the predominant part of the building envelope and should cover both thermal comfort as well the aesthetics of the building. The energy use of a building relies heavily on the energy performance the outer walls. This especially true in high rise buildings where the ratio between wall and total envelope area is high (Sadineni et al. 2011). In an evaluation made by Skanska (2010) they showed that today's increasing demands for energy efficient solutions resulted in for example higher demands on windows and thicker insulation in the building envelope. Berge (2013) shows the thermal conductivities of several insulation types, compared to the thermal conductivity of air. Cellulose, Mineral Wool and EPS (Expanded polystyrene)/XPS(Extruded polystyrene) have a higher thermal conductivity than PUR (Polyurethane), aerogels and VIP (Vacuum insulation panels), and are thus less efficient. Berge (2013) further analyses the application of aerogels and VIP and concludes that the increased cost from using the new materials could be balanced against the additional values that this will bring, for example extra space and aesthetics. However, Berge (2013) also points out that when aerogel blankets and vacuum insulation panels are used in new applications, various considerations appear which have to be investigated thoroughly. When choosing insulation materials consideration needs to be taken, for instance health related factors and flammability (Sadineni et al. 2011).

In the building envelope traditional methods are to a large extent still used(Skanska 2010), which leads to thick insulated walls and thus less functional space within the building. There is a need for better and higher performing insulation materials. Skanska (2010) did a comparative study to investigate different high performing insulation materials:

- Vacuum insulation panel (VIP)
- Aerogels
- Expanded polystyrene (EPS) with graphite
- Polyurethane (PUR)
- Polyisocyanurat (PIR)
- Reflective insulation

The studied materials have the following abilities (Skanska 2010):

Vacuum insulation panel (VIP) has a thermal conductivity of about 0.005 W/(m·K), which up to 10 times better than traditional mineral wool. However there are risks that must not be ignored. In production, transport and mounting careful measures needs to be taken in order to avoid damaging the material, thus reducing its function. This is particularly difficult when VIP is used as supplementary insulation in existing buildings where it is harder to obtain the sufficient precision needed.

Aerogels has a low density which makes it a light material with good mechanical properties. The material is transparent and consists usually of silica materials, but the base materials can also be plastic polymers, carbon or metallic oxides. The commercial building material based on aerogels that exists today has a thermal conductivity of about 0.014 W/(m·K). Today the aerogels are not fully transparent, which limits there use. Further development is needed for the material to reach its full potential in building applications.

Expanded polystyrene (EPS) with graphite has a low density and are stable in form, and it has high compression strength. The closed cellular system allows for low inner convection, low air permeability and a low absorption of water. EPS has a thermal conductivity of 0.031-0.032 W/(m·K), which is 20% lower compared to normal EPS.

Polyurethane (PUR) and Polyisocyanurat (PIR) are high performing insulation materials that are both light and stable in form, and can potentially replace expanded polystyrene (EPS). The thermal conductivity varies between 0.023-0.027 w/(m·K). The materials are flammable, however, less so than EPS.

Reflective insulation has been advocated as an effective alternative with low costs. However, the efficiency as an insulation material is questioned. The material consists of a thin layer of reflecting foil, most common is aluminium. Instead of prevent conduction and convection, as is the case for traditional insulation materials, the purpose is to prevent thermal radiation. Today the applications are rather limited and further development is needed. Measures showed that reflective insulation did not fulfil the given properties, which indicates that an uncertainty exists of the potential of reflective insulation.

In the comparative analysis of the above mentioned materials Skanska (2010) based on a reference wall with 195 mm mineral wool showed the following results:

Table 3: Comparative study of different insulation materials (Skanska 2010)

Insulation material	Thermal conductivity in W/(m·K)	Thickness insulation (mm)	Thickness wall (mm)
Mineral wool	0.037	195	410
Expanded polystyrene (EPS) with graphite	0.031	160	375
Polyisocyanurat (PIR)	0.023	120	335
Aerogel	0.014	70	285
Vacuum insulation panel (VIP)	0.005	25	240

Based on the results in table 1, the respective insulation materials gave rise to the amounts of additional floor space per meter wall (m2/m) in relation to the reference wall of 195 mm mineral wool (Skanska 2010).

- Expanded polystyrene (EPS) with graphite 0.035 m2/m
- Polyisocyanurat (PIR) 0.075 m2/m
- Aerogel 0.125 m2/m
- Vacuum insulation panel (VIP) 0.170 m2/m

If the additional cost for the materials is added the cost in relation to increased floor space is the following (Skanska 2010):

- Expanded polystyrene (EPS) with graphite 0 SEK/m2
- Polyisocyanurat (PIR) 3 343 SEK/m2
- Aerogel 39 530 SEK/m2
- Vacuum insulation panel (VIP) 10 846 SEK/m2

The comparison shows that expanded polystyrene (EPS) with graphite is the most cost effective alternative, while aerogels and VIP may have several years before a return on investment is achieved. However, high performance insulation materials way well have a future in the building industry. The result from the study (Skanska 2010) showed that there is both energy efficient as well as an economic potential with high performance insulation materials. This is especially true when there is a limitation of the thickness of the outer walls, where high performance insulation materials will save floor space.

However, there are uncertainties concerning the efficiency of high performance insulation materials in the retrofitting of existing buildings. Elmi and Eskilsson (2013) conducted a comparison for a curtain wall of three types of insulation, mineral wool, EPS and PIR (Polyisocyanurat), where PIR in theory should be the most energy efficient. The comparison showed that regardless of material or thickness the energy savings where more or less the same. One explanation that Elmi and Eskilsson (2013) suggests for the small differences is that insulated surface in the studied case was too small, which resulted large thermal bridges. However, the result is interesting from a retrofitting perspective. If there are factors beyond the thermal capacity of the insulation material that affect the overall energy saving, there may a condition under which there is no use in investing in a more expensive insulation material. This further promotes the notion that before any retrofitting is carried out there needs to be a thorough analysis of the building to make the appropriate and most cost effective choices.

4. Concluding discussion

A central issue from a sustainability and climate perspective is how existing buildings can be retrofitted in an efficient manner from a variety of perspectives. This study focused on energy savings and life cycle economy. However, the assessment of a retrofitting project and its performance needs to be based on multiple criteria such as technical function, economy, environmental issues, social issues and cultural issues. The retrofitting of a building is a complex undertaking cutting across different technical fields and facing challenges in incorporating renewable energy in a built environment (Xing et al. 2011).

From a decision-making perspective the most crucial factor to successfully carry out energy efficient retrofitting projects is a personal engagement and the right promoters. However, there still needs to be a sufficient base for decision-making. The first and most crucial factor is to gain knowledge about the buildings current status. This can be done with a careful inventory about the building object be retrofitted. However a more long-term measure is to create digitalised building information models(BIM) for both the existing building stock and new buildings in order to better assess measures to be taken when the buildings are to be retrofitted.

Both the empirical results showed that supplementary insulation of the facades has a high energy saving potential, however it is also the measures that is least profitable. This substantiated from literature. For example Mata et al. (2010) showed that improving the U-factor in facades were unprofitable from a life-cycle perspective. However, there seems to be a high potential from an energy saving perspective, which would indicate that there is a need to develop more cost-effective technical solutions for improving the energy performance of supplementary insulation in facades.

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