Cost optimal energy efficiency in multifamily houses

Åsa Wahlström, CIT Energy Management, asa.wahlstrom@cit.chalmers.se

Peter Filipsson, CIT Energy Management, peter.filipsson@cit.chalmers.se

Catrin Heincke, CIT Energy Management, catrin.heincke@cit.chalmers.se

Abstract

More than half of Swedish multi-family buildings were constructed between 1950 and 1975, and most of these are in need of renovation immediately or within a short time. Pursuant to the Directive 2010/31/EU, the National Board of Housing, Building and Planning, has introduced new, stricter rules for making changes in buildings that applies from 2013. These rules state that the same quality requirements that apply to the construction of a new building will apply to changes in buildings. This means, in actuality, that energy consumption requirement for new buildings will also apply to extensive renovations of an existing building.

The purpose with the present study is to analyze which consequences the new building regulation will lead to major renovations of apartment buildings. Which combinations of different heating systems and packages of energy efficiency measures will be necessary to meet the new requirements at major renovation and which combinations of heating systems and packages of measures can optimize costs?

The following four types of heating systems were examined: retaining district heating, complementing district heating with an exhaust air heat pump, converting to a ground-source heat pump or an air-to-water heat pump. The analysis has been performed in accordance with the cost model proposed by the European Commission and thus life cycle costs are estimated based on a calculation period of 30 years, and a discount rate of 3%.

The analysis shows that it is technologically possible to fulfill the requirements of new building regulations with all the heating options in combination with one or more of the six measures.

The results also show that the choice of a heating system is not any obvious one. The margins between the various heating options together with the optimum package of actions are relatively small. Depending on predicts on energy prices and inflation in the future it may be one or the other option that is the most advantageous. Profitability of the different heating packages is also dependent on the district heating price prevailing in the current city. The analyses also shows that the renovation needs of the building in question may be decisive. If renovation costs for facades and windows are considered as maintenances cost and only the additional costs for extra insulation or improved U-value belongs to investment cost it will be possible to meet the requirements of the building regulations in a profitable manner.

Keywords: energy efficiency, regulations, renovation, existing apartment blocks.

Introduction

In the newly recast directive on the energy performance of buildings (Directive 2010/31/EU), there is a demand that “nearly zero-energy buildings” are to be a requirement for the construction of new public buildings from 1 January 2019 and for all new buildings from 1 January 2021. In addition, the member states are to undertake the measures needed to ensure that when buildings undergo a major renovation, the energy performance of the building, or the renovated part of the building, is improved so that it meets the minimum requirements regarding energy performance to the extent that this is technically, functionally and economically feasible. The requirement is to be applied to the renovated building, or the renovated unit, as a whole. The member states are to stimulate the transformation of buildings that are being renovated into nearly zero-energy buildings.

Pursuant to the Directive 2010/31/EU, the National Board of Housing, Building and Planning, has introduced new, stricter rules for making changes in buildings that applies from the 1st of January 2013 (BFS 2011:26). Demands are made in part at the component level and in part for the entire building depending on the extent of the renovation. These rules state that the same quality requirements that apply to the construction of a new building will apply to renovation of buildings. This means, in actuality, that energy consumption requirement for new buildings will also apply to extensive renovations of an existing building. In order to achieve such a change at major renovation, a number of cost-effective measures are needed that also may imply changes of heating systems.

The new requirements

The new building code set by the National Board of Housing, Building and Planning has requirements for the building’s energy performance. The requirements are described in terms of specific energy use (kWh/m^2 A_{temp}) and are shown in Table 1. A_{temp}, the heated area, is defined as the area on the inside of the building envelope, on all floors, that is supposed to be heated to more than 10ºC. The area of interior walls, openings for stairs, shafts, and similar are included. The area of the garage is not included.

The requirements specify not only maximum permitted energy use per square meter, but also the permitted installed electric power for heating, and a mean coefficient of thermal transmittance of the building envelope. In addition, the new building code specifies that energy performance must be verified by measurements within 24 months of completion of the building.

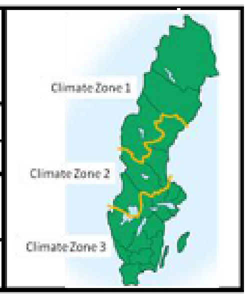
The building’s energy use is defined as the energy that needs to be delivered to the building (often called “purchased energy” in Sweden and “site energy” in the U.S.), at normal use and during a normal year, for heating, comfort cooling, hot tap water, and electricity for the operation of the building. Electricity for domestic purposes is not included.

The requirements differ depending on: in which climate zone the building is placed (Sweden is divided into three climate zones, see Figure 1), if the building has an occupant activity of living (dwellings) or business activities (premises), and if the building is heated by electricity or in another way. The latter means that in most cases heat pumps need to be installed in order to meet the requirements for electrical heated buildings.

Electrically-heated buildings are buildings in which the installed electric power for heating is greater than 10 W/m^2. Installed power is the total electric power that can be received by the electrical heating appliances that are needed to maintain the intended indoor climate, domestic hot water production and ventilation when the maximum power needs of the building prevail, that is, during the design outdoor winter temperature.

Table 1 Requirements for maximum specific energy use in the national building code for residential buildings (kWh/m^2 A_{temp})

Residential buildings	Annual energy use for heating, comfort cooling, domestic hot water provision and other shared services in the building (kWh/m^2)		
	Climate zone		
	1 (north Sweden)	2 (middle Sweden)	3 (south Sweden)
with heating systems other than electric heating	130	110	90
with electric heating	95	75	55



Apartment blocks in Sweden

About half of the population of Sweden lives in apartment blocks. These contain approximately 2.4 million flats, with a total of about 180 million square metres. Energy used for the built environment in Sweden is about 160 TWh yearly and the apartment block sector stands for approximately 25%. In 2011, the apartment block sector used about 24.3 TWh for heating and domestic hot water provision, see Figure 1. Heating was dominated by district heating. Of the total energy use for heating and domestic hot water provision, 92% is from district heating, 5% is from electricity, less than 1% is from oil and the remainder is from natural gas and biofuels (ES 2012:05). Apartment blocks built before 1960 have primarily natural ventilation while the ones built after 1960 have primarily exhaust ventilation.

Just over half of the apartment blocks were built between 1950 and 1975. Apartment blocks can differ greatly regarding size, shape, materials, building technique, etc. Low-rise apartment buildings have been the dominant building type from the 1930s and onwards. They are often 3 to 4 stories high and are built as long, detached structures. Each story can be reached by several stairwells, often without an elevator. During the 1960s and 1970s, high-rise blocks of flats became very common as a part of the industrialized construction of the million homes programme. These high-rise blocks of flats are multi-story buildings, with an elongated form, usually 8 – 9 stories high, built on a rectangular ground plan and equipped with elevators. Tower blocks are free-standing buildings with a stairwell located in the core of the building. Tower blocks began to be used in the 1930s and were four to five stories high, but they became common first in the 1940s. Since the 1950s, the height of the buildings has increased, and often includes eight to ten stories (Björk et al., 2003). Also small apartment blocks with only 6-8 apartments are quite common. Over 80% of the Swedish population lives in climate zone 3 (south Sweden) and a representative apartment block would be a low-rise apartment building built from 1950 to 1960 in south Sweden.

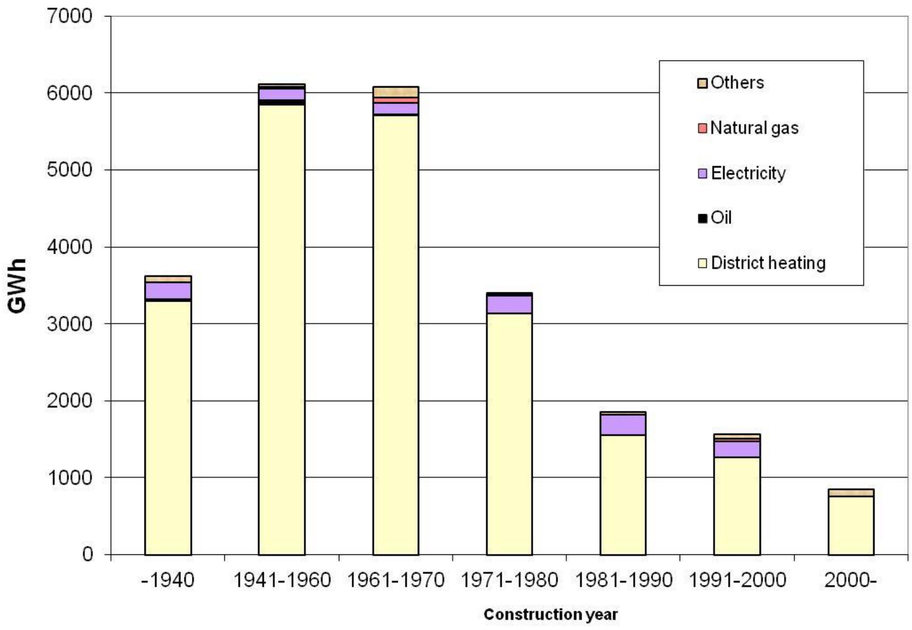


Figure 1 Energy use year 2009 for multifamily houses by year of construction and energy source.

A recent study shows that near 75% of the existing flats needs renovation before 2050 and many of them in the near future. This leads to a renovation need of 50 000 flats yearly requiring totally investments of 2-5 billion Euros per year (IVA, 2012).

Objective

In the present study it has been analyzed how far increasing the energy efficiency of existing multi-family buildings can go and still remain profitable. Which combinations of heating systems and packages of measures can optimize costs?

The analyse method

An analysis has been carried out of optimal life cycle costs of the energy-efficiency measures in combination with different heating systems to meet the new demands during major renovations. The impact analysis has been conducted by different types of buildings being combined with different packages of energy-efficiency measures and different heating systems. The energy performance of each combination has been calculated and compared with the new requirements during major renovations.

Investigated buildings

Four building types were investigated: low-rise apartment buildings, high-rise blocks of flats, tower blocks and a small multi-dwelling building containing 6 flats. The building types were located in Sweden's three different climate zones, and three building ages were investigated. In order to limit the number of calculations the buildings described in Table 2 were investigated. There were thus twelve different combinations considered. U-values (heat transfer coefficients) varied depending on the age of the building (valid building regulations) and its geographical location. For example, buildings built 1961-1975 in climate zone 2 have the following U-values; wall 0.49, floor 0.15, roof 0.16 and windows 2.2 W/m^2. K; and exhaust ventilation with the flow rate 1.26 m^3/h.m^2. Air leakages besides ventilation are 0.13 air exchange rates per hour in summer times and 0.27 air exchange rates per hour in winter times. The estimated heating requirements in these different types of buildings were compared with the national statistics for measured values. Heating requirements varied from 118 to 236 kWh/m^2 for the different combinations considered.

Table 2 Investigated buildings

	Built 1950 -1960	**Built 1961-1975**
Climate zone 1	Low-rise apartment blocks	Low-rise apartment blocks
Climate zone 2	Low-rise apartment blocks	Low-rise apartment blocks
Climate zone 3	Low-rise apartment blocks Tower blocks High-rise blocks Small apartment blocks	Low-rise apartment blocks Tower blocks High-rise blocks Small apartment blocks

Investigated measures and heating systems

In order to investigate how the energy performance of the buildings can be improved, the following energy-efficiency measures were examined:

- Measures addressing electricity use for shared services in the building,
- Hot tap water measures,
- Attic or loft insulation,
- Window replacement,
- Facade renovation with improved insulation and
- The installation of a heat recovery system between the exhaust air and the supply air.

Four different heating systems have been studied:

- Keeping the present district heating,
- Convert to ground source heat pump,
- Convert to air-to-water heat pump,
- Supplement district heating with an exhaust air heat pump. The size chosen here has an installed output of 10 W/m^2, which means that requirements for non-electrically heating buildings apply (i.e., the same requirements as for district heating).

Measures addressing electricity use for shared services in the building include a package of efficiency measures for lighting, electricity for countering ice formation in gutters, etc. Hot tap water measures contain a package of measures to improve efficiency by having better fittings, individual gauges or solar heating. The analyses consider that hot tap water savings are most effective in the summer time then district heating prices are lowest. Season performance factors for the heat pumps are given in Table 3.

Table 3 Used season performance factors in the investigation

	Ground source heat pump	Air to water heat pump	Exhaust air heat pump	
	season performance factors inclusive electricity need at peak power	season performance factors inclusive electricity need at peak power	season performance factors exclusive district heating need at peak power	performance factors the coldest winter day
Climate zone 1	3.1	2.2	2.9	2.65
Climate zone 2	3.2	2.4	2.9	2.65
Climate zone 3	3.3	2.6	2.9	2.65

Used Cost Model

The analysis has been performed in accordance with the cost model proposed by the European Commission (2012/C 115/01) in connection with the implementation of the Directive. In doing so, life cycle costs should be estimated based on a calculation period of 30 years for residential buildings, and a discount rate of 3%.

The cost model is meant to assist the Member States in implementation of the Directive 2010/31/EU and is not legally binding. As such, the guidelines are intended for facilitating the application of the Regulation and reporting to the European Commission. In other words the model is not meant to be used for a specific building.

The model works as follows. The total present value of cost for a packages of energy efficient measures is calculated by summarize the investment, the present value of energy costs for operation during the calculation period, the present value of reinvestments of heating systems, and the present value of the remaining value of the heating system at the end of the calculation period.

Used investment costs for the heating systems inclusive installation and exclusive VAT are given in Table 4. Costs for ground source heat pump and air to water heat pump is given per kilowatt peak power, i.e. inclusive power peak need.

In the calculations the electricity price is set to 1.20 and the district heating price to 0.69 Swedish kronor per kWh (excluding VAT).

Table 4 Investment costs for heating systems

Heating system	Investment costs (SEK excl. moms)
Ground source heat pump	8 500 SEK/kW inclusive bore hole 5 000 SEK/kW exclusive bore hole
Air to water heat pump	7 000 SEK/kW
Exhaust air heat pump	37 500 SEK/kW
District heating	$6500 \cdot \sqrt{Q}$ SEK (Q is the heating power expressed in kW)

Results

The analyses show that technically it is possible to meet the requirements in the new building regulations with all four heating systems in combination with one or several energy efficiency measures. In figure 2 and Table 5 the results is given for the most common apartment building.

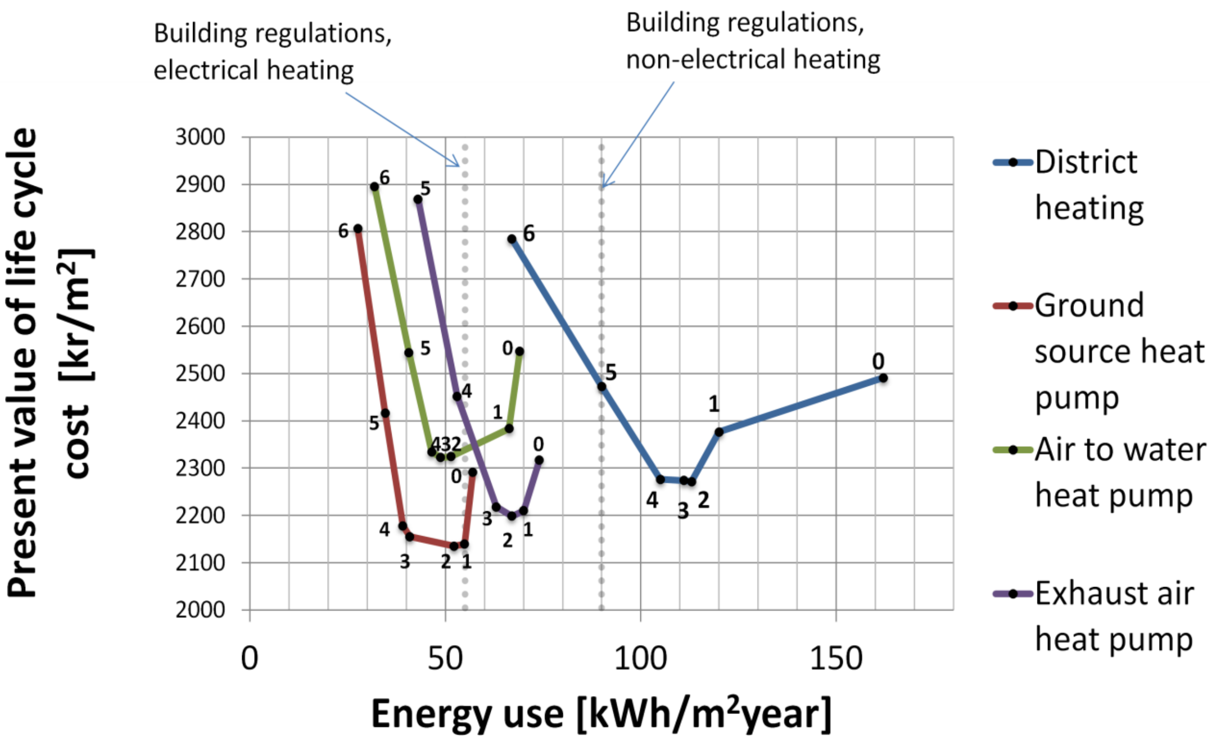


Figure 2 Present value of life cycle cost for different packages of energy efficient measures in combination with different heating systems at renovation of a low-rise apartment blocks in climate zone 3 built 1950-1960.

Table 3 Description of which energy efficient measures that corresponds to each point in Figure 3.

Point	0	1	2	3	4	5	6
District heating	existing building	installation of heat recovery	hot tap water measures	electricity for services measures	loft insula-tion	window replace-ment	facade insula-tion
Ground source heat pump	installation of heat pump	hot tap water measures	electricity for services measures	installation of heat recovery	loft insula-tion	window replace-ment	facade insula-tion
Air to water heat pump	installation of heat pump	hot tap water measures	installation of heat recovery	electricity for services measures r	loft insula-tion	window replace-ment	facade insula-tion
Exhaust air heat pump	installation of heat pump	hot tap water measures	electricity for services measures	loft insulation	window replace-ment	facade insula-tion	

In Figure 2 the present value of life cycle cost for different packages of energy efficient measures in combination with different heating systems at renovation of a typical apartment block. The point 0 for district heating (existing building) shows the present value of cost for operational energy during the next 30 years if no measures are performed. The point 0 for each heat pump system shows the present value of investment costs for the heat pump and the cost for operational energy during the next 30 years. For each heating system thereafter the packages of measures are shown. Point 1 for each heating system shows result with one single measure, point 2 shows result with two measures in a package and so on. In Table 5 description of which energy efficient measures that corresponds to each point is given.

The first packages of measures are profitable, i.e. they will reduce both the life cycle cost and the energy use. The optimal packages of energy efficient measures is the point there the present value of life cycle cost is the lowest. Thereafter will additional measures be not profitable, i.e. reduce the energy use but at the cost of increased life cycle cost.

To reach the requirements by the building regulation while keeping district heating, a package of 5 energy efficient measures is required (point 5). This may, in special circumstances, be considered as profitable in the sense that the life cycle cost is less than not doing any measures (point 0). Over 60 kWh per square meter has been reduced which make the building less sensitive for increase in energy prices.

Sensitivity analyses

A sensitivity analyses has been performed for changes in district heating prices, since the locally prices are quite different. In Figure 3 the same low-rise apartment blocks in climate zone 3 built 1950-1960 are examined as in Figure 2.

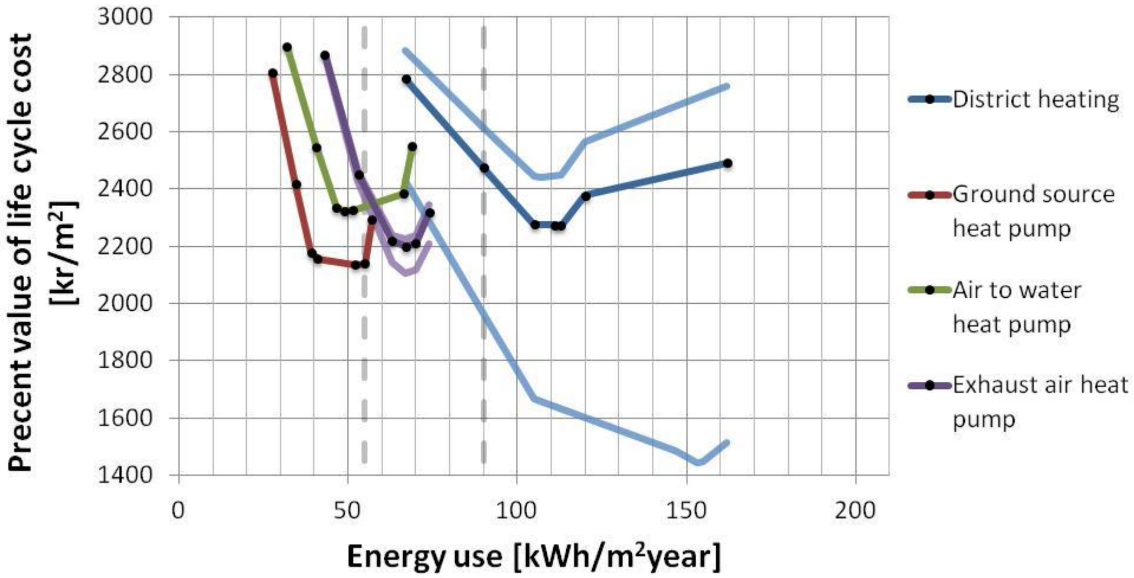


Figure 3 Toned lines are for district heating prices of 0.78 and 0.35 SEK/kWh respectively, which should be compared to the dark lines with a price of 0.69 SEK/kWh.

A next sensitivity analysis has been performed for future changes in electricity prices with an increase of 1.5% per year above the inflation. District heating prices are fixed. In Figure 4 the same low-rise apartment blocks in climate zone 3 built 1950-1960 are examined as in Figure 2.

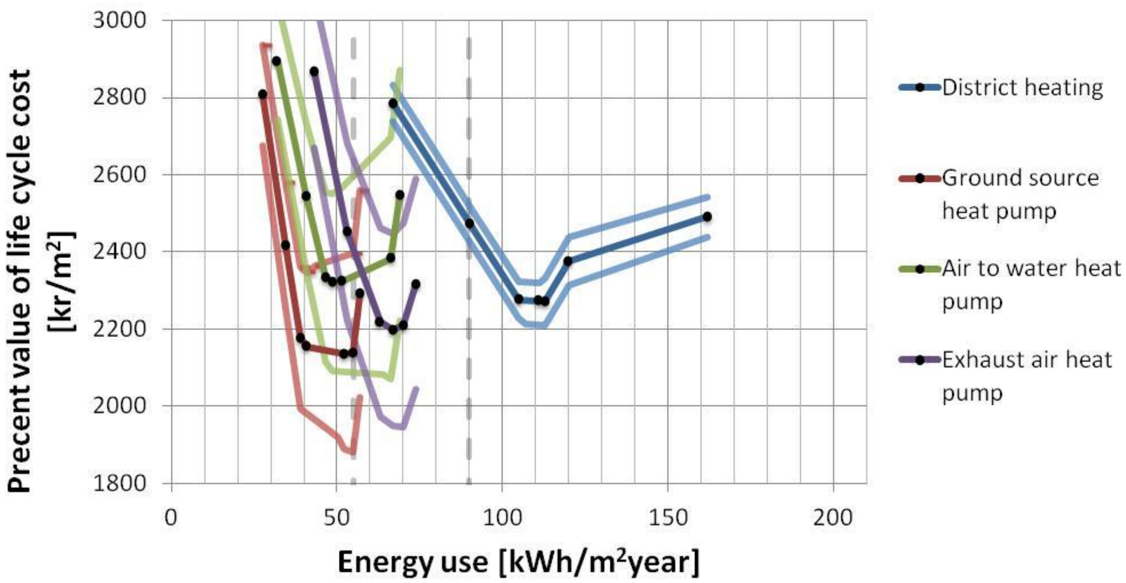


Figure 4 Toned lines are for an increase respectively decrease in electricity prices of 1.5%.

A next sensitivity analysis has been performed for another discount rate of 8%. In Figure 2 the discount rate is set to 3%, which is slow, but may be acceptable in a social economical point of view. Many building owners use a higher discount rate then making investments. A discount rate of 8% will in practice implies that an investment of equipment with 20 years life time must be paid off within 10 years. In Figure 5 the same low-rise apartment blocks in climate zone 3 built 1950-1960 are examined as in Figure 2.

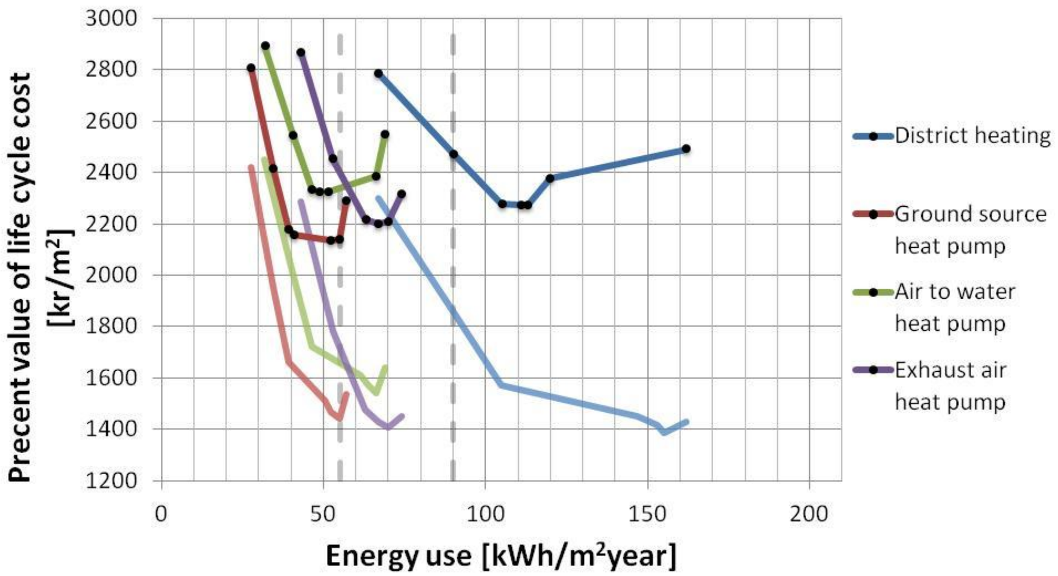


Figure 5 Toned line is for a discount rate of 8%.

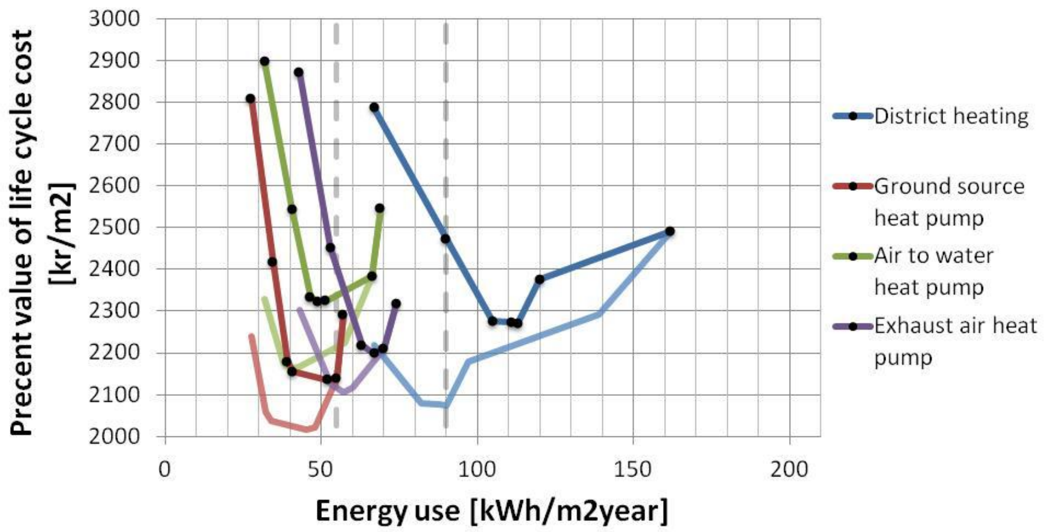


Figure 6 Toned lines corresponds then only additional costs are considered for measures of facade insulation and window replacement.

Many energy efficient measures imply not only reduction in energy use but also other quality improvements. In previous calculations the energy efficiency measures fully fund the cost of the investment. This is regardless of whether an action, such as adding insulation, is connected with facade renovation of maintenance purposes. In this sensitivity analyses only the additional costs for extra insulation or improved U-value in windows have been considered while the other costs belong to maintenances and not investments. The costs for facade insulation is reduced with 82% which is the cost for new facade rendering and for window replacements the costs is reduced with 14% which corresponds for painting and maintenance of the existing windows. In Figure 6 the same low-rise apartment blocks in climate zone 3 built 1950-1960 are examined as in Figure 2.

Discussion and conclusions

The analysis shows that it is technologically possible to fulfill the building regulation requirements with all the heating options in combination with one or more of the six measures to increase energy efficiency.

An installation of a ground source heat pump will only require some extra measures in order to reach the requirements in the building regulations and the air to water heat pump requires some more additional measures. Installation of a ground source heat pump is a profitable investment in itself considering that the present value of the life cycle costs is lower compared not to do anything with the existing building and a discount rate of 3%. An installation of an air to water heat pump requires several energy efficiency measures in order to be profitable.

The exhaust air heat pump will reach the requirements for non-electrical heated buildings with profitability without any additional measure, i.e. lower life cycle cost compared to do nothing at all.

Sensitive to energy price increases then the share of the life cycle cost consists of a larger part of energy costs in comparison with capital investment. Life cycle cost for ground source heat pump consists to a larger extent of investment, reinvestment and maintenance costs compared to the exhaust heat pump which has a large share of running costs.

This implies that the installation with a ground source heat pump is less sensitive to increases is electricity prices.

Profitability for the various heating packages is also dependent of the district heating price prevailing in the locality in question. More expensive district heating means better profitability for heat pumps, while cheaper district heating makes it more difficult to financially justify heat pumps or measures to increase energy efficiency.

To keep district heating and still reach the requirements in the building regulations requires an extensive package of measures, at least five and for some type buildings all six measures are needed. In order to reach the requirements non-profitable measures need to be performed, i.e. that increase the life cycle cost. If six measures are required it implies a higher life cycle cost compared with not doing anything at all while five measures will give a life cycle cost that is less than not doing any measures. This may, in special circumstances, be considered as profitable in the sense that over 60 kWh per square meter has been reduced which make the building less sensitive for increase in energy prices.

However, in the present base analysis, the energy savings derived should fully cover the cost of the measures. The fact that a measure, such as additional insulation, is done in conjunction with a facade renovation is not taken into account. Only the additional costs for extra insulation or improved U-value in windows should be considered while the other costs belong to maintenances and not investments. A calculation that takes into account the need of a building for upkeep of its facade and windows shows that it is possible to meet the requirements of the building regulations in a profitable manner.

The results also show that the choice of a heating system is not any obvious one. The margins between the various heating options together with the optimum package of actions are relatively small. Which option is better depending on one's opinions regarding energy price trends over time and the renovation needs of the building in question.

According to the revised Directive on the energy performance of building, minimum requirements regarding energy performance must be fulfilled in the case of major renovations to the extent those are feasible.

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