Cooperation between construction and energy sector to decrease the carbon emissions and primary energy use in Sweden

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Keywords

district heating, energy efficiency, carbon emissions, primary energy, Sweden, excel based tool, cost efficiency

Abstract

WSP and Fourfact have together with the Construction and Energy sector in Sweden investigated and calculated which measures should be accomplished to decrease the carbon emissions and the primary energy use. The cost efficiency has been calculated for all measures, and one result was that the profit is generally higher for measures in the energy supply system compared to measures in the individual buildings.

Because of huge variations between district heating networks and because of the quantity of energy consumed by households is similar all over Sweden, the location of single houses and buildings is more important for their carbon footprints and for their primary energy use, than their individual energy consumption.

Our calculation shows, that the most efficient way to decrease carbon emissions and primary energy use in Sweden, is to convert all single houses heated by electricity into district heating. Since we use marginal energy for the calculations, the effect of converting single houses is greater compared to if the environmental factors from marginal energy were not used.

Since a majority of all single houses are heated by electricity, the potential of converting them to be heated by district heating is great.

In this project, we have created the useful excel tool Sture. With Sture, analyses of Sweden can be done, but also a person with basic knowledge of his or her house and energy use, can calculate which measures are suitable and cost efficient.

Introduction

The project is a co-operation between companies of the Construction and Energy sectors in Sweden, with the aim to identify which measures in existing buildings (single-family houses, apartment blocks and offices) on one hand, and in energy supply systems, on the other hand, can decrease the carbon emissions and primary energy use from a cost-efficient point of view. A tool should also be created from which people with an interest should be able to do their own calculations.

The project was funded by SBUF (Swedish Contractors Development Fund), Swedish District Heating Association and Sweden Energy Agency and the companies represented were NCC, Fortum Värme, Veidekke, Skanska, JM, Tekniska Verken i Linköping, E.ON, Göteborg Energi, Svensk Fjärrvärme and Byggherrarna. Consultants have been Hans Nilsson Fourfact and Ola Larsson WSP.

Method

Data was collected from the official Swedish statistics from Statistics Sweden and was organized to divide Sweden into 15 regions and 8 larger cities. In the data for each region and city there were construction year, energy supply system, total area and energy use.

Due to the fact that the building regulations have changed over the years, it would be interesting and necessary also to investigate variations of energy use, depending of construction year. Therefore the constructions were divided into three age categories, buildings erected before 1940, between 1940 and 1970, and finally after 1971.

The energy supply system also varies between the types of building. The single-family houses have six different systems; (1) district heating, (2) air to air heat pump, (3) direct radiating

Table 1. The environmental factors being used in the project

Fuel	Primary energy factor	Carbon emission [g/kWh]
Waste heat from industries	0	0
Oil	1.18	324
Coal	1.04	350
Wooden chips, pellets	1.08	8
Gas	1.16	209
Electricity	2.5	360
Waste	0.66	83
Peat	1.04	354

electricity, (4) heat pump with water-radiators; (5) electricity with water-radiators and (6) others. For apartment blocks and offices there are three different systems; (1) district heating, (2) oil and gas and (3) others.

When the energy use was analysed, only small variations between the 15 regions were found. Since it's colder in the northern parts of Sweden, the energy demand is higher. But due to a higher energy demand, the cost efficiency for more insulation and windows with lower U-values are higher compared to the southern part of Sweden.

We calculated the environmental influence, both primary energy use and carbon emissions. The factors used in the calculation were these:

ENERGY SUPPLY SYSTEM

As mentioned, there are two variables that decide the environmental influence energy use and energy supply system. The variations in energy use between the regions in Sweden are rather small; instead it's more crucial which energy supply system that is being used.

Only a minor part of the single-family houses are supplied with district heating. Four out of six supply systems for these houses are based on use of electricity, and the carbon emissions or primary energy per kWh will be the same wherever in Sweden the single house is located.

The district heating system on the other hand varies with great difference since the fuel used varies from plant to plant, city to city and region to region. The fuels are:

- Waste heat from industries   13%
- Oil   5%
- Coal   6%
- Wooden chips   47%
- Gas   4%
- Electricity   1%
- Heat pumps   3%
- Waste   16%
- Peat   6%

From a historical point of view, the electricity in Sweden has been rather cheap due to the fact that nuclear and hydro power has produced almost all electricity in Sweden. However, since the electricity market was deregulated the interest in constructing CHP (Combined Heat and Power) to replace thermal power plants has grown. Today (year 2008) the district heating

companies produce approximately 50 TWh heat and 7 TWh electricity in CHP-plants. 50 TWh heat corresponds to 50% of Sweden's total heat need and 7 TWh electricity corresponds to 5% of Sweden's total electricity end use.

Comparison

Comparison between primary energy-saving measures in buildings and primary energy-saving measures in district heating systems were made. We didn't investigate measures in the production of electricity since during the entire project all energy was seen to be produced from marginal energy point of view.

Marginal energy means that the environmental influence is being calculated from the last added energy production unit instead of the average production. The marginal energy is used in this project, since it is that energy that will be affected when a measure is done.

Professor Sven Werner, the University of Halmstad, showed in a presentation at the Swedish National Energy Convention in 2005, that electricity-saving measures in Denmark decrease the electricity production in Germany and Poland and not the production in nuclear power plant or in hydro plant in Scandinavia. The reason is that the Scandinavian nuclear power production cost is lower than the fossil fuel based power production cost in northern Europe.

For example, instead of using the Swedish electricity mix to calculate the environmental influence, we used electricity produced in Natural Gas Combined Cycle NGCC facility in northern Europe. Because when 1 kWh additional electricity is being used in Sweden, it's not produced in our nuclear power plant or hydro plant, it is produced in northern Europe.

This is a relative new way of looking at the environmental influence of energy saving-measures, but actually it's the same as e.g. the Swedish tax system. For example, if a salary is below 28,000 SEK per month the tax is 30%, but if a salary is above 28,000 SEK you'll be paying a different tax rate for the amount above 28,000 SEK (roughly 50%). If then your salary is decreased, it's the marginal taxes that decreases and not the normal taxes.

MEASURES IN BUILDINGS AND ENERGY SUPPLY SYSTEM

One of the aims of the project was to find out where and what measures should be done to decrease the environmental influence from the best economical point of view.

Measures in the energy supply system

Together with the Swedish district heating associations, typical measures for a district heating system have been calculated and investigated. The measures were the following:

1. Exchange the fossil oil to bio oil – the measure mostly decreased the carbon emissions

2. Fluid gas condensation – decreased the carbon emission and the use of primary energy

3. Increased use of waste heat – decreased the carbon emission and the use of primary energy

4. Combined heat and power – decreased the carbon emission and the use of primary energy

5. Connecting district heating net – decreased the carbon emission and the use of primary energy

6. Solar heat – decreased the carbon emission and the use of primary energy

All these measures were adapted to all district heating nets in Sweden depending on the circumstances in each of them and in order to find the aggregated potential. To make the calculations easier, the measures were combined as packages. Since we calculated on a regional level and on a municipality level the combination of packages differed.

For each applied measure, new primary energy and carbon emission factors were calculated as well as the cost for the measures.

Based on this information, a comparison could then be made with the energy-saving measures in the buildings.

Measures in the buildings
Based on collaboration with four construction companies in Sweden, energy-saving measures in the buildings were combined into packages as well. The measures for the buildings were the following:

• Package 1 – easy measures which are really cost efficient, for example exchange of light bulbs.

• Package 2 – insulation of walls/roof/floors or change to new windows with higher energy performance

• Package 3a – rotating heat exchanger (apartments and offices) or convert energy supply system into district heating (single-family houses)

• Package 3b – heat pump to recover energy losses (apartments and offices) or convert energy supply system into ground source heat pump (single-family houses).

• Package 4 – turn the building into passive house standard.

All of packages lead to decrease energy end use. Depending on the building type the percentage of decrease differs.

WEIGHTED COMPARISON OF MEASURES
It's not reasonable to believe that all measures in buildings are implemented since different obstacles occur. For example, not all building owners have the knowledge or interest of implement measures in their buildings.

Therefore, we used "market diffusion models" to be able to predict what measures possibly being implemented. One of the most famous "market diffusion model" assumes that users have different possibilities to take in new technologies depending on their knowledge and their will to handle new things[1].

Four different categories of people according to "market diffusion models" they are:

• Innovators or early adopter

• Early majority

• Late majority

• Latecomer

When we calculated the total efficient potential for Sweden we had to take this into account. By using dissemination curve we did get a weighted comparison of the measures implemented in buildings. The percentage shown in figure 1 is the one used in the calculations.

Since we know which measures being implemented in the energy supply system, we used only the dissemination curve for energy-savings measures in buildings.

RESULTS
Results from the projects shows that they are a great potential do decrease both the primary energy use in carbon emissions in Sweden.

The registered total carbons emissions from the energy sector, dwellings and offices are roughly 10 million tons if not marginal energy factors are being used. But as mentioned before, we calculated the environmental influence from a marginal energy point of view. Then the carbon emission will increase from 10 million tons to 26 million tons.

We used a dissemination curve to calculate the effect of the measures and our calculation shows that if energy-saving measures are taken both in buildings and in the energy supply system, 26 million tons could decrease with 10 million tons.

As shown in figure 2, it is not surprising that the combination of packages both in the buildings and the energy supply system are the most efficient.

But figure 2 also shows that if all packages in buildings are carried out with the anticipated uptake on the market, according to the dissemination curve, package 3a applied in single-family houses, apartments and offices leads to the least carbon emissions. This is due to the fact that package 3a convert the energy supply system for single-family houses from electricity (heat pump, and electric heating) to district heating with much lower carbon emissions.

Other general conclusions from the project are the following:

• The potential to decrease the environmental impact is really significant in single-family houses, especially the ones with direct electric heating. The economical benefit will differ across Sweden since the price per kWh differs between 0.45 SEK and 0.78 SEK;

• The potential for the district heating companies to convert their production into combined heat and power is huge. The economical benefit to convert into CHP depends on the price of the fuel. The tipping point where it's not profitable for the three fuels use for new CHP plants are; waste

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1. Diffusion of Innovations. Everett M. Rogers.

Marknadsupptagning

Efter-Släntrare (16%)
Sen majoritet (34%)
Tidig majoritet (34%)
Innovators, Early Adopters (16%)

Paket 1
Paket 2
Paket 3 (a-b)
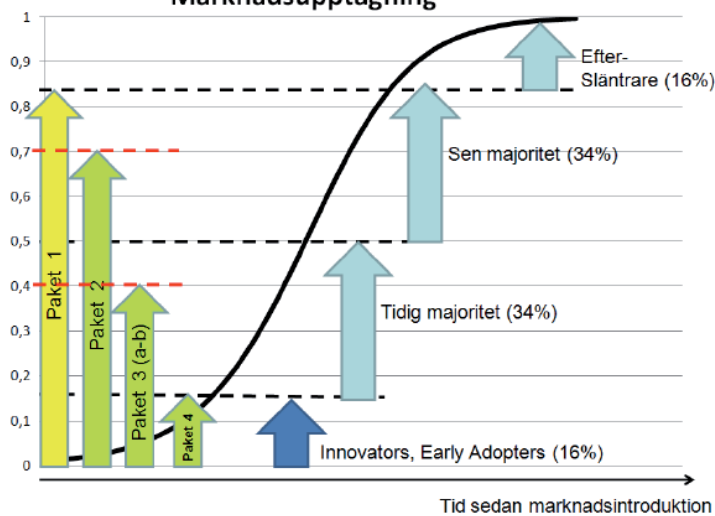Paket 4

Tid sedan marknadsintroduktion

Figure 1. Dissemination curve. The figure shows the dissemination curve used in the project.

0.52 SEK per kWh, Bio fuel 0.69 SEK per kWh and natural gas 1.13 SEK per kWh;

- The greatest potentials are in the three largest cities (Stockholm, Göteborg and Malmö). Measures in these three cities will have a major influence on the total emissions of carbon dioxide. But also in Uppsala (which has a lot of peat in their district heating system) and in Umeå (which is building more combined heat and power) will the measures in the supply system have a significant impact.

EXCEL BASED CALCULATION TOOL – STURE

All calculations during the project have been made by using an excel calculation tool, created within the project, named Sture. All data necessary has been fed into the tool, for example all energy use for all possible combinations, all primary energy factors for each district heating net and the effects of all different measures.

Sture should be used as a support tool for people interested (consultants, city planners, scientist or politicians) to find those measures that will reduce the primary energy use and/or carbon emissions in a cost efficient way.

The calculations we have made for Sweden are based on data from Statistics Sweden, the official statistics of Sweden. Sture is a flexible tool so instead of using the existing data the user can make calculation with their own data.

For example, if the user of Sture has the environmental factors for their district heating net, the energy use and the data for the measures (investment cost, life length, effect of the measure), Sture will present the effect of the measures; if they are cost efficient and the reduction of primary energy and carbon emissions.

These three factors (cost efficient, carbon emissions and primary energy use) are presented in charts in Sture, see figure 3.

References

Energisamverkan, Etapp 2 – Effektiv energianvändning och energiförsörjning ur ett systemperspektiv, Stockholm, Sweden, 2008

Energisamverkan mellan byggbranschen och energibranschen, Stockholm, Sweden, 2006
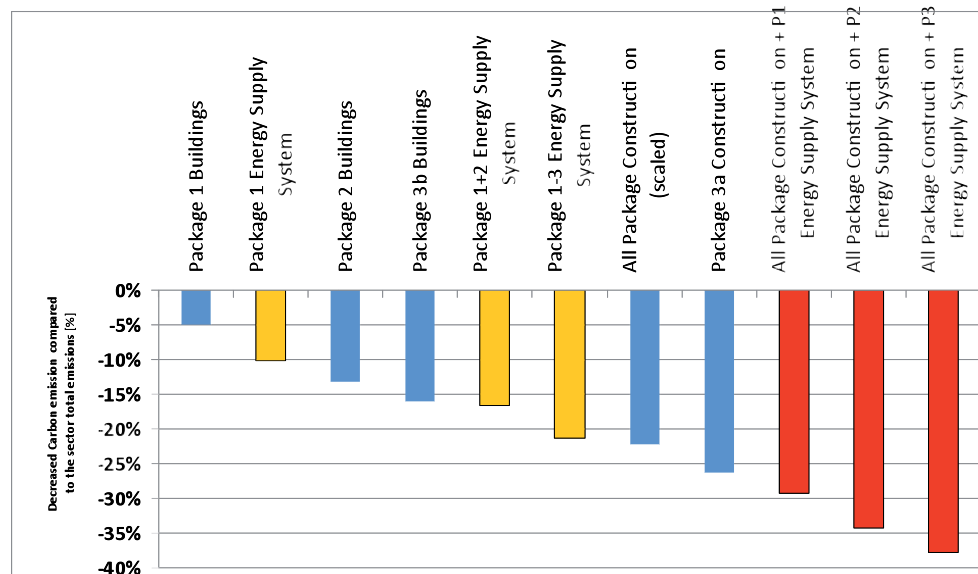
Acknowledgements

Figure 2. Decreased carbon emissions. The figure shows the decrease in carbon emission for different combinations of packages in buildings and in energy supply systems.
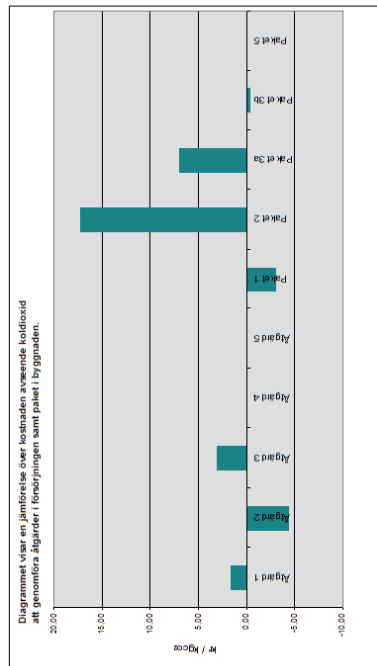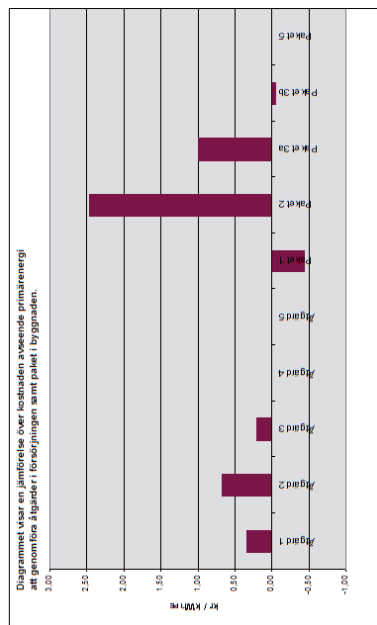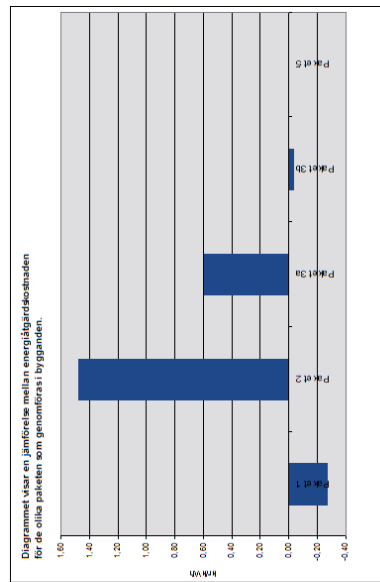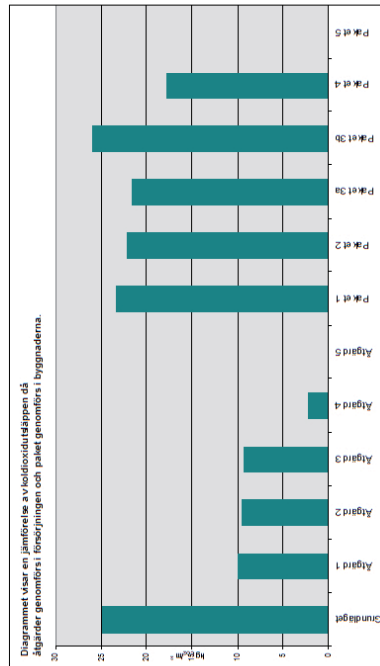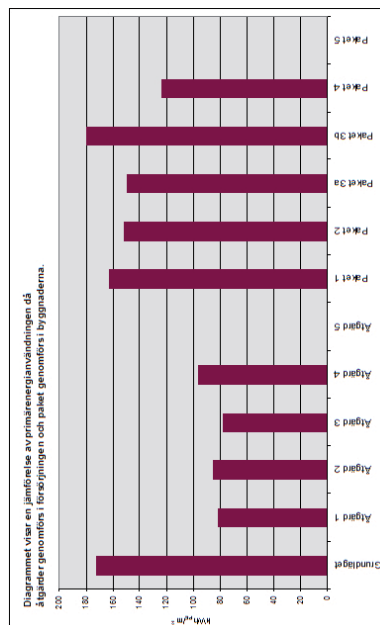
Figure 3. Print screen of Sture. The figure shows a print screen of Sture and the five charts which show which measures with the most environmental impact and which that are cost efficient.

Beräkningsverktyget Sture - Energisamverkan Etapp 2

Egen Energianvändning [kWh/m²]				Värmeanvändning	
Egen värmeanvändning [kWh/m²]	0				
Egen hushållsel / verksamhetsel [kWh/m²]	0			Värmeanvändning [kWh/m²]	141,7
Egen fastighetsel [kWh/m²]	0			PE [kWh/m²]	85,0
				CO₂ [kg/m²]	12,2
				Kostnad köpt energ [kr/m²]	98,8
Inkluderad elanvändning eller ej	Med el			Elanvändning	
				Hushållsel / Verksamhetsel [kWh/m²]	25
Lokalisering				PE [kWh/m²] - hushållsel	62,5
Kommun/Region	Skåne del 1			CO₂ [kg/m²] - hushållsel	9,0
				Kostnad köpt energ [kr/m²]	25,0
Byggnadstyp					
Småhus/Flerbostadshus/Lokal	Flerbostadshus			Fastighetsel [kWh/m²]	10
Byggår	Klass3			PE [kWh/m²] - fastighetsel	25,0
				CO₂ [kg/m²] - fastighetsel	3,6
Elanvändning				Kostnad köpt energ [kr/m²]	10,0
Hushållsel / Verksamhetsel [kWh/m²]	25	Elpris [kr/kWh]	1		
Fastighetsel [kWh/m²]	10	PE-faktor	2,5	Total energianvändning	
Miljövärdering	Marginal lång	CO₂ [g/kWh]	360		
				Total användning [kWh/m²]	176,7
Uppvärmningssätt	Fjärrvärme	PE-faktor	0,60	PE [kWh/m²]	172,5
		CO₂ [g/kWh]	86	CO₂ [kg/m²]	24,8
Ekonomiska förutsättningar		Egen PE-faktor	0,00	Kostnad köpt energ [kr/m²]	133,8
Eget värmepris [kr/kWh]	0	Egen CO2 [g/kWh]	0		
Värmepris [kr/kWh]	0,70				
Kalkylränta [%]	4				

Åtgärder i försörjningen

Åtgärd 1

Olja-Rökgas-Spillvärme-Kraftvärme	Faktor och värde efter åtgärd	PE-användning [kWh/m²] samt koldioxidutsläpp [kg/m²]
PE-faktor	-0,04	81,8
CO2 [g/kWh]	-19,0	9,9
Energiåtgärdskostnad [kr / kWh_PE]	0,32	
Energiåtgärdskostnad [kr / kg_CO2]	1,59	

Åtgärd 2

Ihopkoppling nät	Faktor och värde efter åtgärd	PE-användning [kWh/m²] samt koldioxidutsläpp [kg/m²]
PE-faktor	-0,02	84,7
CO2 [g/kWh]	-22,0	9,5
Energiåtgärdskostnad [kr / kWh_PE]	0,67	
Energiåtgärdskostnad [kr / kg_CO2]	-4,45	

Åtgärd 3

Solvärme	Faktor och värde efter åtgärd	PE-användning [kWh/m²] samt koldioxidutsläpp [kg/m²]
PE-faktor	-0,07	77,6
CO2 [g/kWh]	-24,0	9,2
Energiåtgärdskostnad [kr / kWh_PE]	0,20	
Energiåtgärdskostnad [kr / kg_CO2]	3,03	

Åtgärd 4

Framtida alternativet	Faktor och värde efter åtgärd	PE-användning [kWh/m²] samt koldioxidutsläpp [kg/m²]
PE-faktor	0,06	96,0
CO2 [g/kWh]	-73,0	2,3
Energiåtgärdskostnad [kr / kWh_PE]	#SAKNAS!	
Energiåtgärdskostnad [kr / kg_CO2]	#SAKNAS!	

Åtgärd 5

Eget alternativ	Faktor och värde efter åtgärd	PE-användning [kWh/m²] samt koldioxidutsläpp [kg/m²]
PE-faktor		
CO2 [g/kWh]		
Energiåtgärdskostnad [kr / kWh_PE]		
Energiåtgärdskostnad [kr / kg_CO2]		

Åtgärder i byggnaden

		Inklusive elanvändningen

Paket 1

Värmeanvändning efter åtgärd [kWh/m²]	124,7	
PE-användning efter åtgärd [kWh_PE/m²]	74,8	162,3
Koldioxidutsläpp efter åtgärd kg_CO2/m²	10,7	23,3
Energiåtgärdskostnad [kr/kWh]	-0,27	
Energiåtgärdskostnad [kr / kWh_PE]	-0,45	
Energiåtgärdskostnad [kr / kg_CO2]	-3,2	

Paket 2

Värmeanvändning efter åtgärd [kWh/m²]	107,7	
PE-användning efter åtgärd [kWh_PE/m²]	64,6	152,1
Koldioxidutsläpp efter åtgärd kg_CO2/m²	9,6	22,2
Energiåtgärdskostnad [kr/kWh]	1,48	
Energiåtgärdskostnad [kr / kWh_PE]	2,47	
Energiåtgärdskostnad [kr / kg_CO2]	17,2	

Paket 3a

Värmeanvändning efter åtgärd [kWh/m²]	62,3	
PE-användning efter åtgärd [kWh_PE/m²]	37,4	149,9
Koldioxidutsläpp efter åtgärd kg_CO2/m²	5,4	21,6
Energiåtgärdskostnad [kr/kWh]	0,59	
Energiåtgärdskostnad [kr / kWh_PE]	0,98	
Energiåtgärdskostnad [kr / kg_CO2]	6,9	

Paket 3b

Värmeanvändning efter åtgärd [kWh/m²]	37,7	
PE-användning efter åtgärd [kWh_PE/m²]	22,6	180,1
Koldioxidutsläpp efter åtgärd kg_CO2/m²	3,2	25,9
Energiåtgärdskostnad [kr/kWh]	-0,04	
Energiåtgärdskostnad [kr / kWh_PE]	-0,07	
Energiåtgärdskostnad [kr / kg_CO2]	-0,5	

Paket 4

Värmeanvändning efter åtgärd [kWh/m²]	35,0	
PE-användning efter åtgärd [kWh_PE/m²]	21,0	123,5
Koldioxidutsläpp efter åtgärd kg_CO2/m²	3,0	17,8
Energiåtgärdskostnad [kr/kWh]	7,65	
Energiåtgärdskostnad [kr / kWh_PE]	12,75	
Energiåtgärdskostnad [kr / kg_CO2]	88,9	

Paket 5

Värmeanvändning efter åtgärd [kWh/m²]		
Elanvändning efter åtgärd [kWh/m²]		
Ny primärenergifaktor för uppvärmning		
Ny koldioxidfaktor för uppvärmning [g/kWh]		
PE-användning efter åtgärd [kWh_PE/m²]	0	0
Koldioxidutsläpp efter åtgärd kg_CO2/m²	0	0
Värmepris [kr/kWh]		
Elpris [kr/kWh]		
Förändrad värmeanvändning [kWh/m²]	141,7	
Förändrad elanvändning [kWh/m²]	35	
Investeringskostnad [kr]		
Livslängd [år]		
Annuitetsfaktor	#DIVISION/0!	
Energiåtgärdskostnad [kr/kWh]	#DIVISION/0!	
Energiåtgärdskostnad [kr / kWh_PE]	#DIVISION/0!	
Energiåtgärdskostnad [kr / kg_CO2]	#DIVISION/0!	