UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

A CEA of Energy Conservation

A case study of Katjas Gata 119

Bachelor Thesis 15 hp
Bachelor Course in Economics, NEK 300
Department of Economics
Spring 2013

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Abstract

This paper includes a cost-effectiveness analysis of different energy efforts when renovating a typical building of Miljonprogrammet. We have chosen to proceed from the conditions of a building in Backa Röd, Katjas Gata 119 in Gothenburg, which is owned by Gothenburg's residential company Poseidon AB. They made an extensive renovation of Katjas Gata 119 in 2009.

We live in a time when energy efficiency is highly on the agenda. The government has for example adopted a vision of net zero emissions until 2050 and in order to reach that, all sectors need to contribute. The residential sector comprises more than 40 % of the final energy use in Sweden today, therefore it is obvious that a variety of interventions in energy efficiency should be implemented and policies, due to this purpose, should be created. Renovating buildings is a once-only change and today it is a window of opportunity to reduce energy use extensively at the same time of the needed renovation.

We have analyzed ten different energy efforts, four of them were implemented on Katjas Gata 119 and the others were actions of our choice. Cost-effectiveness analysis investigates the costs, energy savings (in kWh), savings (in SEK) and the cost-effectiveness ratio for each energy effort.

To decrease the gap between the financial and socio-economic potential some interventions from the government is needed. We discuss different market failures in energy efficiency: information failures like principal agent and uncertainty, and innovative failures. Policies to correct for the market failures are discussed together with the different energy efforts.

According to our analysis, the most cost-effective energy efforts are Windows, Visualising energy use, Walls, Individual Measuring and Charging of Warm Water, Ventilation and Solar cells. There are only a few of these that will be implemented without governmental intervention.

List of abbreviations

A_{temp}	*Area, measured in square meters, that is heated to more than 10 degrees*
CBA	*Cost-Benefit Analysis*
CEA	*Cost-Effectiveness Analysis*
CER	*Cost effectiveness ratio*
CO_2	*Carbon dioxide*
CO_2e	*Carbon dioxide equivalents*
Klimp	*Climate investment program*
KWh	*Kilo Watt hours*
SEK	*Swedish crowns*
TWh	*Tera Watt hours*

Definitions

Energy efficiency: using less energy to achieve the same result or using the same amount of energy to produce a better result (ABB, 2009).

Energy labeling: a way of helping the consumer to see energy use of different appliances or other products. The different levels are graded from G to A+++, where A+++ is the most energy efficient. (Energimyndigheten, 2013b)

U-value: Measures the heat transfer, the higher U-value, the higher heat transfer and vice versa. A low U-value is desirable. The U-value is measured in Watt per square meter and degrees. The degrees are measured in Kelvin and indicate the difference in temperature between indoor and outdoor. (Nationalencyklopedin, 2013)

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Appendix: Calculations for the CEA

Acknowledgement

We would like to offer our special thanks to our tutor Gunnar Köhlin at the Department of Economics, Cathrine Gerle at Poseidon AB, Ylva Norén Bretzer at the School of Public Administration, Kristina Käck at Västra Götalandsregionen and Åsa Löfgren at the Departments of Economics for helping us with this paper.

Introduction

The European Union, and thereby Sweden, are facing major challenges due to increased dependence of imported energy and scarce resources, as well as the need to restrict the climate change and master the economic crisis. Energy efficiency is a valuable way to deal with these challenges. (Europaparlamentet, 2012) Today the residential sector comprises more than 40 % of the final energy use in Sweden and there is an obvious need for the implementation of a variety of interventions in energy efficiency and creation of policies (Energimyndigheten, 2012b). The residential sector needs to contribute to lowering our emissions, which is particularly pointed out in policy documents (SOU 2008:25).

In the 1950´s there was a major lack of accommodation and to solve this crisis, the Miljonprogram areas were developed. The construction occurred in a period when there were no thought about energy crisis or sustainable development. Now, in the 21th century, a majority of these buildings needs to be renovated. The challenge today is to achieve an economic and energy efficient renovation. The older the buildings get the more topical the renovation of the buildings get.

"The existing level of technology is available to reduce specific energy consumption by 50 percent by 2050 " (IVA, 2012)

Technical solutions are available, but a majority of them are not adapted, why? According to Cathrine Gerle, Project Manager at Poseidon AB, the problem is not to find technical solutions but to comprise a cost-effective solution and there are several energy efforts today that are cost-effective but not comprised. For decades there have been researching about energy efficiency and better technologies, but still there is a lack of cost-effective energy efficiency in buildings. The social science in this area is still in its early stages and needs to be improved. (ClueE-gruppen, 2013) This report can be seen as a pilot study in a nascent research area.

There is a gap between the financial and socio-economic potential that needs to diminish in order to reduce energy use. Renovating the buildings of Miljonprogrammet is a once-only change and if we want to decrease energy use until 2050 something needs to be done today, it is a window of opportunity! The buildings we renovate today will exist and be used in 100 years so it is important that we have an extra-long perspective. (IVA, 2012)

Aim

Rational and cost-effective solutions are an important basis for a comprehensive renovation. This paper will compare different levels of alternatives of energy efficiency in Backa Röd, Gothenburg by using Cost Effectiveness Analysis (CEA). In our CEA we will investigate the cost, energy savings (in kWh), savings (in SEK) and the CER for each energy effort. With our paper we intend to evaluate how to achieve energy efficiency that is cost-effective and investigate why we do not reduce our energy use enough. Furthermore we will discuss different market failures in energy efficiency and different governmental interventions.

Research Questions

Which of our chosen efforts are the most cost-effective?

Which alternatives ought society aim for and should society correct for market failures?

Background

Miljonprogrammet

After World War II and until 1960 there was an economic development in Sweden and there were major demographic changes, such as urbanization and a growing population. This led to an increased demand for apartments in the cities and in 1965 the government decided to build one million apartments, known as Miljonprogrammet. Mainly, the aim was to decrease the shortage of dwellings and increase the average size and standard of the apartments. (Viden and Lundahl,

1992) The program started in 1964 and lasted until 1975 and it resulted in 1.006.000 new apartments (Nationalencyklopedin) and about 1/4 of Sweden's population live in these areas today (Skanska, 2012). At first, the apartments in the Miljonprogram areas were immensely popular, but today they are mainly associated with social and economic disadvantage. (Energimyndigheten, 2010)

The buildings were constructed when oil was cheap and thought to be never ending and this resulted in less energy efficient buildings. A typical Miljonprogram building annually uses 220 kWh / m^2. Today newly constructed houses are only required to use 110 kWh (household electricity excluded) annually, which means that Miljonprogram buildings consume almost the double amount of energy compared to new buildings. (Energimyndigheten, 2010)

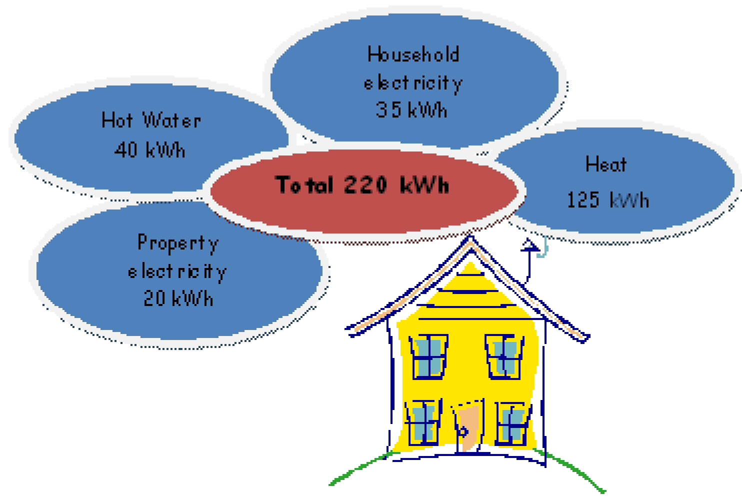

Figure 1 Energy use in Miljonprogram buildings

It is important to remember that every building is unique, and no general solutions for energy efficiency exist. (Mjörnell et.al 2011) There are two ways for property owners to finance these actions: increased rents and/or decreased energy costs. Increasing the rent is a sensitive question and might have a huge negative impact on the tenants' economic situation, some people might even have to move if the rents increase. Therefore it is important to take this into consideration when deciding on how far the energy efficiency should go.[1] There are approximately about 650.000 apartments which have not been modernized and have to be renovated in the near future. Since the renovations are extensive it would be inefficient not to make the buildings more energy efficient at the same time. Further, considering the goals and visions for energy efficiency adopted by the Swedish Government, one must take the opportunity to make the building more

[1] Cathrine Gerle, Poseidon AB, meeting [2013-04-18]

energy efficient at the same time. Otherwise it would probably not take place before 2050, which lowers the probability of achieving the goals and visions. (Energimyndigheten, 2010)

Backa Röd

Poseidon AB is a residential company owned by Göteborgs Stad. Poseidon AB has 1 566 apartments in the area Backa Röd which is located on the island Hisingen, about a 15 minutes away from the central parts of Gothenburg. (Poseidon AB) Together with SP (Technical Research Institute of Sweden) and Chalmers, Poseidon AB renovated a building on Katjas Gata 119 from the Miljonprogrammmet built in 1971. They accomplished a major difference in energy use (household electricity excluded), from using about 180 kWh/m^2 (A_{temp}) they decreased it until 52 kWh/ m^2 (A_{temp}). (Mjörnell et.al, 2011) Household electricity per apartment is estimated to be about 25- 40 kWh/m^2 (Energirådgivaren, 2011). This renovation was a pilot and research program and several of the actions for energy efficiency was carried out to receive more knowledge for upcoming renovations. (Hiller and Kurkinen, 2013)

Figure 2 Before the renovation of Katjas Gata 119

Figure 3 After the renovation of Katjas Gata 119

Energy Use in the Residential Sector in Sweden

Sweden has lower emissions than many other countries today, but there are several improvements which are possible to achieve and needs to be done in order to reduce the greenhouse effect. The last decades the final energy use has increased, in 1970 energy use was 375 TWh and in 2010 it was 395 TWh. In 2011 energy use in the residential and service sector was 147 TWh, which represented 40 % of the final energy use in Sweden. (Energimyndigheten, 2012b) The Swedish Environmental Agency claim that the potential reduction of energy use until 2050, in the residential and premises sector, is 80-100% compared to 1990. The identified key techniques within the residential and service sector to reach a low carbon dioxide economy are:

- *Energy efficiency, partly by the actions in the electricity sector*
- *Heat pumps, solar energy and biofuel*
- *Decreased demand for energy by improved climate shell on buildings*

(Naturvårdsverket, 2012)

Environmental Goals and Visions

Most scientists today agree that the rapid climate change is due to humans. In the past few decades the average temperature on earth has increased more rapidly than normal. Human activity emits huge amounts of greenhouse gases by for example transports, industry and energy production. This development is concerning since the temperature rise might lead to several consequences such as sea level rise, extreme weather and increased costs for natural disasters. Therefore several nations have started to develop strategies for reducing their greenhouse gas emissions. (WWF, 2013)

One of the goals in Sweden is to decrease energy use with 20 % until year 2020, compared to 2008, by energy efficiency. Decreasing energy use has a positive impact on several of Sweden's environmental goals, for example limited climate impact and a good settled environment. (Energimyndigheten, 2012a) The European Union has a goal to lower the greenhouse gas emissions by 80% until 2050 compared to 1990 levels. The member states formulate their own climate goals to reduce their emissions. Accordingly, the Swedish government framed a vision about net zero emissions until 2050: "By this time Sweden has a sustainable and resource effective energy supply and no net emissions of greenhouse gases to the atmosphere"[2]. (Naturvårdsverket, 2012, p. 6)

Energy efficiency is not given much attention in the long-term priorities pointed out by the government, but published energy and climate scenarios shows otherwise. All of Sweden´s published energy and climate scenarios include energy efficiency in buildings. Examples of actions that are mentioned are photovoltaic, insulation and more energy efficient windows. (Naturvårdsverket, 2012) As Norén Bretzer and Thynell (2013) argue it is reasonable to think

[2] Authors' translation

that the residential sector should, by energy efficiency, contribute to the reduction of greenhouse gas emissions.

Limitations of the Study

To make this study possible we have chosen to make some limitations of our study. To begin, we chose to only investigate the building on Katjas Gata 119 in the area Backa Röd at Hisingen, Gothenburg. This because of two reasons, the first reason is that it is easier to conduct a cost-effectiveness analysis when having a tangible project. Second, every Miljonprogram building is unique in itself and therefore you cannot make any generalizing conclusions about all of Sweden's Miljonprogram buildings. Time constraints prevented us from gathering all data by ourselves and therefore we use secondary data from Poseidon AB together with our own data obtained from various sources. Further, lack of time prevented us from investigate all possible energy efforts, therefore we have investigated efforts which we see as the most possible to go through with due to Sweden's energy situation. The situation might be totally different in another country.

Theory

Cost-Effectiveness Analysis

Cost-effectiveness Analysis is a way to estimate the costs of different alternatives. The underlying idea is to be efficient. Being cost-effective means getting the biggest "bang for the buck". The analysis takes the objective as given and then sort out various alternative ways of attaining the objective. In a project it is important to attain cost-effectiveness for both the firms and the environment, with a less costly project and increased energy efficiency as result. If an energy effort achieves an environmental improvement at the least possible cost or if it produces the maximum environmental improvement possible for the resources being expended, it is cost-effective. An energy effort needs to be at least be cost-effective to be efficient. (Field and Field, 2013) This means that the energy action chosen is not necessarily the most effective, but it is the most cost-efficient, another method might be more effective but resulting in additional costs. The cost-effectiveness ratio can be used to see how much more it will cost to implement the most effective alternative. (Economic and Development Resource Center, 1997) The purpose of cost-effectiveness analysis is to compare two or more alternatives, with similar objectives, different costs and effects. It is important that the different objectives have the same indicators of effectiveness, otherwise we cannot use a CEA to compare the cost-effectiveness. The measures of effectiveness need to consider two concepts: reliability and validity. (Levin and McEwan, 2011)

It is important to consider the distributional effects among the different alternatives, some constituencies will receive a greater effect than others. Different interventions might not have equal effects, for example it can be distributional effects among income groups. The most cost-efficient alternative might differ among groups and depend on which goal you aim for and a given option will alter between the groups. (Levin and McEwan, 2011)

Stages of CEA

A) Identify possible energy efforts

First, all the possible efforts that can be implemented in order to reach the goals, should be identified. The identification should be broadening in order to investigate as many relevant energy efforts as possible and a gross list should be created.

B) Describe how the identified energy efforts can contribute to meet the goals and visions.

All energy efforts identified in the previous step should be described in a way so that it is possible to understand to what extent the energy efforts can contribute to achieving the goals.

C) Consider which energy efforts that might be adequate and realistic.

Here the gross list from the first step is transformed into a net list of efforts that are realistic and adequate. Experts and other actors ought to be consulted in order to make an appropriate decision.

D) Collect information about the costs for the energy efforts which is considered to be adequate and realistic.

All costs for the actions should be collected. Normally it is the additional costs that emerges when going further than status quo (no additional undertaken actions in order to reach the goals), that should be accounted for. The costs might be divided into direct and indirect costs. Direct costs refer to the costs that the property owner will pay, for example the investment cost for each energy effort. The indirect costs occur as a consequence of the energy efforts, for example possible negative impact on the consumer or producer surplus. Describe the direct and indirect costs in monetary terms, as far as possible.

E) Collect information about the environmental effects of these energy actions

The environmental impacts generated by the efforts need to be identified. The impacts need to be measured in terms which make it possible to connect them with the goals of interest.

F) Rank the energy efforts by marginal cost or total cost per (environmental) effect

In this step the identification of the most cost-efficient energy effort begins. Either the marginal cost or the total cost can be practiced.

G) Give a provisional conclusion about which energy effort and which combination that is the most cost-efficient; which alternative reach the goal or vision at the least possible cost.

To identify the cost-efficient combination of actions, the marginal cost for achieving the goal needs to be the same for all energy efforts. When knowledge or data are missing in order to analyze the marginal costs, the ranking generated in step F can be practiced instead. The ranking gives a hint of which energy effort has the lowest cost per effect.

H) Make a sensitivity analysis

Here the conclusions from step G are evaluated, and their sensibility when changing assumptions and uncertain factors are being observed. Factors that can vary in a sensitivity analysis if for example the lifespan, costs and environmental impact.

I) Give a final judgment about which energy effort that is most cost-efficient and analyse the distributional impacts.

This includes a final recommendation of which energy efforts that should be undertaken and it should also be discussed who suffers from the financial consequences.

(Naturvårdsverket, 2008)

Different Potentials of Energy Efficiency

It is important to find a balance between the efficiency process and the achieved utility for society. If the costs exceed the utility there will be utter nonsense. How much energy efficiency that will take place depends on what you actually will achieve and at what cost. When discussing energy efficiency it is important to distinguish between the different potential of energy efficiency. The potentials are described below and are illustrated in figure 4.

Physical potential

The physical potential for energy efficiency is restricted by the theoretical minimum energy level, which is required to carry out a decided activity, given the level of knowledge. The only way to lower energy use further is to not carry out the activity.

Technical potential

This presents what is technically possible, regardless of the cost in the form of other resources. It can be divided into two different efficient potentials; the first one is the potential which can be achieved with the most modern technique which is available at the market. Second is the energy efficiency which can be reached with existing but non available technique.

Socio-economic potential

From a socioeconomic point of view this corresponds to the optimal energy use. If the financial potential reaches the socio-economic potential you should achieve energy use that is the most efficient from a socioeconomic point of view. This potential is therefore the one to endeavor. The exact size of the potential is difficult to calculate and it is lower than the technically potential but larger than the financial potential.

Financial potential

This potential follow the cyclical fluctuations, when we have an economic upward trend there are a lot of investments and vice versa. In the financial potential you take into account the implicit costs which in one way or another place a role in the firms' decision. Capital is often a limited resource and firms need to prior between the different uses and therefore this potential is lower than the socioeconomic potential. A few investments that might be profitable do not go through because the property owner might find other investments that he finds even more profitable. (Boverket, 2005)

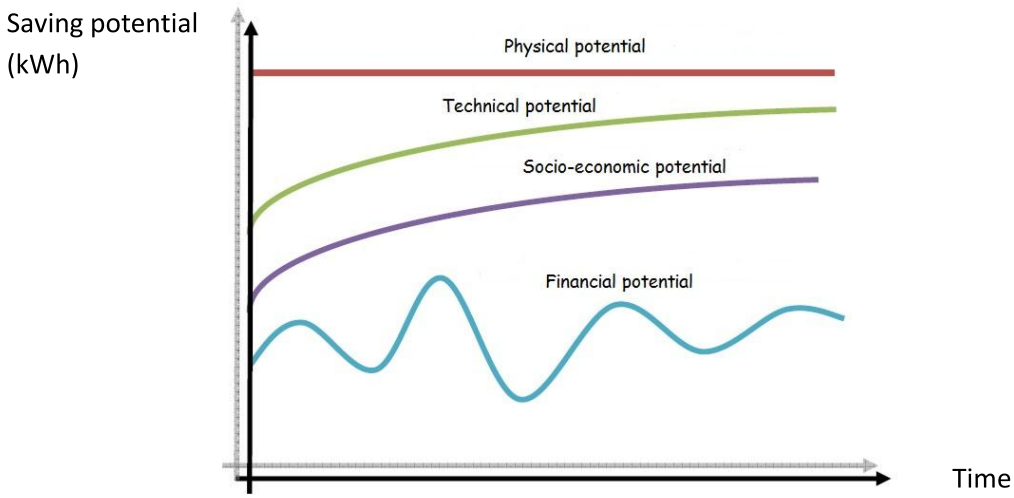

Figure 4 Different potentials of energy efficiency.

The ability of the economy to allocate resources where they make the most beneficial impact is called socio-economic efficiency. When society´s marginal utility of using one additional unit equals the cost of using it there are socio-economic efficiency. When having a perfect market, the social marginal cost does not differ from the private marginal cost. In a non perfect market world, due to market failures and market barriers, the private marginal cost does not equal to the social marginal cost. It is important to correct for different market failures to achieve effective allocation of the world's resources. A good basis of the choice of energy efficient strategy is to let the market allocate society's resources in the most cost efficient way and try to identify and correct for market failures, which might prevent a socio-economic optimal energy efficiency. (Ejdemo and Söderholm, 2010)

Market Failures in Energy Efficiency

In the presence of a market failure, the market cannot manage to achieve efficient outcomes, and there will be differences between the market value and the social value. Examples of market failures are externalities, public goods and asymmetric information. (Perloff, 2011) As presented below in figure 6, the market equilibrium generates a lower price (P1) and a higher quantity consumed (Q1) than what is social desirable in the presence of a market failure. From society's point of view, the optimal price would be P2 and the optimal quantity consumed would be Q2.

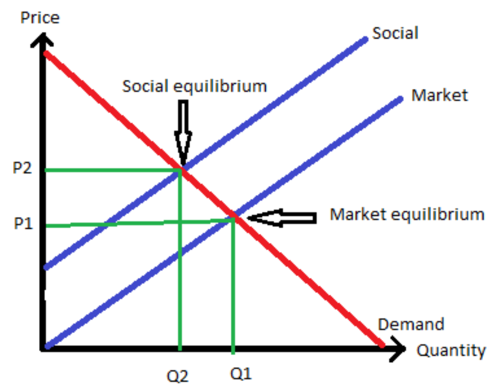

Figure 5 Social and market equilibrium

Even if an action is profitable from a financial and/or socio-economic perspective, it is not always implemented. This phenomenon is called market failure or market barriers. Market failure is what we described above. Market barriers do not mean that the market is inefficient, but they somehow affect the decision makers to not undertake actions for energy efficiency. Market barriers are not alone the root of the problem to achieve an energy efficient market, but the barriers can be reason to why we have market failures. (Ejdemo and Söderholm, 2010)

Information Failure in Energy Efficiency

There are several market failures that might prevent actions for energy efficiency, one of them are "information failure". There are situations when lack of information leads to inefficient energy use. Two kinds of information failures in energy efficiency are described below:

Principal Agent Problem (split incentives) occurs when the decision maker (the agent) is not the one who benefit from that decision (the principal) (Perloff, 2011). For example if the house owner buys the appliances but it is the renter that pays for the electricity. Then it might be the case that the owner does not invest in new, more energy efficient appliances because of lack of incentives, even though the renter might benefit substantially in terms of lower electricity bills. Additional there can be lack of incentives for the owners to lower the use of water. Often the tenants only pay a part of the total use of water, instead if the tenants pay for their own individual use of warm water there will be an incentive for them to lower the use. (Ejdemo and Söderholm, 2010)

New Information is a public good, which means that when new information about the use of energy efficient technologies is available it can be used by other actors at a lower cost. The individual actor who invests in a new energy effort cannot benefit fully from the investment. Therefore there is a lack of incentives for the individual actor to undertake the energy effort. The implementation of new technologies is an important source of information to other actors and leads to positive external effects. This phenomenon is called *Learning by using*. (Ejdemo and Söderholm, 2010)

Innovative Failures is a market failure which appears when new knowledge of technology enters the market and can be used by other actors at a lower cost. The individual innovator will not benefit fully from the investments because the knowledge will spill over to other actors. The incentives to invest in new knowledge will therefore be low from a socio-economic perspective. (Ejdemo and Söderholm, 2010)

Uncertainty is not a market failure, but it is a market barrier. Uncertainty about future energy prices makes it difficult to decide which energy efforts a company should undertake. For example if the energy prices will rise significantly in the future, the energy efficiency should be taken further to reach additional energy savings, but if the price decreases it will be the reverse. Also there is always a technical uncertainty, for example there might be even more efficient insulation on the market in a couple of years, which might make it more profitable to implement the energy efforts at a future stage. (Ejdemo and Söderholm, 2010)

Policies

Political goals alone are not enough to get individuals and companies to act, instead it is necessary to use different kind of policies. The goals constitute a common level of ambition for what political and administrative decisions will reach at a certain point through different policies. The residential sector is particularly pointed out in important policy documents (SOU 2008:25) and in the regulatory letters in 2010, the Swedish Energy Agency is ordered to analyse if there is a need for new incentive-based policies to realise the potential for energy efficiency in the residential sector (Ejdemo and Söderholm, 2010). Kolstad (2011) intend that many regulations around the world are far from cost effective in achieving goals. It is important to reach given emission targets in a least costly way. Below we discuss prescriptive regulations and incentive based policies, which are supposed to correct for market failures.

Prescriptive Regulations

With prescriptive regulations the regulator needs to gather information about the physical actions to control pollution and then decide specific steps to reduce the pollution. This is also called Command-and-Control regulation. Technological standards and performance standards are two types of prescriptive regulations and they can be combined with other types of policies like fines and penalties. To reach the optimal cost for pollution control it is important make an attempt to satisfy the equimarginal principle. The marginal costs of pollution need to be equal between different polluters who generate the same pollution. (Kolstad, 2011)

Incentive-based Policies

Incentive-based policies are designed to rectify for the drawbacks of prescriptive regulations approach to pollution control. Regulations have a major problem with adverse selection, firms (the principal) often have more information about means, procedures and techniques than the government (the agent), which they can use to reduce energy use. This resulting in either to low or to high standards. One way to deal with this problem is to introduce incentive-based policies, which leaves the firms enough latitude to adopt cost-effective energy efficient procedures and technologies. The public authority is the one who set the overall objectives and rules. According to Field and Field (2009) environmental economists have favored the idea of incorporating incentive-based policies for a long time into environmental policies. They also argue that in many cases incentive-based policies are strong enough and put more teeth into environmental problems. One type of incentive-based policy is subsidies. A subsidy works like a reward and implementing a subsidy will give the firm/polluter a certain amount of money for each reduced unit of emission. The subsidy works like an opportunity cost for the firm, because if a firm choose to not reduce energy use they will forgo the subsidy payment. (Field and Field, 2009)

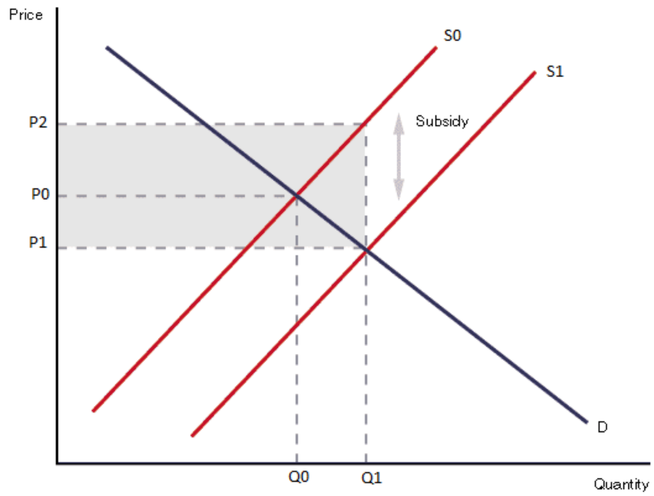

Figure 6 Subsidy. Källa: Axelsson et al. (1998), s. 180

The subsidy will shift the supply curve downwards with the subsidy, resulting in a higher quantity (Q1) produced at a lower cost (P1). The same result will occur if the subsidy were targeted for the consumers instead of the suppliers. (Axelsson et.al, 1998) When discussing energy efficiency, a higher quantity indicates a higher level of energy reduction.

How to Correct for Market Failures in the Residential Sector

Policies for Information Failures

Ejdemo and Söderholm (2010) intend that it is difficult to find a specific policy to solve the problems of information failures and split incentives. Energy prices should be shared between the actors to create incentives for energy efficiency and the lease should be designed so all the actors meet the cost of energy. In connection to newly constructed houses or major renovation projects the Swedish law today adjusts for the performance of buildings. Research indicates that the regulations act more like a norm than a minimum. This reveals the weaknesses of standards, when the limited values are achieved the change in behavior will fall. One of the most important policies to correct for information failures are different kinds of program of information (labeling), but also regulations as standards of products. (Ejdemo and Söderholm, 2010)

- Labeling of products with environmental and energy information gives the consumer information about energy saving products. Another way of information policy is energy counseling from the municipalities. Energy declarations are developed according to EG-directive. The declarations embrace buildings energy need and values to compare from similar buildings, they also contain recommendations on which actions that should be taken. (Boverket, 2005)

- A possible solution to correct for asymmetric information due to lack of incentives is to install individual measuring of warm water, heating or electricity. Then the tenants will have incentive to lower their use of energy and their behavior will change. (Ejdemo and Söderholm, 2010) Individual measuring of warm water and heating will become a requirement in newly constructed buildings and renovation from June 2014 if the investment is possible from technical and economical perspective in relation to the energy saving which can be achieved. (Börjesson, 2013)

Policies for Innovative Failures

From a socio-economic point of view it is important to discuss policy actions for technology that is technic neutral. The most efficient way of technical learning is not to necessarily to aim for the development of specific technologies, instead it is important to take care of the spill-over effects and deal with the problem of imperfect information. In situation where market failures can be identified to specific technologies there can be worth considering having specific technique policies. Some techniques are dependent of new infrastructure and supporting networks, but services like this often offers public goods and the private incentives to invest in different kind of new techniques is often weak. This can lead to important lock-in effects and will aggravate the entrance of new technique on the market. (Ejdemo and Söderholm, 2010) Examples of existing subsidies to correct for innovative failures are:

- *Klimp* is a program aiming to encourage actions which decreases energy use and limits the release of greenhouse gases. The program is primarily supposed to work for municipalities and municipalities' cooperation with firms. This is funded by the Swedish Environmental Agency. (Boverket, 2005)

- *Grants for solar cells* are a way of contributing to the development of new techniques and make the energy sector more renewable. All actors might receive the grant, both firms and individuals. From 2013, the grant can cover up to 35 % of the investment cost. (Energimyndigheten, 2013a)

- *Contribution to actions for an efficient and environmentally-adapted energy supply* is another way to improve the energy efficiency in buildings. This grant is administrated by the Swedish Energy Agency and aims to encourage the development, procurement and introduction of efficient energy technologies. Contribution is given to environmental protection, technology procurement and development of energy before being introduced in the market. (Boverket, 2005)

Uncertainty

The uncertainty about future policies can reduce the investments in energy efficiency renovations. If the investors expect a future subsidy of a specific technique they will wait with performing energy efficiency until the government decides whether or not to subsidies the technique. This will stop the renovations and prevent energy efficiency, instead of contributing to learning by using effects. Therefore it is important that the government have good information about future policies and work for a better and more stable market. (Ejdemo and Söderholm, 2010)

Previous Research

Today it is highly on the agenda to try to fill the gap between financial efficiency and socio-economic efficiency. Previous research had tried to identify reasons for why not enough energy efficiency in the residential sector is performed. Especially Ejdemo and Söderholm (2010), which we have based our theory on, try to solve this by identifying different market failures. ClueE, Collaborating Learning for urban energy Efficiency, is a research project between SP (Technical Research Institute of Sweden) and Gothenburg University. Their aim is to highlight different obstacles and possibilities in energy efficiency in municipal buildings from a social science perspective. To solve this they investigate behaviour, economical, legal and political obstacles.

Several cost-effectiveness analyses have been carried out in health economics. But as far as we know, a cost-effectiveness analysis when renovating buildings has not been conducted. There are a few papers that discuss the cost-effectiveness of energy policies, for example Naill et.al wrote the working paper "An analysis of the cost effectiveness of US energy policies to mitigate global warming"[3], but that working paper only discuss policies.

Method and Material

In this CEA we proceed from the following nine steps, described in the previous chapter. (A) First we identified possible energy efforts that could lower the energy use. At first we received Poseidon AB's energy efforts from their pilot project Katjas Gata 119: Ventilation, Roof, Windows, Insulation of Walls and Balconies. Further we investigated other possible alternatives to reduce the energy consumption: Green Roofs, Solar cells, Combined refrigerator and freezer, Dishwasher, Individual Measuring and Charging of Warm Water and Visualising energy use, Lightning, Tumble dryer, Washer, Oven, and Stove. (B) Thereafter we described the actions and how they contributed to the goals and visions. (C) The actions that we considered to be adequate and realistic were Green Roof, Solar cells, Combined Refrigerator and Freezer, Dishwasher, Individual Measuring and Charging of Warm Water, Visualising Electricity Use and Poseidon AB's energy efforts except from Balconies. In order to get reliable actions we contacted different experts and Cathrine Gerle at Poseidon AB. In step (D) we collected information about the cost for each action which was considered to be adequate and realistic. Further, we collected information about energy use/savings for each energy effort (E) and ranked the actions by total cost per (environmental) effect (F). At stage (G) we gave a provisional conclusion about which action and which combination that is the most cost-efficient, in other words, meet the goals at the least possible cost or. In the following step a sensitivity analysis were performed (H), which analysed the reliability of the calculations, costs, kWh saved and SEK saved. Finally we give a conclusive judgment about which policy that is most cost-efficient and analyse the distributional impacts (I). When presenting our results, we decided to separate the calculations into three different analyses: energy, economic and CER. We consider this be a clear way of presenting the results. The exact calculations are presented in the appendix.

[3] Naill et.al *An analysis of the cost effectiveness of US energy policies to mitigate global warming*. http://www.systemdynamics.org/conferences/1990/proceed/pdfs/naill826.pdf (15 May 2013)

Assumptions

We do not take the maintenance costs into consideration and do not consider the fact that one effort might depend on another effort in order to work. We see the actions as individual actions that do not depend on each other. The prices of the eleven energy efforts are without taxes. All of our costs and savings are calculated for the entire building on Katjas Gata 119.

For some of the energy efforts, there are several attributes that might proceed from a renovation. Since we are only considered about the energy attributes, we want to know the extra costs that are obtained when lowering energy use. Therefore we have compared two different renovation alternatives (standard and ambitious) for those actions that we assume to have other attributes. For example the walls needed to be updated in order to not fall apart, so we took the difference in investment cost and energy consumption between the necessary renovation (standard) and the less energy demanding option (ambitious). For some of our energy efforts we assumed that there is no other attributes, like for example visualising energy use or solar cells.

Energy Efforts

For energy effort 1-4 we have received costs and benefits from Poseidon AB and for these we assume a lifespan of 30 years. The prices are from the pre study of Katjas Gata 119, from 2008, but do not differ remarkably from the final costs in 2009. For further calculations, please note Appendix.

Ventilation (1)

According to Cathrine Gerle the ventilation was the largest energy consuming part of the building on Katjas Gata, thus this energy effort has a major efficiency potential.

Standard: Using the existing system and switching of F aggregate engine[4]
Ambitious: FTX ventilation with heat exchanger, radiator, crawl space and construction of a new fan room.

Roof (2)

Additional insulation reduces heat losses and increases the thermal comfort and air density, plus that it decreases noise levels.[5]

[4] Authors' translation, F-aggregatsmotor

Standard: Using the existing roof and performing maintenance actions

Ambitious: Additional insulation, new roof construction and new fan room ceiling

Windows (3)

New windows result in energy savings, better thermal comfort, decreased air leakage between window frame and wall and usually better soundproof. (Hiller and Kurkinen, 2013) To reach a decreasing energy use in a building changing window is a simple way. [6]

Standard: New windows with the U-value 1,3. New attachment included.

Ambitious: New windows with the U-value 0,9. New attachment included.

Walls (4)

The U-values in the buildings are often major. To reduce the energy leak and meet the standards of newly constructed buildings, the additional insulation often need to be about 200 millimeter. When achieving energy savings this is one of the most important efforts project to carry out. (Mjörnell et.al, 2011)

Standard: Maintenance of the existing wall, such as painting and concrete reparation

Ambitious: New outer wall, 200 millimeter insulation, new utfackningsvägg[7]

For energy effort 5-10 we have received costs and benefits from different sources, since these actions were not carried out by Katjas Gata 119.

Green Roofs (5)

There are several positive aspects from green roofs, such as reduced energy use, increased lifespan of the roof, it absorbs rainwater and lowers noise levels (Skanska, 2009). In this case we choose to look at sedum roof, which is a commonly used type of vegetation for green roofs.

Solar Cells (6)

Solar cells transform the renewable solar energy into electricity. Creating electricity by using solar cells is emission free and the production of the solar cells requires a low amount of energy compared to what they produce during its lifetime. (Eon)

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[5] Cathrine Gerle, Poseidon AB, meeting [2013-04-18]

[6] Cathrine Gerle, Poseidon AB, meeting [2013-04-18]

[7] Swedish term, no English translation found.

There are no constraints to have both green roof and solar cells together. On the contrary, the green roof can increase the efficiency of the solar cells. The green roof lowers the heat and makes the roof cooler and since the solar cells will work more efficient at lower temperatures the combination of green roofs and solar cells are good. (Köhler et.al, 2007)

Combined Refrigerator and Freezer (7)

Approximately 22 % of the electricity in a household is consumed by the refrigerator and freezer. By choosing appliances with a high energy label, like A+++, the electricity bill might decrease visibly. (Energimyndigheten, 2011)

Standard: The standard case is combined refrigerator and freezer with A labeling

Ambitious: The ambitious case is combined refrigerator and freezer with A+++ labeling

Dishwasher (8)

A modern dishwasher use about 35 % more energy efficient than an old dishwasher. (Grästorp Energi). Installing a new dishwasher can thereby decrease the energy use.

Standard: The standard case is dishwasher with A labeling.

Ambitious: The ambitious case is dishwasher with A+++ labeling

Individual Measuring and Charging of Warm Water (9)

Electricity is often individually charged in Sweden, but one can also individually charge for heating and water use. It creates an incentive for the tenants to reduce their own use of energy. (Hiller and Kurkinen, 2013) When installing individual measurement equipment, the tenants becomes more aware of their energy consumption. We have chosen to only focus of individual measuring and charging of warm water since the tenants already are being charged for household electricity and to charge for heating will decrease the owners (Poseidon AB) incentive to renovate as energy efficient as possible. By individual warm water measuring energy use might decrease with 25- 30 %. [8]

[8] Ingvar Rundbäck, KTC, phone call [2013-05-08]

Energy Display for Visualising the Electricity Use (10)

The tenants have a definitive impact of the aggregate energy use. Energy use is often invisible for the tenants and therefore it is difficult for them to feel responsible for their behaviour. By using technique to visualise the energy use is a way to change the tenants behaviour. (Martinac et.al., 2013) Visualising the electricity use can generate a decrease with up to 24 %. We decided to investigate the cost-effectiveness of an energy display (label Eliq), which can be placed anywhere in the apartment. (Eliq)

Excluded Energy Efforts

Washer and tumble dryer have not been evaluated since Poseidon has separate laundry buildings which have not been included in their renovation on Katjas Gata 119. It is also difficult to obtain an estimation on the kWh saved when switching from an old to a new washer/tumble dryer. Oven and stove have neither been investigated. This because we considered it difficult to estimate the energy savings. How much energy the stove and oven consume depends on how much tenants use it and how they use it. Therefore these energy efforts are not included. We also chose to not analyse Lightning because it was difficult to obtain estimations about energy use. The last energy effort implemented by Poseidon, Balconies, were not included since it only have a limited effect on energy use.

Data sources and collection

Our data are mainly gathered from Poseidon AB, but also from other different sources like Vattenfall and Veg Tech. We received information about the costs form Poseidon AB for alternative 1-4 and for alternative 5-10 we collected data by ourselves. Please note the appendix for details about where the information where gathered.

Results

Below the results of the CEA are presented, both the economical, energy and CER results.

Energy Analysis

In this section the environmental analysis will be explained. In table 1 the following are presented:

Annual energy use before renovating (kWh): How much energy each part of the building used before the renovation

Annual energy use after renovating (kWh): How many kWh the energy effort will use/emit

Efficiency rate: The energy savings divided with the annual energy use before the renovation

Annual savings (kWh): How many kWh the energy effort annually save compared to before the renovation

Savings in annual energy use (kWh) between standard and ambitious: The difference in used kWh between standard and ambitious

Lifespan: How many years each action is estimated to last

Energy savings during lifespan (kWh): The annual savings in kWh times the expected lifespan

Table 1 Energy Analysis

Energy Effort	Annual energy use before renovating (kWh)	Annual energy use after renovating (kWh)	Efficiency rate	Annual savings (kWh)	Savings in annual energy use (kWh) between standard and ambitious	Lifespan (years)	Energy savings during lifespan (kWh)
Ventilation (1)							
Standard	81 963	78 028	4,8 %	-	68 936	30	2 068 080
Ambitious		9 092	88,9 %	-		30	
Roof (2)							
Standard	10 992	5 835	46,9 %	-	4 071	30	122 130
Ambitious		1 764	84 %	-		30	
Windows (3)							
Standard	35 961	14 656	59,2 %	-	9 364	30	280 920
Ambitious		5 292	85,3 %	-		30	
Walls (4)							
Standard	39 896	46 952	-17,7 %	-	43 831	30	1 314 930
Ambitious		3 121	92,2 %	-		30	
Green roofs (5)							
Sedum roof	-	-	-	1 868	-	15	28 020
Solar cells (6)							
Solar cells	-	-	-	33 440	-	25	836 000
Combined refrigerator and freezer (7)							
Standard	-	5 600	-	-	3 136	8	25 088
Ambitious	-	2 464	-	-		8	
Dishwasher (8)							
Standard	-	4 944	-	-	1 360	8	10 880
Ambitious	-	3 584	-	-		8	
Individual warm water measuring and charging (9)							
Measuring	43 424	32 568	25%	10 856	-	13	141 128
Energy Display for Visualising the Electricity Use (10)							
Energy display	40 000	30 400	24 %	9 600	-	10	96 000

As we can see in this table, the energy effort with the highest energy savings during the lifespan is Ventilation (1) with 2 068 080 kWh saved. In second place we find Walls (4) with 1 404 930. Dishwasher (8) is the alternative with the lowest kWh saved during its lifespan, only 10 880 kWh.

Economic Analysis

The results of the economic analysis are summarized below. It will include all the direct financial cost and benefits due to each effort[9]. Taxes are excluded in all calculations. Below the calculations are explained:

Investment cost (SEK): The investment cost (taxes excluded) in SEK for each energy effort. Material costs and in some cases labour costs are included. Labor costs are not included in the calculations for Combined Refrigerator and Freezer (8) and Dishwasher (9), because of missing data.

Investment cost due to energy savings (SEK): The difference in investment costs in SEK between the standard and ambitious case. This cost therefore represents the extra cost for achieving a lower energy use.

Annual savings: when calculating the annual savings we use the average price for electricity/district heating that Göteborgs Energi (Din El) had during 2012, and multiply that with the annual savings in kWh. The average electricity price was 82,94 öre/kWh and the average price for district heating was 82,4 öre/kWh. Both prices include energy and sales taxes. For example the annual savings for green roofs are 1539 SEK (1867,5 kWh times 0,824 SEK).

Lifespan: How long each energy effort is estimated to last

Savings during lifespan (SEK): The annual savings in SEK times the expected lifespan

[9] Maintenance costs excluded

Table 2 Economic Analysis

Energy Effort	Investment cost (SEK)	Investment cost due to energy savings (SEK)	Annual savings (SEK)	Lifespan (years)	Savings during lifespan (SEK)
Ventilation (1)					
Standard	100 000	1 584 000	56 803	30	1 704 090
Ambitious	1 684 000			30	
Roof (2)					
Standard	200 000	1 640 000	3 355	30	100 650
Ambitious	1 840 000			30	
Windows (3)					
Standard	1 309 600	84 962	7 716	30	231 478
Ambitious	1 394 562			30	
Walls (4)					
Standard	1 540 000	484 000	36 117	30	1 083 510
Ambitious	2 024 000			30	
Green roofs (5)					
Sedum roof	168 750	168 750	1 539	15	23 085
Solar cells (6)					
Solar cells	664 400	664 400	27 735	25	693 378
Combined refrigerator and freezer (7)					
Standard	64 000	92 800	2 601	8	20 808
Ambitious	156 800			8	
Dishwasher (8)					
Standard	51 200	57 600	1 121	8	8 968
Ambitious	108 800			8	
Individual warm water measuring and charging (9)					
Measuring	56 000	56 000	8 945	13	116 285
Energy Display for Visualising the Electricity Use (10)					
Energy display	31 936	31 936	7 962	10	79 620

The energy effort with the highest investment cost (adjusted for other attributes) is Roof (2) with the investment cost 1 640 000 SEK, followed by Ventilation (1) with 1 584 000 SEK in investment costs. Energy display for visualising the electricity use (10) has the lowest investment cost, 31 936 SEK.

Ventilation (1) has a high potential in reducing the district heating costs, 1 704 090 SEK can be saved during the lifespan. Using energy efficient Dishwashers (8) saves 8 968 SEK during its lifespan. Annual Savings help us to see how much we actually save each year after the implementation of the energy effort. After the energy reduction there will be savings since less energy is consumed. This is important to account for before the implementation of each strategy. It does not contribute to the CEA and the ranking of the energy efforts' ratios but it is an opportunity cost that is important to consider.

Cost-Effectiveness Ratio

Below our calculation of the Cost-effectiveness ration is presented. The CER are used when evaluating which of the eleven chosen energy efforts that are the most cost-effective. Below the calculations are explained:

(Difference in) Investment cost (SEK): Note economic analysis

Energy savings during lifespan (kWh): Note energy analysis

CER: The investment costs (difference in investment cost between standard and ambitious, if several attributes exists) divided by the energy savings during lifespan. This calculation will show how many SEK each saved kWh will cost.

Table 3 Cost-Effectiveness Ratio

Energy Effort	Investment cost due to energy savings (SEK)	Energy savings during lifespan (kWh)	CER
Windows (3)	84 962	280 920	0,30
Energy Display for Visualising the Electricity Use (10)	31 936	96 000	0,33
Walls (4)	484 000	1 314 930	0,37
Individual Measuring and Charging (9)	56 000	141 128	0,40
Ventilation (1)	1 584 000	2 068 080	0,77
Solar cells (6)	664 400	836 000	0,80
Combined refrigerator and freezer (7)	92 800	25 088	3,70
Dishwasher (8)	57 600	10 880	5,29
Green Roof (5)	168 750	28 020	6,02
Roof (2)	1 640 000	122 130	13,43

As table 3 shows, the most cost-efficient energy effort is Windows (3) with a cost of 0,30 SEK per saved kWh. Roof (2) has a cost of 13,43 SEK per saved kWh, which is relatively high compared to the other energy efforts. It is twice as expensive as the second worse alternative, Green Roof (5) which costs 6,02 SEK per saved kWh.

Sensitivity Analysis

There are several aspects that might be questionable and can affect the results. The three main variables that ought to be given special attention in this study is uncertainty for costs, energy savings and lifespan.

The given lifespans might vary for some of the energy efforts. For instance is the lifespan of the green roofs very uncertain. In the calculations (note appendix) the minimum lifespan of 15 years has been used, but according to the producers it might be the double. When calculating with a lifespan of 30 years we get a Cost-Effectiveness Ratio of 3,01 instead of 6,02 as the previous calculation revealed. This is a reduction by half of the cost per saved kWh, which obviously affects to what extent green roofs will be implemented. Also the lifespan of the four energy efforts from Poseidon AB is questionable. It is assumed that they all have the same lifespan of 30 years, which probably is unreliable since these four energy efforts are very different.

There are two types of uncertainties when considering the costs: energy price and investment costs. Energy prices might vary in the future. It does not affect the CER, but it certainly affects the annual savings in SEK. It might also depend among different energy companies. We have used averages from Göteborg Energi, other companies might have higher or lower prices. Investment costs affect the CER and thereby also the ranking of different energy efforts. For example the costs of a combined refrigerator and freezer are averages, and they might be cheaper due to for example quantity discounts. If the difference between A and A+++ would be only 70 000 SEK, the CER will be 2,79 instead of 3,70. This is a difference of 1 SEK per kWh, which is relatively significant.

The energy savings also need to be considered and questioned. We especially identify the CER calculations for Individual warm water measuring and charging and energy displays for Visualising the electricity use as very uncertain regarding saved kWh. These two energy efforts highly depend on the behaviour of the tenants, and implementing these energy efforts do not automatically save energy, like for example additional insulation would. If for instance an energy display only decrease the electricity use with 10 %, the CER would be 0,80 instead of 0,33 and if the electricity use decreased with 30 %, the CER would be 0,27 This obviously affects to which extent energy displays will be implemented. Also the expected savings from Green Roofs are uncertain, since we use approximations from Toronto.

Conclusion

Which of our chosen efforts are the most cost-effective?

As we can see in table 3, the energy efforts with the lowest CER are: Windows (3), Energy Display for Visualising the Energy Use (10), Walls (4), Individual Measuring and Charging of warm water (9), Ventilation (1) and Solar cells (6). These are the most cost-effective according to our analysis.

Which alternatives ought society aim for and should society correct for market failures?

In our experience, property owners will realize those energy efforts they have incentives for: Windows (3), Walls (4) and Ventilation (1), as long as the tenants do not pay for heating. Individual Measuring and Charging of Warm Water (9) might be implemented by the property owner, but that depends on the situation and the preferences of the specific property owner. It would be unnecessary and a waste of resources for the government to intervene and correct for those energy efforts, since property owners probably will realize these anyway.

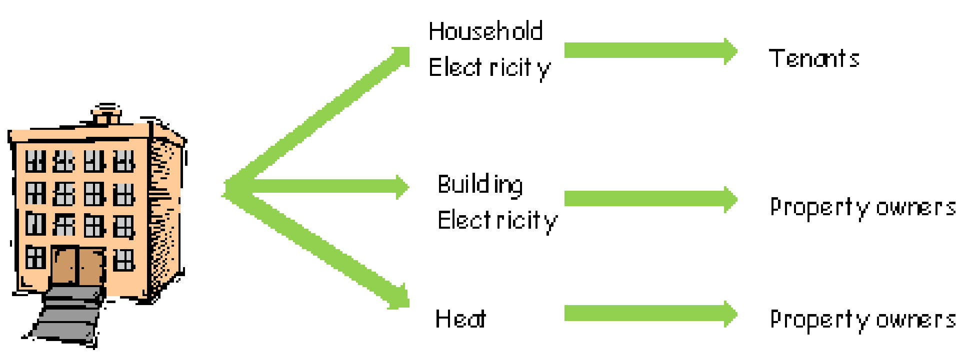

Figure 7 Where are the incentives?

Furthermore, we can observe that Energy Display for Visualising the Energy Use (10) and Solar cells (6) are also cost-effective, but property owners lack incentives to implement these energy efforts. When installing energy displays, property owners will pay for the installation costs, but the tenants will benefit from it. This is a typical example of the Principal Agent Problem, and governmental intervention is needed. Two types of applicable policies are subsidies or prescriptive regulation. A subsidy would imply additional costs for society, and there would still be an uncertainty if property owners would install the energy displays since the lack of incentives remains. A prescriptive regulation would enforce property owners to install energy displays. Important to notice is that this results in higher costs for the property owner, which might eventually also affect the tenants negatively.

Installing solar cells would not only generate renewable energy for the property, but would also contribute to achieving the environmental goals. Today, property owners can benefit from the grant that is available when installing solar cells. Despite this, the installation of solar cells on Miljonprogram buildings is progressing very slowly. Uncertainty about the future energy prices and progressing technology might be the underlying reason for this phenomena. Also, installing solar cells on apartment blocks is relatively uncommon, resulting in lack of information about the advantages and disadvantages when implementing solar cells on apartment blocks. Therefore the first actor, who installs solar cells, will not benefit fully from the investment since other actors will be able to use the knowledge at a lower cost. The incentives might therefore be too low, which ought be corrected by the government. The government should consider supporting property owners with information about the advantages resulting from solar cells, but also increasing the grant. Thereby the knowledge level will increase and the economic incentives for investing in this renewable energy source will rise. The positive external effect *Learning by using* might also arise from this situation.

Discussion

To develop this paper it would have been interesting and relevant to investigate energy efforts in additional areas than Backa Röd, since it probably would have contributed to the research. It would have made the calculations more reliable and could have shown variation among different areas and buildings. Comparing for example different types of windows and insulation would also have contributed to the essay. There is an uncertainty regarding the costs, lifespan and kWh saved for many of our energy efforts, which lowers the reliability of our research. Our prices were calculated during different periods, and since for example the inflation is not being considered, there might be a bias.

Further it would have been interesting to investigate the social and environmental benefits from the different efforts. To do this a Cost-Benefit Analysis would be preferable, but it requires exact information about the social and environmental externalities. It would result in a more interesting conclusion from a socio-economic point of view. From a socio-economic point of view there might also be more moderate to undertake energy efficiency in other sectors, such as the transport- or the industrial sector. Performing energy efficiency in the residential sector might not be the best way to reach our goals and visions, which is important to have in mind. The government could for example perform similar CEAs in other sectors to find out where it is most cost-effective to reduce the energy use. Also, including behavioral economics would have been interesting since a significant part of the household electricity depends on the behaviour of the tenants. A closer look at the distributional impacts would also have been preferable, but lack of information about elasticities prevented us from doing this.

Why Energy Efficiency?

The political environmental goals in Sweden and EU are ambitious and in order to reach them, all sectors needs to contribute. The residential sector in Sweden consumes a large part of the total energy use, and there is a great potential energy reduction. As mentioned, a majority of the Miljonprogram buildings need to be renovated in the next few years, and in order to reduce the energy use significantly, the energy efforts ought to be completed while renovating. The renovation can be seen as a once-only change and therefore the energy savings needs to be done now. It would probably be much more costly to add energy efforts, for example 10 years after the renovation, instead of implement them while renovating.

As discussed before, there are six actions that will be profitable to carry out since they are cheaper than the current energy prices. The question is which of the remaining four actions that will be profitable in the long run. Possibly, the energy prices will rise in the future because of an increased demand. After the six profitable actions, the next action with the lowest cost per kWh is Combined refrigerator and freezer with a cost of 3,70. At the present, it seems doubtful that the energy prices will rise so that action will be profitable, in spite of an increased demand. Therefore, if nothing unexpected happens, the remaining four actions will not be profitable in the nearest decades. Even though the energy prices would fall, we consider the four most profitable actions to still be profitable, since it is doubtful that the energy price would fall to around 0,3-0,4 SEK.

Cost-Effectiveness and Socio-Economic Efficiency

The biggest bang for the buck is the idea of Cost-Effectiveness Analysis. To reach our goals and visions we need to lower our energy use and the residential sector needs to contribute. The cost-effectiveness ratio can be used to see how much more it will cost per kilo watt hour to implement the most effective alternative.

The gap between financial and socio-economic potential is obvious and there are several changes due to social and economic obstacles that needs to be solved. The technical potential or the technique that is available on the market is high enough to reach our goals and visions. The technical knowledge about energy efficiency in buildings is enough and this especially shows Katjas Gata 119, which achieved a huge energy reduction with available technique. The question is how the financial potential could reach the socio-economic potential, the potential that from society's point of view is the optimal use of energy. Therefore it is important to decide what the society should aim for and discuss what the socio-economic potential ought to be.

Market failures prevent a socio-economic optimal energy use and it is important to correct for them and achieve an effective allocation of the world's resources. But at least as urgent as identifying the market failures, we think it is to find a cost-effective solution from an energy perspective. The CER help us with that. For example our analysis shows that Visualising the Electricity Use and Individual Measuring of Warm Water are very cost-effective. If Poseidon AB would have conducted a CEA they might have changed their mind (in a perfect market world) and also implemented these energy efforts, which have low CERs in our analysis. If we should reach our goals at the least possible cost it is important to conduct cost-effectiveness analysis as a complement to other analyses.

Increase the Energy Efficiency

Apparently there are no or less technical problems to reduce the energy use, so the question is why the energy efforts default. The problem seems to be either economical or behavioral, or in some cases both. Even though many energy efforts are profitable, the investment costs tend to scare the property owners. Some of the investments favor the tenants in form of reduced electricity bills, therefore the property owner has weak or no incentives to realize these projects.

Therefore it is important that society investigate which energy efforts that is cost-effective, where the incentives can be found and if society needs to intervene with some kind of policy.

To increase the energy efficiency further there must exist incentives for the property owners to reduce the energy use. There is lack of incentives for the first property owner who considers investing in new available technique, since he/she stands for all the costs, but the gains are scattered among many others. This might be one of the reasons why so few energy efforts are carried out, even though they might be profitable in the long run. One alternative for the government to solve the problem is to intervene and maybe subsidies pilot projects. This might be an effective way to speed up the energy effort. A judgment about where you can find the biggest energy potential needs to be done and after that there can be decided which policies that should be implemented.

Further, if we do not lower our energy use and if we believe that there might be even higher energy prices in the future, there is a risk that we will have higher energy bills. This can be seen as a alternative cost to not renovate the buildings today. Prescriptive regulations are a way we consider as good to achieve an energy efficient renovation. We think that it should exist more technological standards that are mandatory. Considering buildings long lifespan and the available technology the standard 110 kWh in newly built houses could be lowered further.

When it comes to reducing the household electricity, a lot of actions are connected with behavior and habits. Behavioral aspects of the tenants energy use is difficult to correct for but not less important to try to solve. Understanding and procedural knowledge is important to change the behaviour of the tenants. It is also important to distinguish Individual measuring and charging of warm water, and Visualising the energy use from the other energy actions. All the other alternatives generate reduced energy use but raise the welfare at the same time. Individual measuring and Visualising the energy use will lower the energy use but at the expense of welfare loss. The tenants will probably decrease their energy use by using less warm water and less electricity and this result in a welfare loss for the tenants. It is urgent to have this in mind while choosing which of the renovations that should be conducted. From June 2014 it will be required to install Individual Measuring in all renovations and newly constructed buildings. The risk of the requirement to install individual measuring is that the property owners' incentives to undertake other energy efforts to reduce the energy use will be lower if they see that the tenants can reduce the energy use by themselves. If this will be the case there is a risk that the investment in energy use will be lower and we might not reach our goals and visions. The major parts of the incentives need to lie on the property owners.

Renovating and implementing different energy efforts is expensive for the property owner, and as discussed the rent might be negatively affected. It is important to consider this since even though achieving energy efficiency is important, increased rents might be devastating to the tenants' economy. Therefore governmental intervention ought to be considered in order to support the energy reduction and at the same time avoiding social dilemmas, otherwise a tradeoff between energy use reduction and social equity will occur. Poseidon AB, among a lot of other residential companies, is owned by the local authorities. It can be argued that the local authorities should lead by example and increase the amount of energy efforts being carried out. Simultaneously, it is important to consider the potential effects regarding the rents. Miljonprogrammet are refurbished and will probably become more popular to live in and this can be seen as a socio-economic gain for the municipalities.

Produce more Renewable Energy?

Even if we perform energy efficiency actions it is important to notice that energy efficiency necessarily does not mean that the total energy use decrease. Energy efficiency is always positive from an environmental point of view, but it is important to notice that the environmental impact can differ among buildings depending on which type of energy the buildings use. Besides from reducing the energy use it is at least equally important to find "clean energy" and consider the energy that is actually consumed after the energy efficiency.

It is worth considering producing more renewable energy, from for example solar or winding power, as a complement to reduce the energy consumption. From society's point of view the cost-effectiveness of each alternative ought to be calculated in order to recognize the most efficient solution. As we can see in our Cost-Effectiveness Analysis the CER are 0,80 which means that it is relatively cost-effective. Although it might be more cost-effective to produce new clean energy, it is still important to reduce the energy consumption. The future energy supply might be more uncertain due to less reliable energy sources and an increased demand. Therefore it will be a risk not to reduce the energy use, especially when renovating buildings since there is a lock-in effect since the buildings will not be renovated again within the next fifty years. The best alternative would of course be to both minimize the energy use and only use renewable energy sources.

Finally…

Since all buildings are unique, it is not preferred to implement our findings in other Miljonprogram buildings. But the results might contribute as guidance for if the government needs to intervene and support the reduction of energy use in the building sector. Especially since the goal for 2020 and the vision for 2050 are ambitious, and now is the time if we want to transform the Miljonprogram buildings to less energy demanding buildings. Everyone needs to contribute to reach the goals and vision, and someone needs to take the first step. If the residential sector takes their responsibility, the other sectors need to take their responsibility as well. Our cost-effectiveness analysis shows that six of our chosen efforts are profitable. The challenge is to decrease the gap between financial and socio-economic potential, in order to reach the environmental goals and visions. This paper reveals that it is important to deal with the incentive problems to decrease the gap. Well considered and correctly targeted policies are important to reach a cost-effective energy reduction.

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Appendix - Calculations for the CEA

Conditions on Katjas Gata 119:

- 16 apartments
- A_{temp} 1 357 m^2
- Outer roof area, 450 m^2

Energy prices:

We have used the average prices for electricity/district heating, which Göteborgs Energi (Din El) had during 2012.

Electricity price: 0,8294 SEK/kWh (energy and sales taxes included)

District heating price: 0,824 SEK/kWh (energy and sales taxes included)

Calculations for each energy effort:

Ventilation (1):

We received the numbers and expected lifespan from Poseidon AB.

<u>Energy analysis</u>

Annual energy use before renovating (kWh): 60,4*1357=81 963

Annual energy use after renovating (kWh), standard: 57,5*1357=78 028

*Annual energy use after renovating (kWh), ambitious: (*5,5+1,2)*1357= 9 092

Efficiency rate, standard: (81 963-78 028)/81 963=4,8 %

Efficiency rate, ambitious: (81 963-9 092)/81 963= 88,9 %

Savings in annual energy use (kWh) between standard and ambitious: 78 028-9 092= 68 936

Lifespan (years): 30

Energy savings during lifespan (kWh): 68 936*30= 2 068 080

<u>Economic analysis</u>

Investment cost (SEK), standard: 125 000/1,25=100 000

Investment cost (SEK), ambitious: (1 450 000+655 000)/1,25=1 684 000

Investment cost due to energy savings (SEK): 1 684 000-100 000=1 584 000

Annual savings (SEK): 68 936*0,824=56 803

Lifespan (years): 30

Savings during lifespan (SEK): 56 803*30=1 704 090

<u>Cost-effectiveness analysis</u>

CER: 1 584 000/2 068 080=0,77

Roof (2):

We received the numbers and expected lifespan from Poseidon AB.

<u>Energy analysis</u>

Annual energy use before renovating (kWh): 8,1*1357=10 992

Annual energy use after renovating (kWh), standard: 4,3*1357=5 835

Annual energy use after renovating (kWh), ambitious: 1,3*1357=1 764

Efficiency rate, standard: (10 992-5 835)/10 992=46,9 %

Efficiency rate, ambitious: (10 992-1 764)/10 992=84 %

Savings in annual energy use (kWh) between standard and ambitious: 5 835-1 764=4 071

Lifespan (years): 30

Energy savings during lifespan (kWh): 4 071*30=122 130

<u>Economic analysis</u>

Investment cost (SEK), standard: 250 000/1,25=200 000

Investment cost (SEK), ambitious: 2 300 000/1,25=1 840 000

Investment cost due to energy savings (SEK): 1 840 000-200 000=1 640 000

Annual savings (SEK): 4 071*0,824=3 355

Lifespan (years): 30

Savings during lifespan (SEK): 3 355*30=100 650

<u>Cost-effectiveness analysis</u>

CER: 1 640 000/122 130=13,43

Windows (3)

We received the numbers and expected lifespan from Poseidon AB.

Energy analysis

Annual energy use before renovating (kWh): 26,5*1357=35 961

Annual energy use after renovating (kWh), standard: 10,8*1357=14 656

Annual energy use after renovating (kWh), ambitious: 3,9*1357=5 292

Efficiency rate, standard: (35 961-14 656)/35 961=59,2 %

Efficiency rate, ambitious: (35 961-5 292)/35 961=85,3 %

Savings in annual energy use (kWh) between standard and ambitious: 14 656-5 292=9 364

Lifespan (years): 30

Energy savings during lifespan (kWh): 9 364*30=280 920

Economic analysis

Investment cost (SEK), standard: 1 637 000/1,25=1 309 600

Investment cost (SEK), ambitious: 1 743 203/1,25=1 394 562

Investment cost due to energy savings (SEK): 1 394 562-1 309 600=84 962

Annual savings (SEK): 9 364*0,824=7 716

Lifespan (years): 30

Savings during lifespan (SEK): 7 716*30=231 478

Cost-effectiveness analysis

CER: 84 962/280 920=0,30

Walls (4)

We received the numbers and expected lifespan from Poseidon AB.

Energy analysis

Annual energy use before renovating (kWh): 29,4*1357=39 896

Annual energy use after renovating (kWh), standard: 34,6*1357=46 952

Annual energy use after renovating (kWh), ambitious: 2,3*1357=3 121

Efficiency rate, standard: (39 896-46 952)/39 896= -17,7 %

Efficiency rate, ambitious: (39 896-3 121)/39 896=92,2 %

Savings in annual energy use (kWh) between standard and ambitious: 46 952-3 121= 43 831

Lifespan (years): 30

Energy savings during lifespan (kWh): 43 831*30= 1 314 930

Economic analysis

Investment cost (SEK), standard: 1 925 000/1,25=1 540 000

Investment cost (SEK), ambitious: 2 530 000/1,25=2 024 000

Investment cost due to energy savings (SEK): 2 024000-1 540 000=484 000

Annual savings (SEK): 43 831*0,824=36 117

Lifespan (years): 30

Savings during lifespan (SEK): 36 117*30=1 083 510

Cost-effectiveness analysis

CER: 484 000/1 314 930=0,37

Green roofs (5)

We received the numbers and expected lifespan from Veg Tech[10]. The prices were estimated under the assumptions that the roof has a slight incline and the roof area is 450 m^2. According to Banting et.al (2005)[11] the potential energy saving from green roofs are 4,15 kWh per square meter and year. This number was calculated for the city of Toronto, but we make an assumption that the climate and building conditions are similar.

Energy analysis

Annual savings (kWh): 4,15*450=1868

Lifespan (years): 15

Energy savings during lifespan (kWh): 1868*15= 28 020

Economic analysis

Investment cost (SEK): 375*450=168 750

Annual savings (SEK): 1868*0,824=1539

Lifespan (years): 15

Savings during lifespan (SEK): 1539*15=23 085

[10] Received 130429

[11] Banting, Doug et.al (2005). *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto.* Ryerson University, Toronto

Cost-effectiveness analysis

CER: 168 750/28 020=6,02

Solar cells (6)

We received the numbers and expected lifespan from Vattenfall[12].

We assume that:

- The solar cells are placed southwards and optimally inclined
- We only place solar cells on half of the roof area, since we take into consideration that the roof might be needed for other purposes
- When it comes to solar solar cells, we assume that it is just as good to produce renewable energy as it is to reduce energy use

Energy analysis

Annual savings (kWh): 33 440 (in this case production instead of savings)

Lifespan (years): 25

Energy savings during lifespan (kWh): 836 000

Economic analysis

Investment cost (SEK): 664 400

Annual savings (SEK): 33 440*0,8294=27 735

Lifespan (years): 25

Savings during lifespan (SEK): 27 735*25=693 378

Cost-effectiveness analysis

CER: 664 400/836 000=0,80

Combined refrigerator and freezer (7)

We have used average costs and energy use from appliances available on the market[13]. For the A labeled (standard), the average energy use is 350 kWh annualy and the cost is 5 000 SEK. For

[12] Received 130425

[13] http://www.toptensverige.se/kylskap/kategori/kombiskap_kyl_frys/ and www.elgiganten.se. Received 130425

A+++ labeled (ambitious), the average energy use is 154 kWh and the cost is 12 250 SEK. We assume that an A-labeled appliance can satisfy the basic needs, and a A+++-labeled appliance is the best alternative when considering energy use.

Energy analysis

Annual energy use after renovating (kWh), standard: 350*16=5 600

Annual energy use after renovating (kWh), ambitious: 154*16=2 464

Savings in annual energy use (kWh) between standard and ambitious: 5 600-2 464=3 136

Lifespan (years): 8

Energy savings during lifespan (kWh): 3 136*8=25 088

Economic analysis

Investment cost (SEK), standard: (5000*16)/1,25=64 000

Investment cost (SEK), ambitious: (12 250*16)/1,25= 156 800

Investment cost due to energy savings (SEK): 156 800-64 000=92 800

Annual savings (SEK): 3 136*0,8294=2 601

Lifespan (years): 8

Savings during lifespan (SEK): 2 601*8= 20 808

Cost-effectiveness analysis

CER: 92 800/25 088=3,70

Dishwasher (8)

We have used average costs and energy use from appliances available on the market[14]. For the A labeled (standard), the average energy use is 309 kWh and the cost is 4 000 SEK. For the A+++ labeled (ambitious), the average energy use is 224 kWh and the cost is 8 500. We assume that an A-labeled appliance can satisfy the basic needs, and an A+++-labeled appliance is the best alternative when considering energy use.

Energy analysis

Annual energy use after renovating (kWh), standard: 309*16=4 944

[14] www.pricerunner.se. Received 130502

Annual energy use after renovating (kWh), ambitious: 224*16=3 584

Savings in annual energy use (kWh) between standard and ambitious: 1 360

Lifespan (years): 8

Energy savings during lifespan (kWh): 1360*8=10 880

<u>Economic analysis</u>

Investment cost (SEK), standard: (4000*16)/1,25=51 200

Investment cost (SEK), ambitious: (8500*16)/1,25=108 800

Investment cost due to energy savings (SEK): 108 800-51 200=57 600

Annual savings (SEK): 1 360*0,824=1 121

Lifespan (years): 8

Savings during lifespan (SEK): 1 121*8=8 968

<u>Cost-effectiveness analysis</u>

CER: 57 600/10 880=5,29

Individual warm water measuring and charging (9)

We received the numbers from KTC[15]. According to KTC, 32 kWh/A_{temp} is used annually for warm water in an apartment, and the potential energy reduction by having individual measuring and charging is 25 %. The cost is 3 500 SEK per apartment.

<u>Energy analysis</u>

Annual energy use before renovating (kWh): 32*1357=43 424

Annual energy use after renovating (kWh): 43 424*0,75= 32 568

Efficiency rate: 25 %

Annual savings (kWh): 43 424*0,25=10 856

Lifespan (years): 13

Energy savings during lifespan (kWh): 10 856*13=141 128

<u>Economic analysis</u>

Investment cost (SEK): 3500*16=56 000

Annual savings (SEK): 10 856*0,824=8 945

[15] Received 130508

Lifespan (years): 13

Savings during lifespan (SEK): 8 945*13=116 285

Cost-effectiveness analysis

CER: 56 000/141 128=0,40

Energy display for visualising the electricity use (10)

We decided to investigate the cost-effectiveness of an energy display (label Eliq), which can be placed anywhere in the apartment. We received the numbers and expected lifespan from Eliq[16]. We assume that each apartment consumes 2 500 kWh electricity annually[17]. According to Eliq it is possible to achieve a 24 % reduction of the electricity use by installing an energy display.

Energy analysis

Annual energy use before renovating (kWh): 2 500*16=40 000

Annual energy use after renovating (kWh): 40 000*0,76=30 400

Efficiency rate: 24 %

Annual savings (kWh): 40 000*0,24=9 600

Lifespan (years): 10

Energy savings during lifespan (kWh): 9 600*10=96 000

Economic analysis

Investment cost (SEK): (2 495*16)/1.25=31 936

Annual savings (SEK): 9 600*0,8294=7 962

Lifespan (years): 10

Savings during lifespan (SEK): 79 620

Cost-effectiveness analysis

CER: 31 936/96 000=0,33

[16] Received 130510

[17] http://www.energiradgivaren.se/2011/09/elforbrukning-i-en-genomsnittlig-villa-respektive-lagenhet/. Received 130510

Sensitivity analysis

Green roofs:

Investment cost (SEK): 168 750

Lifespan (years): 30

Energy savings during lifespan (kWh): 1868*30= 56 040

CER: 168 750/56 040=3,01

Combined refrigerator and freezer

Investment cost due to energy savings (SEK): 70 000

Energy savings during lifespan (kWh): 25 088

CER: 70 000/25 088=2,79

Energy display for visualising the electricity use. Decreasing 10 %

Annual savings (kWh): 40 000*0,10=4 000

Lifespan (years): 10

Energy savings during lifespan (kWh): 4 000*10=40 000

Investment cost (SEK): 31 936

CER: 31 936/40 000=0,80

Energy display for visualising the electricity use. Decreasing 30 %

Annual savings (kWh): 40 000*0,30=12 000

Lifespan (years): 10

Energy savings during lifespan (kWh): 12 000*10=120 000

Investment cost (SEK): 31 936

CER: 31 936/120 000= 0,27