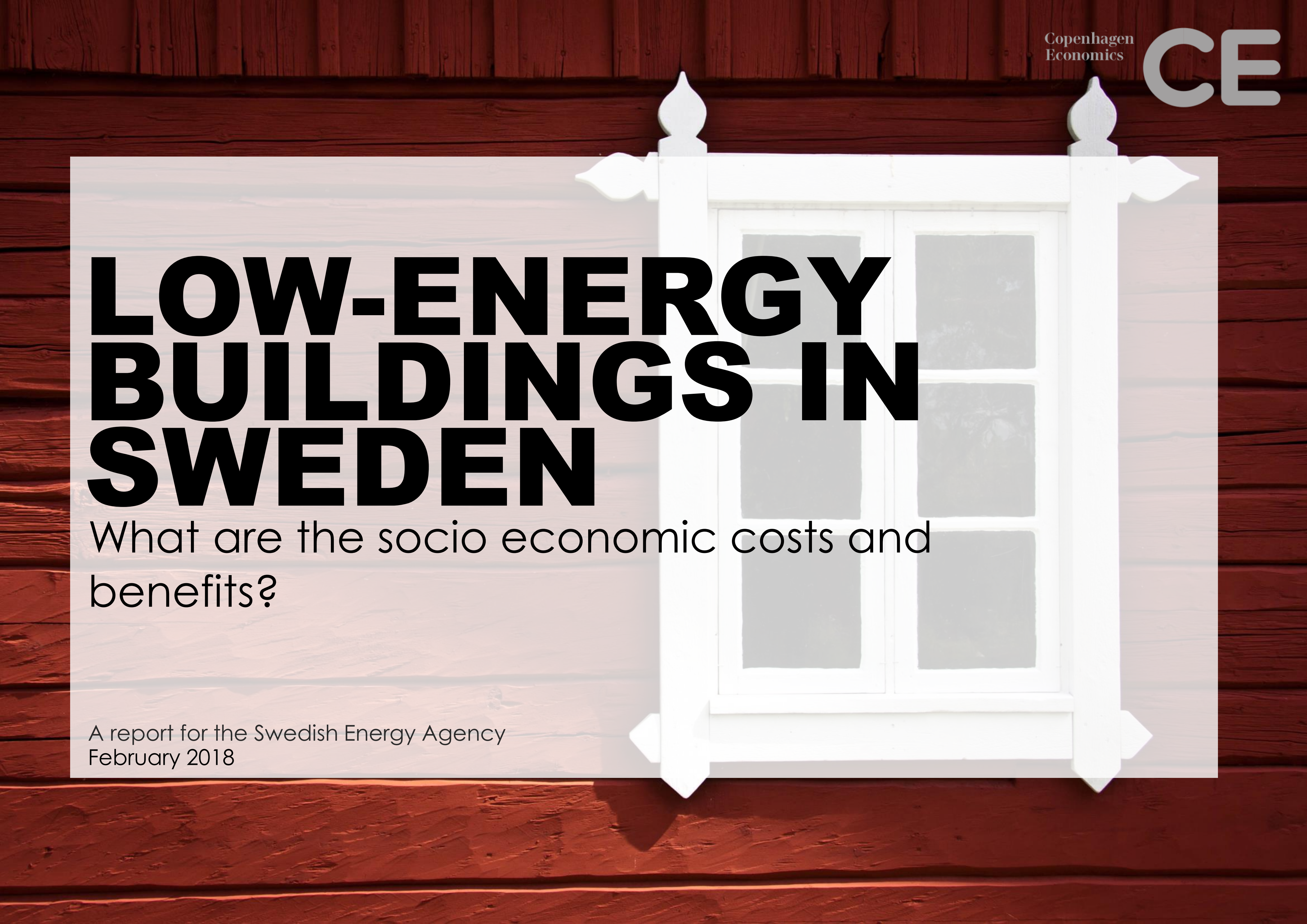


Copenhagen Economics

LOW-ENERGY BUILDINGS IN SWEDEN

What are the socio economic costs and benefits?

A report for the Swedish Energy Agency
February 2018

Executive summary

Energy requirements for new buildings is a primary policy instrument to influence the energy use in new buildings. As focus on energy savings has increased over time, energy requirements have regularly been tightened.

The European Union's (EU) Energy Performance of Buildings Directive (EPBD) requires EU Member States to make sure all new buildings from 2021 are so-called nearly zero energy buildings. It is up to the individual EU Members States to set an appropriate "nearly zero" level on a cost-effective basis. Sweden is currently in the process of defining its own 'nearly zero'-definition and the corresponding energy requirement for new buildings.

Higher energy standards will typically lead to higher building cost, however it will also result in benefits. These benefits are primarily savings from reduced energy cost but there can also be so called 'multiple benefits' related to e.g. health improvements (see e.g. Copenhagen Economics, 2016). An important, and so far unresolved, question is whether increasing the energy requirements for new buildings in Sweden is likely to add significant costs or if it might even be cost efficient, also taking into account so-called multiple benefits.

Over the past years, a number of buildings have built to the so-called low-energy building-definition (defined as 25% less energy consumption than the energy requirement in the current building code). A sample of 16 of these buildings have been measured and assessed over a few years, and generated data that can be used to shed light on the actual costs, energy savings, and indoor air quality related to building up to a stricter energy performance criteria.

Based on this, we provide an answer to the overall question: Do these 16 concrete buildings provide evidence of higher energy requirements being cost effective, when also taking into account 'multiple benefits?

SOCIO ECONOMIC ANALYSIS INDICATES MIXED SAVINGS POTENTIAL

The assessment we have of the sixteen concrete low-energy buildings is based on 1) Actual measurements of energy consumption in these buildings (re-calculated to match 'normal circumstances' such as winter temperature, household size and composition etc.) and 2) an estimated additional construction cost of building to this low-energy class than otherwise required if a 'more standard' building has been built, and a similar estimated energy consumption in the 'standard building' (calculations have been done by CIT). Such assessments are naturally associated with uncertainty as to the exact counterfactual, and the results we depict here should be keep this uncertainty in mind.

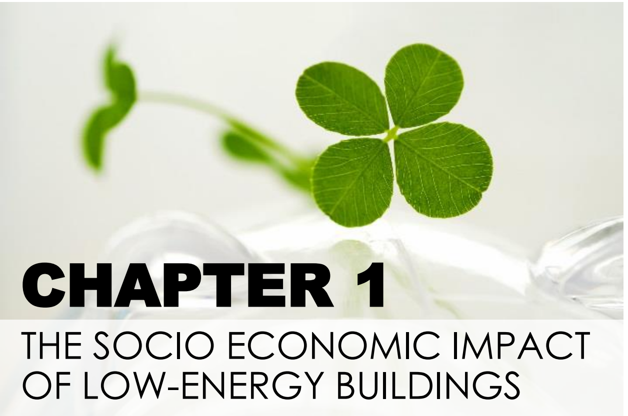
On average, we see that the low-energy buildings are estimated to have saved about 15 percent energy for single-family houses and apartment buildings and about 35 per cent for commercial buildings and schools compared to BBR22 standard. If all new residential buildings (only single-family houses and apartments) had the same characteristics of the ones in our sample, Sweden could reduce energy consumption in the building sector by 2 TWh cumulatively to 2050 (on average 55 GWh per year from now to 2050). Adding to this, would be energy savings from commercial buildings, public buildings etc.

Based on the engineering assessment of construction cost and energy saved, we estimate that about half of the 2 TWh energy savings seem to be cost effective when taking into account both energy cost savings, avoided CO_2 emissions and local air pollution. Avoided energy costs is the largest driver of this potential with about 50 million SEK saved per year. Health and environmental benefits from reduced air pollution and CO_2 reductions corresponds to about 7-17 million SEK per year.

One of the major drivers of cost savings related to building costs is obtaining a sufficiently well insulated building envelope that allow for scaling down the heating system.

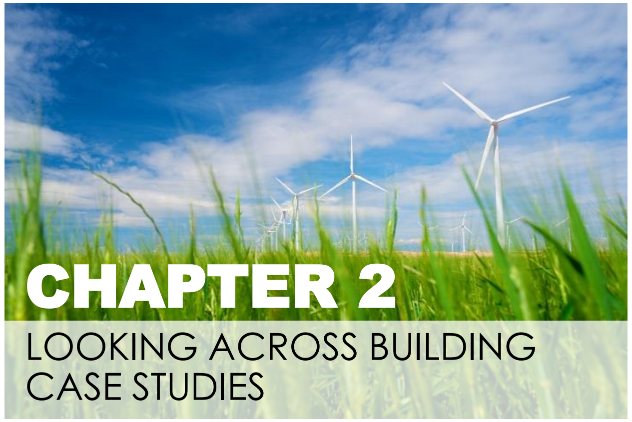
We also find that the low-energy buildings in general have quite good indoor air climate (except for a few). In many instances better than existing buildings, which indicates that air climate improving measures has also been taken within the construction costs. Identified problems have been related to too much direct sunlight and overheating in the summer.

It should be stressed that the results are based on a relatively small number of buildings, and therefore not necessarily representative.



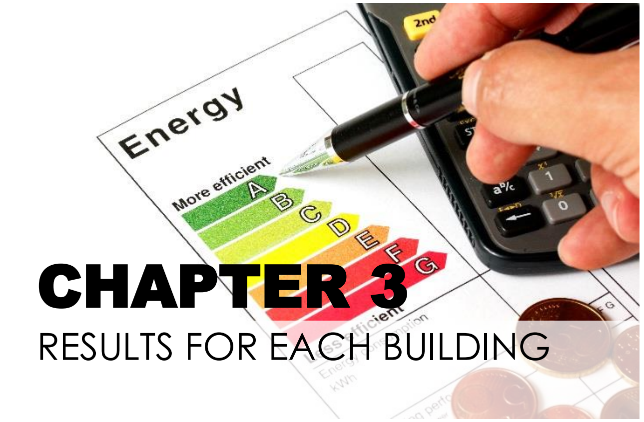
CHAPTER 1

THE SOCIO ECONOMIC IMPACT OF LOW-ENERGY BUILDINGS



CHAPTER 2

LOOKING ACROSS BUILDING CASE STUDIES



CHAPTER 3

RESULTS FOR EACH BUILDING

THE SOCIO ECONOMIC IMPACT OF LOW-ENERGY BUILDINGS

Chapter 1

The history of energy requirements in new buildings in Sweden

ENERGY REQUIREMENTS FOR NEW BUILDINGS

Sweden has a long history of setting specific building standards (including on energy) as the first national requirements were set in the 1950's. In 2002 the first energy requirements were included, and a major step was taken in 2006 with the first implementation of the EU Energy Performance of Buildings Directive (EPBD) with requirements on the maximum use of energy.

Since 2006, energy requirements have evolved and become more detailed and complex (see graph in next slide). In 2006 there where three climate zones and two building types (residential and commercial), and in 2015 there are four climate zone and residential buildings have been split into single and multiple family buildings.

The Swedish energy regulation is published in Boverket's Building Requirements (BBR for Bovkerets Byggregler), which includes all building requirements including energy requirements. These are updated roughly every year although energy requirements since 2006 (BBR12) have changed only in 2009 (BBR16), 2012 (BBR19) and in 2015 (BBR22).

The energy requirements are specific for building types, climate zone (see top figure) and whether the building is heating by electricity and fuels other than electricity (e.g. district heating).

LOW-ENERGY BUILDINGS

A building can be classified as a **low-energy building** if the energy consumption is at least 25 per cent below the requirements (in BBR21). This definition is used throughout this report.

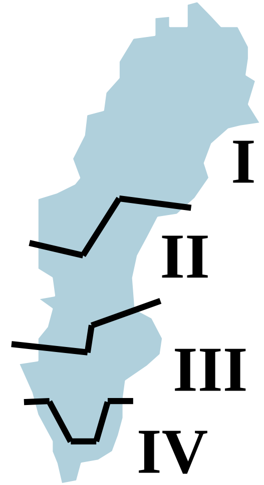
Since 2010, the amount of new low-energy buildings have increased significantly albeit from a very low starting point (see bottom graph). The total amount of m2 being built in Sweden every year has been around 130,000-150,000 m2 both in residential and commercial. The share of low-energy buildings in all new buildings has been around 5-7 per cent. This is of course still a quite low number compared to the 400 million m² of the entire Swedish building stock

NEARLY ZERO ENERGY BUILDINGS

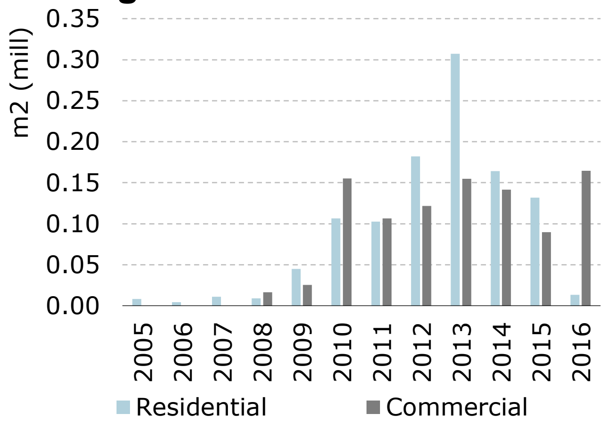
EU's Energy Performance of Buildings Directive (EPBD) from 2010 requires EU Member States to make sure all new buildings from 2021 are so-called nearly zero energy buildings. It is up to the individual EU Members States to interpret "nearly zero" and to set the concrete energy requirements on a cost-effective basis.

In this context, it is important for Swedish authorities to know what experiences we can draw from existing low-energy buildings. To what extent have they delivered socio economically beneficial outcomes when also considering so-called multiple benefits?

Climate zones in Sweden



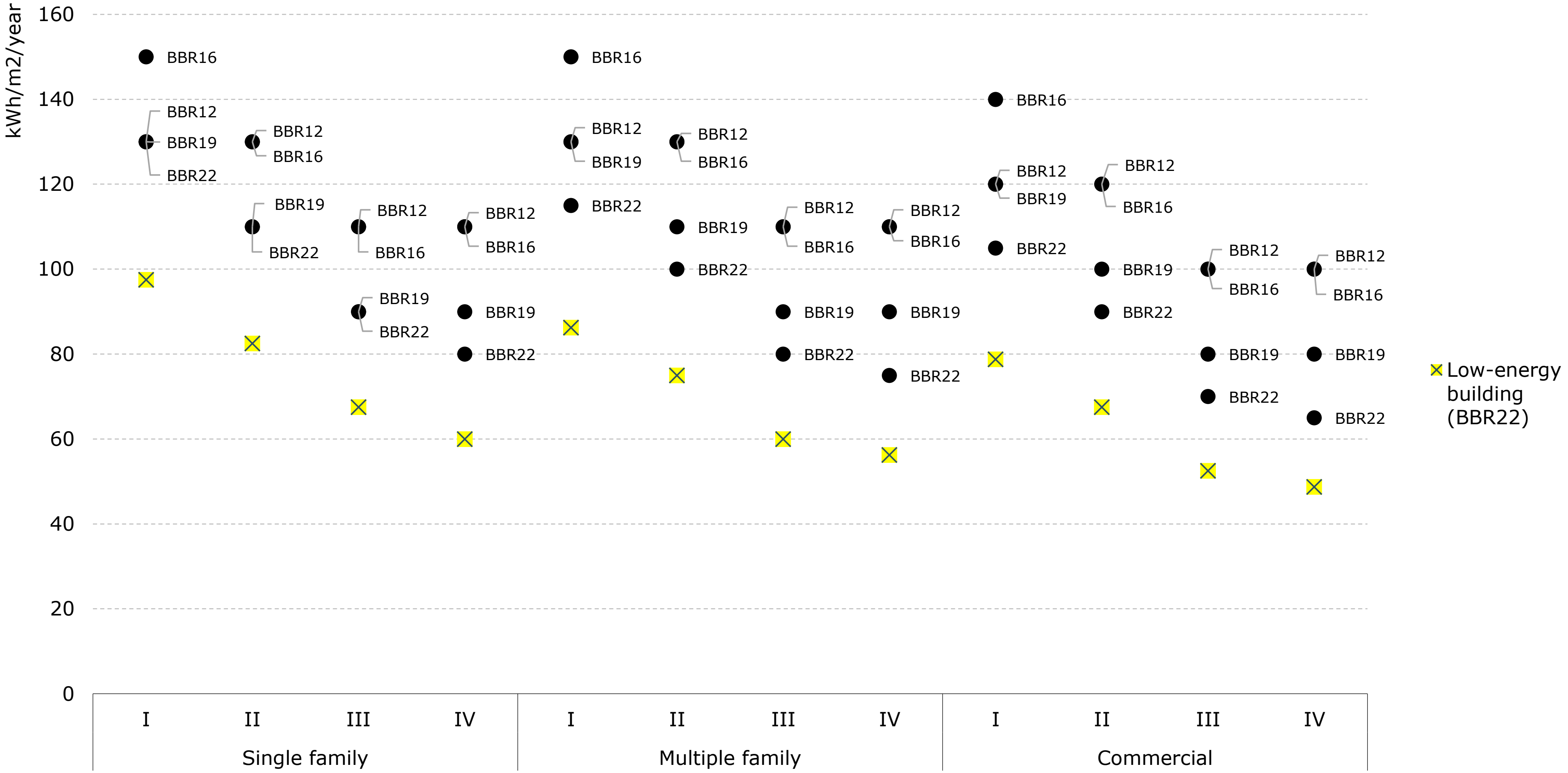
Construction of low-energy buildings



Source: website salis.laganbygg.se.

Energy requirements have been tightened over time

BBR's energy requirements since 2006 for different building types and climate zones (non-electricity)



Note: The graph shows energy requirements for buildings heated by other fuels than electricity. For electricity-heated houses, the requirements are generally more strict
Source: Swedish building regulations available at https://www.boverket.se.

A socio economic assessment includes multiple benefits

A socio economic cost-benefit analysis includes *all* costs and *all* benefits for *all* members of society. This means that the analysis looks beyond the effects for the building owner in terms of investments costs and energy savings. The analysis includes all external effects on other members of society, which are in this report called *multiple benefits*. There exists a range of multiple benefits of lower energy consumption (see below). In the rest of the report, we focus on energy cost savings, local air pollution, CO_2 emissions and indoor air climate.

Energy cost savings	Reducing energy consumption means lower energy bills for consumers. This saving means lower costs for consumers, but also implicitly avoided capital costs in power and heating plants. This is a socio economic benefit.
Local air pollution	Lower energy consumption mean lower local air pollution, when energy production is polluting. The Swedish heat production is mainly produced by renewable biomass, the burning of which emit SO_2, NO_x and $PM_{2.5}$. These pollutants harms the environment and effects public health. Reducing consumption of space heating will therefore be a socio economic benefit in terms of avoided local air pollution.
CO_2 emissions	When energy production is emitting CO_2 this is a cost to society as CO_2 contributes to global warming. The cost associated with CO_2 emissions is notoriously difficult to estimate. However, energy production is regulated through the European Union's Emissions Trading System (ETS). This puts a price on CO_2 emissions.
Indoor air climate	The indoor air climate is an important aspect of the quality of a building. People living in industrialised countries are in an indoor environment in more than 90 per cent of the time. It is thus important to evaluate how more energy efficiency affects the indoor environment. A worse (or better) indoor air climate is a socio economic cost (or benefit in the case of a better indoor air climate).
Renewable energy investments	Lower energy use means lower need for renewable energy investments. This is a benefit is there is a national renewable energy target. Sweden has a target of reaching 50 per cent renewable energy as a share of total energy use in 2020. This target has already been reached whereby there is no additional benefit by lowering energy consumption. We therefore disregard this benefit in our analysis.
Strategic energy security	If energy production is dependent on resources from politically unstable regions, lower energy use is a benefit. As previously mentioned, the Swedish energy production does not have this problem to a significant extent. We therefore disregard this benefit in our analysis.
Increased economic activity	Increased investments in energy-efficient buildings will stimulate economic activity and potentially move people from unemployment to employment. This can said to be the case when there is a macro economic output gap, i.e. current GDP is lower than its structural level. However, there are currently no indications that Sweden has an output gap. We therefore disregard this benefit in our analysis.

Impact assessment is based on case studies of 16 existing low-energy buildings

TECHNICAL BUILDING DESIGN AND COSTS

The socio economic cost-benefit analysis of low-energy in this report is based on 16 case studies of existing low-energy buildings. The 16 buildings vary (amongst other things) in building type (house, apartment building and commercial building), location (climate zones), and heating fuel.

Each case study is an analysis of the energy consumption in the building and how the energy consumption would be different if the building had been constructed as a standard building instead of a low-energy building. For each building, two alternative constructions are designed: a BBR19- and a BBR22-version of that building. The BBR19-version is how the building would be designed if it had been built to be in line with BBR19 requirements (and likewise with the BBR22-version).

Each case study includes the difference in investment costs and energy consumption between the existing building and the alternative designs. These differences forms the basis for the cost-benefit analysis, and each case study concludes whether the existing building is more cost-effective than the alternative designs. I.e. the case studies answer the question: Is the low-energy building cheaper (over its lifetime) for the owner compared to standard buildings?

These case studies are done by CIT.

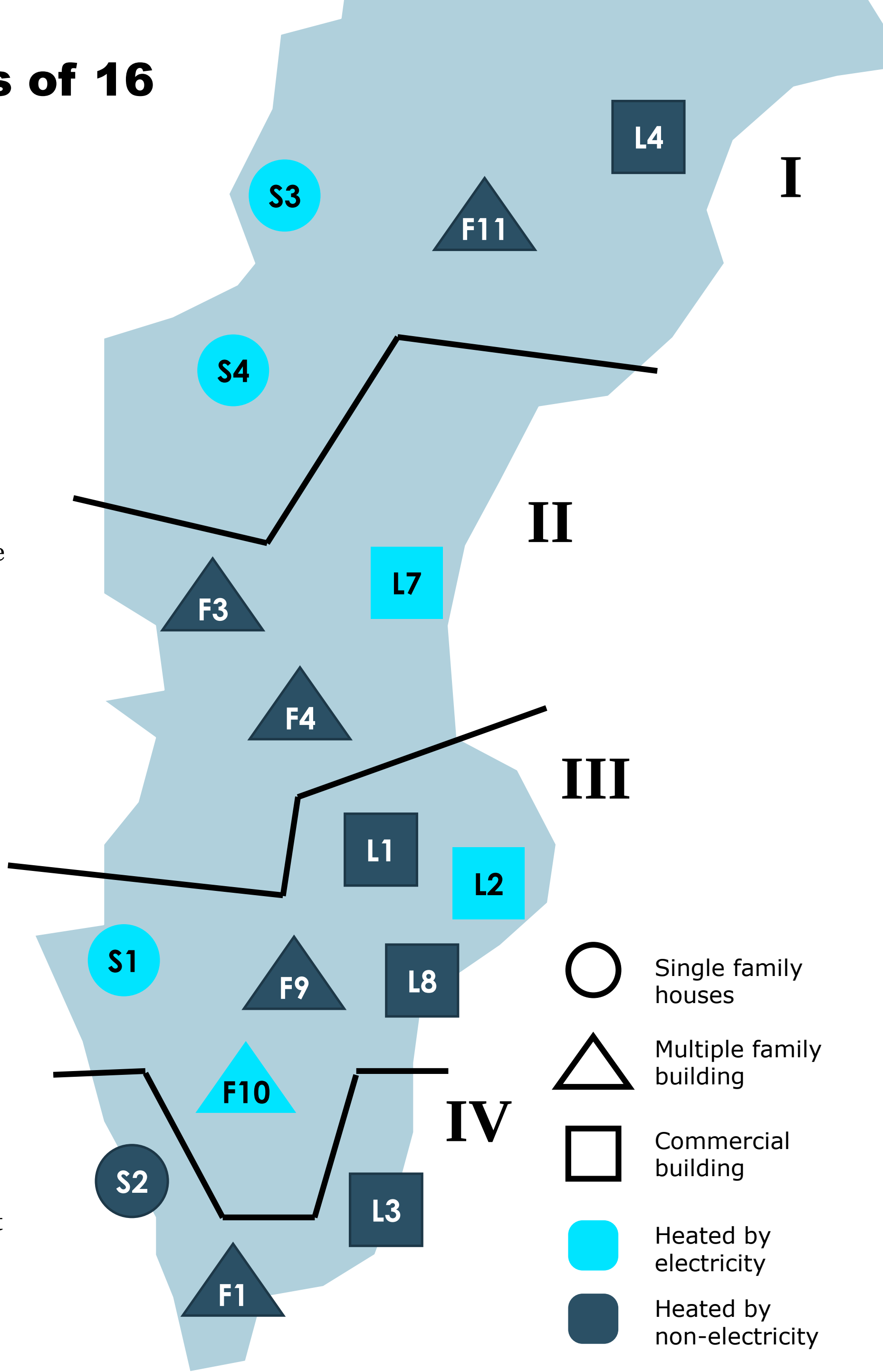
SOCIO ECONOMIC IMPACT ASSESSMENT

In the current report, the building specific case studies are used to analyse the socio economic costs and benefits of low-energy buildings. To do this, we adjust and expand the costs and benefits included in CITs analysis to be applicable on a socio economic level. Specifically, we add the multiple benefits which the owner of the buildings will not take into account in his or her investment decision. I.e. the present analysis answers the question: Is the low-energy building cost-effective from a societal point-of-view taking into account the multiple benefits of lower energy consumption?

We have done these calculations for each building and an indicative calculation of the cost-effectiveness of low-energy buildings in Sweden in general.

The building specific results can be seen in chapter 3. For each building multiple benefits are added, and a conclusion is made on whether this building is cost-effective from a societal point-of-view. The calculation method can be seen in the appendix. The following slides present the overall results.

The foundation of our calculations is the preceding calculations done by CIT. For our results to be valid, these have to be valid. Specifically, one important assumption is that the BBR-versions of each building indeed reflect standard BBR buildings. When this can be debated for specific buildings, this affects the validity of the assessment of whether a low-energy building is cost-effective or not.



Quick overview of the 16 buildings

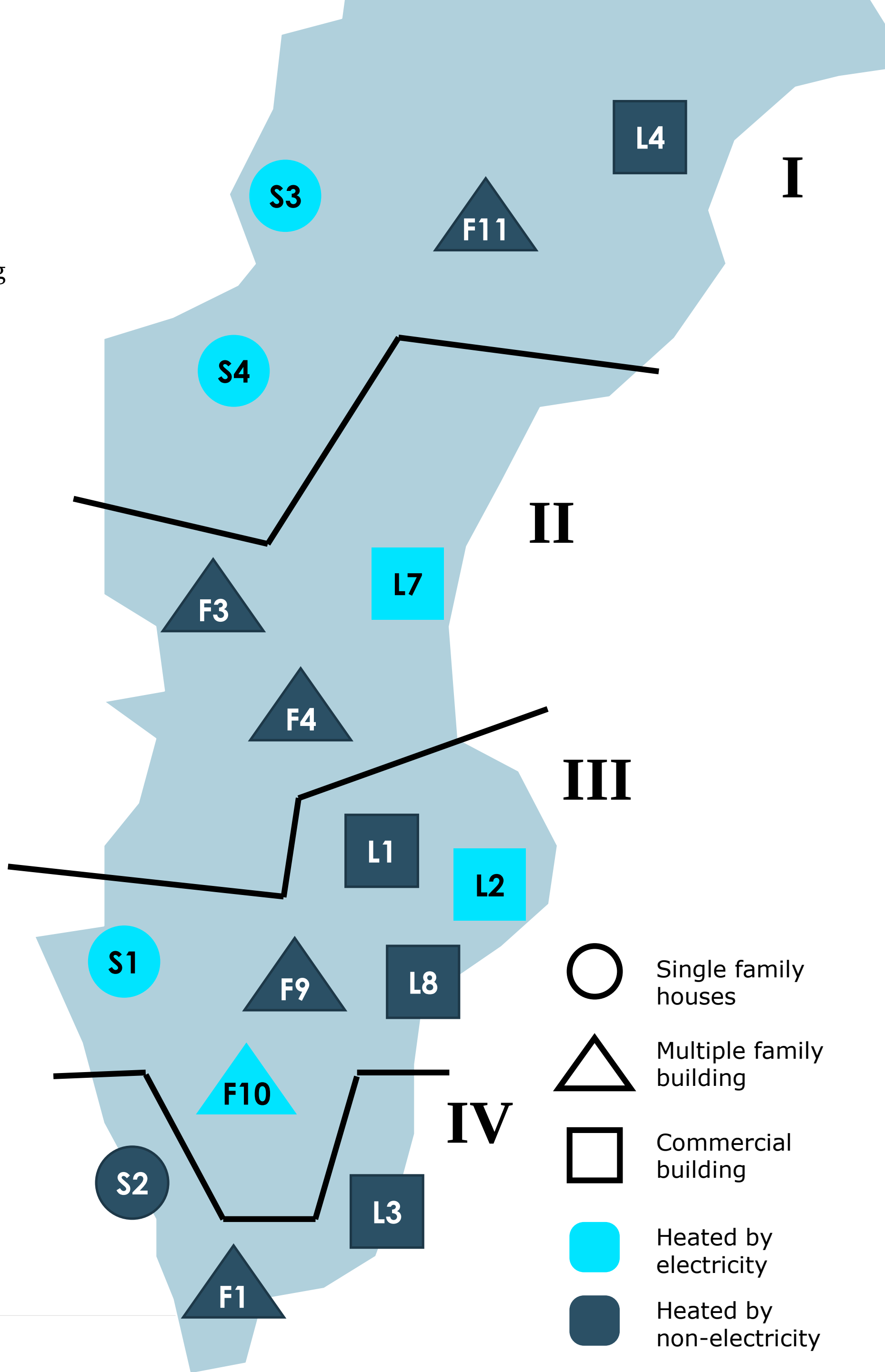
For each building there is:

- One existing building
- One hypothetical building according to BBR19 regulations
- One hypothetical building according to BBR22 regulations

The table below provides an overview of the buildings and the differences between the energy use in the existing buildings compared to the two alternative buildings (the BBR19- and BBR22-versions). The energy requirements in BBR22 are stricter than in BBR19 whereby the buildings in the BBR22-version have lower energy use than the BBR19-version. The existing building is a low-energy building and thus have the lowest energy use of the three. Hence, the difference in energy use between the existing building and the BBR22-version is smaller than the difference in energy use between the existing building and the BBR19-version.

Aggregated results

	Number of cases	Average energy savings per m2 compared to BBR19	Average energy savings per m2 compared to BBR22
		Building types	
S: Houses	4	-28%	-17%
F: Apartment buildings	6	-33%	-25%
L: Commercial buildings	6	-51%	-46%
		Climate zones	
Climate zone I	4	-35%	-24%
Climate zone II	3	-42%	-35%
Climate zone III	6	-38%	-31%
Climate zone IV	3	-39%	-35%
		Heating system	
Non-electricity	10	-40%	-34%
Electricity	6	-36%	-26%



Results for houses show a mixed picture

The four houses gives a mixed picture of the cost-effective energy savings potentials in houses.

S1 does not meet the requirements of being a low-energy building, as its energy use is too high. The alternative versions of S1 differ only from the existing building on the building's envelop. The calculations show that the BBR19 version is the cheapest building seen over the lifetime. This indicates that investments in the building envelop is not enough for energy efficient investments to be cost-effective. To be effective, the investments needs to be complemented by changes in the heating system (see chapter 2).

S2 is an interesting case as this house is a prefabricated (i.e. standardised) house similar to its neighbour houses and only different in its higher energy efficiency. The calculations show that this house is cost-effective. However, this house has a common water heating system with the neighbouring houses, which helps to bring the costs down.

S3 is not a low-energy building to begin with and the alternative designs for this house are special. Most of all, the BBR22-version of this house has a lower energy use than the existing house because the BBR22-version relies more on heating from a heat pump, which is more efficient than the heating system in the existing building. As an example of the costs and benefits of energy efficiency in new buildings, this house is thus less relevant.

S4 is a low-energy building, but it is not cost-effective compared to the alternative versions. This building's heating system is special, and this is kept in the alternative versions, whereby the alternatives do not represent pure standard new houses. Thereby, it is uncertain whether the result for this house is representative of the costs and benefits of energy efficiency in new houses.

For more information, see the results for each building in chapter 3.

Energy use in the houses (green circle indicates the most cost-effective version of this building)

kWh/m2	Existing building		BBR22 version	BBR19 version	
S1	44		46	51	●
S2	47	●	79	90	
S3	80	●	75	90	
S4	77		109	126	●

Results for apartment buildings shows that all six existing buildings are more cost-effective than their alternative versions

Of the 16 building case studies, six are apartment buildings, and for every one of these the existing building is more cost-effective than the alternative designs. If these buildings are representative of the potential in all new apartment buildings, this suggests that it would be cost-effective for Sweden to tighten energy requirements for apartment buildings.

The six apartment buildings are very similar in design both in the existing building and the alternative versions, which allow for decent comparison (F10 is, however, different).

For more information, see the results for each building in chapter 3.

Energy use in the apartment buildings (green circle indicates the most cost-effective version of this building)

kWh/m2	Existing building	BBR22 version	BBR19 version
F1	46 ●	70	75
F3	85 ●	98	107
F4	60 ●	78	87
F9	40 ●	61	70
F10	35 ●	49	55
F11	85 ●	101	118

Results for commercial buildings suggest some cost-effective savings potential

There are six commercial buildings in this analysis, three office buildings (L2, L3, and L8) and three preschools (L1, L4, and L7).

The results indicate that BBR-requirements for electricity heated commercial buildings are high compared to expected energy use in new buildings. L2 and L7 are heated by electric heat pumps (the rest of the L-buildings are heated by district heating). Both L2 and L7 are very energy efficient compared to BBR-requirements and the alternative versions are also quite efficient. In fact, the alternative versions can also be classified as low-energy buildings. This is because of the efficient heat pumps. Even though L2 and L7 are not cost-effective compared to their respective BBR19-versions, this result indicates that there are cost-effective savings potentials for electricity heated commercial buildings, since the BBR19-version is also a low-energy building.

L1 and L4 are district heated preschools and the cost-benefit analyses show that the low-energy buildings are cost-effective and that the potential energy savings compared to BBR-requirements are quite large. The high energy savings comes from the reuse of heat from the school kitchens, which is not a standard solution in BBR.

For more information, see the results for each building in chapter 3.

Energy use in the commercial buildings (green circle indicates the most cost-effective version of this building)

kWh/m2	**Existing building**	**BBR22 version**	**BBR19 version**
L1	23	77	91
L2	18	25	30
L3	45	64	65.4
L4	54	128	150
L7	18	60	69
L8	59	74	76

The indoor air climate in the buildings is generally good

Based on a questionnaire conducted by *SP Sveriges Tekniska Forskningsinstitut* in the summer 2015, we have analysed the indoor air climate in the 16 low-energy buildings. The analysis shows how the buildings score on air quality, thermal comfort, light, moisture and noise compared to average buildings in Sweden.

The 16 low-energy buildings have on average a good to very good indoor climate. Most low-energy buildings outperform their non-low-energy predecessors on all indoor climate indicators. Especially air quality is reported to be very good.

The majority of inhabitants moreover reports good thermal comfort, which indicates that heating mechanisms are sufficient. However, some people living in low-energy apartment buildings have reported that they find it too cold, and/or difficult to control the room temperature (especially F10).

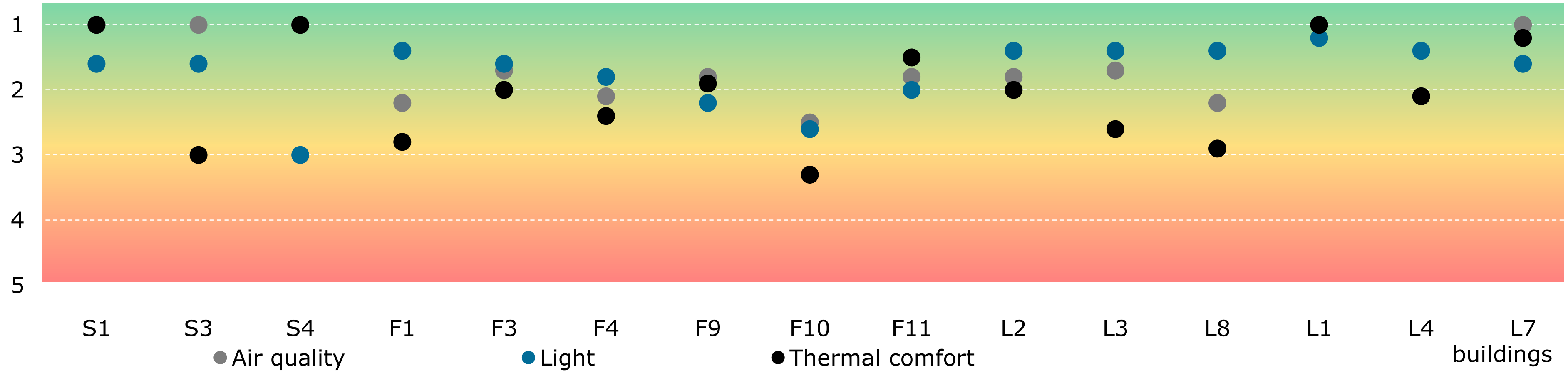
Many low-energy buildings have many windows, and the questionnaire indicates that the existence of sun shields can be important to regulate indoor temperature as well as the incoming light. When buildings use direct sunlight for heating, there might be a trade-off between heating and light.

There are no indications of major problems with other indoor air climate indicators such as moisture or ventilation. Some people working in the commercial buildings have reported to be bothered from noise, but those issues seem unrelated to the fact that the building is a low energy building; the causes are rather the general circumstances (e.g. noisy kids in preschools, rooms close to the canteen in office buildings).

See more information about the quality of the indoor air climate in each building and how it compares to average Swedish buildings in chapter 3. Further, see more information about the methodology in the appendix.

Scores for air quality, light and thermal comfort

Scale 1-5 (1=best, 5=worst)



Source: See chapter 3.

Case studies indicate Sweden can save 2 TWh by 2050 (more than half of this cost-effectively) by reducing energy use in new residential buildings

Based on the technical building designs done by CIT and the cost-benefit analyses of the 16 buildings, we estimate that Sweden can reduce energy use in new residential buildings by 2 TWh in total towards 2050. More than half of this is deemed to be cost effective, which is 18 per cent below the Swedish Energy Agency's expectations for the future energy use in residential buildings. This result depends on CIT cost-assessments reflect average new buildings in Sweden.

ASSUMING REPRESENTATIVE BUILDINGS

For this calculation we assume that the *residential* building case studies are representative of the energy savings potentials in all of Sweden. This is a important and criticisable assumption as we only have four houses and six apartment buildings. The four houses are quite different both in terms of structure and cost-effectiveness. The six apartment buildings on the other hand are similar and are all cost-effective. The results should therefore be seen as indicative.

We calculate the energy savings potential as follows:

- *Technical potential:* We add energy savings in the existing buildings compared to their BBR22-version and divide by the total number of m2. This gives an average energy savings potential in kWh/m2.
- *Cost-effective potential:* We add the energy savings only for buildings in which the low-energy building is cost-effective and divide by the total number of m2 (also including buildings where we don't count in the energy savings).

With this calculation we thus assume that the energy savings in the low-energy buildings compared to their BBR22-versions are representative of the cost-effectiveness of increasing energy efficiency in new buildings in all of Sweden.

SCALING-UP THE RESULTS

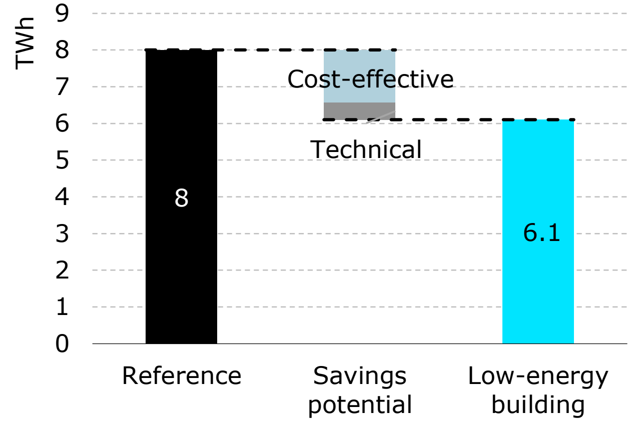
The Swedish Energy Agency estimates that heating in new buildings from today to 2050 will increase Sweden's energy consumption by 8 TWh cumulatively (The Swedish Energy Agency (2017)).

Using the same methodology as the Swedish Energy Agency we have adjusted the energy use in new buildings to take into account our calculation average energy savings potentials. This is done by reducing the assumed kWh/m2 in future new buildings by the calculated amounts in the previous step.

The result is that the energy use would reduce by a little more than 1 TWh if using the cost-effective potential and almost 2 TWh if using the technical potential. This saving is cumulative from today to 2050.

To put these energy savings numbers into perspective, the *yearly* energy use for heating in *all* residential buildings (not just new ones) has been on average about 60 TWh for the last decade. This highlights the importance of energy efficiency potentials in renovations as well as in new buildings. For more on this, see Copenhagen Economics (2016).

Cumulative energy use from today to 2050



Note: Baseline scenario is EU reference scenario from The Swedish Energy Agency (2017).
Source: Copenhagen Economics based on the cost-benefit analyses.

Multiple benefits for Sweden (scaled up)

Energy cost savings: 1,700 million SEK from today to 2050 (or 50 million SEK per year).

Reduced local air pollution: 200-550 million SEK by 2050 (or 6-16 million SEK per year).

Lower CO_2 emissions: 25 million SEK by 2050 (or 0.7 million SEK per year).

Indoor air climate: The low-energy buildings in the case studies have on average a good indoor climate.

LOOKING ACROSS BUILDING CASE STUDIES

Chapter 2

Case studies suggest that marginally increasing the amount of insulation in new buildings above current requirements is less cost-effective

TYPES OF INVESTMENTS

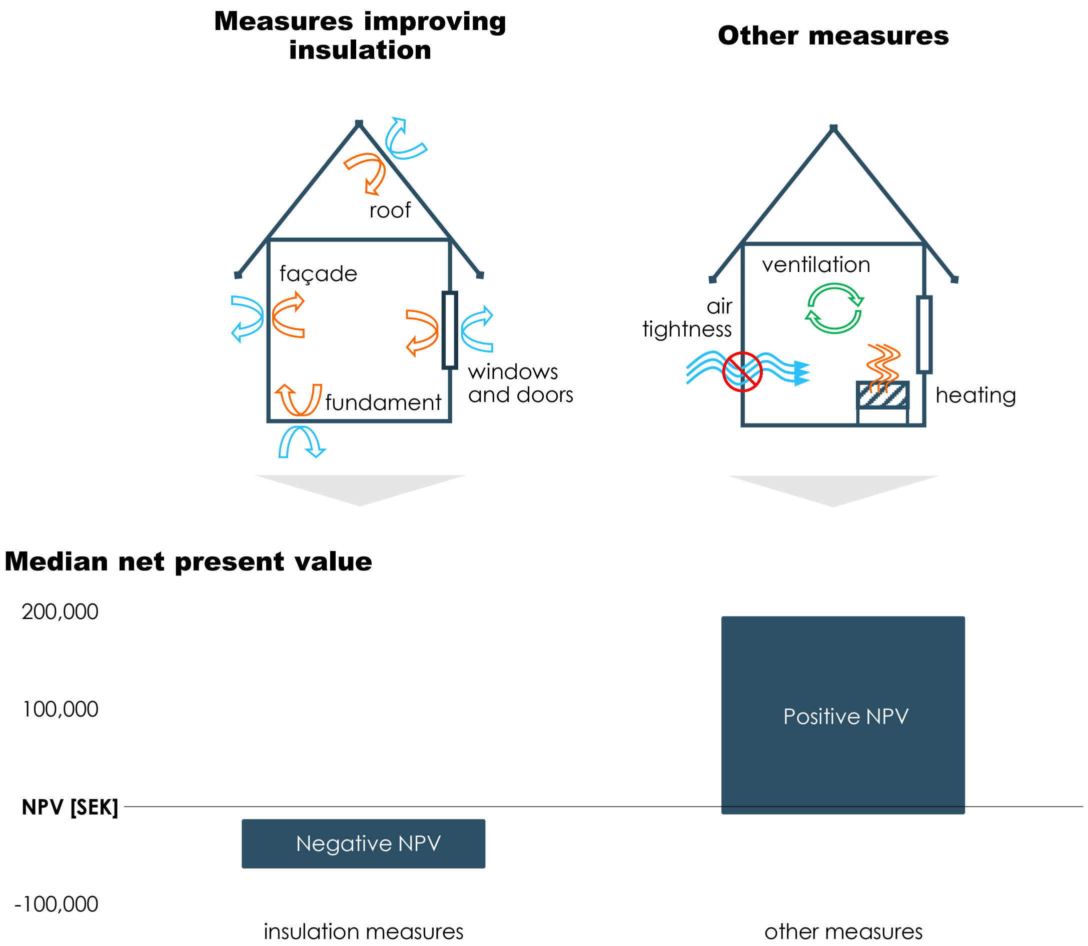
The existing buildings and their alternative design differ on a range of measures. Each measure has an investment cost and energy use effect. Therefore, each measure can be evaluated based on its cost-effectiveness. The types of energy efficiency investments being examined are generally

- **Investments to improve the insulation of buildings**; those measures include better insulation of the roof, façade, fundament and windows and doors.
- **Investments in air tightness**
- **Investments in technical installations** such as improved ventilation and heating measures. The latter includes both changes in the heating system (i.e. installation of a heat pump for warm water) as well as scale effects in heating (i.e. scaling down from radiator heating to floor heating, if that is sufficient in a low-energy building)

Investments in measures improving insulation are in most cases not profitable. That can be concluded from comparing the investment costs associated to those measures and the savings they entail. The median net present value of such investments is negative, meaning that the investments typically do not pay off. The median net present value for improving the insulation of the roof, façade, fundament and windows and doors ranges from -15,000 SEK (insulating the roof) to -60,000 SEK (insulating windows and doors), see figure.

The other energy efficiency measures (improved air tightness, improved ventilation and changes in heating) prove to be profitable in most cases. Their median net present value to a large extent positive, ranging from -6,000 SEK for a change in the heating system to 193,000 SEK for an improved ventilation system, see figure.

Types of investments and their profitability



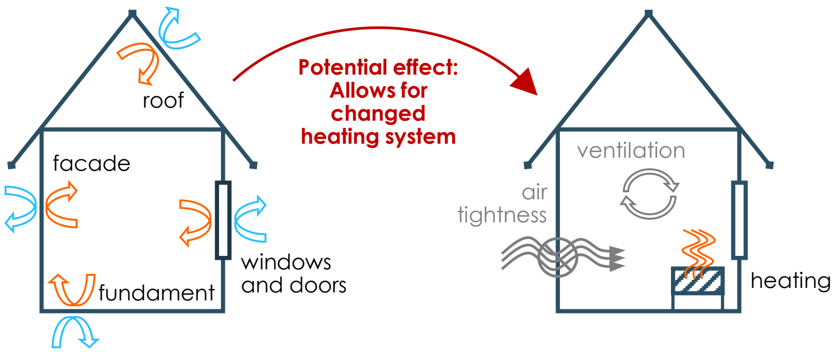
Note: the figure shows the range of the median net present values for the different measures per category. The median is taken across all houses and climate zones. Worth emphasising is that the figure shows the median net present values of investments; that means that there can be insulation measures (other measures) that are profitable (not profitable) in single cases and/or under particular circumstances.

If insulation is improved sufficiently to allow for a change in the heating system, the cost-effectiveness improves

BETTER INSULATION CAN ALLOW FOR A DIFFERENT HEATING SYSTEM

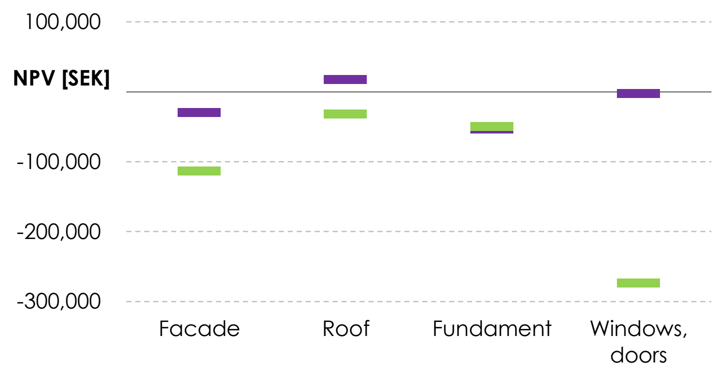
The different categories of investments – especially insulation and investments in heating systems – are only independent of each other to a certain extent. If the insulation of a building is improved sufficiently much, this might allow for a different and cheaper heating system.

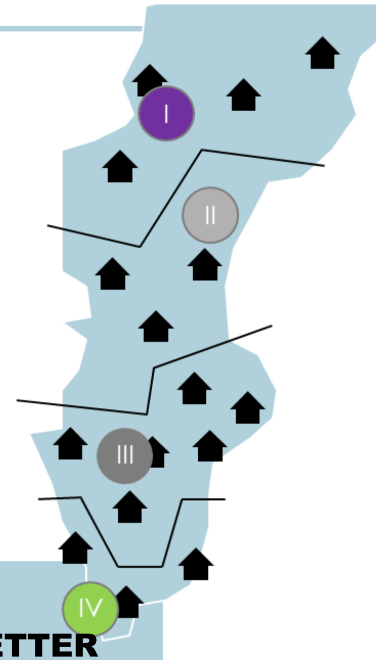
Investments in improved insulation beyond current requirements alone are, as we have seen, typically not profitable and have a negative net present value. However, if insulation is improved beyond a certain point, this allows for a change in the heating system from one technology to another and potentially a downscaling of the size. Such a combined package of investments can be a profitable undertaking. The case of house S1 supports this finding. S1 is the only house in the sample where only insulation measures (and air tightness) have been conducted, and the cost-benefit analysis shows that it is not cost-effective compared to its BBR19- and BBR22-versions.



GEOGRAPHY MATTERS

Median profitability (measured with the net present value) of investments in insulation: North (violet) vs. south (green) Sweden.





THE BUSINESS CASE FOR INSULATION MEASURES IN NORTHERN SWEDEN IS BETTER

The business case for improved insulation is better for houses located in Sweden's colder regions (climate zone I in the north) as compared to Southern Sweden (climate zone IV), see figure above. The insulation of the roof even proves profitable on average in the colder climate of the North. The difference in profitability between North and South Sweden is particularly large for the insulation of windows and doors; this investment has yields a net present value of around zero in northern Sweden, but will cost the investor on average more than 340,000 SEK if conducted in Southern Sweden. For the insulation of the fundament, the difference is smallest.

This could have a relation to the fact that buildings in Northern Sweden have looser energy requirements than buildings in Southern Sweden.

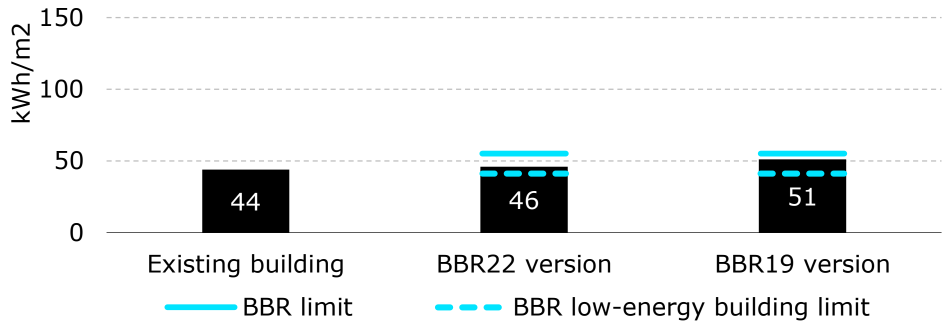
RESULTS FOR EACH BUILDING

Chapter 3

Results for S1

DESCRIPTION

S1 is a 1½ story home located in a residential area in the Southern part of Sweden (climate zone III) heated by electricity (heat pump). **This house has too high an energy consumption to be classified as a low-energy building.** In the alternative designs of this house, only changes to the building envelope has been done as ventilation and heating systems has stayed the same. The results show that investments in a more efficient building envelop in itself is not a cost-effective investment.

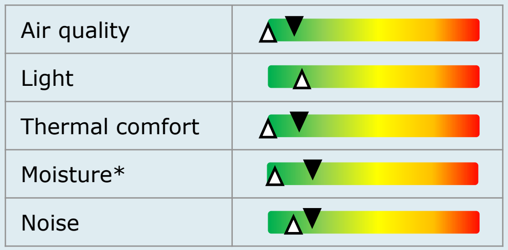


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 190,000 SEK • 930 SEK/m² • 130 SEK/saved kWh	**Energy costs savings** over calculation period: • 34,500 SEK • 170 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 2,000-5,500 SEK • 10-30 SEK/m² • 1-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 300 SEK • 1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • *Negative* 150,000-153,500 SEK • *Negative* 730-750 SEK/m² • *Negative* 100-105 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 55,500 SEK • 270 SEK/m² • 165 SEK/saved kWh	**Energy costs savings** over calculation period: • 9,000 SEK • 40 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 500-1,000 SEK • 2-6 SEK/m² • 1-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 50 SEK • <1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • *Negative* 45,000-46,000 SEK • *Negative* 220 SEK/m² • *Negative* 135 SEK/saved kWh

Indoor health effects

Very good overall indoor environment. Slightly too little direct sunlight coming in has been reported during the winter months. The noise level has been reported as “good” on average.



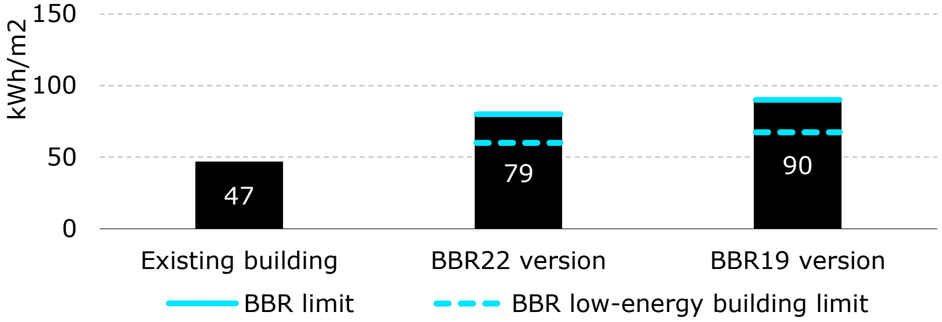
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors’ own interpretation of those qualitative results.*

Results for S2

DESCRIPTION

S2 is a 2 story house located in a residential area in the South of Sweden (climate zone IV) heated by district heating. The houses in this residential area are very similar, although S2 was specially designed to be a low-energy building. The houses in this area have a shared water heating system, which is uncommon. To standardise the building design, a separate water heating system is installed in the alternative designs of this house, and an extra heat pump is installed to ensure thermal comfort. Because of these additional investments, the low-energy house is more cost-effective than the BBR-versions.



Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 59,000 SEK • 420 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 182,500 SEK • 1,300 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 22,000-38,500 SEK • 160-280 SEK/m² • 4-5 SEK/saved kWh	**CO_2 emissions** benefits for society: • 300 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 146,000-162,500 SEK • 1,040-1,160 SEK/m² • 25 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 14,000 SEK • 100 SEK/m² • 3 SEK/saved kWh	**Energy costs savings** over calculation period: • 138,500 SEK • 990 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 16,500-28,500 SEK • 120-200 SEK/m² • 4-5 SEK/saved kWh	**CO_2 emissions** benefits for society: • 300 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 141,000-153,000 SEK • 1,010-1,090 SEK/m² • 30-35 SEK/saved kWh

Indoor health effects

N/A

Air quality	n/a
Light	n/a
Thermal comfort	n/a
Moisture*	n/a
Noise	n/a

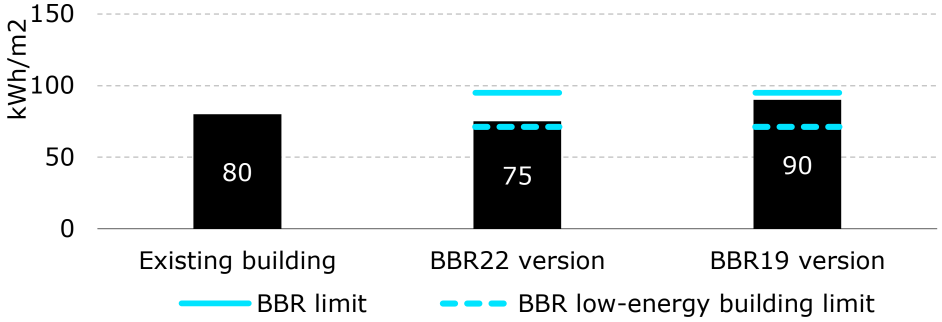
Legend: very good – very bad ∆ This house ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for S3

DESCRIPTION

S3 is a 1½ story house in the Northern part of Sweden (climate zone I) heated by electricity. **This house has too high an energy consumption to be classified as a low-energy building.** In the alternative designs, construction costs are higher because of extra needed investments in heating and distribution to compensate for a less efficient building envelope. The heating system in the alternative designs is changed to be a geothermal heat pump, which is so efficient, that the BBR22 house actually consumes less energy than the low-energy house.

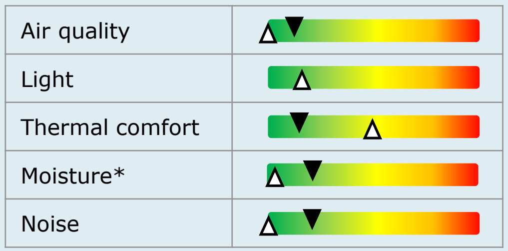


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • ÷58,500 SEK • ÷440 SEK/m² • ÷45 SEK/saved kWh	**Energy costs savings** over calculation period: • 30,000 SEK • 220 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 1,500-4,500 SEK • 10-30 SEK/m² • 1-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 200 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 90,000-93,000 SEK • 670-700 SEK/m² • 70 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • ÷140,000 SEK • ÷1,040 SEK/m² • 230 SEK/saved kWh	**Energy costs savings** over calculation period: • ÷14,000 SEK • ÷110 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • ÷1,000; ÷2,000 SEK • ÷6; ÷20 SEK/m² • 1-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • ÷100 SEK • <÷1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 125,000-123,500 SEK • 920-930 SEK/m² • *Negative* 200-205 SEK/saved kWh

Indoor health effects

Very good indoor environment with regards to air quality, moisture and noise. It is, however, much too warm and also slightly too bright during summer. Both can be related to the house lacking blinds or sun shields at the inside or outside of the windows. The score for thermal comfort is significantly lower than the reference score of an average new house building between 1996-2005.



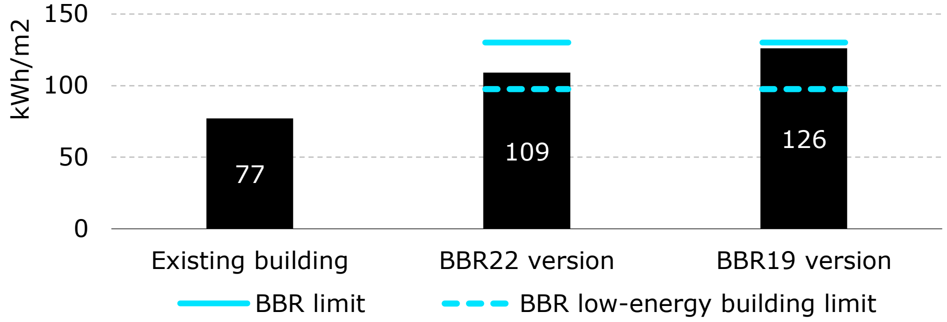
Legend: very good — very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for S4

DESCRIPTION

S4 is a 1½ story house with an attic located in the North of Sweden (climate zone I) heated by a fireplace and solar panels complemented by an electric boiler. In the alternative designs of this house, the solar panel is removed and the fire place is increased in size, hence the use of pellets increases. Pellets is a cheaper heating source than electricity, which diminishes the energy *costs* advantage of the low-energy house. In the BBR22-version of this house, energy costs are actually lower than in the low-energy house, even though the low-energy house uses less energy (in energy units).

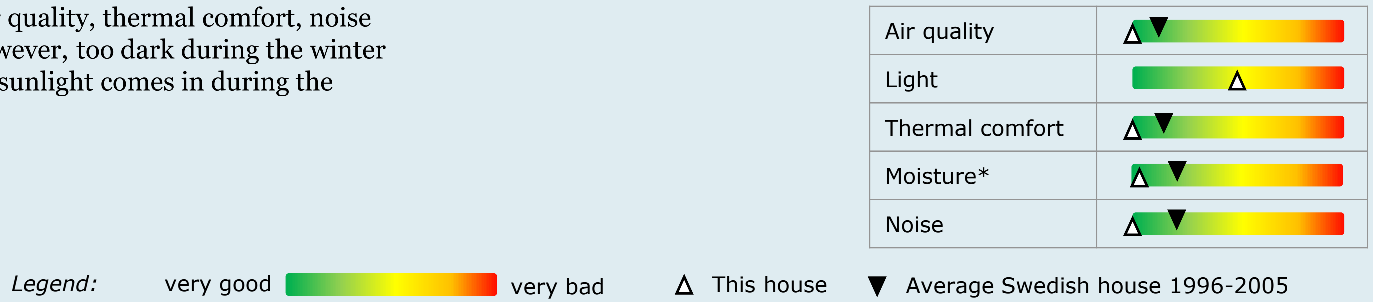


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 808,500 SEK • 4,150 SEK/m² • 85 SEK/saved kWh	**Energy costs savings** over calculation period: • 40,000 SEK • 200 SEK/m² • 4 SEK/saved kWh	**Local air pollution** benefits for society: • 48,500-78,000 SEK • 250-400 SEK/m² • 5-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • ÷700 SEK • ÷3 SEK/m² • <÷1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • *Negative* 691,500-721,000 SEK • *Negative* 3,550-3,700 SEK/m² • *Negative* 75 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 627,500 SEK • 3,220 SEK/m² • 100 SEK/saved kWh	**Energy costs savings** over calculation period: • ÷6,500 SEK • ÷30 SEK/m² • ÷1 SEK/saved kWh	**Local air pollution** benefits for society: • 35,500-57,000 SEK • 180-290 SEK/m² • 5-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • ÷700 SEK • ÷4 SEK/m² • <÷1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • *Negative* 578,000-599,500 SEK • *Negative* 2,960-3,070 SEK/m² • *Negative* 95 SEK/saved kWh

Indoor health effects

Residents report very good overall air quality, thermal comfort, noise and moisture levels. The house is, however, too dark during the winter months, and slightly too much direct sunlight comes in during the summer months.

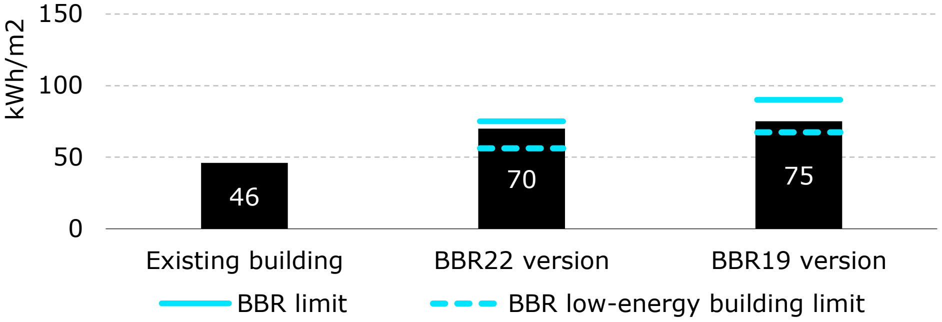


*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F1

DESCRIPTION

F1 is an 8 story apartment building in a residential area located in the South of Sweden (climate zone IV) heated by district heating complemented by solar panels. In the alternative designs of this house, the building envelope is made less efficient, the solar panels are removed, the ventilation system is made less efficient and the heating distribution system is changed. The cost-benefit analysis shows that the low-energy building is cost-effective.

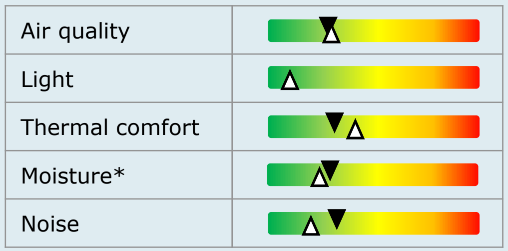


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 733,500 SEK • 270 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 2,404,000 SEK • 870 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 316,000-500,500 SEK • 110-180 SEK/m² • 4-5 SEK/saved kWh	**CO_2 emissions** benefits for society: • 2,300 SEK • <1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 1,989,000-2,173,500 SEK • 720-790 SEK/m² • 25 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 571,500 SEK • 210 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,995,500 SEK • 720 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 261,500-414,000 SEK • 90-150 SEK/m² • 4-5 SEK/saved kWh	**CO_2 emissions** benefits for society: • 2,000 SEK • <1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 1,687,500-1,840,000 SEK • 610-670 SEK/m² • 25 SEK/saved kWh

Indoor health effects

Residents report good to very good light/brightness in the apartments. Air quality, thermal comfort and moisture is not optimal. A quarter of the residents report difficulties getting rid of moist air in the bathroom. A larger share is bothered by (own) cooking smell. Residents experience cold temperatures and floors in winter, and find it difficult to influence the room temperature.



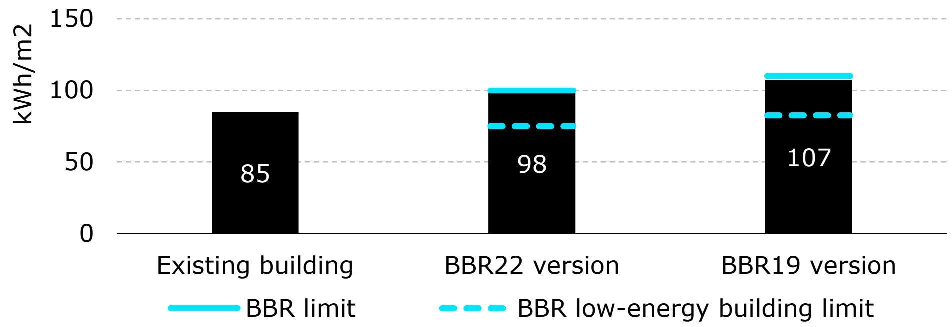
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F3

DESCRIPTION

F3 is a 5 story apartment building located in mid-Sweden (climate zone II) heated by district heating. Water heating is powered by solar panels. **This building has too high an energy consumption to be classified as a low-energy building.** In the alternative designs, the building envelope is made less efficient, the solar panels are removed and a less efficient ventilation system is installed. The cost-benefit analysis shows that the existing building is cost-effective.

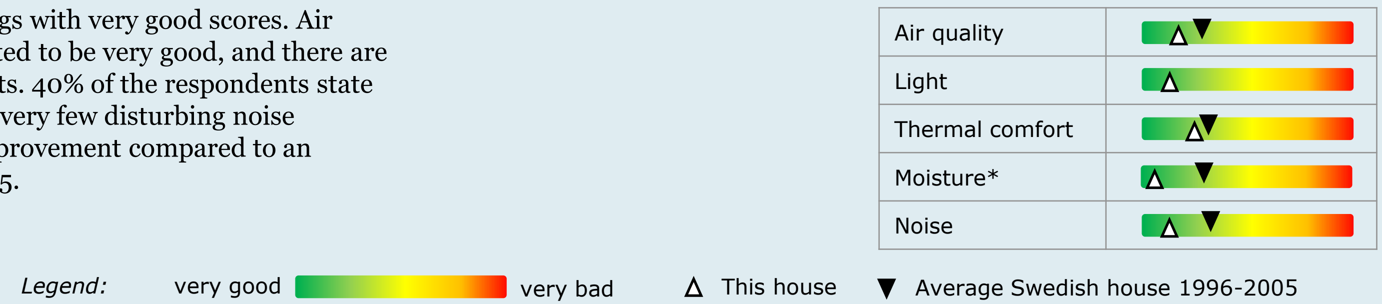


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,667,000 SEK • 430 SEK/m² • 20 SEK/saved kWh	**Energy costs savings** over calculation period: • 2,639,000 SEK • 680 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 49,000 SEK • 10 SEK/m² • 1 SEK/saved kWh	**CO_2 emissions** benefits for society: • 12,500 SEK • 3 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 1,033,000 SEK • 270 SEK/m² • 10 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 604,500 SEK • 160 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,552,000 SEK • 400 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 31,000 SEK • 8 SEK/m² • 1 SEK/saved kWh	**CO_2 emissions** benefits for society: • 6,800 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 985,500 SEK • 260 SEK/m² • 20 SEK/saved kWh

Indoor health effects

Overall one of the apartment buildings with very good scores. Air quality and light/brightness is reported to be very good, and there are no problems with moisture in the flats. 40% of the respondents state that they have bathroom fans. No or very few disturbing noise reported, which is a considerable improvement compared to an average newly build house 1996-2005.

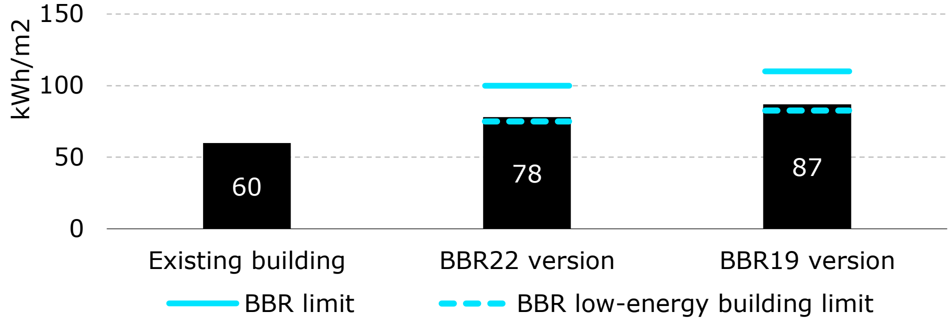


*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F4

DESCRIPTION

F4 is a 13 story apartment building located in mid-Sweden (climate zone II) heated by district heating. Water heating is also supplied by district heating complemented by a heat pump. In the alternative designs, the building envelope is made less efficient, the heat pump is removed, the ventilation system is made less efficient and the heating distribution system is changed to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

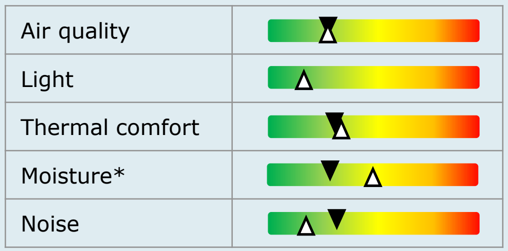


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 697,500 SEK • 520 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 2,705,500 SEK • 2,000 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 325,000-928,000 SEK • 240-690 SEK/m² • 4-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • 13,500 SEK • 10 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 2,346,500-2,949,000 SEK • 1,730-2,180 SEK/m² • 25-30 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 18,500 SEK • 10 SEK/m² • <1 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,894,500 SEK • 1,400 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 234,000-668,000 SEK • 170-490 SEK/m² • 4-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • 9,200 SEK • 7 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 2,119,500-2,554,000 SEK • 1,570-1,890 SEK/m² • 35-40 SEK/saved kWh

Indoor health effects

Good conditions regarding light and noise, but problems with air quality, thermal comfort and moisture. One case of water/moisture damage and one case of visible mould has been reported in the last 12 months. Residents state that it is difficult to steer the indoor temperature, and that draft occurs. A large share of residents is sometimes bothered by own cooking smells.



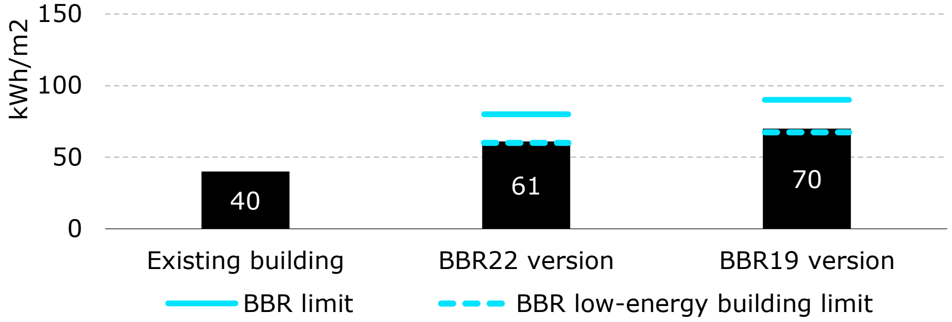
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F9

DESCRIPTION

F9 consists of two 8 story apartment buildings located in a residential area in Southern Sweden (climate zone III) heated by district heating. In the alternative designs, the building envelope is made less efficient, the ventilation system is made less efficient and the heating distribution system is changed to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

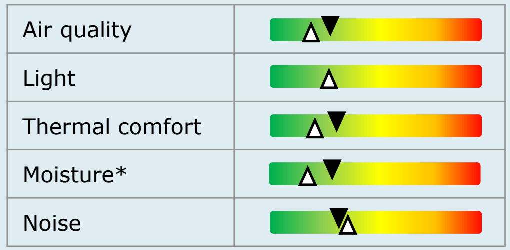


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 47,500 SEK • 8 SEK/m² • <1 SEK/saved kWh	**Energy costs savings** over calculation period: • 4,938,500SEK • 860 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 610,000-1,786,500 SEK • 110-310 SEK/m² • 4-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • 10,100 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 5,511,500-6,688,000 SEK • 960-1,170 SEK/m² • 30-40 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • ÷1,088,500 SEK • ÷190 SEK/m² • ÷10 SEK/saved kWh	**Energy costs savings** over calculation period: • 3,408,000 SEK • 600 SEK/m² • 30 SEK/saved kWh	**Local air pollution** benefits for society: • 419,500-1,228,000 SEK • 70-210 SEK/m² • 3-10 SEK/saved kWh	**CO_2 emissions** benefits for society: • 7,100 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 4,923,000-5,731,500 SEK • 860-1,000 SEK/m² • 40-50 SEK/saved kWh

Indoor health effects

Good indoor air quality. Half of the residents find the apartments too dark during the winter months, and one third also during summer. Single residents complain about the bathroom being too cold, and condensation at the inner side of the windows is reported. The noise level is considered good to acceptable, which is rather negative in comparison with the other new low energy buildings.



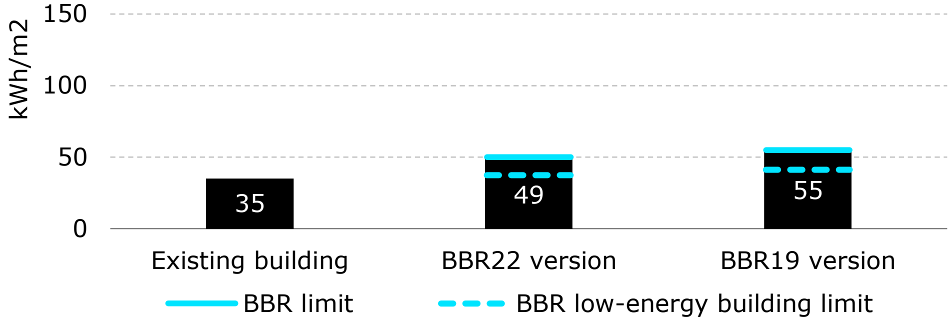
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F10

DESCRIPTION

F10 is an apartment building with 8 apartments located in Southern Sweden (climate zone III). This building is built as a passive building and heating is mainly supplied by reusing heat from internal sources (e.g. body heat and spill-over heat from appliances). Water heating is powered mainly by solar panels. In the alternative designs, the solar panels are removed, the building envelope is made less efficient, the ventilation is made less efficient, the heating distribution is changed and a heat pump is installed. The analysis shows that the building is cost-effective, however there might be some problems with thermal comfort.

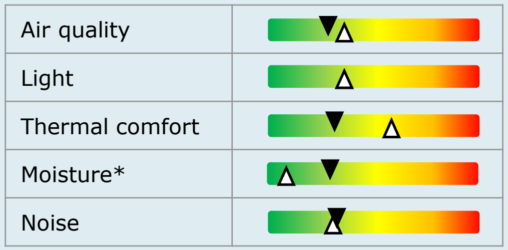


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 207,000 SEK • 270 SEK/m² • 15 SEK/saved kWh	**Energy costs savings** over calculation period: • 364,000 SEK • 470 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 19,000-29,500 SEK • 20-40 SEK/m² • 1-2 SEK/saved kWh	**CO_2 emissions** benefits for society: • 2,700 SEK • 3 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 178,500-189,000 SEK • 230-240 SEK/m² • 10 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 43,000 SEK • 50 SEK/m² • 4 SEK/saved kWh	**Energy costs savings** over calculation period: • 261,000 SEK • 330 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 14,000-21,000 SEK • 20-30 SEK/m² • 1-2 SEK/saved kWh	**CO_2 emissions** benefits for society: • 1,900 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 233,500-241,000 SEK • 300-310 SEK/m² • 20 SEK/saved kWh

Indoor health effects

High score regarding moisture, but problematic in some other regards. The majority of residents state that they cannot steer the room temperature sufficiently, and some complain about the flats being too cold in winter, too warm in summer, and the floor being cold. In addition, the flats are perceived as too dark during winter, and some also state that for the summer months.



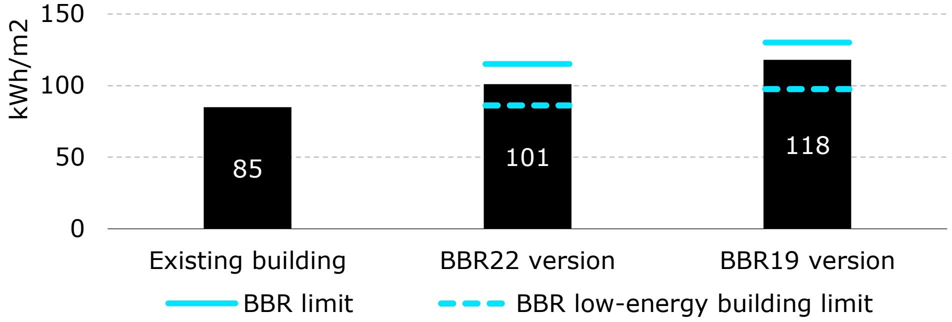
Legend: very good – very bad △ This house ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for F11

DESCRIPTION

F11 is 2 story multifamily residential building located in the North of Sweden (climate zone I) heated by district heating. In the alternative designs, the building envelope is made less efficient, the ventilation system is made less efficient and the heating distribution system is changed to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

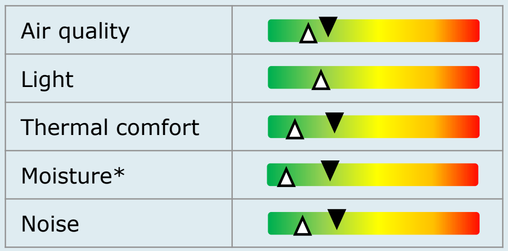


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 813,000 SEK • 870 SEK/m² • 25 SEK/saved kWh	**Energy costs savings** over calculation period: • 824,500 SEK • 880 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 89,500-141,500 SEK • 100-150 SEK/m² • 3-5 SEK/saved kWh	**CO_2 emissions** benefits for society: • 1,900 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 102,500-155,000 SEK • 110-170 SEK/m² • 3-5 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 419,500 SEK • 450 SEK/m² • 30 SEK/saved kWh	**Energy costs savings** over calculation period: • 385,000 SEK • 410 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 33,500-53,000 SEK • 40-60 SEK/m² • 2-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 1,600 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 1,000-20,000 SEK • 1-20 SEK/m² • 1 SEK/saved kWh

Indoor health effects

Good to very good overall indoor environment, with no significant exceptions. This building received better scores than an average new reference building from 1996-2005 in all categories. A third of residents is sometimes bothered by cooking smells originating from the neighbours or the own cooking.



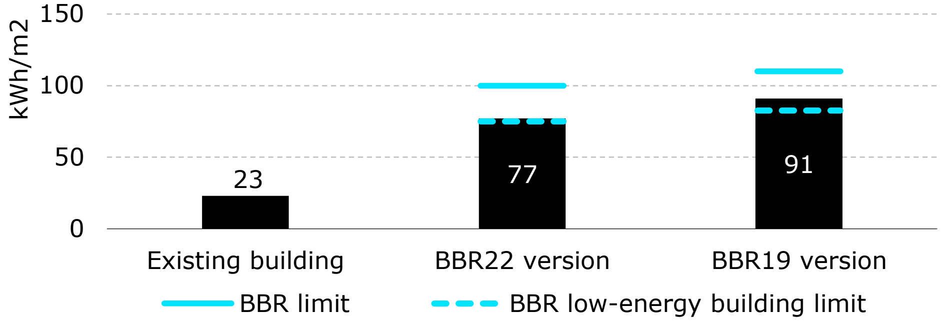
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L1

DESCRIPTION

L1 is a 2 story preschool located in Southern Sweden (climate zone III). The building was built as a passive building. Heating is supplied by district heating and the reuse of waste heat from the kitchen. Water heating is done by reusing hot water from the kitchen (supported by a heat pump). In the alternative designs, the reusing of waste heat is removed, the building envelope is made less efficient and a larger heating system is installed to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

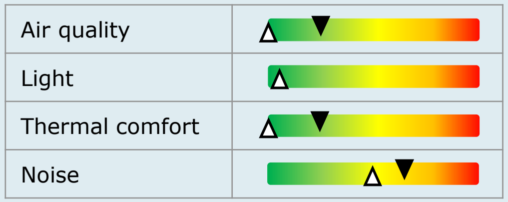


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,426,500 SEK • 1,340 SEK/m² • 20 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,725,000 SEK • 1,620 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 184,000-285,500 SEK • 170-270 SEK/m² • 3-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 16,800 SEK • 20 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 500,000-601,000 SEK • 470-560 SEK/m² • 5-10 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 1,144,000 SEK • 1,070 SEK/m² • 20 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,298,500 SEK • 1,220 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 143,500-222,500 SEK • 130-210 SEK/m² • 2-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 13,200 SEK • 10 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 311,000-390,000 SEK • 290-370 SEK/m² • 5 SEK/saved kWh

Indoor health effects

Very good air quality although airing is not possible, and very good conditions regarding brightness and direct sunlight and thermal comfort as well. Half of the staff reports a disturbingly loud noise level due to the kids, which might partly be due to bad acoustics.



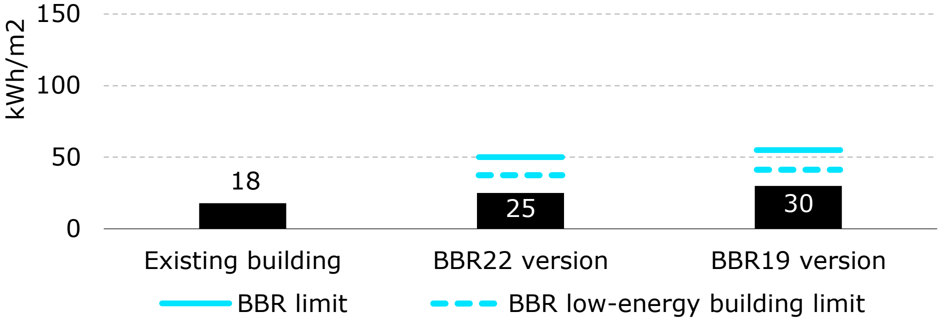
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L2

DESCRIPTION

L2 is a 4 story office building located in Southern Sweden (climate zone III) heated by electricity (heat pump). The building has installed a so-called free-cooling system utilizing cooling from a borehole. In the alternative designs, the free-cooling system is replaced by a standard cooling unit, the building envelope is made less efficient, the ventilation system is made less efficient and the heating system is increased to ensure thermal comfort. The analysis shows that the building is not cost-effective compared to the BBR19-version, but is compared to the BBR22-version. Both are, however, also low-energy buildings.



Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,426,500 SEK • 470 SEK/m² • 40 SEK/saved kWh	**Energy costs savings** over calculation period: • 769,000SEK • 260 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 36,500-99,500 SEK • 10-30 SEK/m² • 1-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 4,600 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • *Negative* 553,000-616,000 SEK • *Negative* 180-200 SEK/m² • *Negative* 15-20 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 126,000 SEK • 40 SEK/m² • 5 SEK/saved kWh	**Energy costs savings** over calculation period: • 399,500 SEK • 130 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 20,000-55,000 SEK • 7-20 SEK/m² • 1-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 2,500 SEK • <1 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 296,000-331,000 SEK • 100-110 SEK/m² • 15 SEK/saved kWh

Indoor health effects

Good air quality. The office cannot be aired, but most people do not feel the necessity to do so either. The premises are considered slightly too bright during summer. Thermal comfort is good during summer, but temperatures a too low in winter. Almost 40% state that they are disturbed by noise from others in the office, and 20% state that acoustics are bad.

Air quality	△ ▼
Light	△
Thermal comfort	△ ▼
Noise	△ ▼

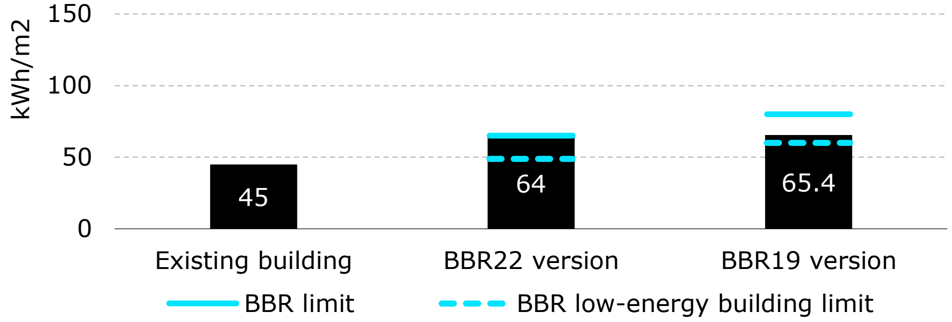
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L3

DESCRIPTION

L3 is a 6 story office building located in Southern Sweden (climate zone IV). Heating is supplied by district heating complemented by a heat pump. Water heating is supplied by electric water heaters and waste heat from the building's process cooling devices. The building has solar panels. In the alternative designs, the solar panels are removed, the heat recovery is removed, the ventilation system is made less efficient, the building envelope is made less efficient and the heating system is increased to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is not cost-effective.



Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 2,475,000 SEK • 610 SEK/m² • 30 SEK/saved kWh	**Energy costs savings** over calculation period: • 2,032,000 SEK • 500 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 206,500-358,500 SEK • 50-90 SEK/m² • 2-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 7,200 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • *Negative* 77,000-229,000 SEK • *Negative* 20-60 SEK/m² • *Negative* 1-3 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 2,354,000 SEK • 580 SEK/m² • 30 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,867,000 SEK • 460 SEK/m² • 25 SEK/saved kWh	**Local air pollution** benefits for society: • 193,000-335,500 SEK • 50-80 SEK/m² • 2-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 6,700 SEK • 2 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • *Negative* 145,000-287,500 SEK • *Negative* 40-70 SEK/m² • *Negative* 2-4 SEK/saved kWh

Indoor health effects

Good air quality apart from a few conference rooms that quickly get bad air. Respondents report that the premises are sometimes unnecessarily darkened due to an automatic sun shield outside the windows. Many find it too cold during winter, and report draft from windows. More than a third report to be bothered by noise from a construction site outside the office.

Air quality	△ ▼
Light	△
Thermal comfort	△ ▼
Noise	△ ▼

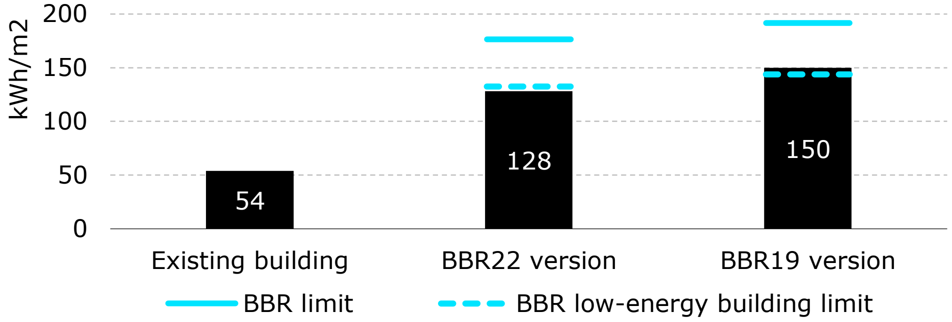
Legend: very good — very bad △ This house ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L4

DESCRIPTION

L4 is a 2 story preschool located in the North of Sweden (climate zone I) heated by district heating complemented by waste heat from kitchen refrigerators. Water heating is supplied by a heat pump. In the alternative designs, the heat recovery system is removed, building envelope is made less efficient, the ventilation system is made less efficient and the heating system is increased to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

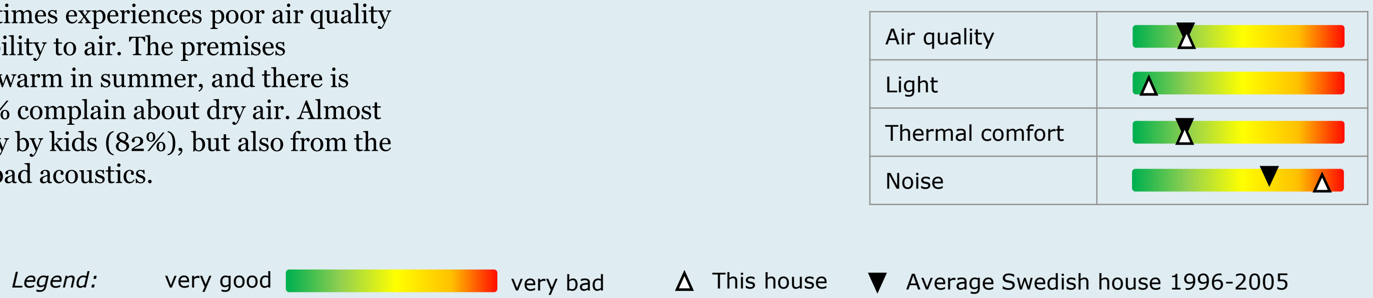


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,177,000 SEK • 1,300 SEK/m² • 15 SEK/saved kWh	**Energy costs savings** over calculation period: • 4,862,500 SEK • 5,390 SEK/m² • 55 SEK/saved kWh	**Local air pollution** benefits for society: • 248,500-385,500 SEK • 280-430 SEK/m² • 3-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 19,800 SEK • 20 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 3,953,500-4,090,500 SEK • 4,380-4,540 SEK/m² • 45 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 794,000 SEK • 880 SEK/m² • 10 SEK/saved kWh	**Energy costs savings** over calculation period: • 3,635,500 SEK • 4,030 SEK/m² • 55 SEK/saved kWh	**Local air pollution** benefits for society: • 193,000-299,500 SEK • 210-330 SEK/m² • 3-4 SEK/saved kWh	**CO_2 emissions** benefits for society: • 15,400 SEK • 20 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 3,050,000-3,156,500 SEK • 3,380-3,500 SEK/m² • 45 SEK/saved kWh

Indoor health effects

Good air quality, although staff sometimes experiences poor air quality in some rooms, and misses the possibility to air. The premises reported to be too cold in winter, too warm in summer, and there is draft from the ventilation system. 45% complain about dry air. Almost all staff complains about noise, mostly by kids (82%), but also from the ventilation system (36%) and due to bad acoustics.

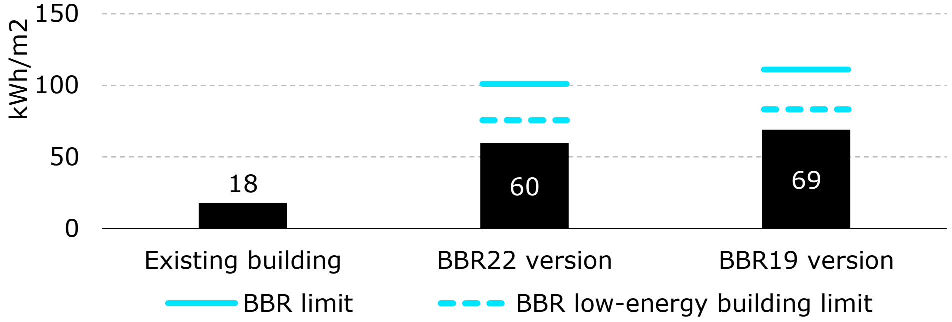


*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L7

DESCRIPTION

L7 is a 1 story preschool located in mid-Sweden (climate zone II) heated by electricity (heat pump). The building has installed a so-called free-cooling system utilizing cooling from a borehole. Further, the building has solar panels. In the alternative design, the solar panels are removed, the building envelope is made less efficient, the ventilation system is made less efficient and the heating system is increased to ensure thermal comfort. The cost-benefit analysis shows that the building is not cost-effective compared to the alternative version, which are however also low-energy buildings.

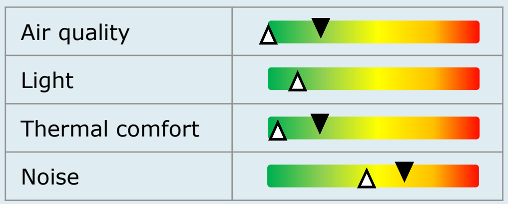


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,839,500 SEK • 1,490 SEK/m² • 30 SEK/saved kWh	**Energy costs savings** over calculation period: • 1,212,500 SEK • 980 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 66,500-182,000 SEK • 50-150 SEK/m² • 1-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 8,500 SEK • 7 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • *Negative* 436,000-552,000 SEK • *Negative* 350-450 SEK/m² • *Negative* 5-10 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 1,371,500 SEK • 1,110 SEK/m² • 25 SEK/saved kWh	**Energy costs savings** over calculation period: • 957,500 SEK • 780 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 54,500-150,000 SEK • 40-120 SEK/m² • 1-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 7,000 SEK • 6 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • *Negative* 256,500-352,000 SEK • *Negative* 210-290 SEK/m² • *Negative* 5 SEK/saved kWh

Indoor health effects

Good air quality, although some miss the opportunity to air in the afternoon, when the air quality in some rooms worsens. There are no blinds apart from the kids' nap room, and the majority reports too much direct sunlight in summer as well as too warm temperatures. Staff is bothered by noise from kids, but less than in the other preschools.



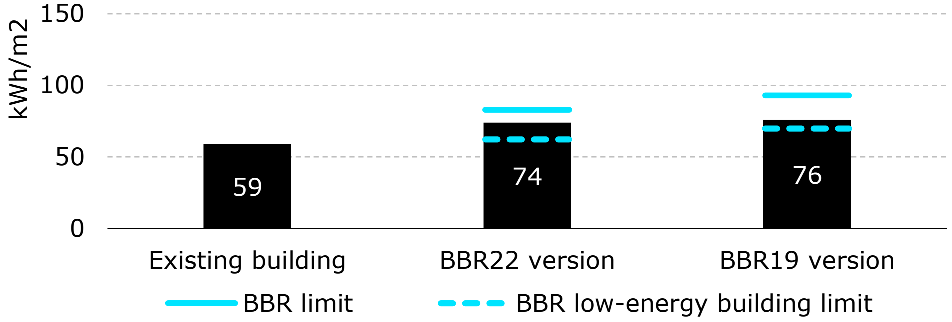
Legend: very good – very bad; △ This house; ▼ Average Swedish house 1996-2005

*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

Results for L8

DESCRIPTION

L8 is 10 story office building located in Southern Sweden (climate zone III) heated by district heating. This building has both a free-cooling system and has access to district cooling. In the alternative designs, the free-cooling system is removed, the building envelope is made less efficient, the ventilation system is made less efficient and the heating system is increased to ensure thermal comfort. The cost-benefit analysis shows that the low-energy building is cost-effective.

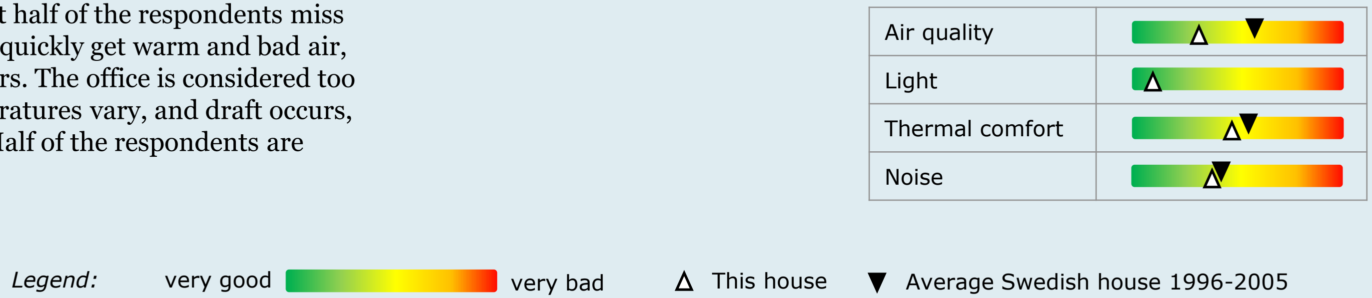


Cost-benefit analysis

	Construction costs	Energy cost savings	Multiple benefits		Sum
From BBR19 to low-energy	Extra **construction costs** for low-energy building: • 1,171,000 SEK • 100 SEK/m² • 5 SEK/saved kWh	**Energy costs savings** over calculation period: • 3,819,000 SEK • 320 SEK/m² • 20 SEK/saved kWh	**Local air pollution** benefits for society: • 368,500-601,500 SEK • 30-50 SEK/m² • 2-3 SEK/saved kWh	**CO_2 emissions** benefits for society: • 56,600 SEK • 5 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR19 version: • 3,073,500-3,306,000 SEK • 260-280 SEK/m² • 15 SEK/saved kWh
From BBR22 to low-energy	Extra **construction costs** for low-energy building: • 594,500 SEK • 50 SEK/m² • 3 SEK/saved kWh	**Energy costs savings** over calculation period: • 2,757,500 SEK • 230 SEK/m² • 15 SEK/saved kWh	**Local air pollution** benefits for society: • 261,500-426,500 SEK • 20-40 SEK/m² • 1-2 SEK/saved kWh	**CO_2 emissions** benefits for society: • 40,100 SEK • 3 SEK/m² • <1 SEK/saved kWh	**NPV of low-energy building** compared to BBR22 version: • 2,464,000-2,629,000 SEK • 210-220 SEK/m² • 15 SEK/saved kWh

Indoor health effects

The office cannot be aired, and almost half of the respondents miss this possibility. Some meeting rooms quickly get warm and bad air, and food smell from the canteen occurs. The office is considered too cold, especially during winter. Temperatures vary, and draft occurs, mainly from the ventilation system. Half of the respondents are disturbed by others in the office.



*Note: A discount rate of 4 percent has been used for the cost benefit analysis. * Mainly qualitative assessments available for moisture. The score is the authors' own interpretation of those qualitative results.*

APPENDIX

Methodology: Socio economic cost-benefit analysis

A socio economic cost-benefit analysis includes *all* costs and *all* benefits for *all* members of society. This means that the analysis looks beyond the effects for the building owner in terms of investments costs and energy savings. The analysis includes all external effects on other members of society, which are in this report called *multiple benefits*.

The multiple benefits included in the present report are local air pollution, CO_2 emissions and indoor air climate. Lower energy use means that the externalities associated with energy production decreases. This is an economic benefit to society, which the building owner might not take into account when deciding to invest in a low-energy building. The next slides explain how we have added these multiple benefits to the analysis.

This slides explains in detail how the socio economic cost-benefit analysis has been done, and specifically how the private economic cost-benefit analysis done by CIT has been changed to reflect socio economic effects. The method follows recommendations and guidelines in Swedish Transport Administration (2016).

FISCAL TAXES ARE SUBTRACTED

A socio economic cost-benefit analysis includes considerations on the effects for public tax revenue. When the building owner saves energy she saves the entire end-user price per saved unit of energy. The end-user price is the wholesale energy price plus taxes. However, when taxes have a purely fiscal objective, these are subtracted from the socio economic benefit of reducing energy use. This is because lower energy use will result in a tax deficit, which is a cost to society. In a socio economic context, the benefit to the building owner nets out with the cost for the public budgets.

In the current analysis we therefore subtract electricity taxes (295 SEK/MWh) from the electricity price. There is no end-user tax for district heating. Ideally, one would also subtract intermediate input taxes (e.g. taxes on fossil fuels used in energy production). This is not done in the present analysis, as fossil fuels represent a small share in both electricity and district heating production and the effect would therefore be small.

ALL VALUES ARE EXPRESSED IN OPPORTUNITY COSTS

The purpose of a socio economic cost-benefit analysis is to make decisions on the best allocation of society's scarce resources. Therefore, all values (costs and benefits) are expressed in opportunity costs, i.e. the value the input could have produced elsewhere in the economy.

For construction costs and energy costs savings this means that they are expressed in consumers willingness-to-pay for these inputs. In practical terms, this means that prices should reflect the average indirect tax burden. This is done by scaling up factor prices (i.e. prices excluding all taxes) by 21%. This is the standard recommended method by Swedish Transport Administration (2016).

The damage of local air pollution and CO_2 emissions are expressed in damage costs (see next slide), whereby they already reflect socio economic costs and thus do not need to be adjusted.

NOTE ON SCRAP VALUE

There is one assumption in the cost-benefit analysis done by CIT which *overestimates* the cost-effectiveness of low-energy buildings, which also applies in the present analysis. This assumption is carried over in the present analysis to ensure comparability.

The cost-benefit analysis has a calculation period of 30 years, and takes into account scrap values for investments with longer lifetimes than 30 years. These scrap values are based on the energy cost savings the investment would enable for the rest of its lifetime. E.g. if a ventilation system has a lifetime of 40 years, then the scrap value at year 30 is 10 years' of energy savings. However, some investments do not have any effect on energy consumption and thus will not have a scrap value. For instance, in many buildings air flow heating as replaced by radiators, which is an investment to ensure thermal comfort, but it does not affect energy consumption in itself. Not including a scrap value for such investments means that the cost-benefit analysis *overestimates* the cost-effectiveness of low-energy buildings.

The scrap values are in our report allocated into the energy costs savings (in each building slide) instead of subtracting them from construction costs.

Methodology: Local air pollution and CO_2 emissions

Our methodology for calculating the benefits in terms of lower local air pollution and CO_2 emissions corresponds to our methodology in the report Copenhagen Economics (2016).

FORMULA

We calculate the benefits of reduced local pollution and CO_2 emissions with the following formula:

Benefit (SEK/year) = Energy reduction (kWh/year)
x Emission factor (ton/kWh)
x Damage cost (SEK/ton)

This is done for electricity and heating for each building separately. The local pollutants included in this analysis are SO_2, NO_x and $PM_{2.5}$. Further, it is done for CO_2 emissions.

The annual energy reductions for each building are available in the material done by CIT. Converting these to emissions and to damage costs are explained below.

EMISSION FACTORS

For *electricity,* we assume that the marginal kWh is produced by nuclear power and electricity from a combined heat and power plant. The marginal emission factor for electricity is therefore a weighted average of emission factors from nuclear power (which is zero) and from combined heat and power plants in Sweden.

For *district heating*, we utilise information about the location (municipality) of the buildings received confidentially from Energimyndigheten. With this information we can use municipality-specific emission factors based on the district heating system in each municipality (from Statistics Sweden).

The emission factors for each fuel use is taken from The Swedish Environmental Protection Agency (2016).

DAMAGE COSTS

For *local pollution*, the damage costs are taken from Swedish Transport Administration (2016). The damage costs includes both health impacts and adverse effects on the environment such as eutrophication and acidification.

The damage costs are area specific meaning that costs are higher in more densely populated areas and lower in rural areas. We utilise the information on the location of the buildings to have building specific damage costs in our calculation.

The damage cost for small particles is in particular highly uncertain. Therefore we apply a range defined by the recommendation by the Swedish Transport Administration as the high range, and an estimate from the literature on this topic as the lower range, see Copenhagen Economics (2016).

For CO_2 emissions, the damage cost is equal to an assumed average price of emissions allowances in the EU Emission Trading System (ETS) of 25 €/ton over the period. This is based on forecasts from Thomson Reuters Point Carbon.

Average emission factors

g/kWh	Electricity	District heating
CO_2	42.8	39.7
SO_2	0.043	0.096
NO_X	0.085	0.204
$PM_{2.5}$	0.025	0.070

Source: Copenhagen Economics based on The Swedish Environmental Protection Agency (2016), energy statistics from Statistics Sweden (tables EN0203AC and EN0105A6).

Average damage costs

SEK/kg	
CO_2	0.23
SO_2	176
NO_X	133
$PM_{2.5}$, high	4,675
$PM_{2.5}$, low	2,024

Source: Copenhagen Economics based on The Swedish Transport Administration (2016), IVL (2014) and EEX.

Methodology: Indoor air climate and health

In our report each building has an assessment of the indoor air climate. The purpose is to evaluate whether the low-energy building has better or worse indoor air climate than "normal" buildings. A better indoor climate could count as a multiple benefit in the socio economic cost-benefit analysis.

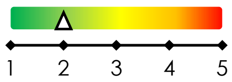
The scores in this assessment of each building are based on a questionnaire conducted by *SP Sveriges Tekniska Forskningsinstitut* in summer 2015.
The scores we gave each building – the white arrow on the colour scale – are based on quantitative data in that questionnaire. The score for moisture is the only exemption, it is based on qualitative data.

The buildings' scores are compared to a "normal", i.e. non-low-energy baseline. This baseline is the BETSI survey for single homes (S) and apartments (F), and the MM survey for premises such as offices and preschools (L). More information on those can be found in the questionnaire and its appendices.

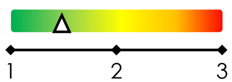
FROM SEVERAL TO ONE CONSISTENT SCALE

Different scales are used throughout the survey for different types of questions (e.g. 5 units from "very good" to "very bad", or just 2 options "problems" and "not problems"). For this analysis, all those different scales have been translated into one consistent colour scale from green (best) to red (worst). The following scales are used in the survey:

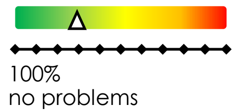
- **5-unit-scale** from "very good" (1) to "good", "acceptable", "bad" and "very bad" (5). This scale is used most commonly throughout the survey. The final score for one indicator and one house is calculated as an average of the responses. This average is then placed on the colour scale as follows; in this example, the house has an average score of 2.0.



- **3-unit-scale**. In some cases, respondents can choose between 5 options, but with the extreme options representing a bad state and the middle option representing the optimal state (e.g. "much too light", "a little too light", "just right", "a little too dark", "much too dark"). This is in fact a scale with three units from good (middle) to less good (+/-1 from the middle) and bad (the extremes, i.e. +/-2 from the middle). This type of scale is mostly used for questions about light in the survey. The final score for one indicator in one house is calculated as an average of the responses, which the middle being "1" and the extremes being "3". If there are several relevant tables, then the overall score is a simple average of the score per table. The score is place don the colour scale as follows; this example shows a house with a score of 1.5:



- **2-unit-scale.** In some cases, the survey only distinguishes between "problem" or "no problem", and then provides the percentage of respondents in each category (summing up to 100%). Those percentages are placed on the colour scale as follows: If 30% reported a problem and 70% did not, then the arrow will be placed 3/10 away from the green end:



- **Qualitative assessment**. For moisture, which is one of the indicators for single family homes and apartments, only qualitative assessments are available, both for the houses themselves and the baseline BETSI they are compared to. The score on the colour scale is our interpretation of those qualitative descriptions.

DETAILED SOURCES FOR THE SINGLE INDICATORS

- *Air quality:* table 94 and 29 in the main document for S and F buildings; table 2 and 9 in the appendix for L buildings.
- *Light:* table 113-115 and 55-57 in the main document for S and F buildings; table 7 and 11 in the appendix for L buildings.
- *Thermal comfort:* table 106 and 46 in the main document for S and F buildings; table 2 in the appendix for L buildings.
- *Moisture*: qualitative data and tables 95, 97,105 and 121 in the main document for S buildings; qualitative data and tables 30, 32, 33 and 65 in the main document for F buildings. No data for F *buildings.*
- *Noise:* table 116 and 60 in the main document for S and F buildings; table 2 and 9 in the appendix for L buildings.

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