EU 7th Framework Programme – EeB-ENERGY

School of the Future

Towards Zero Emission
with High Performance Indoor Environment

Project number: 260102

Report

Screening of Energy Renovation Measures for Schools – Denmark

Authors: Ove Mørck & Anton Paulsen, Cenergia Energy Consultants
Simone Steiger, Heike Erhorn-Kluttig
& Hans Erhorn, Fraunhofer IBP
Michele Zinzi, ENEA
Karin Buvik, SINTEF
Kirsten Engelund Thomsen, SBi/AAU

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ABOUT 'SCHOOL OF THE FUTURE'

'School of the Future' is a collaborative project within the 7th Framework Programme of the European Union in the energy sector. It started in February 2011 and will run for 5 years. The aim of the "School of the Future" project is to design, demonstrate, evaluate and communicate shining examples of how to reach the future high performance building level. School buildings and their primary users: pupils – the next generations – are in the focus of the project. Both, the energy and indoor environment performance of 4 demo buildings in 4 European countries and climates will be greatly improved due to holistic retrofit of the building envelope, the service systems, the integration of renewables and building management systems. The results and the accompanying research and dissemination efforts to support other actors dealing with building retrofits will lead to a multiplied impact on other schools and on the residential sector, since the pupils will act as communicators to their families. The user behaviour and the awareness of energy efficiency and indoor environment will be improved due to tailored training sessions.

Zero emission buildings are a main goal in various country roadmaps for 2020. The demonstration buildings within the project may not completely reach this level as the aim of the call is cost efficiency and multiplication potential. The retrofit concepts will, however, result in buildings with far lower energy consumption than in regular retrofits with high indoor environment quality - thus leading the way towards zero emission. They can be considered as schools of the future. Results from national examples of zero emission schools will complete the information used for developing the deliverables such as guidelines, information tools, publications and a community at the EU BUILD UP portal.

The project is based on close connection between demonstration, research and industry represented by the "design advice and evaluation group". The proposal idea was introduced at the E2B association brokerage event with high interest which results in a consortium including well-known partners from the building industry.

TECHNOLOGY SCREENING

This report presents the results of the technology screening carried out in the School of the Future project.

The objective of this work is to develop an overview on the available building and system retrofit technologies for energy efficient school buildings including their impact on the energy performance and indoor environment quality and their economic feasibility. This intended audience for the report are designers and planners of school buildings. The idea is that municipalities all over Europe can use the screening results and can find useful technologies for their specific school buildings. Also the work constitute background knowledge for further work in the project, especially the design guidelines to be developed but also the extension of the information tool.

The results of this work are reported in four individual documents presenting the results for each of the four countries:

1. Denmark – actual document
2. Germany
3. Norway
4. Italy

PARTNERS WITHIN THE 'SCHOOL OF THE FUTURE' PROJECT

Country	Partner
Germany	Fraunhofer Institute for Building Physics (Fraunhofer IBP, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung), Coordinator
	Landeshauptstadt Stuttgart
Italy	ENEA (Agenzia Nazionale Per Le Nuove Tecnologie, L'Energia E Lo Sviluppo Economico Sostenibile)
	Comune di Cesena
	Aldes Spa
Denmark	Cenergia Energy Consultants ApS
	Aalborg Universitet - SBi
	Ballerup Kommune
	Saint-Gobain Isover a/s
	Schneider Electric Building Denmark AS
Norway	Stiftelsen SINTEF
	Drammen Eiendom KF
	Glass og Fasadeforeningen

CONTENT

1. INTRODUCTION

After analysing existing school buildings in the participating countries a school typology based on factors such as year of construction, geometry, utilisation, building and system technologies was developed and reference buildings were set up for the most typical schools in the 4 countries.

A survey of retrofit technologies for improved energy performance and indoor environment quality was made covering the following topics:

- Reduction of heat losses from the building envelope
- Optimal handling of gains
- Heating, ventilation and lighting systems
- Energy supply/generation systems

The identified measures / retrofit technologies were organized according to these headlines and are briefly presented in this report. A more thorough description and guidelines on how to implement them are given in the report: School of the Future Retrofit Guidelines.

The impacts of the different measures have been analysed with calculation and simulation tools for the selected type buildings regarding energy use, indoor environment quality, investment and operational costs. The overall requirement is to maintain high indoor environmental quality meaning that the temperatures are kept within comfort level, the air is exchanged to keep the CO_2-levels down and the light level – a combination of daylight and electrical light is above required standards. The calculations have been carried out for one representative climate in Norway, Germany and Denmark and 3 representative climates in Italy (Turin,Terni and Taranto).

2. SCHOOL BUILDING TYPOLOGIES

2.1. THE THREE TYPOLOGIES IDENTIFIED

School buildings appear in many shapes and sizes with a variety of plan layouts, floors and building materials. Regarding assessment of retrofitting measures, three typical plan layouts are calculated; side corridor, central corridor and compact plan. A fourth typology was also considered: Open plan. However, this typology was not included, because it is quite similar to other school types, except for the partition walls.

Side corridor

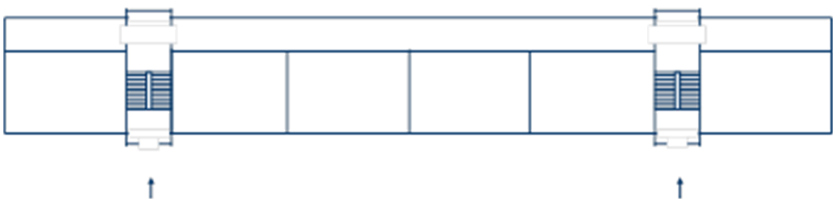


Figure 1: Floor plan of side corridor school. The corridor is located towards north

Classrooms are situated on only one side of a corridor. Thanks to clerestory windows in the corridor wall, daylight is allowed to penetrate the classrooms from two sides, and fresh air is provided by natural cross-ventilation.

The side corridor layout is used in stand-alone buildings and building structures often called comb-shaped. Typical schools have one, two or three floors.

The side corridor school was analysed for all 4 countries.

The areas and window/floor relations are shown in table 1 below.

Table 1: Floor and window area distributions for the side corridor school

Side Corridor	Class-room	Corridor	Total
Floor area	70 %	30 %	
Floor area	2100 m²	900 m²	3000 m²
Window/ Floor-area	25 %	25 %	25 %
N/W/S/E [%]	0/0/70/0	30/0/0/0	30/0/70/0
	N/S	E/W	N° of floors
Façade length	86.5 m	11.5 m	3

Central corridor

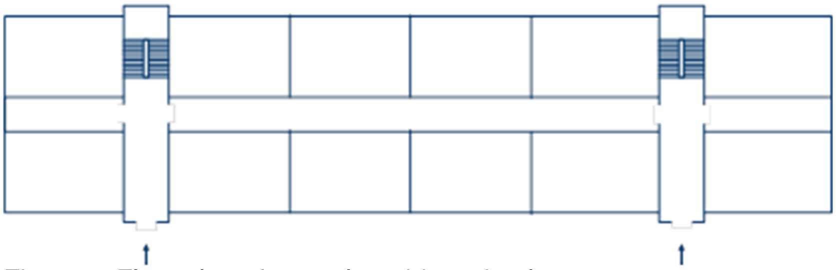


Figure 2: Floor plan of central corridor school

Classrooms are situated on both sides of a corridor. This layout is very economical in terms of circulation area. High classrooms provide daylight and ventilation air volume. Air change is provided by opening windows.

In modern schools the central corridor is wider than the old schools corridor, forming a «street», a common mingling area with meeting places. The street has often roof glazing to provide daylight and can also be used to ventilate the classrooms.

The central corridor layout is used in stand-alone buildings and building structures called comb-shaped. Typical schools have one, two or three floors.

The central corridor school was analysed for Germany and Italy.

The areas and window/floor relations are shown in table 2 below.

Table 2: Floor and window area distributions for the central corridor school

Central Corridor	Class-room	Corridor	Total
Floor area	80 %	20 %	
Floor area	2400 m²	600 m²	3000 m²
Window/ Floor-area	25 %	0 %	20 %
N/W/S/E [%]	50/0/50/0	0/0/0/0	50/0/50/0
	N/S	E/W	N° of floors
Façade length	64.5 m	15.5 m	3

Compact plan

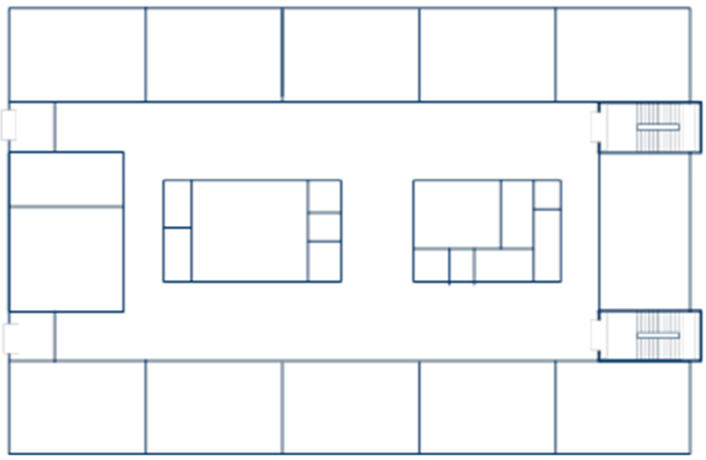


Figure 3: Floor plan of compact plan school

Classrooms are situated around a core area, which might contain an open central hall, or closed spaces as shown in the illustration. The compact plan schools appeared after ventilation systems were introduced to schools.

Typical schools have one or two floors.

The compact plan school was analysed for Denmark, Norway and Italy.

The areas and window/floor relations are shown in table 3 below.

Table 3: Floor and window area distributions for the compact plan school

Compact Plan	Class-room	Corridor	Total
Floor area	60 %	40 %	
Floor area	1800 m²	1200 m²	3000 m²
Window/ Floor-area	25 %	0 %	15 %
N/W/S/E [%]	40/10/40/10	0/0/0/0	40/10/40/10
	N/S	E/W	N° of floors
Façade length	64.8 m	46.3 m	1

3. SURVEY OF ENERGY RENOVATION MEASURES

3.1. REDUCTION OF LOSSES FROM THE BUILDING ENVELOPE

3.1.1. Additional roof insulation

Short description

The thickness of the roof insulation influences the buildings heat exchange with the outside and thereby its heating and/or cooling energy demand.

Depending on the geographical location and age of existing school buildings they will have different thicknesses of roof insulation – from none in Southern Italy to perhaps 200 mm in an already partly renovated school in the Nordic countries. The possibility to add extra layers of insulation will depend on the roof construction – in some situations it is very easy and in other it will require the construction of a new roof. Often thermal bridges can be reduced when roof insulation is added.

Technical characteristics

The thermal transmittance of insulation materials is characterised by their ʎ-values. In Denmark a ʎ-value of 0.037 W/m/K is used as standard for the insulation. To compensate for non-perfect finishing and linear thermal transmittance of envelope connections and floor slabs a ʎ-value of 0.04 W/m/K has been used for the screening. The thicknesses used for each country/location are listed in the country results reports.

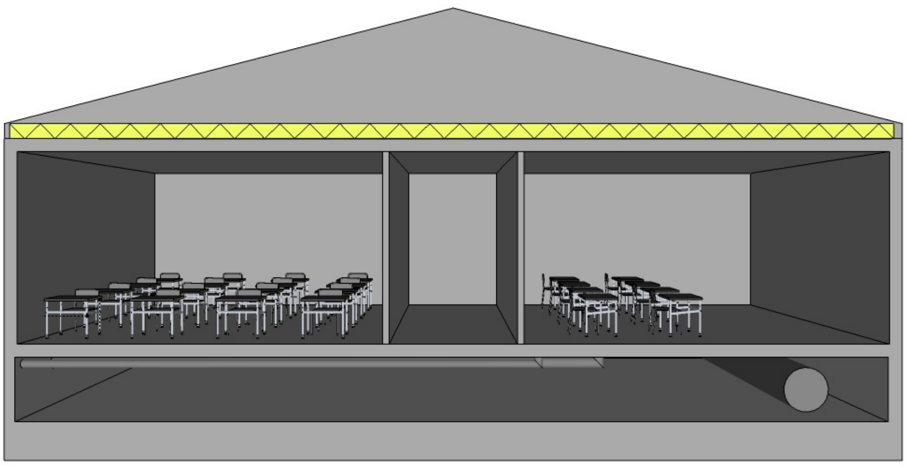


Figure 4: Additional roof insulation in an attic space

Costs – general comments

The costs for the additional roof insulation have been estimated on the basis of an assumption that it will be possible to place an additional amount of insulation directly on a flat ceiling – on top of the existing layer, if any. The costs are in all other ways the complete costs. However the investments costs vary considerably from country to country.

3.1.2. Additional floor insulation towards basement/crawl space/cellar

Short description

The thickness of the floor insulation influences the buildings heat exchange with the outside ground or unheated cellar and thereby its heating and/or cooling energy demand.

Depending on the geographical location and age of existing school buildings they will have different thicknesses of floor insulation – often it is zero. The possibility to add extra layers of insulation will depend on the floor construction. In this analysis only simple situations where insulation can be added from underneath are considered.

Technical characteristics

The thermal transmittance of insulation materials is characterised by their ʎ-values. In Denmark a ʎ-value of 0.037 W/m/K is used as standard for the insulation. To compensate for non-perfect finishing and linear thermal transmittance of envelope connections a ʎ -value of 0.04 W/m/K has been used for the screening. The thicknesses used for each country/location are listed in the country results reports.

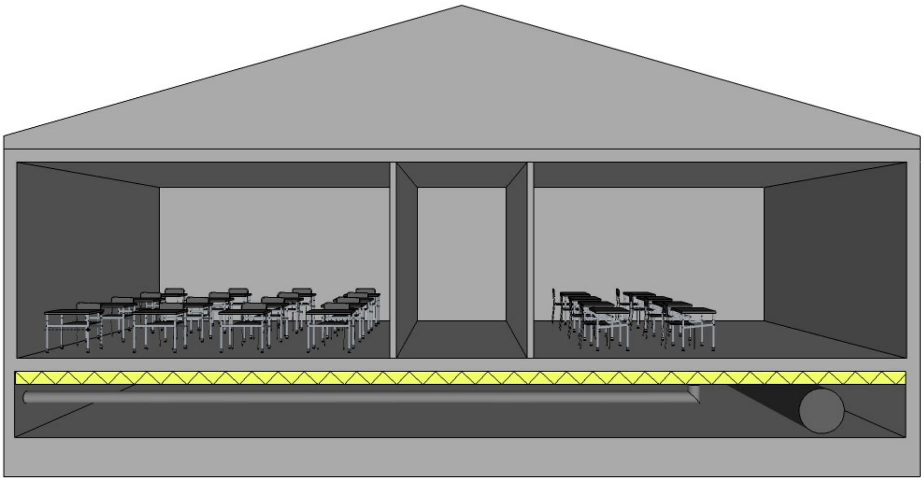


Figure 5: Additional floor insulation in a crawl space

Costs – general comments

The costs for the additional floor insulation have been estimated on the basis of an assumption that there will be enough space in the basement or crawl space for the installer to work safely under the floor. The costs are in all other ways the complete costs. However the investments costs vary considerably from country to country.

3.1.3. Exterior wall insulation

Short description

The thickness of the wall insulation influences on the buildings heat exchange with the outside and thereby its heating and/or cooling energy demand.

Depending on the geographical location and age of existing school buildings they will have different thicknesses of wall insulation – from none to 100 mm for the references analysed. An extra layer of insulation may be added on the inside or on the outside, the latter being more efficient, but generally also more costly. The inside insulation is however reducing the available floor area.

Technical characteristics

Additional wall insulation can be one of many different types. The thermal transmittance of insulation materials are characterised by their ʎ-values. In Denmark a ʎ-value of 0.037 W/m/K is used as standard for the insulation. To compensate for non-perfect finishing and linear thermal transmittance of envelope connections and floor slabs a ʎ-value of 0.04 W/m/K has been used for the screening. The thicknesses used for each country/location are listed in the country results reports. When considering using insulation with another ʎ-values be careful to look-up the results for a thickness and cost that matches.

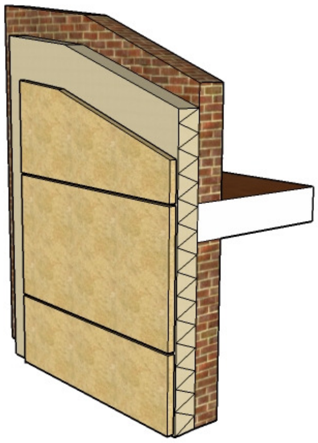


Figure 6: Wall insulation added on the outside of an existing external wall

Costs – general comments

The costs for the additional wall insulation have been estimated on the basis of an assumption that there will be a scaffold present, which has been put up for other purposes. The costs are in all other ways the complete costs including some sort of external cladding.

3.1.4. Window replacement

Short description

Windows have undergone a strong development over the last years. Both the frames and the glazing have improved considerably. When old windows need to be replaced it is obviously a good idea to look for a replacement which constitutes the best long term investment. Choosing a low-e-coated double or triple glazed window will often be the best choice.

Technical characteristics

For the screening calculations windows are characterized by three parameters: heat loss, solar energy gain, and light transmittance. These are referred to as the thermal transmission coefficient (U-value, in W/m²K), the solar energy gain coefficient (or the solar energy transmittance) (g-value) and the visible light transmittance, τ. One window might for example have a relatively high τ and relatively low g-value, which can be an advantage when the internal heat gains are high like in offices and schools as it contributes to prevent overheating.

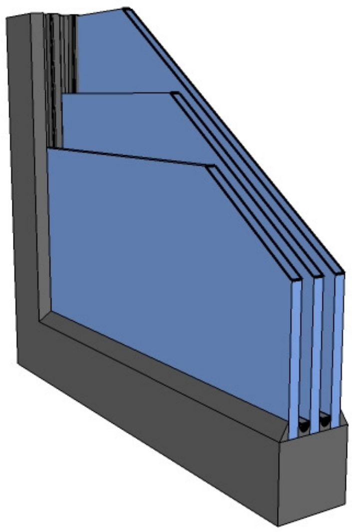


Figure 7: Triple-glazed low-energy window

Costs – general comments

The costs for the window replacement have been estimated on the basis of an assumption that there will be a scaffold present, which has been put up for other purposes. The costs are in all other ways the complete costs and if the window replacement is an anyway measure the overall costs have to be reduced correspondingly.

3.2. OPTIMAL HANDLING OF GAINS

3.2.1. Reduction of overheating/preventing cooling demand

3.2.1.1. Solar control glazing

Solar control in the glass is good because it always works even with diffuse radiation. However, the need for low g-value (total solar energy transmission) cannot be considered separately as it is linked to the light transmission.

A glass package may let in light/heat in the relationship 2/1. This means that the solar control glass lets in for example 70 % light and 35 % of the heating energy (g-value 0.35). A description code 70/35 is used for this type of glass pane.

In some countries the building regulation says that the g-factor should be max 0.15 if there is a cooling system in the building (e.g. Norway BR 2010). This is quite a strong requirement, see table 3 showing light transmission, the U-value and the g-value for 9 different glass panes.

Table 3: Solar control glass

Description code	Double	Triple	Light trans. τ	U-value	g-value
70/35	x		70	1.0	0.35
70/35		x	65	0.8	0.35
70/35		x	63	0.6	0.34
50/25	x		50	1.0	0.27
50/25		x	46	0.8	0.25
50/25		x	45	0.6	0.24
30/17	x		30	1.1	0.19
30/17		x	28	0.8	0.17
30/17		x	26	0.5	0.15

Choosing glass with low g-values automatically leads to lower visible daylight transmission (τ).

3.2.2. Controls: Building Energy Management System (BEMS)

Short description

Schools are subject to quick changes in internal gains; a class room goes from 0 to 32 inhabitants in a matter of seconds. Additionally thermal gains are present from electrical lighting, computers and other equipment and finally the sun can provide large passive solar gains. Most Northern and Central European countries have installed thermostat controllers to prevent the heating system from continuing to heat when internal temperatures have reached the comfort zone, but this is not yet common in Italy.

A building energy management system (BEMS) may be used for several purposes, but energy-wise a BEMS system can reduce heating distribution system losses, e.g. by closing down the system, when there is no heating need or reducing the temperatures in the distribution system to what is precisely required. Besides it can provide a continuous overview of the state of the system and thereby contribute to locating any malfunctioning. As the initial case for Norway is a school heated with electrical heaters a BEMS system cannot be analyses as an individual measure for Norway.

Technical characteristics

For the BEMS system a simple assumption of its ability to cut down on distribution losses has been used in the calculation tool. For Denmark the reduction is assumed to be 50%.

Costs – general comments

The costs for installing a BEMS system are based on experiences in the countries.

3.3. HEATING, COOLING, VENTILATION AND LIGHTING SYSTEMS

3.3.1. Ventilation

Short description

In Italy, Germany and Denmark natural ventilation systems are used as the reference. In Norway it is a mechanical exhaust air system. With the current trend to improve the air quality in working environments – here particularly in schools – comes a need for considerably higher ventilation rates than before. Without changing the ventilation system this will result in higher thermal losses and thus higher heating needs/bills. A balanced mechanical ventilation system with heat recovery of the exhaust air (MVHR) may improve this situation strongly. However, this requires that the buildings become more airtight and a good efficiency of the ventilation systems with respect to heat recovery and electricity consumption for the fans. Even when installing a new good MVHR system the heating requirements may increase, because the ventilation rates will be higher than before the renovation. This will influence on the economic calculations.

Technical characteristics

In the calculation for Denmark two MVHR systems have been analysed – one with average efficiency and one with high efficiency. Besides calculations has been performed for a balanced system without heat recovery and an exhaust air system with and without a heat pump. The details can be found in the country result reports and the appendix with the detailed data.

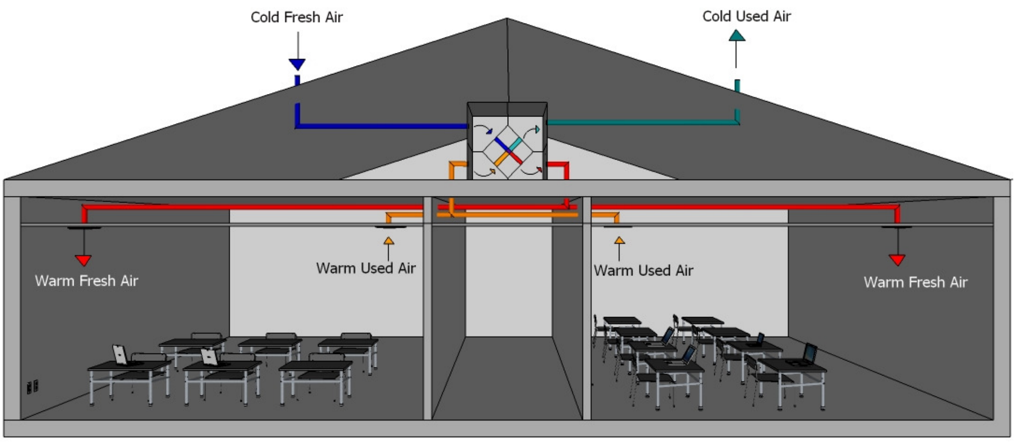


Figure 8: Schematic of mechanical ventilation system with heat recovery (MVHR).

Costs – general comments

The costs for the installation of a MVHR system have been estimated based on available statistics and experiences of the project partners.

3.3.2. Electrical lighting systems with controls

Short description

Energy consumed by the electrical lighting system can be saved by installing better light emitting technology, better control systems (occupancy and daylight dependent dimming) and a possibility for a control of the light depending on the location within the room – near the windows or far from the windows – so-called zoning. Often this is done as one package because the marginal costs for including the control and zoning is rather limited when a new lighting system is installed. In the calculations a complete package is therefore analysed.

Technical characteristics

The efficient lighting systems considered are new light tubes – T5, compact fluorescent light (CFL) and light emitting diodes (LED) lamps. Two different controls have been calculated: manual and continuous dimming and 2 zones instead one in the reference case have been analysed.

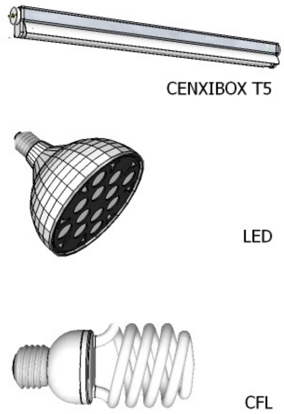


Figure 9: Three types of energy efficient electrical lighting lamps

Costs – general comments

The costs are based on national statistics and experiences. Details are given in each national results chapter.

3.4. ENERGY SUPPLY/GENERATION SYSTEMS

3.4.1. Integration of PV in the built environment

Short description

The integration of photovoltaic cells (PV) in the built environment has become quite common in many European countries – often thanks to a favourable feed-in tariff. The cells produce electricity from the energy of the solar rays that reach them. They have no moving parts and are generally very reliable with a long life-time (more than 25 years). Parts of the system are so-called inverters that transform the electrical output from the cells in the form of direct current (DC) to alternating current (AC) as commonly used. The inverters have a shorter lifetime and replacement of these has to be taken into account.

Technical characteristics

The solar cells produce electricity at varying efficiencies depending primarily of the type of cells used. For the screening we have chosen to consider amorphous, polycrystalline and monocrystalline cells (for Italy only the two first types), but the efficiency/cost relationship do not differ much, so the results can be transferred to other types of cells. A PV system can be either grid connected or independent (partly including a battery). However, most common are the grid connected systems as the battery storage systems are still very costly.

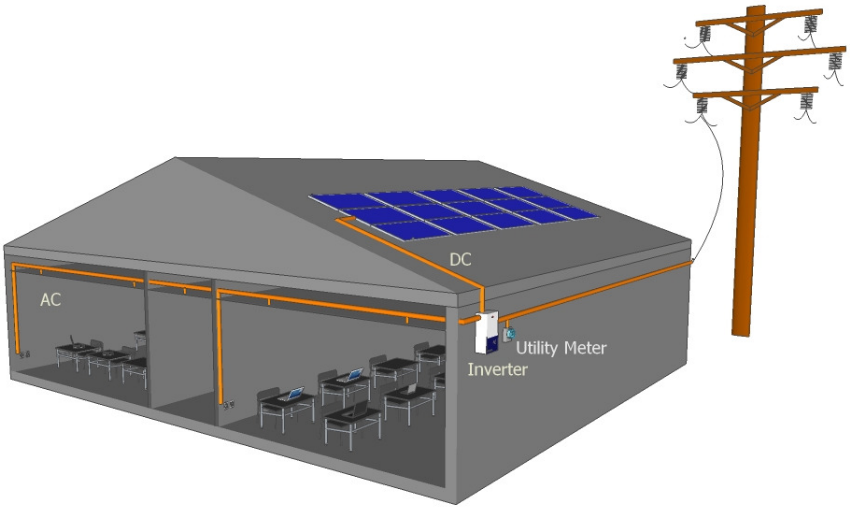


Figure 10: Grid connected PV-system

Costs – general comments

The costs for the installation of PV on the roof of the school building has been estimated on the basis of an assumption that there will be a scaffold present, which has been put up for other purposes. The costs are in all other ways the complete costs.

3.4.2. Solar DHW systems

Short description

Solar thermal systems are commonly used on private homes as solar domestic hot water (DHW) and in some countries very large solar thermal collector arrays are connected to district heating systems and large storages that provide partly seasonal storage. For schools it is often argued that the buildings are not in use for the time of the year where the output of a thermal system is at its highest and that the hot water consumption is relatively small. For the screening it was decided only to consider schools with a gym which means a higher hot water consumption for showers and therefore the solar thermal systems may be economically viable.

Technical characteristics

Solar thermal systems have not been analysed for Germany and Norway. In Denmark 2 system sizes were judged reasonable for a 3000 m² school has been analysed: 13 m² and 20 m² collector area. In Italy the area analysed are: 6, 8 and 10 m² for Terni and Turin and 4, 6 and 8 m² for Taranto.

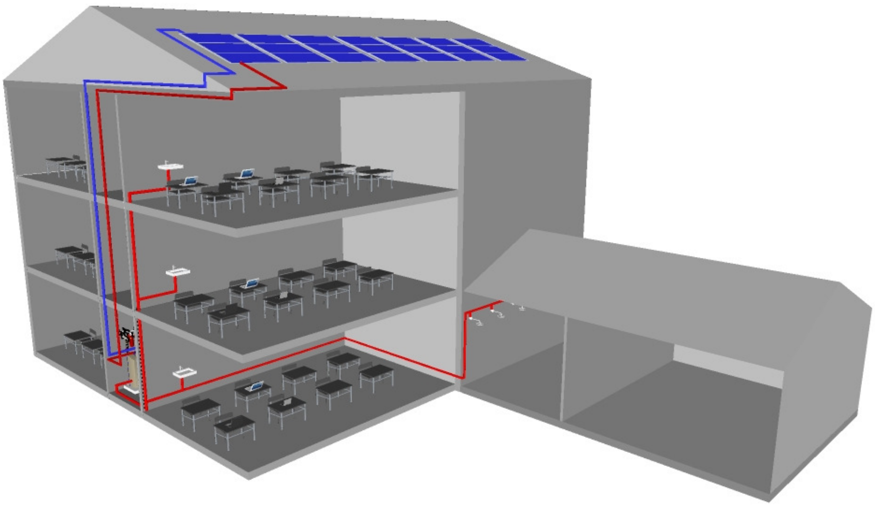


Figure 11: Thermal solar system for heating of hot water

Costs – general comments

The costs for the mounting of the solar collectors have been estimated on the basis of an assumption that there will be a scaffold present, which has been put up for other purposes. The costs are in all other ways the complete costs.

3.4.3. Heat supply

Short description

For the analyses it has been assumed that the reference buildings in Denmark, Germany and Italy have heating supply from an old gas boiler. In Norway the reference building was heated by electrical heating. The different possibilities to improve and replace the reference system analysed in the 4 countries are shown in table 4.

Table 4: Overview of reference heating supply and screened new systems in the 4 countries

Heat supply systems	Denmark	Norway	Germany	Italy
Old gas boiler	Reference		Reference	Reference
Electrical heating		Reference		
New high efficiency gas boiler	Analysed	Analysed	Analysed	
New condensing gas boiler	Analysed		Analysed	Analysed
District heating system	Analysed	Analysed	Analysed	Analysed
Electrical heat pump	Analysed	Analysed	Analysed	

Technical characteristics

The technical characteristics of each of the above replacement technologies are primarily efficiencies which represent the best available technologies today and which can be found in the data sheets for these technologies. For the heat pump a yearly COP of 3.2 was used.

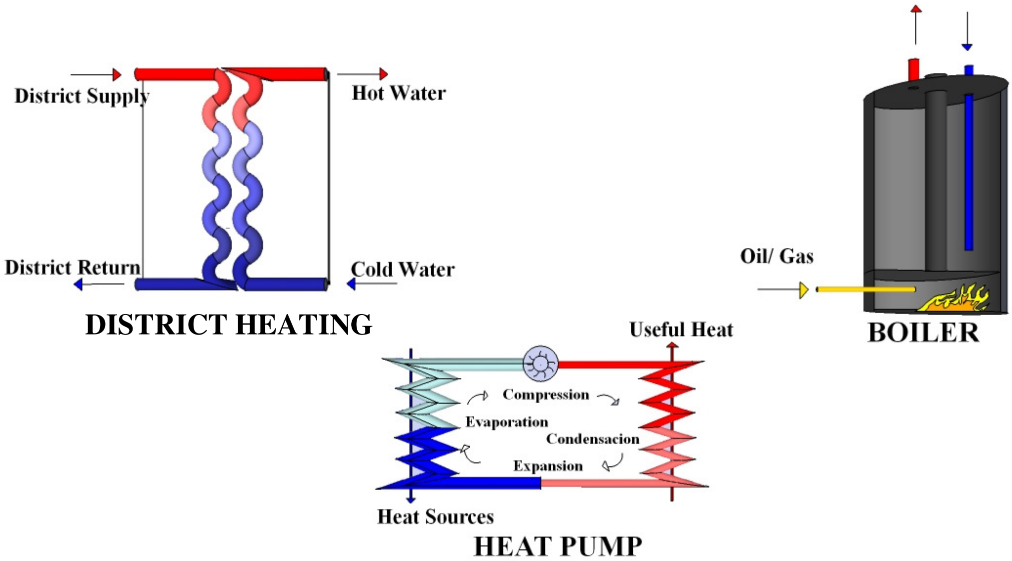


Figure 12: Three different types of heating supply systems

Costs – general comments

The costs of these technologies vary quite a lot from country to country and the costs used for each country are listed in the country results reports. One of the differences was that for some countries it was assumed that the existing distribution system could be re-used when installing a heat-pump (i.e. Denmark) and in another a new distribution system was considered necessary (i.e. Germany).

3.5. PACKAGES OF MEASURES

After completing the screening of the individual measures packages of measures were created to investigate the overall potential for energy saving and reduction emissions.

The packages were created by choosing the measures with the highest net present value as the primary criteria.

If the package don't have a positive NPV another example of energy renovation package with a positive NPV is created and investigated for energy savings and reduction of emission. In the package, only the technologies with a positive NPV are chosen to ensure a positive NPV for the whole package.

4. CALCULATION AND SIMULATION PROGRAMS USED FOR THE SCREENING

4.1. THE ENERGY CALCULATION TOOL – ASCOT

All the calculations of energy savings – and corresponding reduced CO_2-emissions – were carried out using the calculation program ASCOT: Assessment tool for additional construction cost in sustainable building renovation.

The purpose of the ASCOT tool is to assist the user in evaluating and thereby optimise the costs of a building renovation project in relation to sustainable development issues.

The tool is based on earlier development work in various EU- and national (DK) projects.

The tool is designed to take into consideration:

- all investment and operation costs over the total lifetime of the building
- the savings from the investments with respect to sustainable issues (Heat, electricity, water) over the total lifespan of the building
- the reduced environmental impact from the energy savings

The ASCOT model allows a comparison between a reference building and different sustainable concepts for the renovation of the building. This comparison will take into account usage savings during the total lifetime of the building and the frequency of future replacing of building components and systems. The tool is primarily intended for use in the early stage of the design process. It can be used for both new constructions and renovation projects.

The ASCOT tool can be used to define sustainability categories and to classify buildings according to these categories based on the calculated reduced environmental impacts.

The ASCOT tool is characterised by a simple structure that is very flexible to future changes and upgrading. Its use and results are easy to understand - enabling a steep learning curve.

The ASCOT tool calculations are based on international standards for energy calculation: *Thermal performance of buildings – Calculation of energy use for space heating and cooling* [4]; *Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies* [5] – (Part 2.2.6 and Part 4-3).

4.2. INDOOR ENVIRONMENT SIMULATIONS

The indoor environmental simulations were done with the simulation program VE-Pro. For the simulation of natural ventilation the tool MacroFlo was used, which is able to calculate natural ventilation and effects from wind turbulence on air exchange, considering special features like the aspect ratio and sash type of the opening. It is essential to get realistic results for the air change rate, as for most calculated reference scenarios natural pulse ventilation is used for the ventilation of the classrooms,. Both air quality and indoor temperature are affected by this issue and indoor temperature in return has also an effect on the possible air change rate due to thermal effects

The calculations were done in 1 minute steps to achieve realistic results for natural and especially natural pulse ventilation. The results are derived from 6 minute averages of the calculation.

Under this supposition, the surface temperatures and draught risk near windows were for simplification calculated afterwards from simulation results with the following formulas **Fejl! Henvisningskilde ikke fundet.**

$$\theta_{si} = \theta_i - \frac{U(\theta_i - \theta_e)}{h_{si}}$$

with:

Θ_i external air temperature in °C

Θ_{si} external air temperature in °C

U thermal transmittance coefficient in W/m²K

h_{si} heat transfer coefficient on the inner surface in W/m²K (= 7.7 W/m²K)

$$v_{max} = \frac{0{,}143}{x + 1{,}32}\sqrt{\Delta\theta H}$$

with:

v_{max} maximum speed in m/s

x distance form wall or window in m (= 0.5 m)

H height of wall or window in m

ΔΘ difference of inner surface and inner air temperature in K

5. ASSUMPTIONS AND PRESENTION OF RESULTS

5.1. ASSUMPTIONS FOR THE CALCULATIONS

To be able to carry out the screening a large number of data for the calculations had to be fixed. This data are technical specifications for each measure and the costs associated with the installation/implementation of each measure. The technical specifications are generally well known, but as a measure most often can be implemented using one out of a large number of different products the specifications had to be selected/assumed for each measure.

The costs specifications are much more difficult as it is generally experienced that costs for the same building task may differ quite a lot from case to case. However, for each country the cost of each measure have been established based on available statistics and experiences. In all situations the costs assumed include all costs to establish the measure in question, but not any additional costs, such as for example costs for scaffolding. This choice was made for simplicity as the measures often are implemented together – for example external wall insulation and replacement of windows and secondly because energy renovation often are carried out at the same time as other building renovation measures are made.

Tables with all technical specifications and costs are included as an Appendix to each screening report.

In contrary to energy and costs, where the calculations were done for a whole building with indoor environment simulations only one typical room was used for each country in different orientations (north and south). It is assumed, that the room has only one external surface and there is no heat transfer to the adjacent rooms. This approach covers most rooms of the presented school typologies (chapter 2). Rooms directly below the roof or corner rooms may have more serious problems with indoor climate, for example with overheating. This influence was not covered by the simulations, but the fundamental effect of the single measures is transferable.

5.2. THE PRESENTATION OF RESULTS

For each energy renovation measure the results of the energy calculation screening are presented on 4 plots showing:

- Simple payback & physical lifetime,
- Net present value & investment,
- CO_2-reduction
- Saved energy – heating, electricity and total primary

Most people relate easily to the simple payback time which is the amount of years it takes before the economic savings balance the investment. Obviously, this should be shorter than the physical lifetime of the measure.

The net present value (NPV) is calculated as the sum of the present value of all future savings for a chosen number of years (25 years was chosen for this work) minus the investments costs. A positive value indicates that this investment is sound. It is interesting to compare the NPV to the investment as this provides a measure of "size of scale".

The reduction of CO_2-emissions is of interest with respect to the Global Warming situation.

Finally, the saved energy presented as saved heating, electricity and total primary energy consumptions can be directly related to the energy consumption of the reference case. The primary energy is calculated using the established factors used in each country. In Norway a political decision has not been made concerning this issue for the electrical energy distribution and therefore the primary energy factors for Denmark have been used for Norway.

The results of the indoor environment calculations are presented as plots showing:

- Surface temperatures on the North facing external wall in winter
- Surface temperatures on the North facing windows in winter
- Cold air drop next to North facing windows in winter
- Mean radiant temperatures in winter
- Dry resultants temperatures in summer (south facing rooms)
- Carbon dioxide level in winter

The results are presented in the two separate chapters following the references. Finally follows an appendix with an overview table of the technical and cost data used for the simulations.

6. REFERENCES

[1] Glass og Fasadeforningen: "Background Equations for U-Value and downdraught tool", 01/2013, Available at www.glassportal.no.

[2] Energy saving and cost optimisation tool: ASCOT available from cenergia@cenergia.dk.

[3] Indoor environment simulation tool: IES VE, Available at www.iesve.com/software/download-centre.

[4] ISO/DIS 13790:2004; Thermal performance of buildings – Calculation of energy use for space heating and cooling.

[5] CEN/TC 228:2004; Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – (Part 2.2.6: The performance of other renewables heat and electricity and Part 4-3: Heating generation systems, thermal solar systems).

7. RESULTS OF THE ENERGY CALCULATIONS FOR DENMARK

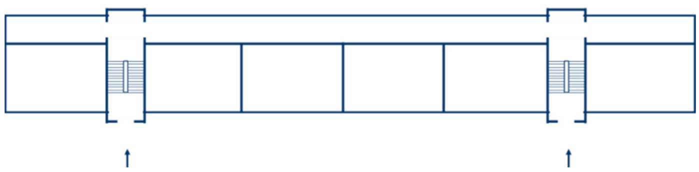
7.1. SIDE CORRIDOR

Economic parameters

Discount rate	5.0%
Tax of interest income	0.0%
Inflation on energy costs	4.5%
Inflation on maintenance costs	3.0%
Expected economic lifetime	25

School typology

Side corridor



Side Corridor	Class-room	Corridor	Total
Floor area	70 %	30 %	
Floor area	2100 m²	900 m²	3000 m²
Window/ Floor-area	25 %	25 %	25 %
N/W/S/E [%]	0/0/70/0	30/0/0/0	30/0/70/0
	N/S	E/W	N° of floors
Façade length	86.5 m	11.5 m	3

Reference building

The school typology side corridor is investigated for 1950's, where it is assumed that there is poor insulation in the walls and the construction is medium heavy.

There is natural ventilation and no cooling. The basement is not heated.

The heat supply is an older gas boiler, the hot water use is for a school with gym, and radiators with thermostats are used to heat the building. There is no building energy management system (BEMS) installed.

The period of usage is 201 days a year and from 8 am to 5 pm.

The reference building uses 206.5 kWh/m^2 per year of heating and 21.0 kWh/m^2 per year of electricity (including electrical light, pumps and fans).

Denmark	Electricity	District Heating	Oil	Gas
CO_2 Conversion factor [kg/kWh]	0,343	0,113	0,279	0,202
Primary energy factor	2,5	1	1	1

The primary energy use of the reference building is 206.5 kWh/m^2 per year for heating and 52.5 kWh/m^2 per year for electricity. The total primary energy consumption for the building is 259.0 kWh/m^{2}per year.

Existing lighting

The installed power of the existing lighting from 1970 is set to 14 W/m^2 (source: http://www.sbi.dk/indeklima/lys/lyset-i-skolen/renovering-med-enkle-midler-tingbjerg-skole)
It is assumed that the classrooms are in use 90 % of the time.
The light transmittance is set to 75 %.

Ventilation

The classrooms are each assumed to be 60 m^2 and used by 30 persons. This requires a ventilation rate of $2.2\ l/sm^2$ to comply with category 2 of *DS/EN 15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. The natural ventilation in the reference school is also assumed to fulfill the requirement of $q_{tot} = 2.2\ l/sm^2$.
When using natural ventilation or only mechanical exhaust air, the infiltration is a part of the ventilation rate ($2.2\ l/sm^2$) and when ventilating with a mechanical balanced system the infiltration is beside the ventilation rate. Balanced mechanical ventilation with heat recovery (MVHR) is screened with an average and a good efficiency.
The heating energy consumption of the reference school is slightly higher than the average heating consumption of Danish schools, also because the ventilation rate is set to fulfill the optimised hygienic recommendations.

Screened technologies:

Screened technologies	**Data**

Solar thermal heating	Production [kWh/(m$^2_{floor}$)]
Starting point: none	0.0
13 m^2	2.5
20 m^2	3.8

Photovoltaics (120 m^2)	Max effect [kWpeak]
Starting point: none	0.0
Amorpheus	7.7
Polycrystalline	12.9
Monocrystalline	14.4

Extra external wall insulation	Resulting U_{Wall} [W/m²K]
Starting point:	0.57
+ 150 mm	0.17
+ 200 mm	0.14
+ 250 mm	0.12
+ 300 mm	0.10

Extra floor insulation	Resulting U_{Floor} [W/m²K]
Starting point:	0.40
+ 50 mm	0.26
+ 100 mm	0.19
+ 150 mm	0.15
+ 200 mm	0.13
+ 250 mm	0.11
+ 300 mm	0.09

Extra roof insulation	Resulting U_{Roof} [W/m²K]
Starting point:	0.40
+ 100 mm	0.19
+ 150 mm	0.15
+ 200 mm	0.13
+ 250 mm	0.11
+ 300 mm	0.09

Windows	Resulting U_{Window} [W/m²K]
Starting point: Double glazed	3.1
Double glazed (low-e-coated)	1.2
Triple glazed (low-e-coated)	0.7

Ventilation system	SEL [kJ/m³]	Efficiency [%]	COP [-]	Airtightness (50 Pa) [l/sm²]
Starting point: Natural ventilation				4.0
Mechanical exhaust air	1.5			0.6
Mechanical exhaust air with heat pump	1.5		3.2	0.6
Balanced mechanical ventilation	2.3			0.6
Mechanical vent. with average system efficiency	1.5	75		0.6
Mechanical vent. with good system efficiency	1.2	90		0.6

Heat supply	Efficiency [-]	COP [-]
Starting point: Gas: old boiler	0.75	
Gas: new boiler with high efficiency	0.83	
Gas: new boiler condensing	1.02	
District heating	1.0	
Heat pump		3.2

Illuminance and control	Max power [W/m²]	Min power [W/m²]	Max lightlevel [Lx]	Min lightlevel [Lx]
Starting point: Censibox T8	14.0	0.0	200	0
Censibox T5	4.0	0.8	216	43
Downlights (Compact Fluorescent Lamps)	6.0	0.3	300	21
LED	3.4	0.3	207	21
Control	Sensetivity: [Lux above required lightlevel]		Zones	
Starting point: Manual control	200		1	
Automatic control	100		2	
Continuous automatic dimming control	50		2	

BEMS – Building energy management system	Reduction of energy loss [%]
Starting point: No control	0
Installed	50

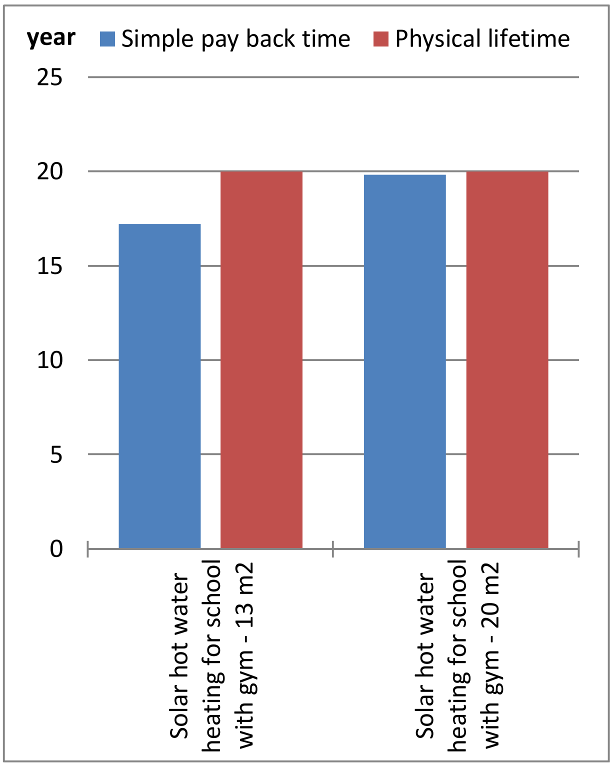
Total energy renovation package	**Chosen technologies**
Solar thermal heating	13 m²
Photovoltaics (120 m²)	Monocrystalline
Extra external wall insulation	+ 200 mm
Extra floor insulation	+ 200 mm
Extra roof insulation	+ 250 mm
Windows	Double glazed (low-e-coated)
Ventilation system	Mechanical vent. with good system efficiency
Heat supply	District heating
Illuminance	Downlights (Compact Fluorescent Lamps)
Control	Continuous automatic dimming control
BEMS – Building energy management system	Installed

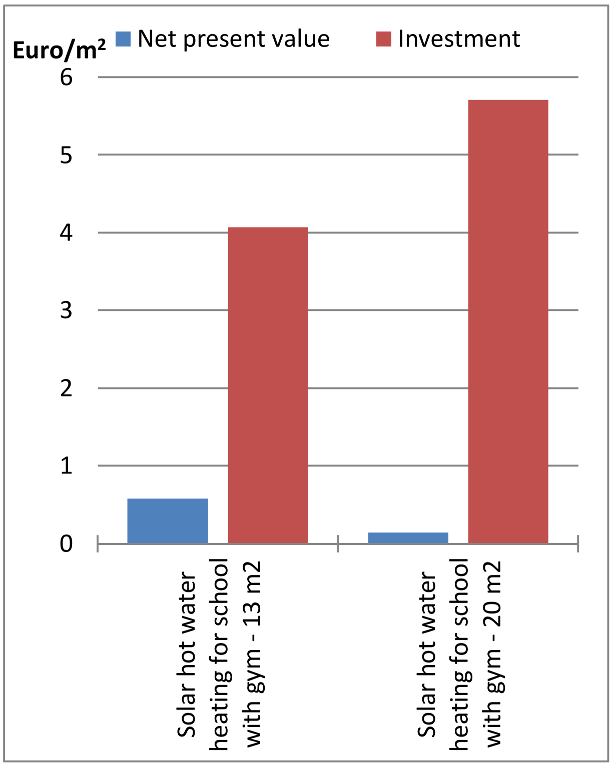
Graph of results:

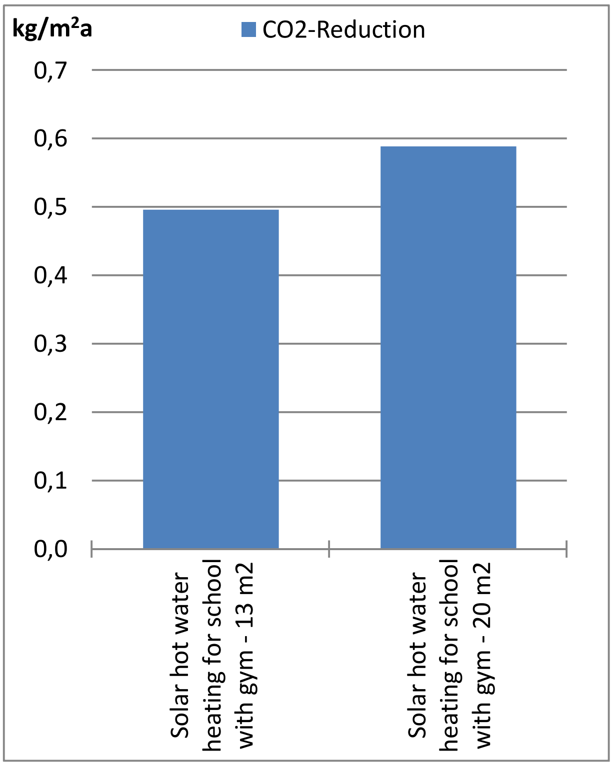
Solar Heating – [Starting point: none]

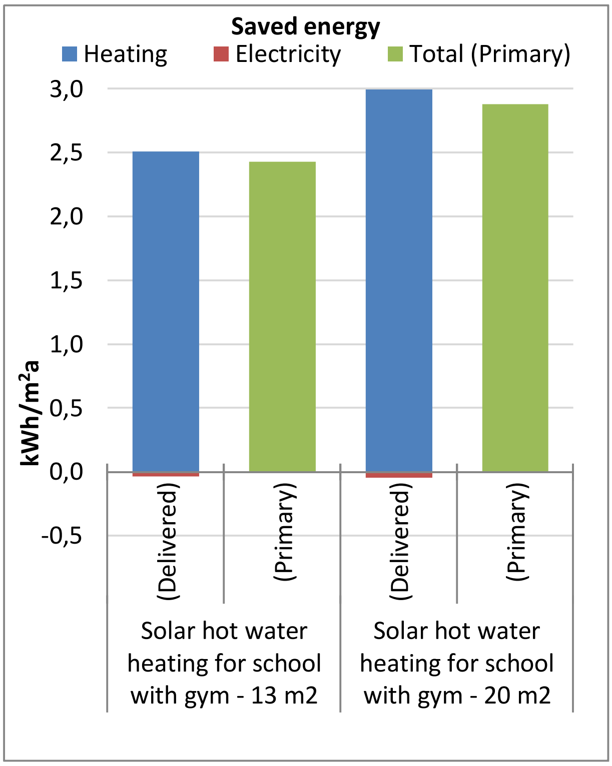
- 13 m² / 20 m²

Low NPV due to the high investment cost.





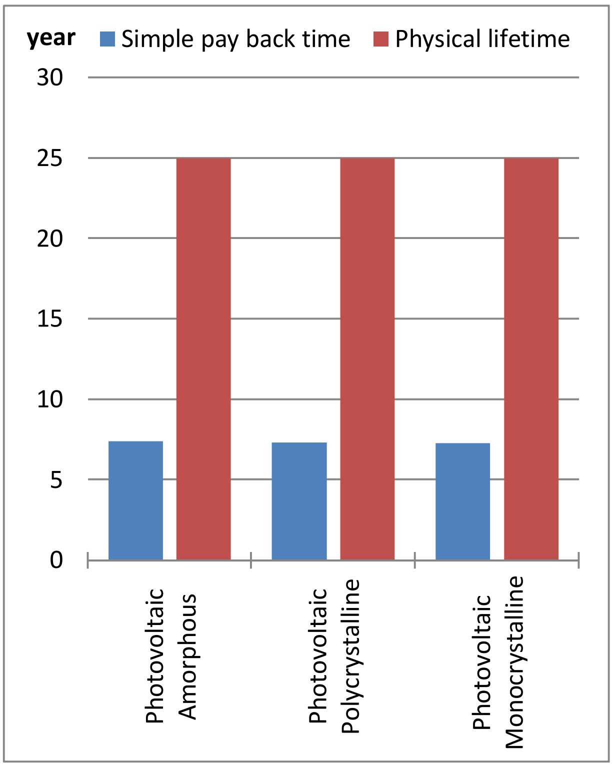


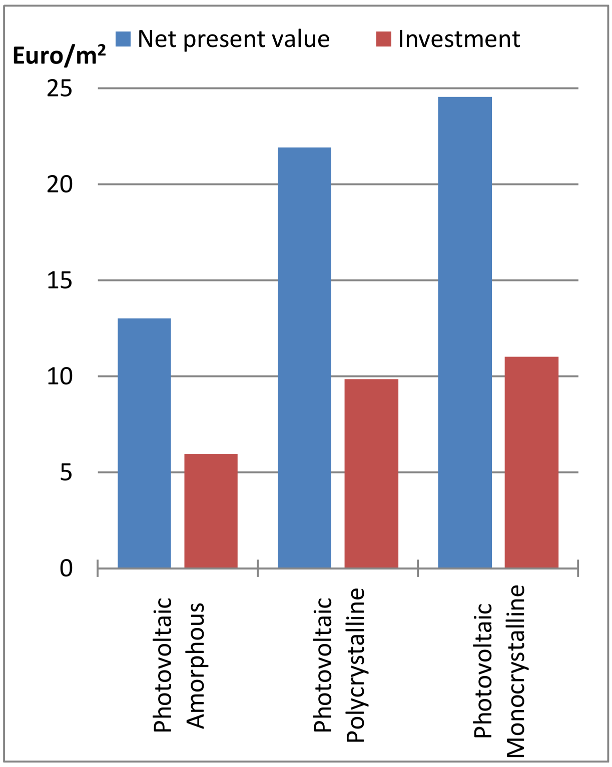


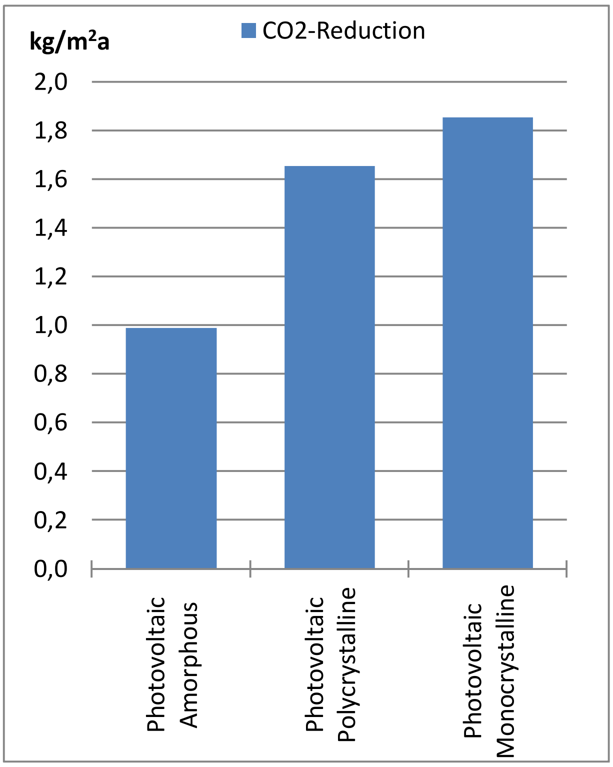
Photovoltaics – 120 m^2– [Starting point: none]

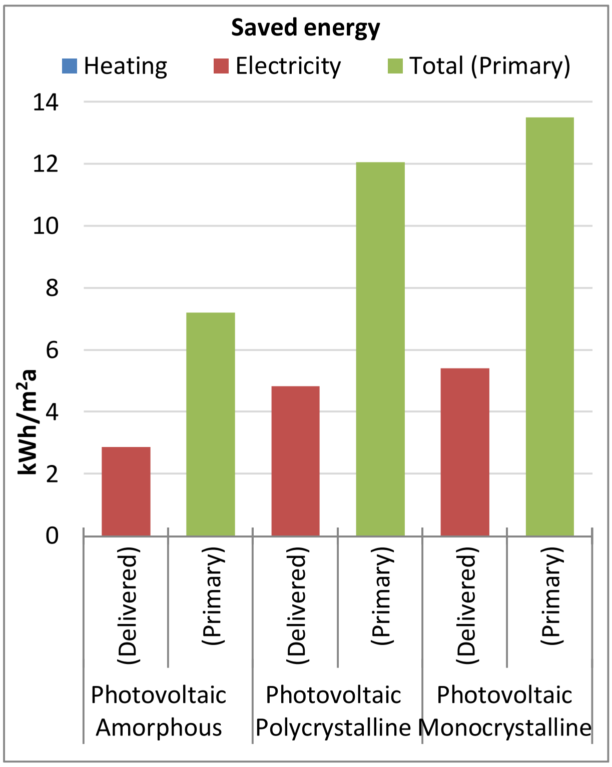
- Amorpheus (kW$_{peak}$=7.7) / Polycrystalline (kW$_{peak}$=12.9) / Monocrystalline (kW$_{peak}$=14.4)

The higher the investment is the higher is the NPV, due to the increase of energy saving. The NPV is high compared to the investment and the payback time is low compared to life time.





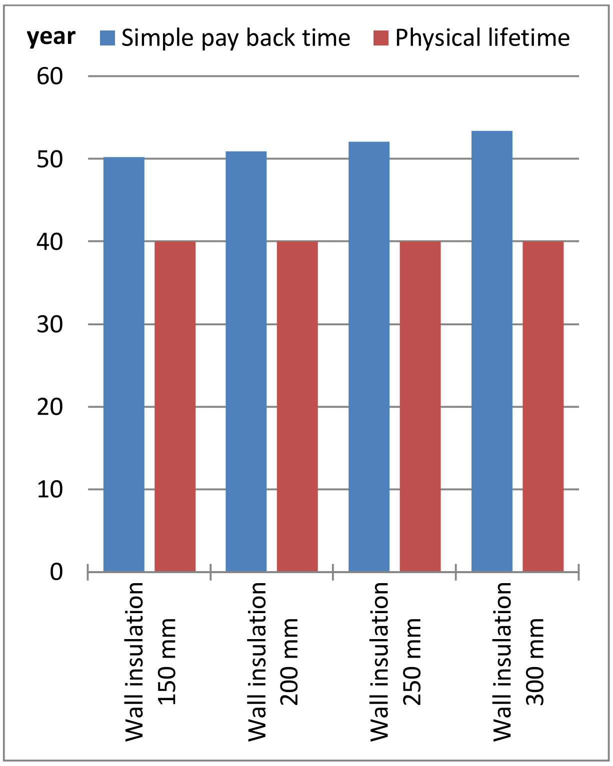


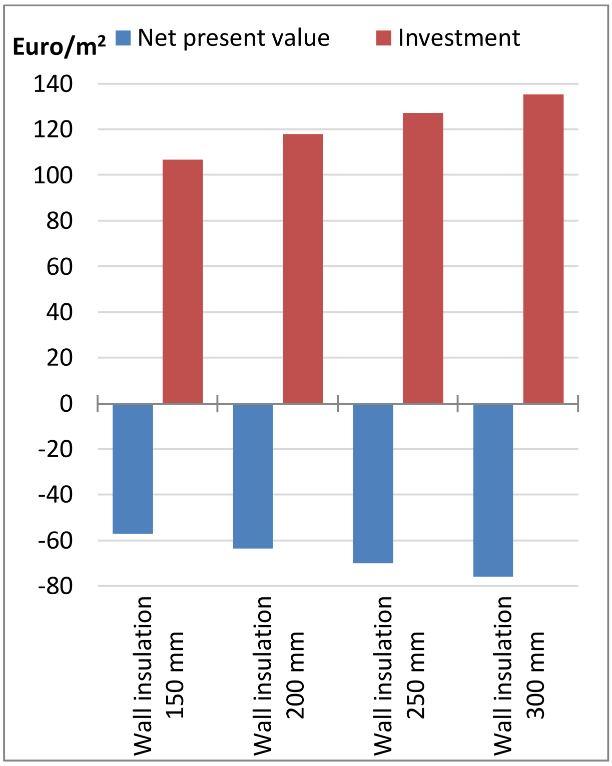


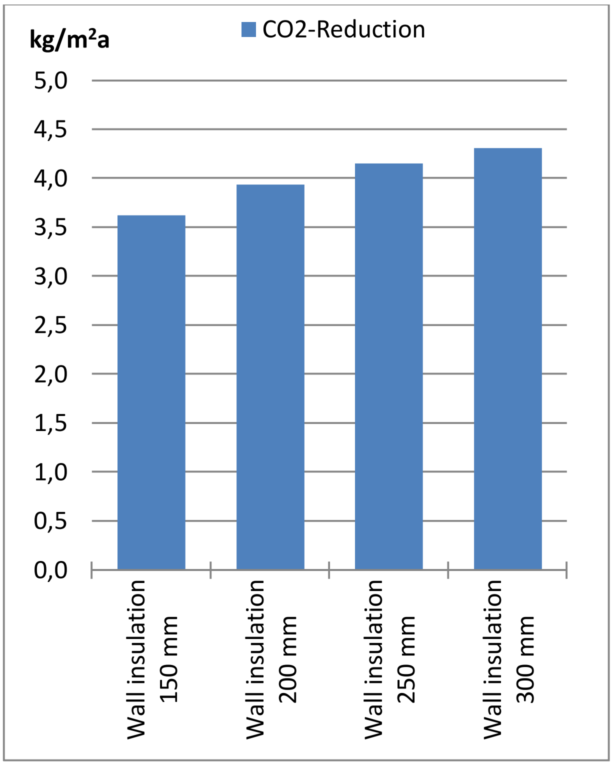
Extra wall insulation – [Starting point: U-value = 0.57 W/m²K]

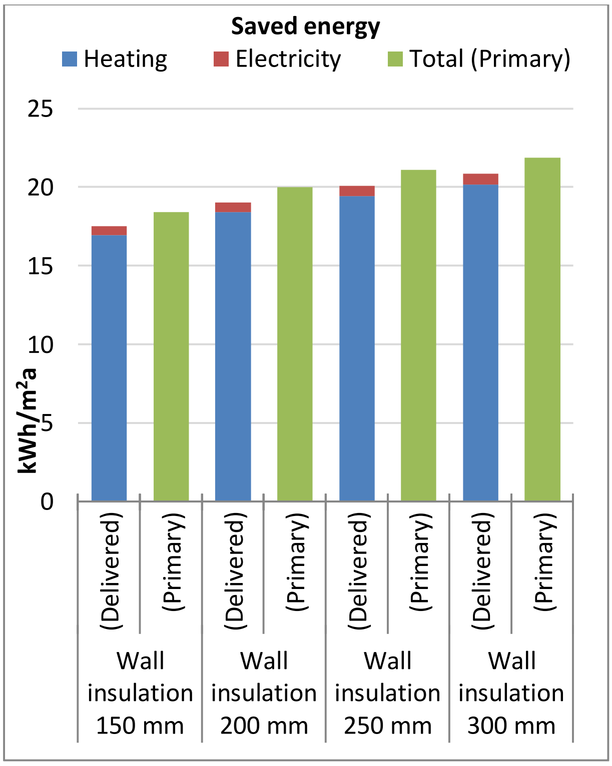
- 150 mm (U_{Wall} = 0.17 W/m^{2}K) / 200 mm (U_{Wall} = 0.14 W/m^{2}K) / 250 mm (U_{Wall} = 0.12 W/m^{2}K) / 300 mm (U_{Wall} = 0.10 W/m^{2}K)

Extra wall insulation has a high investment and mainly therefore the NPV is negative despite the energy savings. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system.





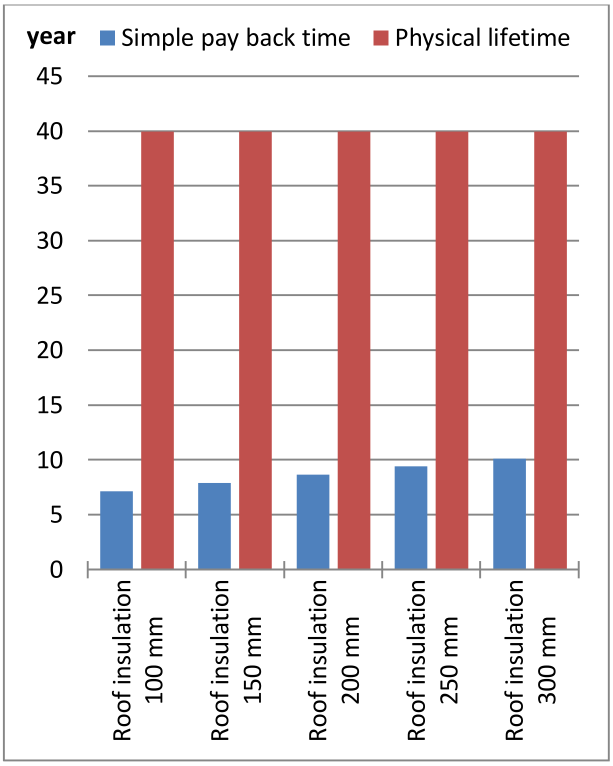


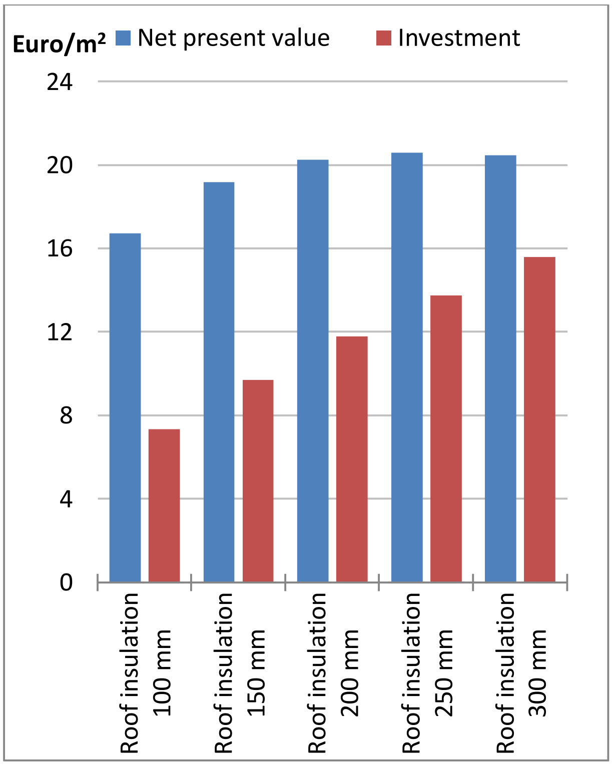


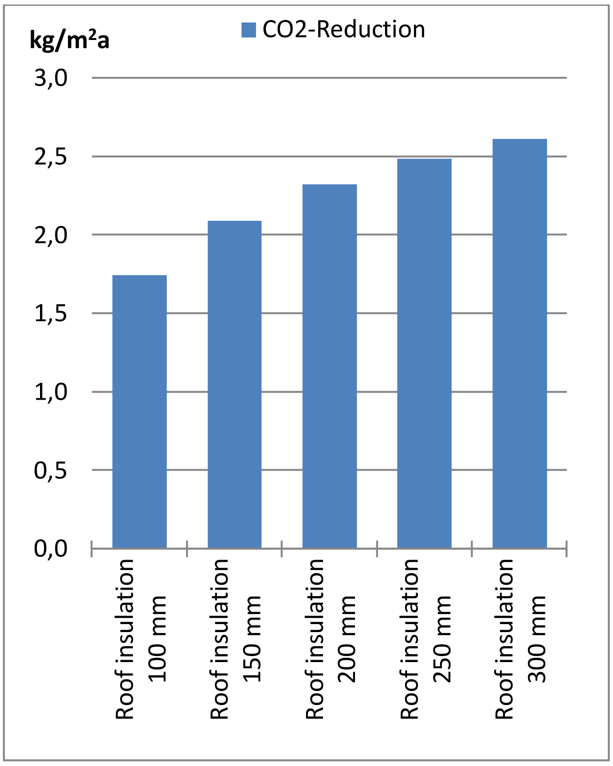
Extra roof insulation – [Starting point: U-value = 0.40 W/m²K]

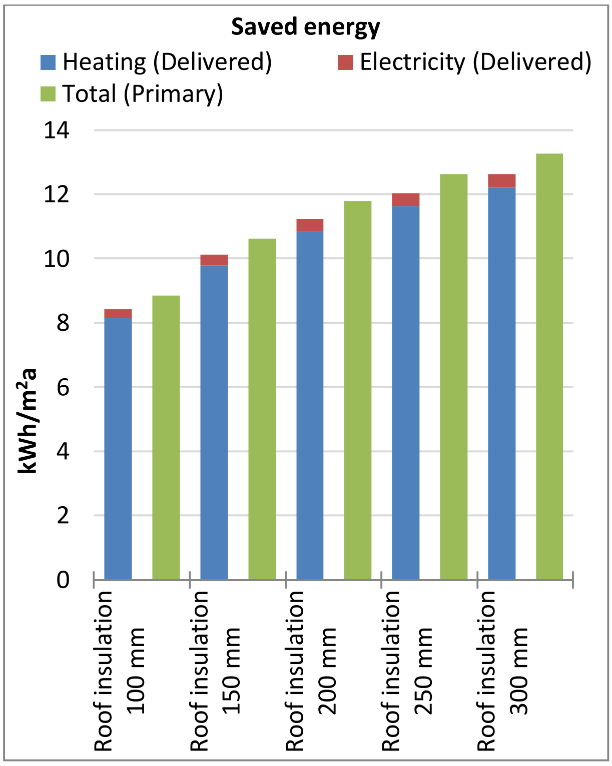
- 100 mm (U_{Roof} = 0.19 W/m²K) / 150 mm (U_{Roof} = 0.15 W/m²K) / 200 mm (U_{Roof} = 0.13 W/m²K) / 250 mm (U_{Roof} = 0.11 W/m²K) / 300 mm (U_{Roof} = 0.09 W/m²K)

Higher investment leads to higher $C0_2$–reduction due to the increase of energy savings. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system. Note: NPV decreases with insulations thicker than 250 mm.





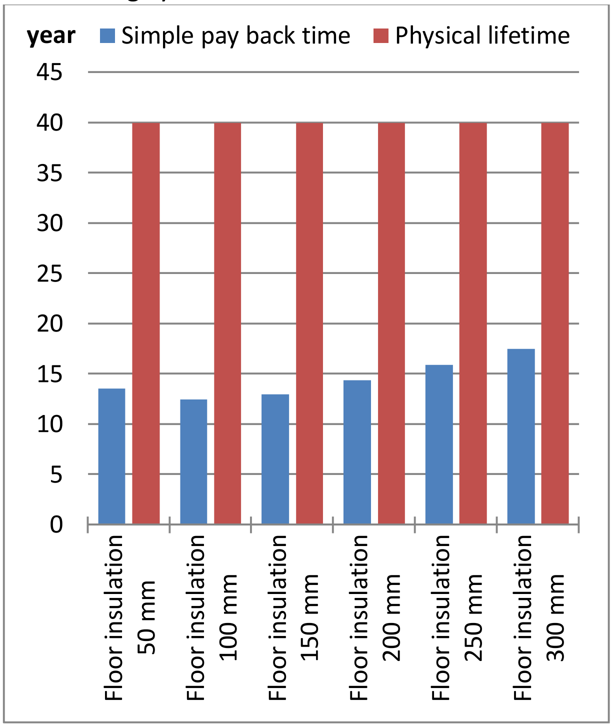


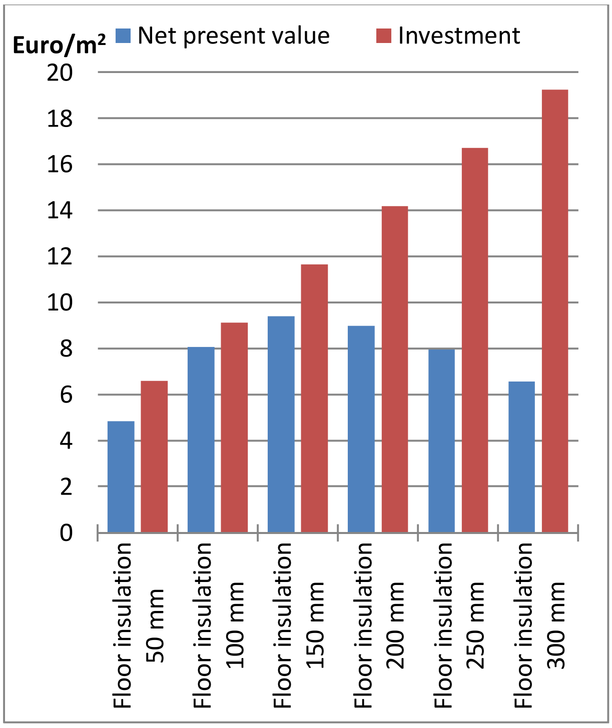


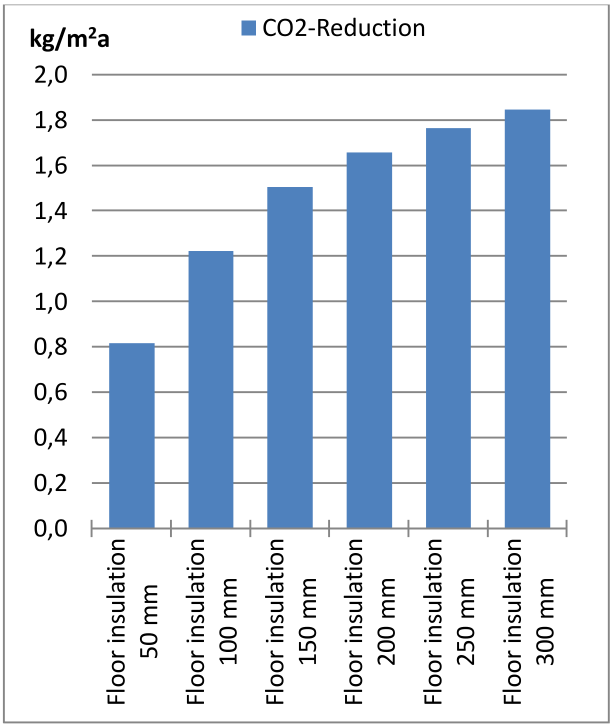
Extra floor insulation – [Starting point: U-value = 0.40 W/m²K]

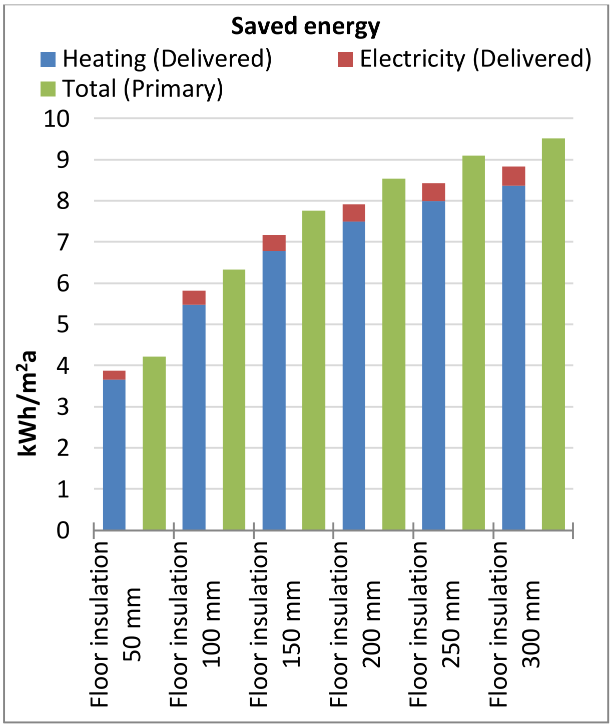
- 50 mm (U_{Floor} = 0.26 W/m²K) / 100 mm (U_{Floor} = 0.19 W/m²K) / 150 mm (U_{Floor} = 0.15 W/m²K) / 200 mm (U_{Floor} = 0.13 W/m²K) / 250 mm (U_{Floor} = 0.11 W/m²K) / 300 mm (U_{Floor} = 0.09 W/m²K)

The thicker insulation the higher the investment, but more energy is saved and more CO_2 reduced. For insulation thicker than 150mm the NPV decreases. The prices for the floor insulation are given for a school where there is easy access to insulate the floor from beneath through crawl space or basement. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system.





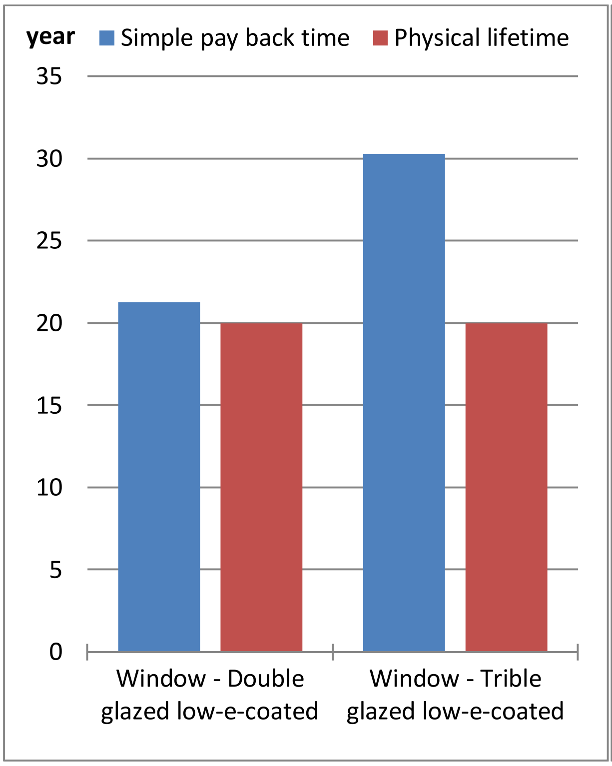


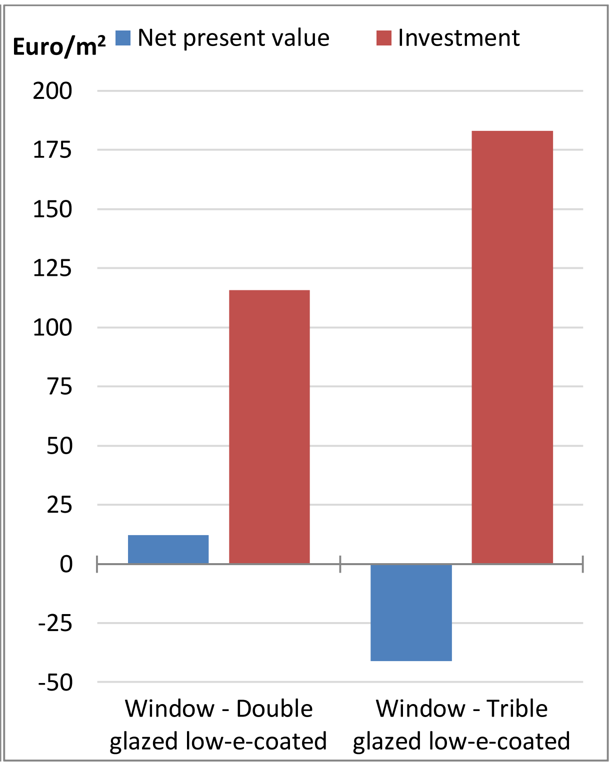


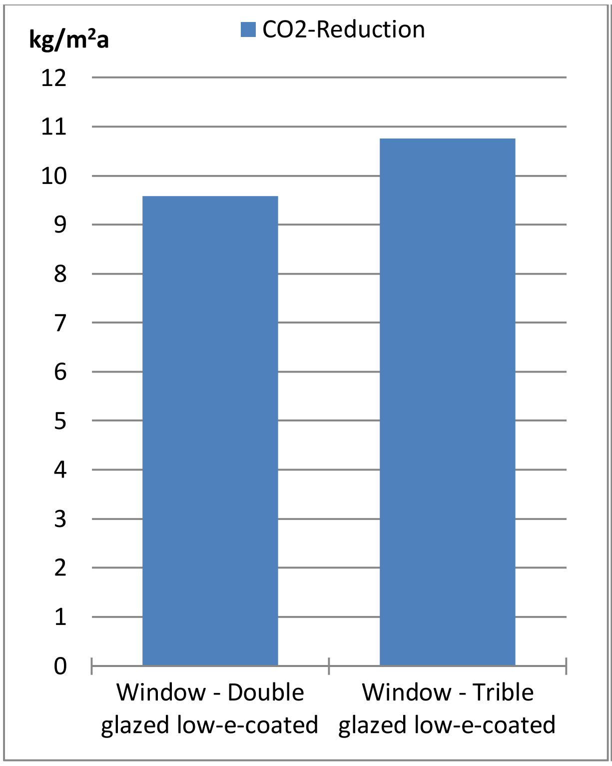
Windows – [Starting point: Double glazed; U-value = 3.1 W/m²K]

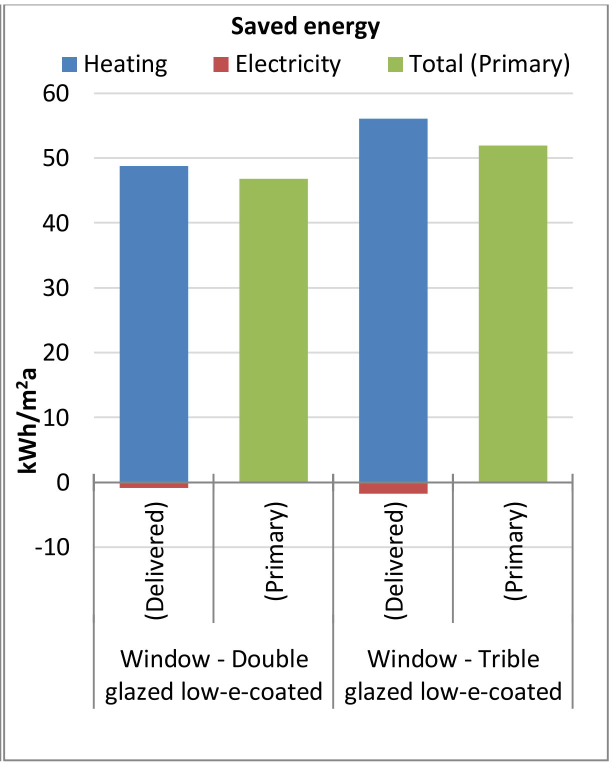
- Double glazed low-e-coated (U_{Window} = 1.2 W/m²K) /
  Triple glazed low-e-coated (U_{Window} = 0.7 W/m²K)

There is not much overheating to reduce in the building from the beginning, but much energy to save for heating. Due to the fact that the investment for a triple glazed window is so high, the NPV is negative and has a longer payback time than the double glazed window.





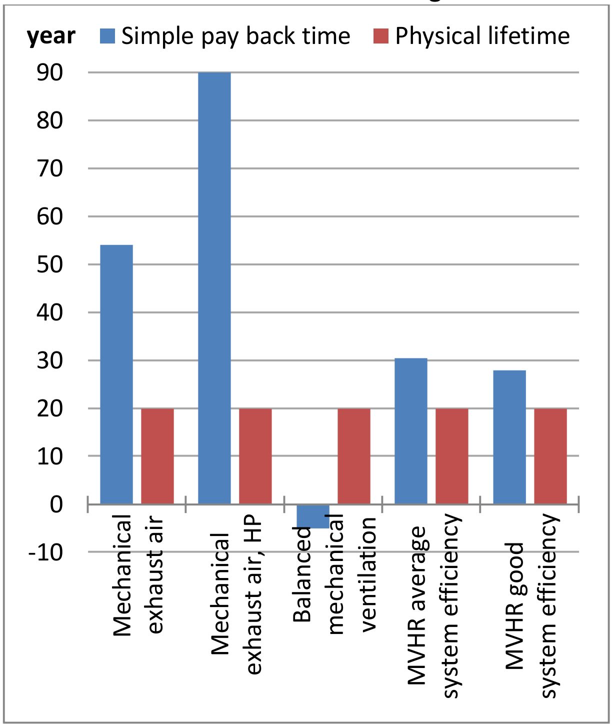


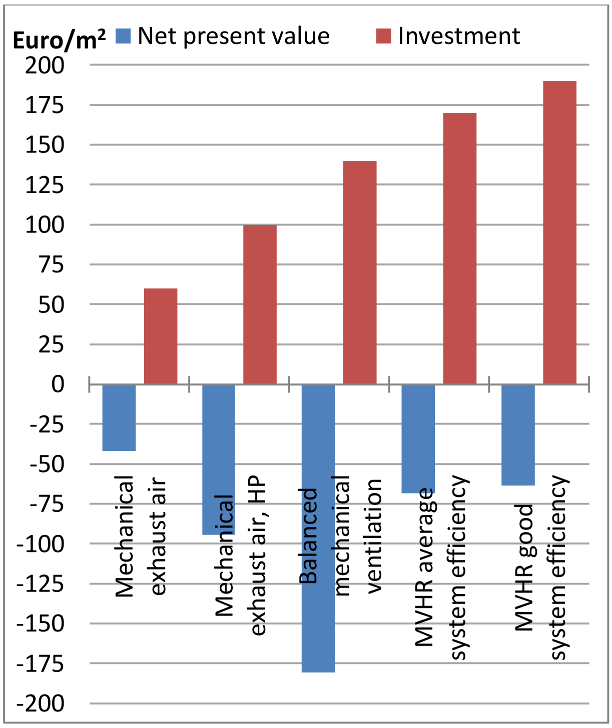


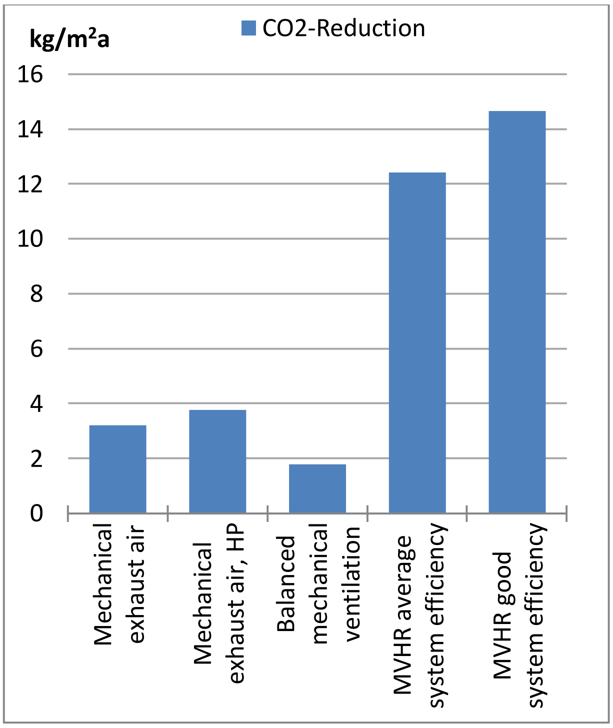
Ventilation – [Starting point: Natural ventilation]

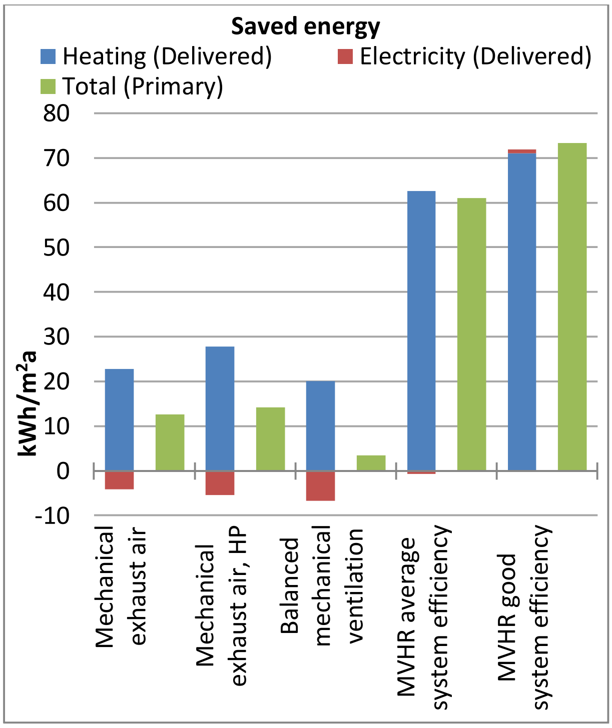
- Mechanical exhaust air (SEL=1.5 kJ/m^3) / Mechanical exhaust air, HP (SEL=1.5 kJ/m^3; COP=3.2)/ Balanced mechanical ventilation (SEL=2.3 kJ/m^3) / MVHR Average system efficiency (75%; SEL=1.5 kJ/m^3) / MVHR Good system efficiency (90%; SEL=1.2 kJ/m^3)

Both Exhaust air and balanced mechanical ventilation gives a better indoor environment, but don't reduce the energy consumption enough to give a positive NPV. However, MVHR system reduces energy consumption and reduces CO_2 highly. The airtightness with these systems is assumed to be optimized to "passive house" standard and that results in an additional energy savings caused by the low infiltration outside hours of usage.





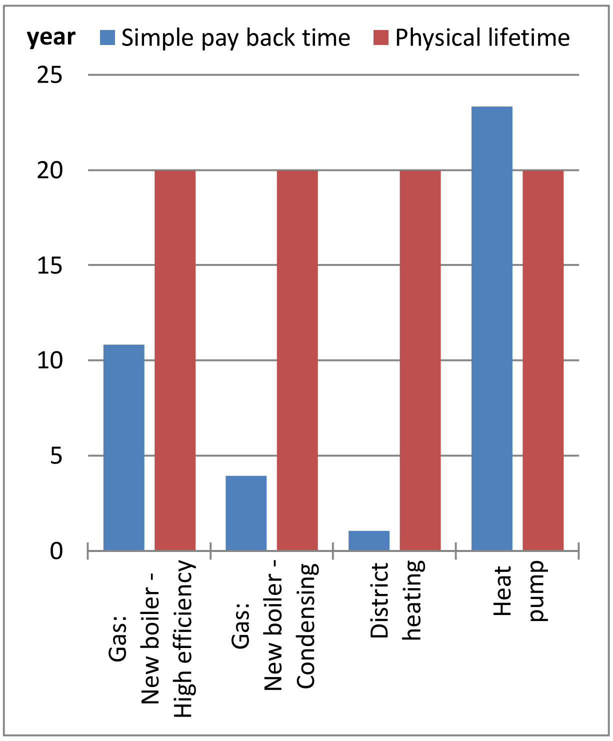


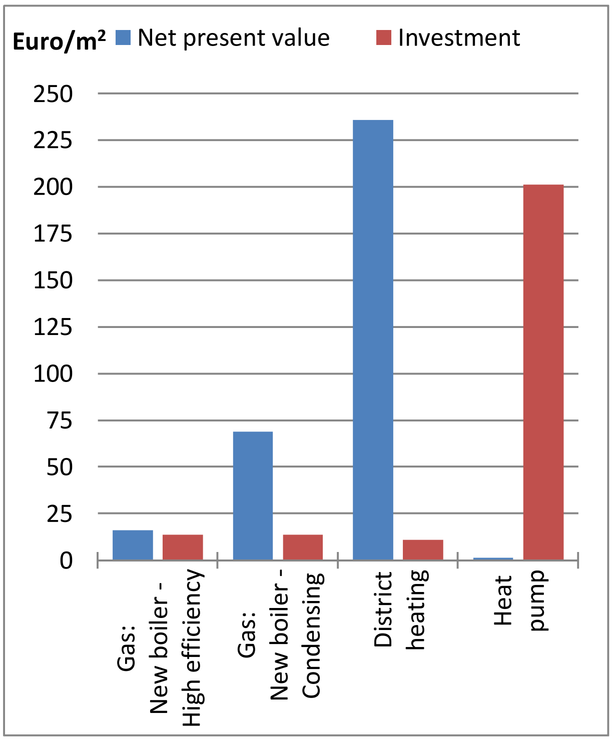


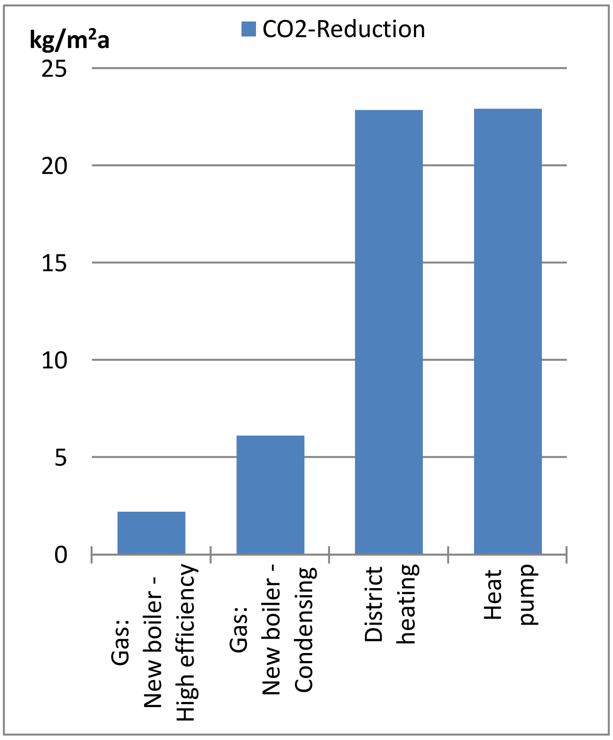
Heat supply – [Starting point: Gas: Old boiler (efficiency = 0.75)]

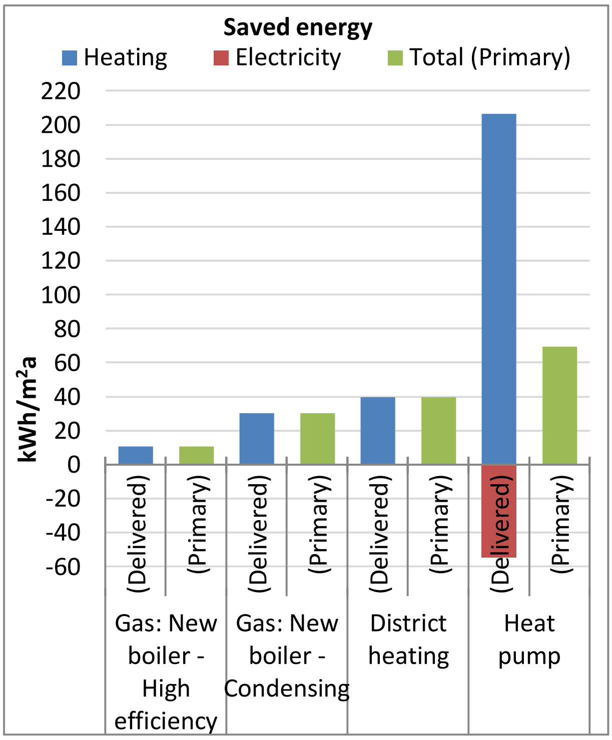
- Gas: New boiler high efficiency (eff. = 0.83) / Gas: New condensing boiler (eff. = 1.02) / District heating (eff. = 1.0) / Heat pump (COP = 3.2)

In the calculations it is assumed that the pipes in the building and the radiators are not replaced when changing the heat supply. Heat pump: includes pipes in the ground and depends of the power demand of the building. That is why the district heating system has the cheapest investment, best NPV and earlier payback, but the heat pump results in a higher amount of saved energy although it consumes electricity.





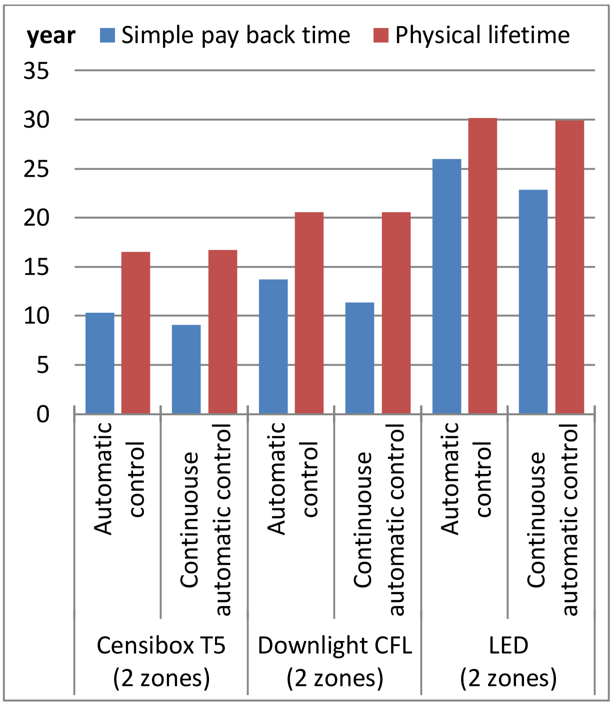


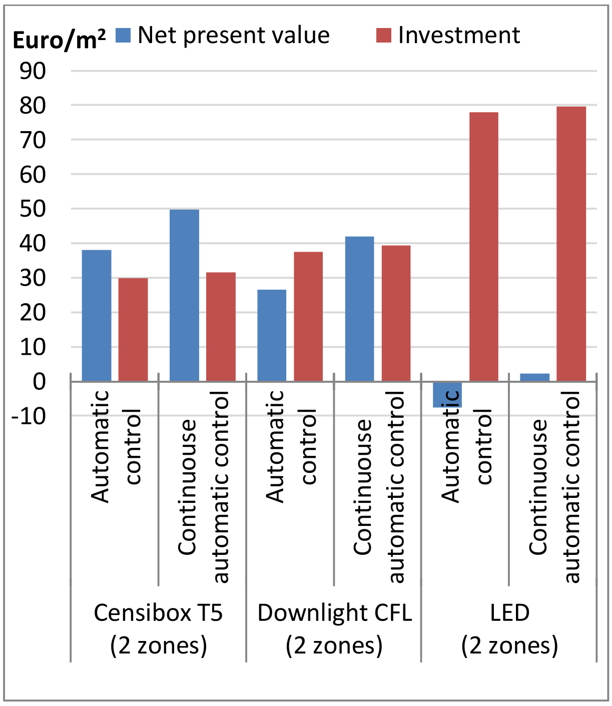


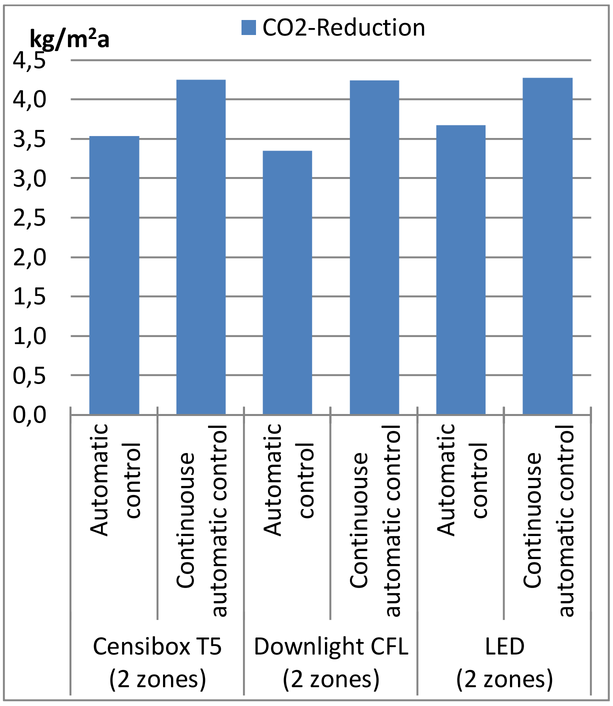
Illuminance and control – [Starting point: Censibox T8; max power: 14 W/m²; manually control (1 zone)]

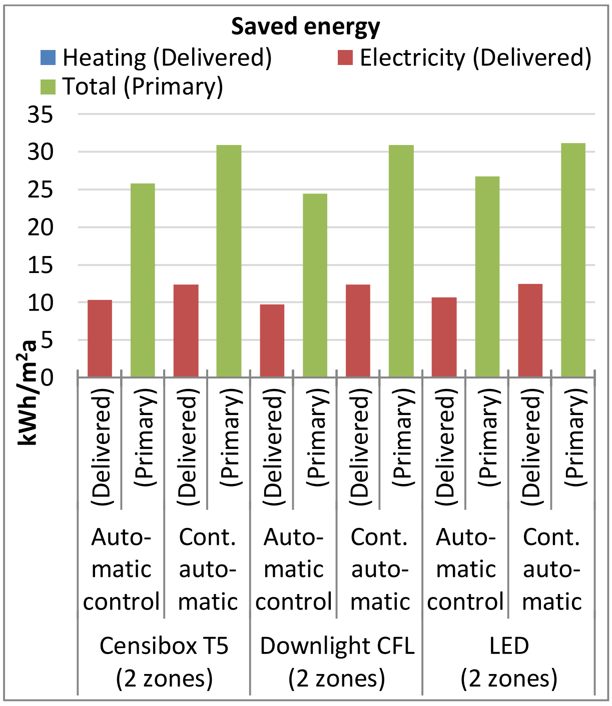
- Censibox T5 rectangular 142x1515 (max power = 0.80 W/m²) / Downlights (CFL) (max power = 0.34 W/m²) / LED Circular 450 (2012) (max power = 0.34 W/m²) with automatic control or continuous automatic dimming control.

The NPV of the LED is low or negative because the investment is high. It is expected that the future developments of LED will lower the price of LED in the future. We assume that the classroom has already the Censibox-system with T8 installed. A big amount of the energy saving and CO_2-reduction is also caused by the optimized control system. The advantage of fewer replacements for LED-fixtures during the period of analysis is not included in the NPV which would give a more equal NPV for the three different luminaires.





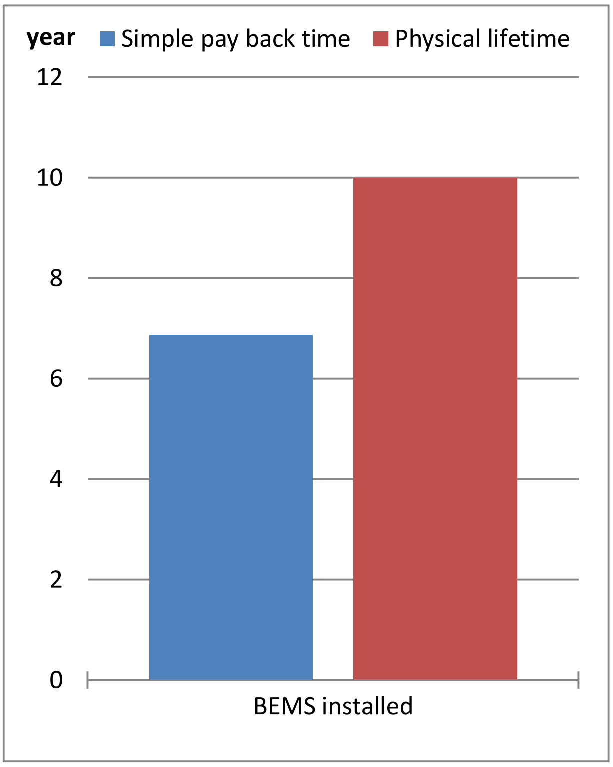


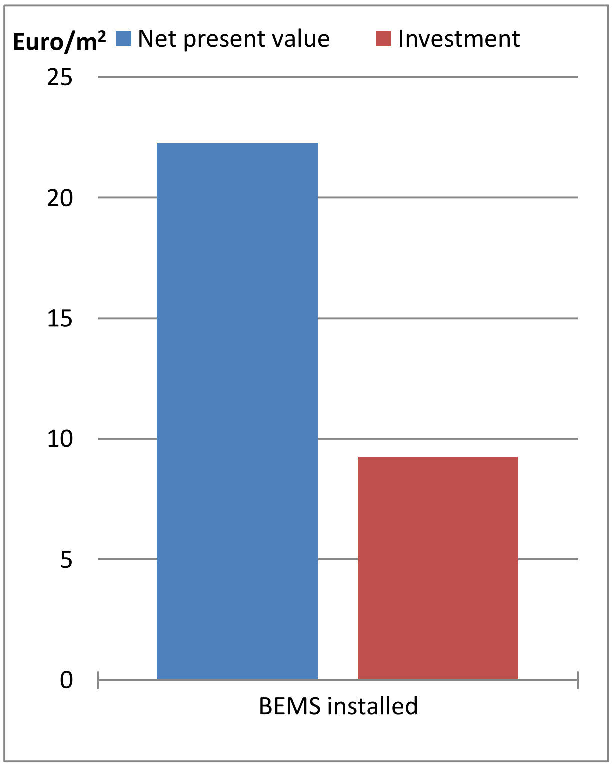


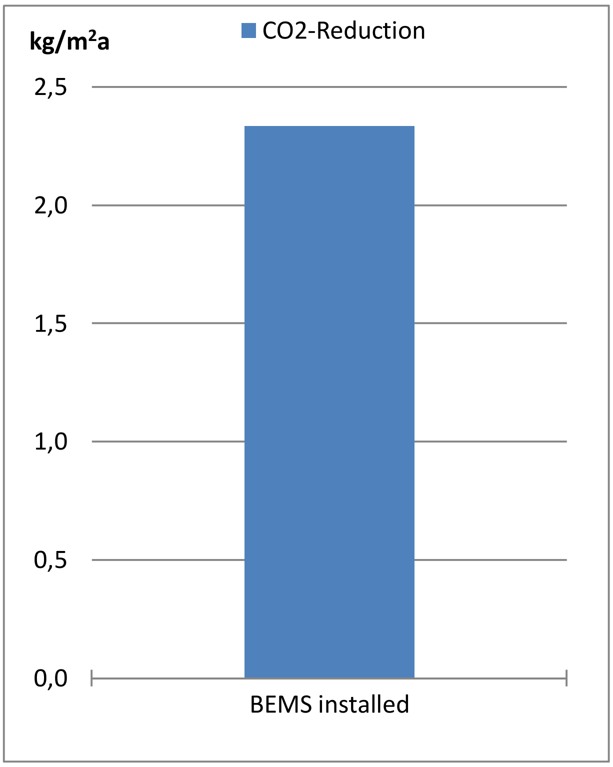
BEMS – Building energy management system [Starting point: none]

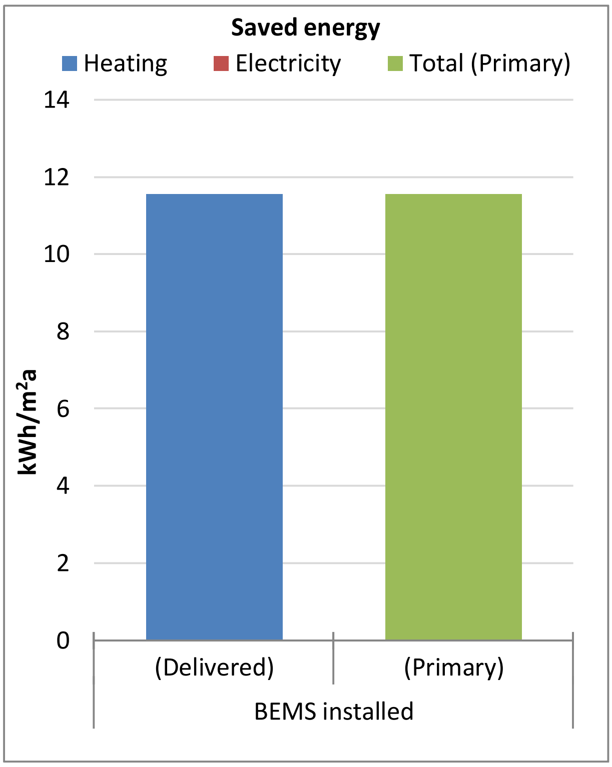
- Installed (50% reduction)

The energy consumption of the school is reduced with the installation of a BEMS and the NPV is high.





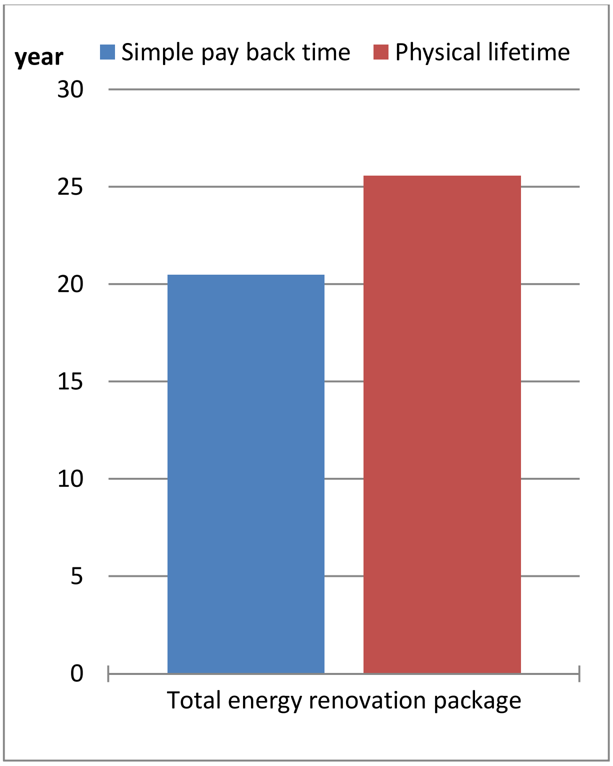


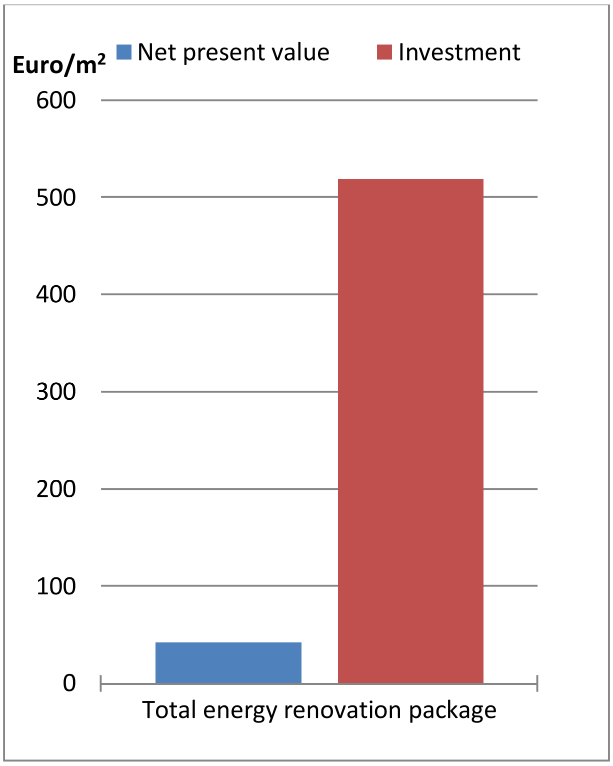


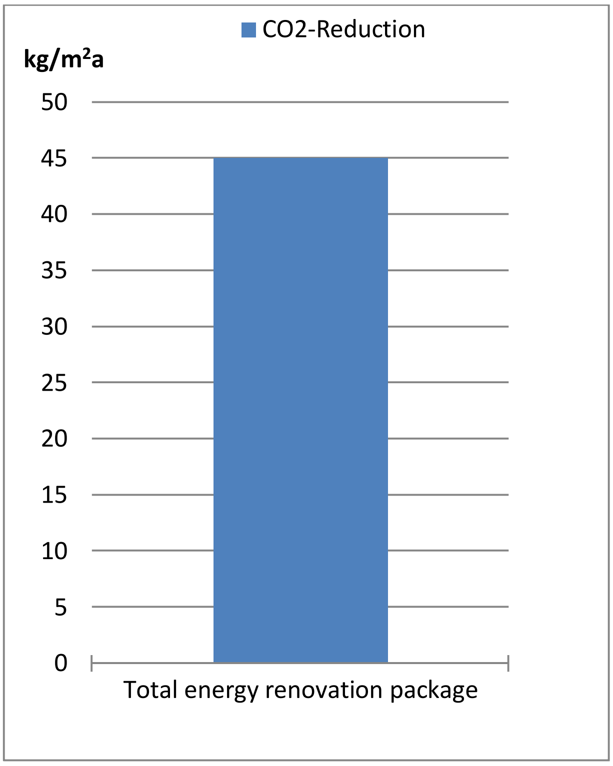
Total energy renovation package

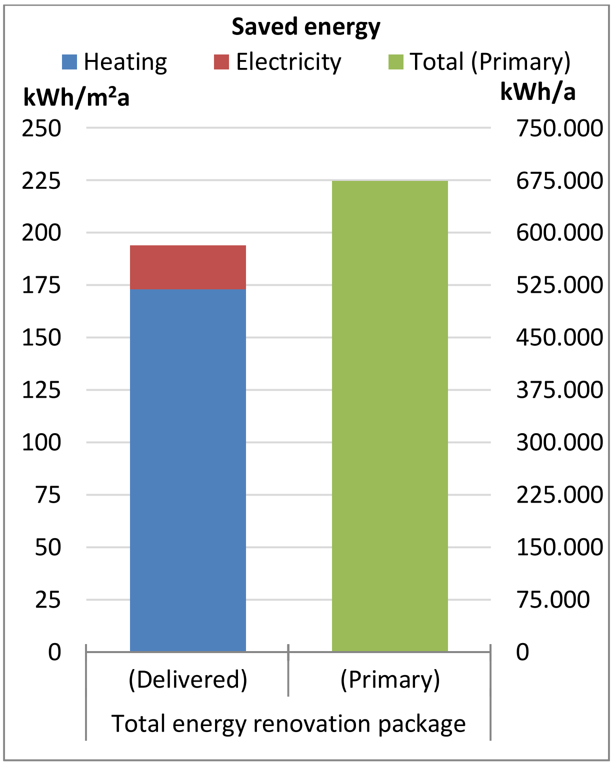
For each technology is it generally the option with the best NPV that has been chosen for the total renovation concept. If it's not, an option with reasonably energy saving or good economy was chosen. The payback time is lower than the average lifetime and the NPV is positive, but not high. Much energy is saved and the emission of CO_2 is much reduced compared with the starting point.

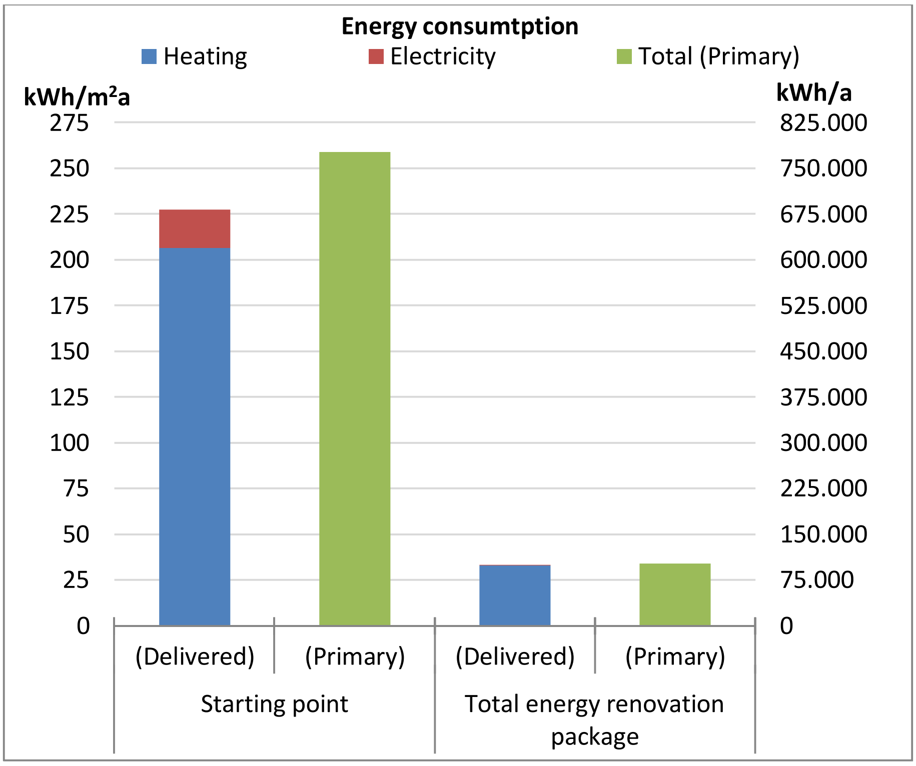
Total energy renovation package	Chosen technologies
Solar thermal heating	13 m^2
Photovoltaics (120 m^2)	Monocrystalline
Extra external wall insulation	+ 200 mm
Extra floor insulation	+ 200 mm
Extra roof insulation	+ 250 mm
Windows	Double glazed (low-e-coated)
Ventilation system	Mechanical vent. with good system effeciency
Heat supply	District heating
Illuminance	Downlights (Compact Fluorescent Lamps)
Control	Continuous automatic dimming control
BEMS – Building energy management system	Installed






CO2-Reduction
kg/m²a
50
45
40
35
30
25
20
15
10
5
0
Total energy renovation package


Saved energy
Heating
Electricity
Total (Primary)
kWh/m²a
kWh/a
250
225
200
175
150
125
100
75
50
25
0
750.000
675.000
600.000
525.000
450.000
375.000
300.000
225.000
150.000
75.000
0
(Delivered)
(Primary)
Total energy renovation package


Energy consumtption
Heating
Electricity
Total (Primary)
kWh/m²a
kWh/a
275
250
225
200
175
150
125
100
75
50
25
0
825.000
750.000
675.000
600.000
525.000
450.000
375.000
300.000
225.000
150.000
75.000
0
(Delivered)
(Primary)
(Delivered)
(Primary)
Starting point
Total energy renovation package

Yearly energy consumption	Heating [kWh/m^{2}a]	Electricity [kWh/m^{2}a]	Total (Primary) [kWh/m^{2}a]	Total (Primary) [kWh/a]
Starting point	206,5	21,0	259,0	776.994
Total energy renovation package	33,2	0,4	34,2	102.593
Energy saving	173,3	20,6	224,8	674.401

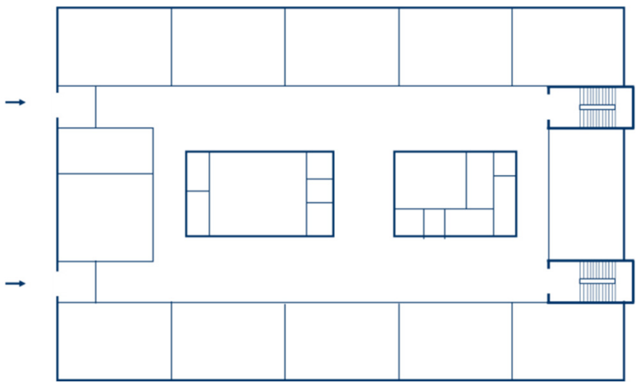
7.2. COMPACT PLAN

Economic parameters

Discount rate	5.0%
Tax of interest income	0.0%
Inflation on energy costs	4.5%
Inflation on maintenance costs	3.0%
Expected economic lifetime	25

School typology

Compact plan



Compact Plan	Class-room	Corridor	Total
Floor area	60%	40%	
Floor area	1800 m²	1200 m²	3000 m²
Window/ Floor-area	25%	0%	15%
N/W/S/E [%]	40/10/40/10	0/0/0/0	40/10/40/10
	N/S	E/W	N° of floors
Façade length	64.8 m	46.3 m	1

Reference building

A compact plan school is investigated for 1950's, where it is assumed that there is no insulation in the walls and the construction is medium heavy. It is assumed that the roof has been changed and 200 mm insulation has been added to the roof.

There is natural ventilation and no cooling. The basement is not heated.

The heat supply is an older gas boiler, the hot water use is for a school with gym, and radiators with thermostats are used to heat the building. There is no building energy management system (BEMS) installed.

The period of usage is 201 days a year and from 8 am to 5 pm.

The reference building uses 203.2 kWh/m^2 per year of heating and 23.4 kWh/m^2 per year of electricity (including electrical light, pumps and fans).

Denmark	Electricity	District Heating	Oil	Gas
CO_2 Conversion factor [kg/kWh]	0,343	0,113	0,279	0,202
Primary energy factor	2,5	1	1	1

The primary energy use of the reference building is 203.2 kWh/m^2 per year for heating and 58.6 kWh/m^2 per year for electricity. The total primary energy consumption for the building is 261.9 kWh/m^{2}per year.

Existing lighting

The installed power of the existing lighting from 1970 is set to 14 W/m^2 (source: http://www.sbi.dk/indeklima/lys/lyset-i-skolen/renovering-med-enkle-midler-tingbjerg-skole)
It is assumed that the classrooms are in use 90 % of the time.
The light transmittance is set to 75 %.

Ventilation

The classrooms are each assumed to be 60 m^2 and used by 30 persons. This requires a ventilation rate of 2.2 l/sm^2 to comply with category 2 of *DS/EN 15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. The natural ventilation in the reference school is also assumed to fulfill the requirement of $q_{tot} = 2.2\, l/sm^2$.
When using natural ventilation or only mechanical exhaust air, the infiltration is a part of the ventilation rate (2.2 l/sm^2) and when ventilating with a mechanical balanced system the infiltration is beside the ventilation rate. Balanced mechanical ventilation with heat recovery (MVHR) is screened with an average and a good efficiency.
The heating energy consumption of the reference school is slightly higher than the average heating consumption of Danish schools, also because the ventilation rate is set to fulfill the optimised hygienic recommendations.

Screened technologies:

Screened technologies	Data

Solar thermal heating	Production [kWh/(m$^2_{floor}$)]
Starting point: none	0.0
13 m^2	2.5
20 m^2	3.8

Photovoltaics (120 m^2)	Max effect [kWpeak]
Starting point: none	0.0
Amorpheus	7.7
Polycrystalline	12.9
Monocrystalline	14.4

Extra external wall insulation	Resulting U_{Wall} [W/m^{2}K]
Starting point:	0.57
+ 150 mm	0.17
+ 200 mm	0.14
+ 250 mm	0.12
+ 300 mm	0.10

Extra floor insulation	Resulting U_{Floor} [W/m^{2}K]
Starting point:	0.40
+ 50 mm	0.26
+ 100 mm	0.19
+ 150 mm	0.15
+ 200 mm	0.13
+ 250 mm	0.11
+ 300 mm	0.09

Extra roof insulation	Resulting U_{Roof} [W/m^{2}K]
Starting point:	0.17
+ 100 mm	0.12
+ 150 mm	0.10
+ 200 mm	0.09
+ 250 mm	0.08
+ 300 mm	0.07

Extra roof insulation (without the 200mm added insulation)	Resulting U_{Roof} [W/m^{2}K]
Starting point:	1.9
+ 100 mm	0.31
+ 150 mm	0.22
+ 200 mm	0.17
+ 250 mm	0.14
+ 300 mm	0.12

Windows	Resulting U_{Window} [W/m^{2}K]
Starting point: Double glazed	3.1
Double glazed (low-e-coated)	1.2
Triple glazed (low-e-coated)	0.7

Ventilation system	SEL [kJ/m³]	Efficiency [%]	COP [-]	Airtightness (50 Pa) [l/sm²]
Starting point: Natural ventilation				4.0
Mechanical exhaust air	1.5			0.6
Mechanical exhaust air with heat pump	1.5		3.2	0.6
Balanced mechanical ventilation	2.3			0.6
Mechanical vent. with average system efficiency	1.5	75		0.6
Mechanical vent. with good system efficiency	1.2	90		0.6

Heat supply	Efficiency [-]	COP [-]
Starting point: Gas: old boiler	0.75	
Gas: new boiler with high efficiency	0.83	
Gas: new boiler condensing	1.02	
District heating	1.0	
Heat pump		3.2

Illuminance and control	Max power [W/m²]	Min power [W/m²]	Max lightlevel [Lx]	Min lightlevel [Lx]
Starting point: Censibox T8	14.0	0.0	200	0
Censibox T5	4.0	0.8	216	43
Downlights (Compact Fluorescent Lamps)	6.0	0.3	300	21
LED	3.4	0.3	207	21
Control	Sensetivity: [Lux above required lightlevel]		Zones	
Starting point: Manual control	200		1	
Automatic control	100		2	
Continuous automatic dimming control	50		2	

BEMS – Building energy management system	Reduction of energy loss [%]
Starting point: No control	0
Installed	50

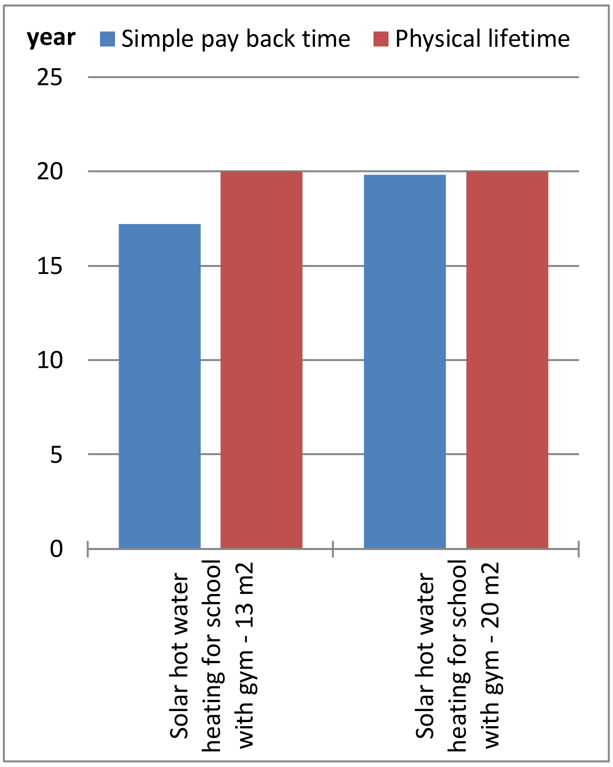
Total energy renovation package	**Chosen technologies**
Solar thermal heating	13 m^2
Photovoltaics (120 m^2)	Monocrystalline
Extra external wall insulation	+ 200 mm
Extra floor insulation	+ 200 mm
Extra roof insulation	+ 200 mm
Windows	Double glazed (low-e-coated)
Ventilation system	Mechanical vent. with good system efficiency
Heat supply	District heating
Illuminance	Downlights (Compact Fluorescent Lamps)
Control	Continuous automatic dimming control
BEMS – Building energy management system	Installed

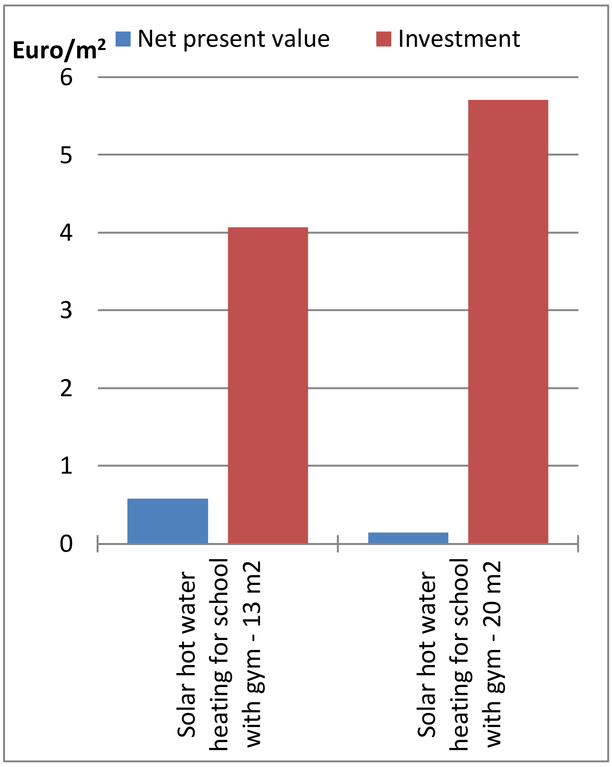
Graph of results:

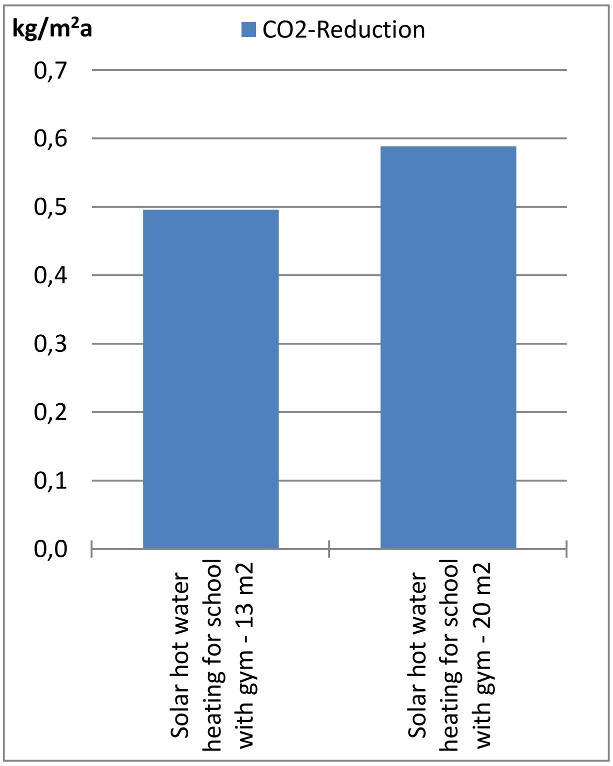
Solar Heating – [Starting point: none]

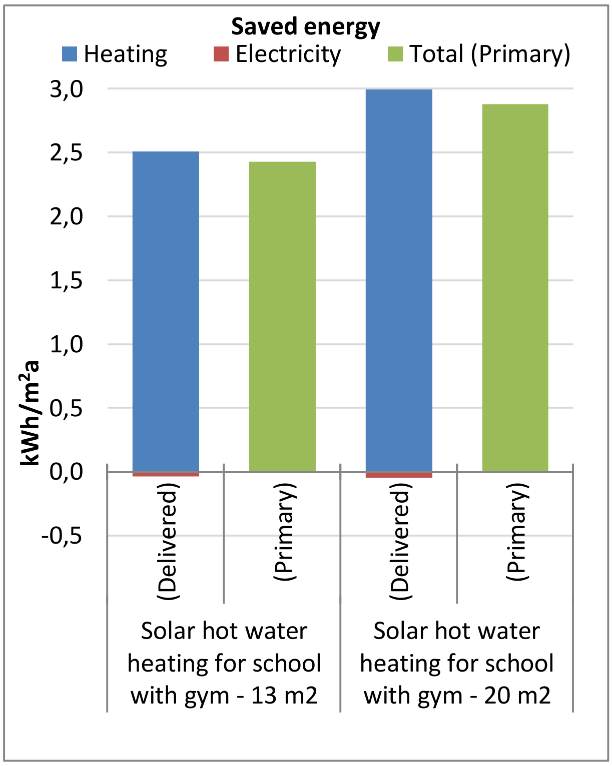
- 13 m² / 20 m²

Low NPV due to the high investment cost.





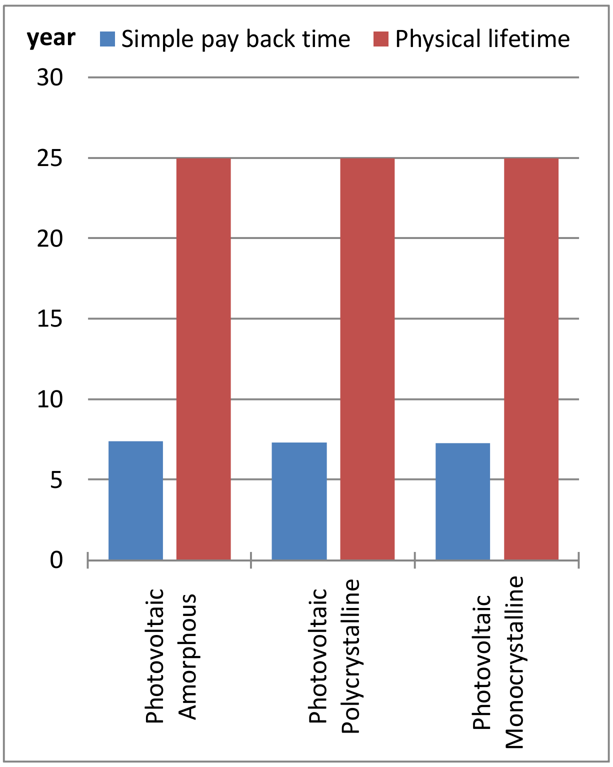


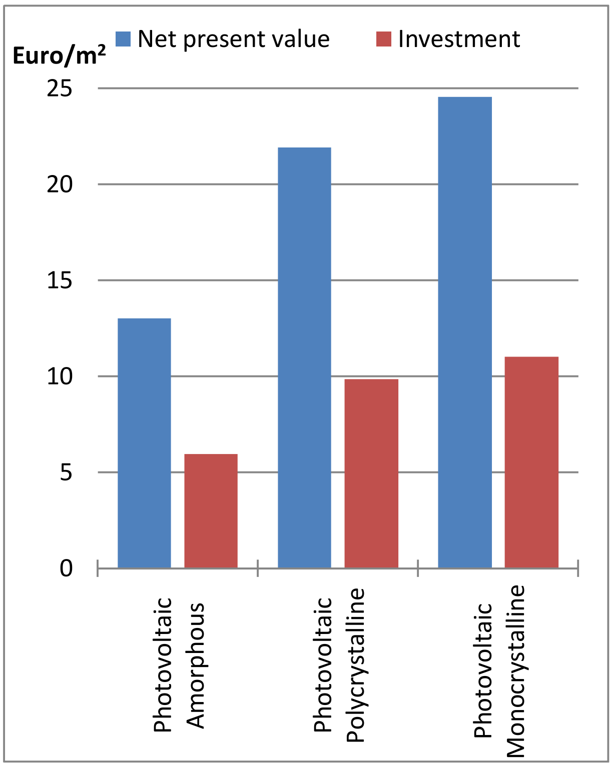


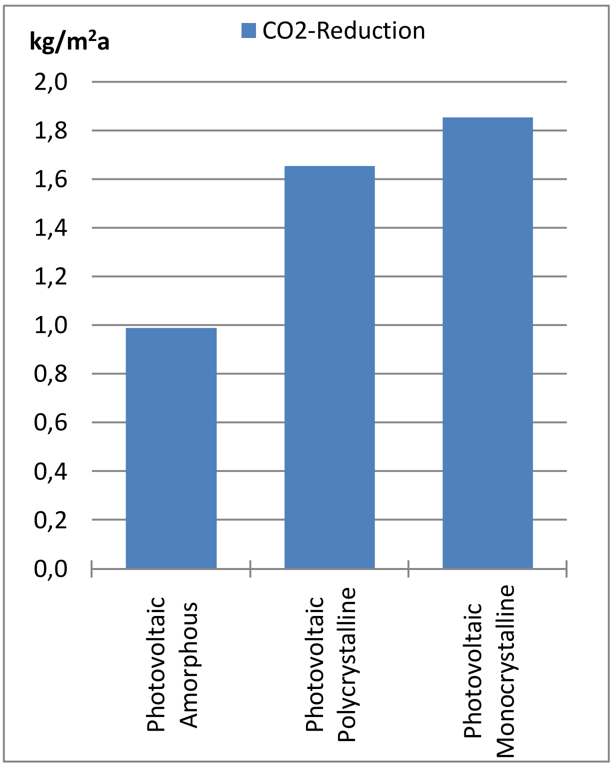
Photovoltaics – 120 m²– [Starting point: none]

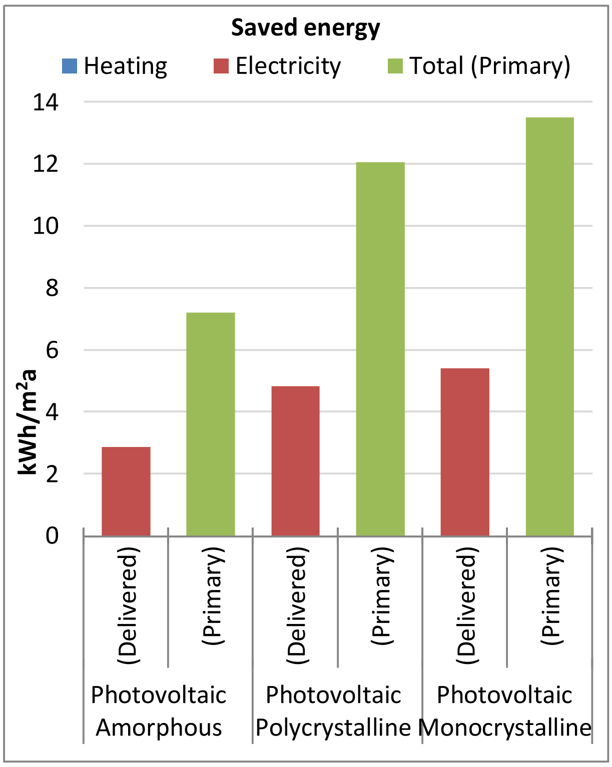
- Amorpheus (kW_{peak}=7.7) / Polycrystalline (kW_{peak}=12.9) / Monocrystalline (kW_{peak}=14.4)

The higher the investment is the higher is the NPV, due to the increase of energy saving. The NPV is high compared to the investment and the payback time is low compared to life time.





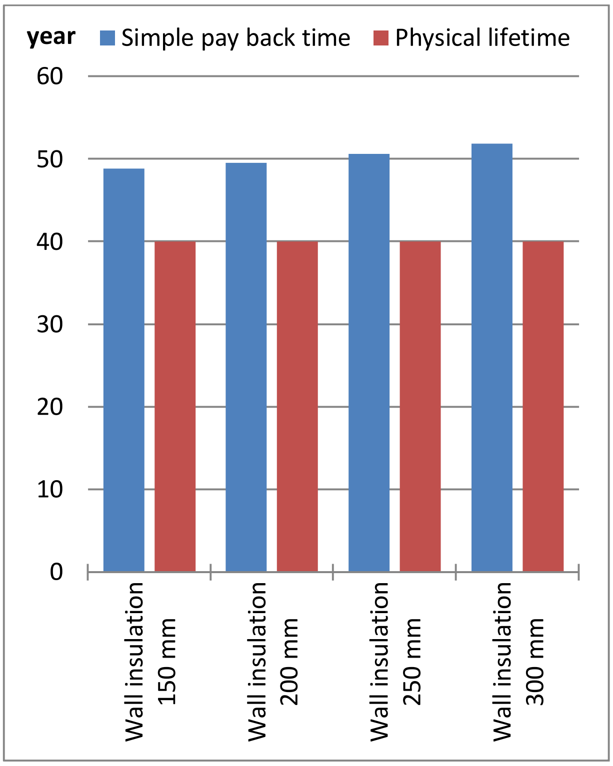


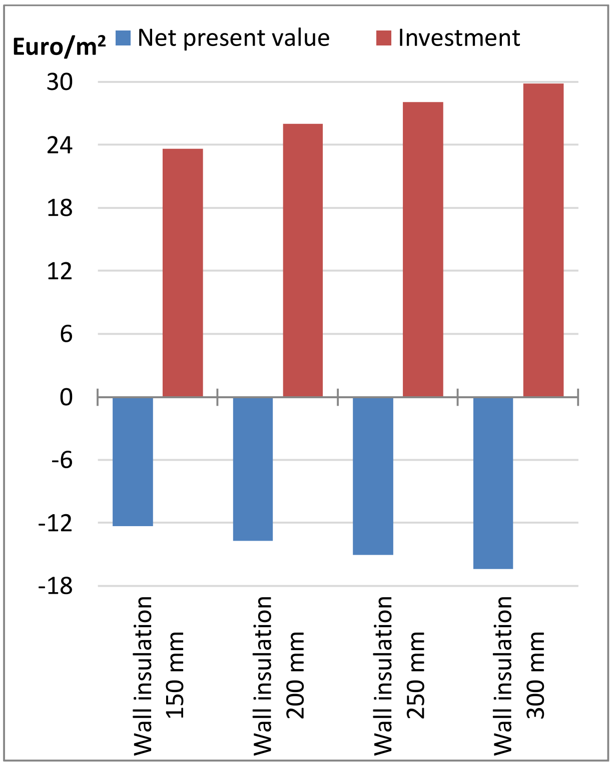


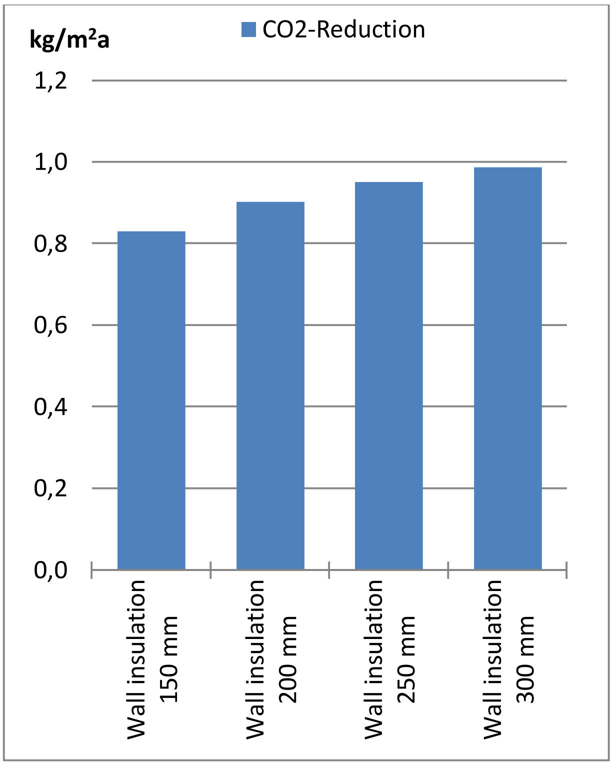
Extra wall insulation – [Starting point: U-value = 0.57 W/m²K]

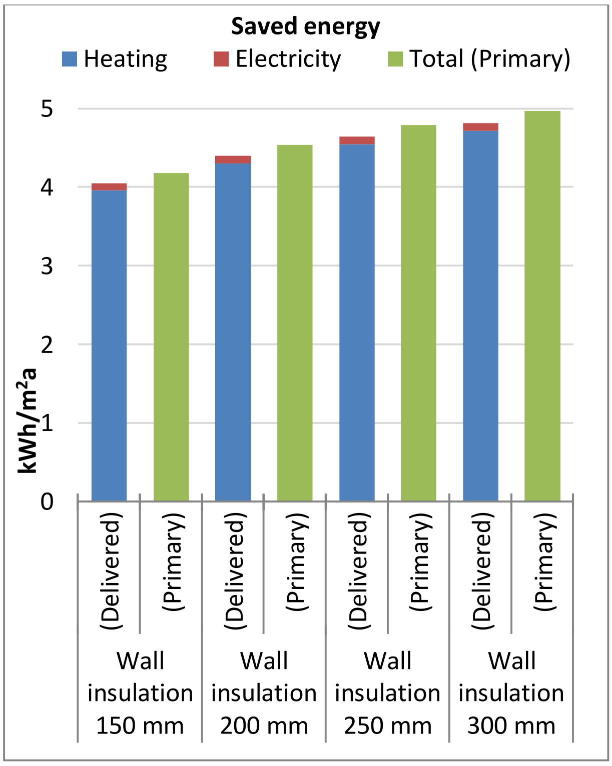
- 150 mm (U_{Wall} = 0.17 W/m²K) / 200 mm (U_{Wall} = 0.14 W/m²K) / 250 mm (U_{Wall} = 0.12 W/m²K) / 300 mm (U_{Wall} = 0.10 W/m²K)

Extra wall insulation has a high investment and mainly therefore the NPV is negative despite the energy savings. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system.





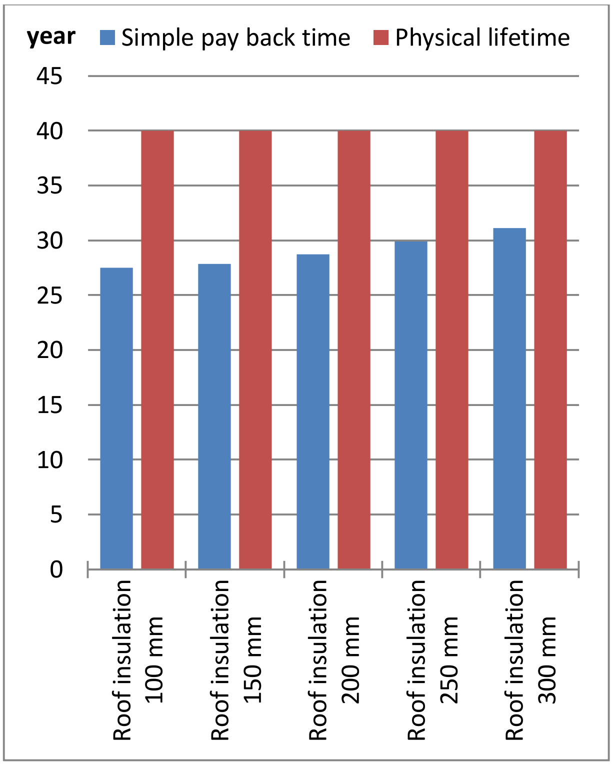


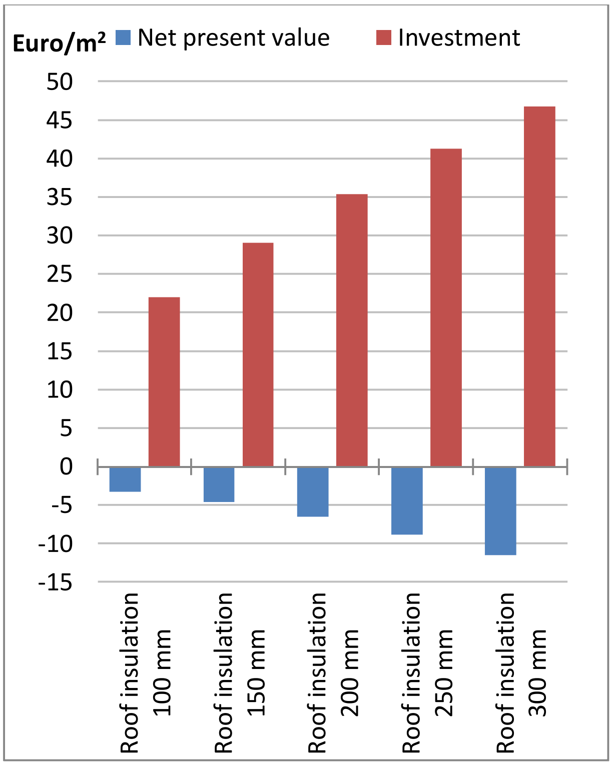


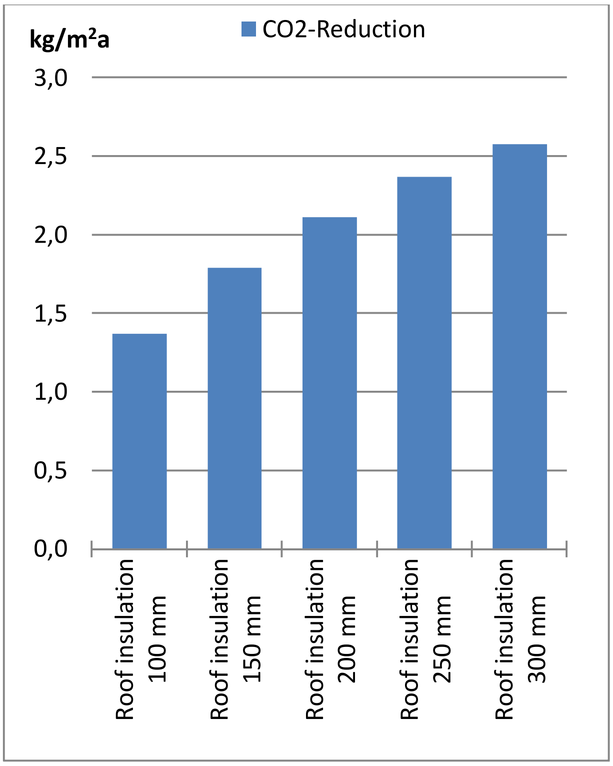
Extra roof insulation – [Starting point: U-value = 0.17 W/m²K]

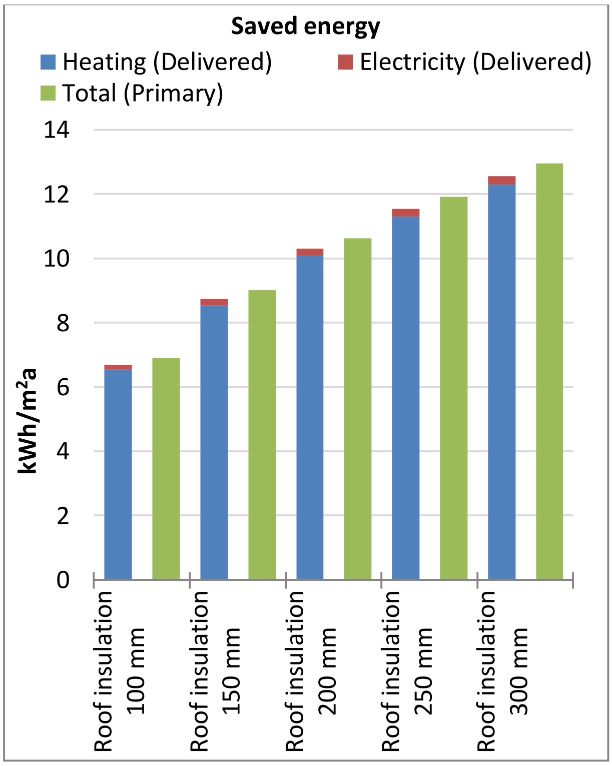
- 100 mm (U_{Roof} = 0.12 W/m²K) / 150 mm (U_{Roof} = 0.10 W/m²K) / 200 mm (U_{Roof} = 0.09 W/m²K) / 250 mm (U_{Roof} = 0.08 W/m²K) / 300 mm (U_{Roof} = 0.07 W/m²K)

Mainly caused by the high investment the payback times are high - and the NPV's are low despite the energy savings. The roof is assumed to have been insulated with 200 mm insulation after the school was built. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system.





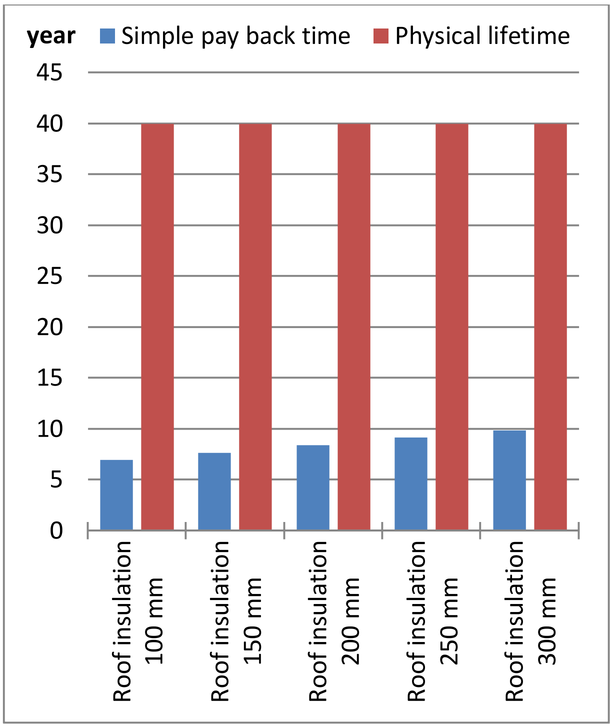


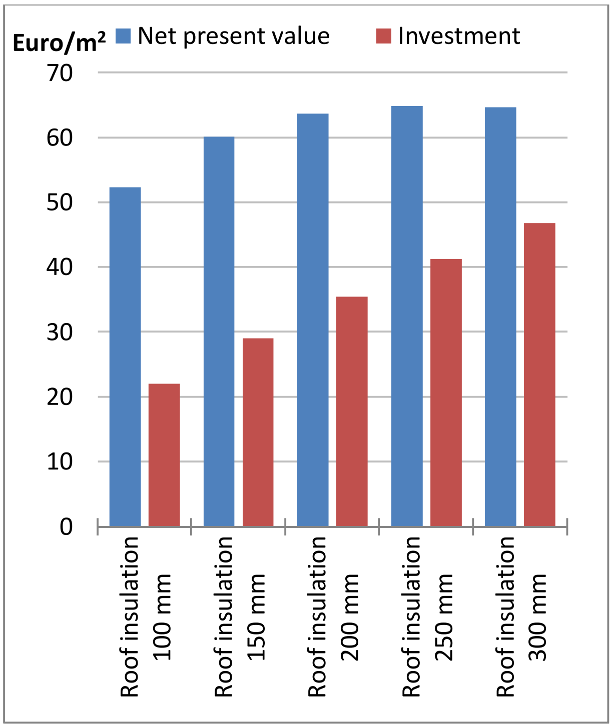


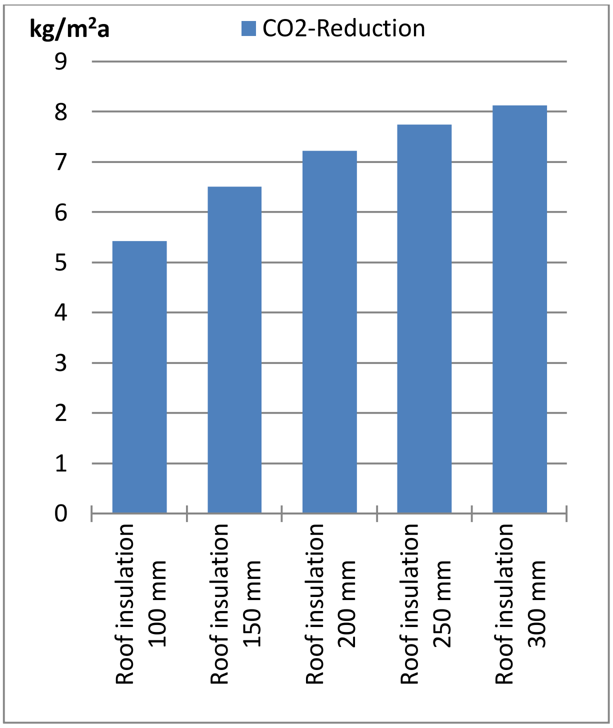
Extra roof insulation (without the 200mm added insulation) – [Starting point: U-value = 1.9 W/m²K]

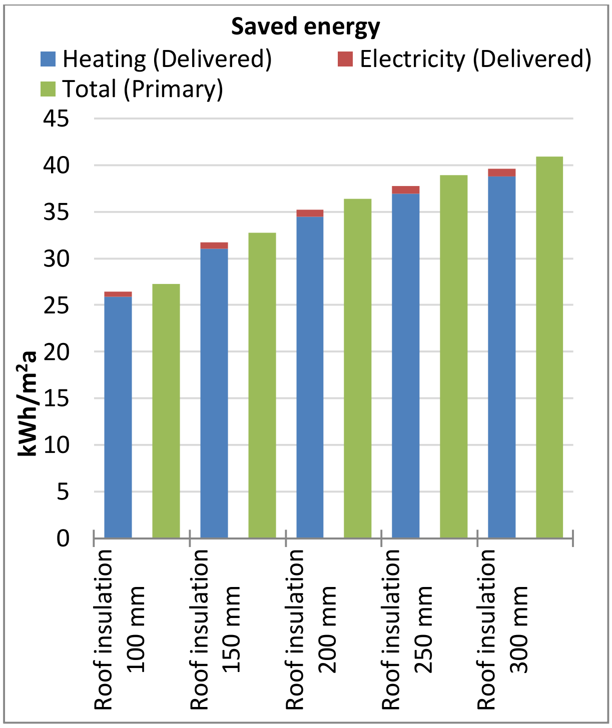
- 100 mm (U_{Roof} = 0.31 W/m²K) / 150 mm (U_{Roof} = 0.22 W/m²K) / 200 mm (U_{Roof} = 0.17 W/m²K) / 250 mm (U_{Roof} = 0.14 W/m²K) / 300 mm (U_{Roof} = 0.12 W/m²K)

In the graphs below the effect of insulation of the roof are showed, if the roof hadn't been extra insulated with 200 mm after the school was built. Higher investment leads to higher $C0_2$ –reduction due to the increase of energy savings. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system. Note: NPV decreases with insulations thicker than 250 mm.





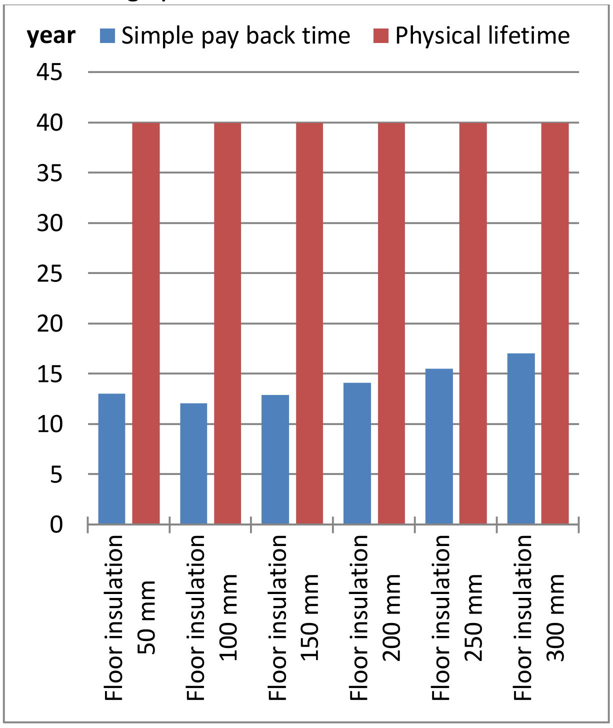


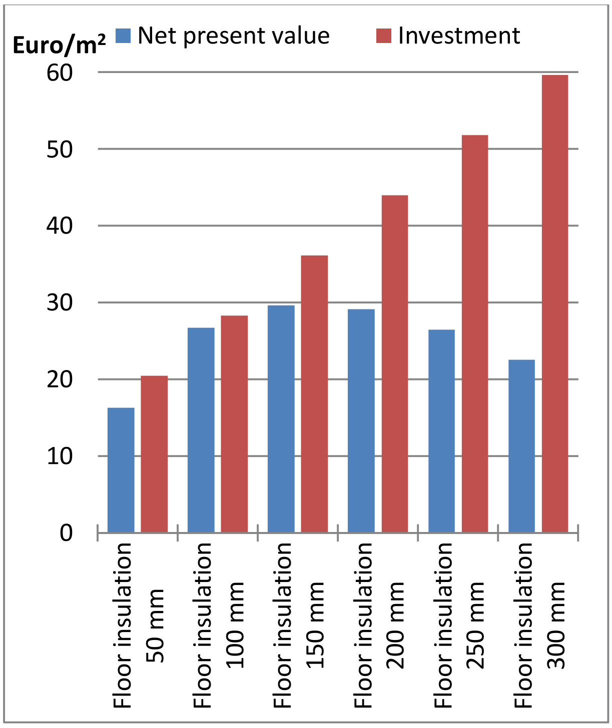


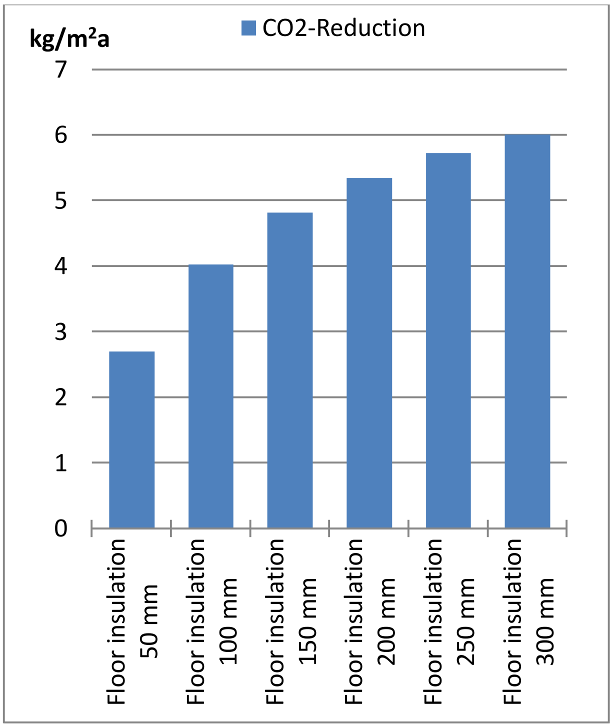
Extra floor insulation – [Starting point: U-value = 0.40 W/m²K]

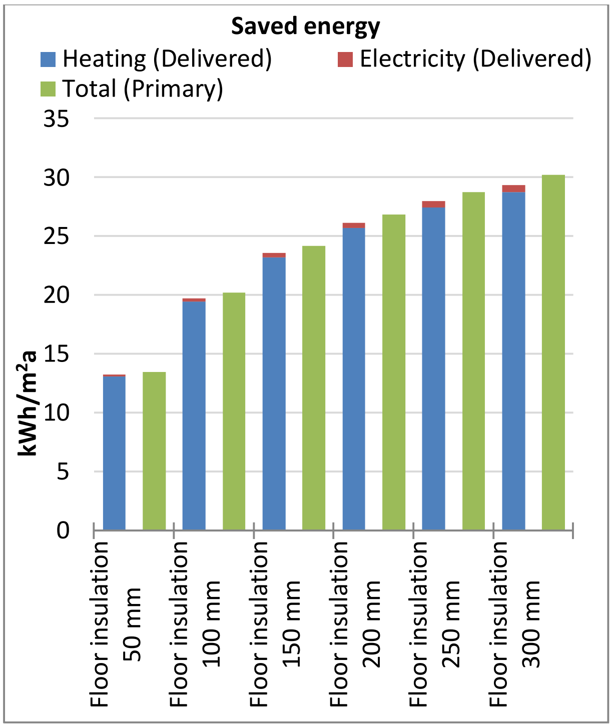
- 50 mm (U_{Floor} = 0.26 W/m²K) / 100 mm (U_{Floor} = 0.19 W/m²K) / 150 mm (U_{Floor} = 0.15 W/m²K) / 200 mm (U_{Floor} = 0.13 W/m²K) / 250 mm (U_{Floor} = 0.11 W/m²K) / 300 mm (U_{Floor} = 0.09 W/m²K)

The thicker insulation the higher the investment, but more energy is saved and more CO2 reduced. For insulation thicker than 150mm the NPV decreases. The prices for the floor insulation are given for a school where there is easy access to insulate the floor from beneath through crawl space or basement. The consumption of electricity is reduced due to less use of the pumps to transport the hot water for the heating system.





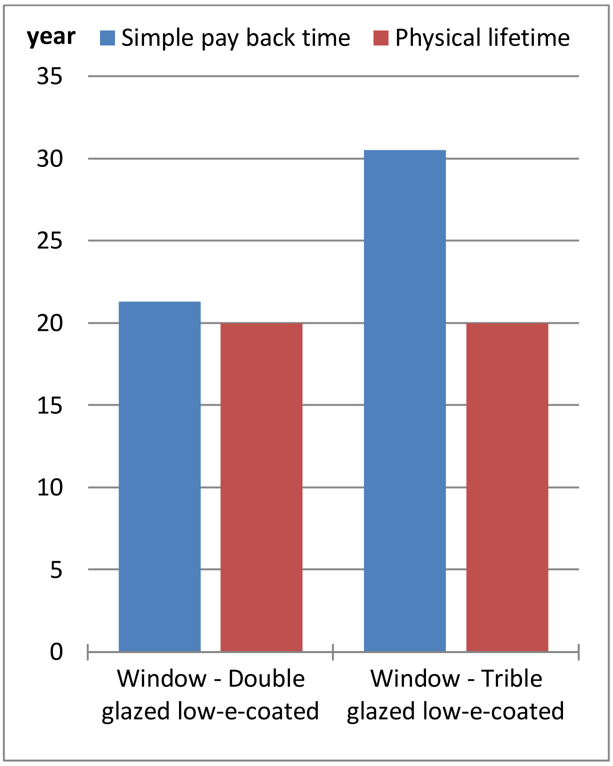


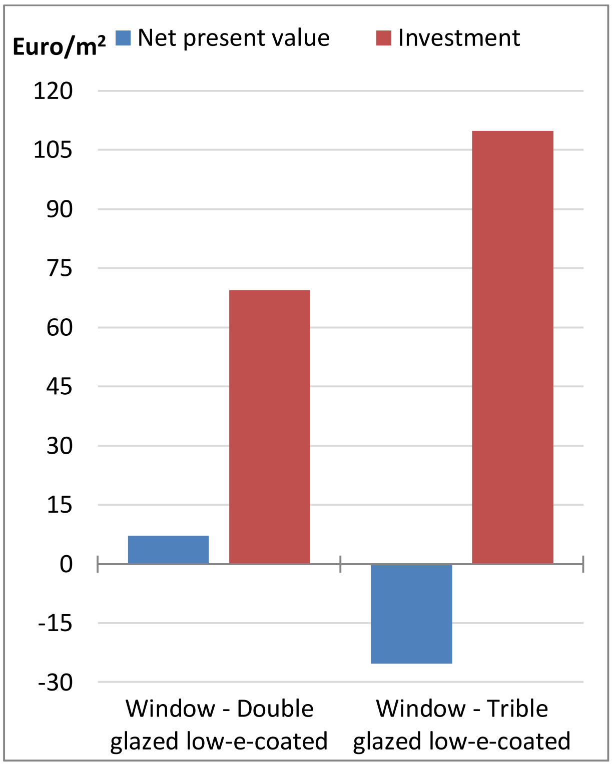


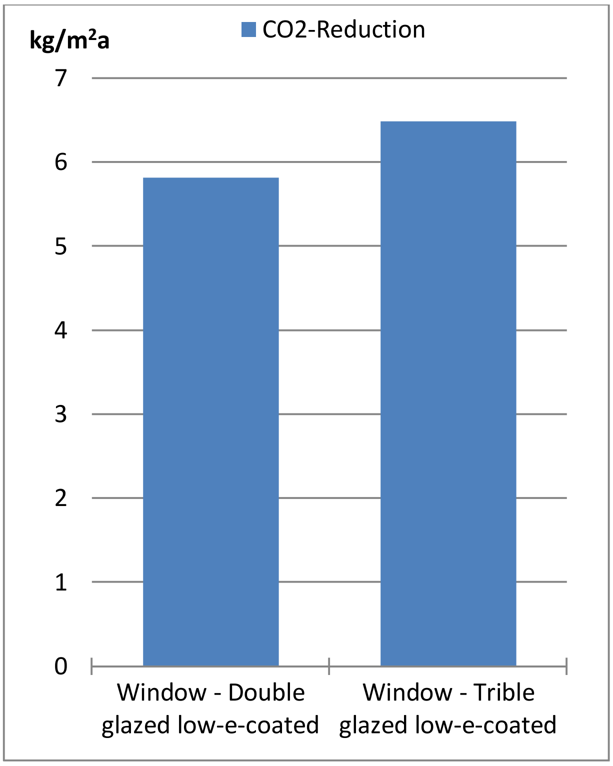
Windows – [Starting point: Double glazed; U-value = 3.1 W/m²K]

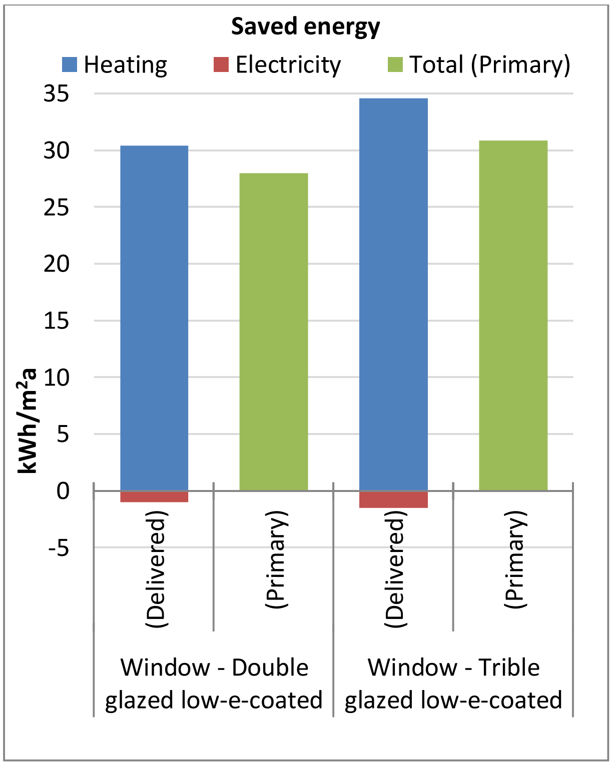
- Double glazed low-e-coated (U_{Window} = 1.2 W/m^{2}K) /
  Triple glazed low-e-coated (U_{Window} = 0.7 W/m^{2}K)

There is not much overheating to reduce in the building from the beginning, but much energy to save for heating. Due to the fact that the investment for a triple glazed window is so high, the NPV is negative and has a longer payback time than the double glazed window.





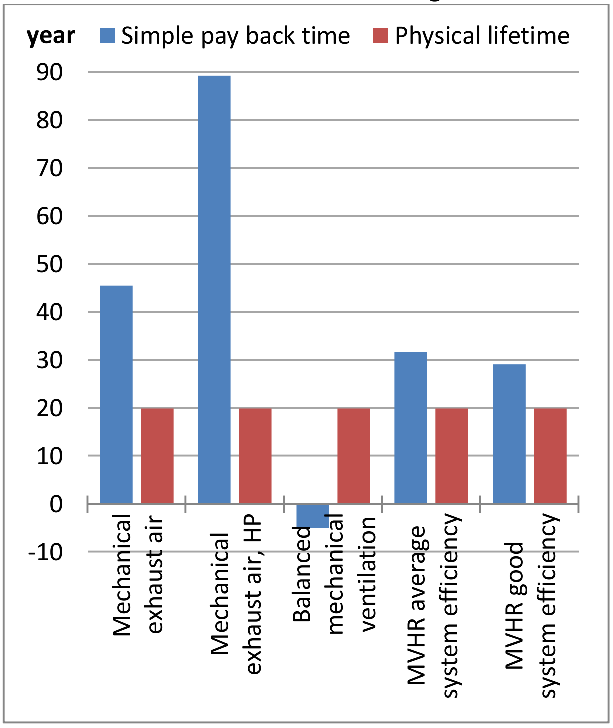


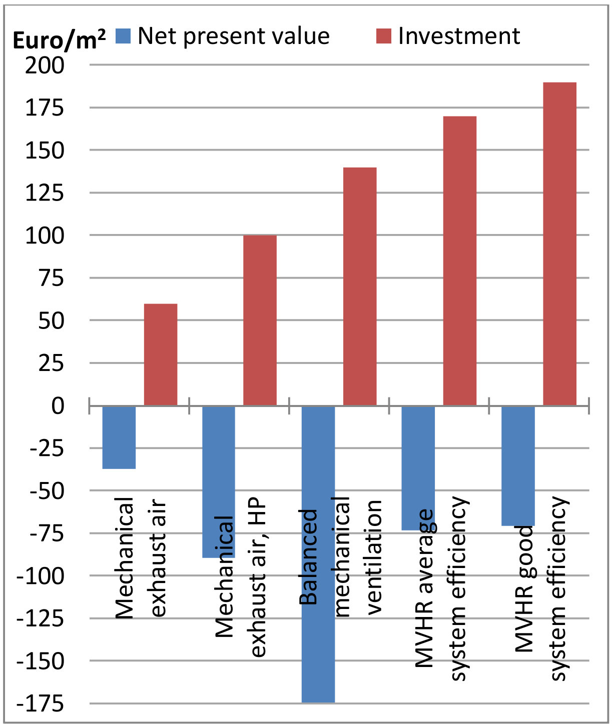


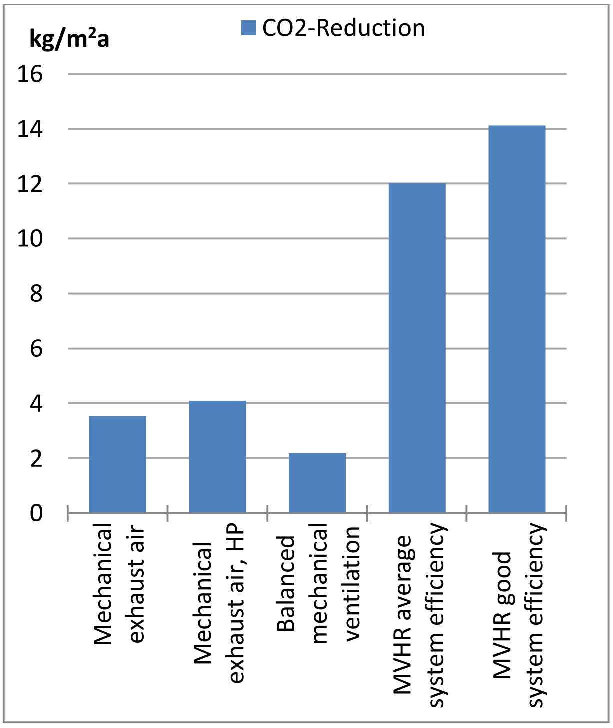
Ventilation – [Starting point: Natural ventilation]

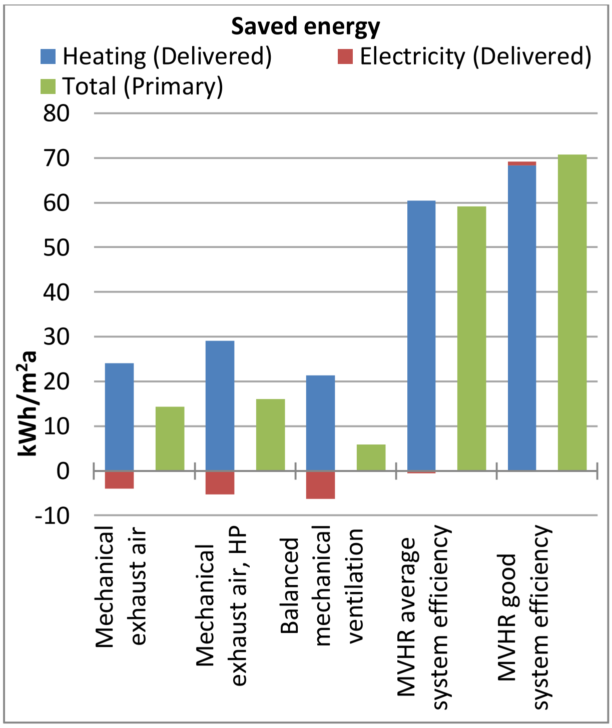
- Mechanical exhaust air (SEL=1.5 kJ/m^3) / Mechanical exhaust air, HP (SEL=1.5 kJ/m^3; COP=3.2)/ Balanced mechanical ventilation (SEL=2.3 kJ/m^3) / MVHR Average system efficiency (75%; SEL=1.5 kJ/m^3) / MVHR Good system efficiency (90%; SEL=1.2 kJ/m^3)

Both Exhaust air and balanced mechanical ventilation gives a better indoor environment, but don't reduce the energy consumption enough to give a positive NPV. However, MVHR system reduces energy consumption and reduces CO_2 highly. The airtightness with these systems is assumed to be optimized to "passive house" standard and that results in an additional energy savings caused by the low infiltration outside hours of usage.





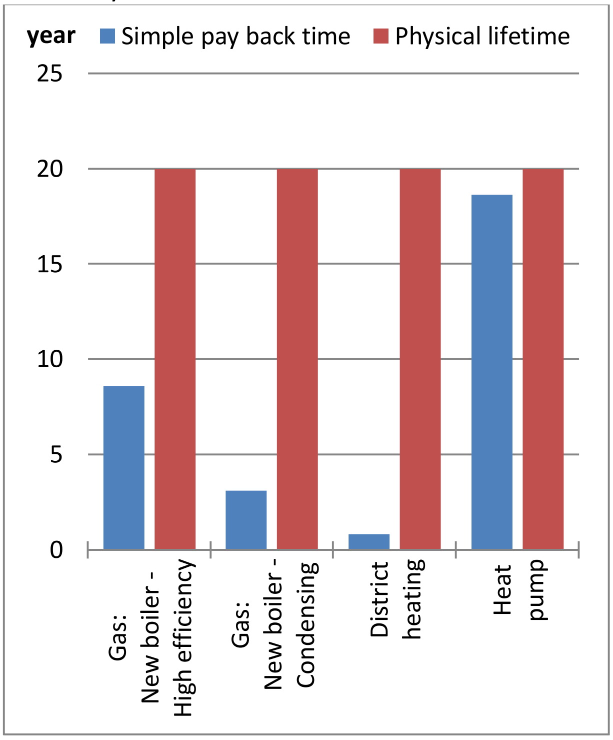


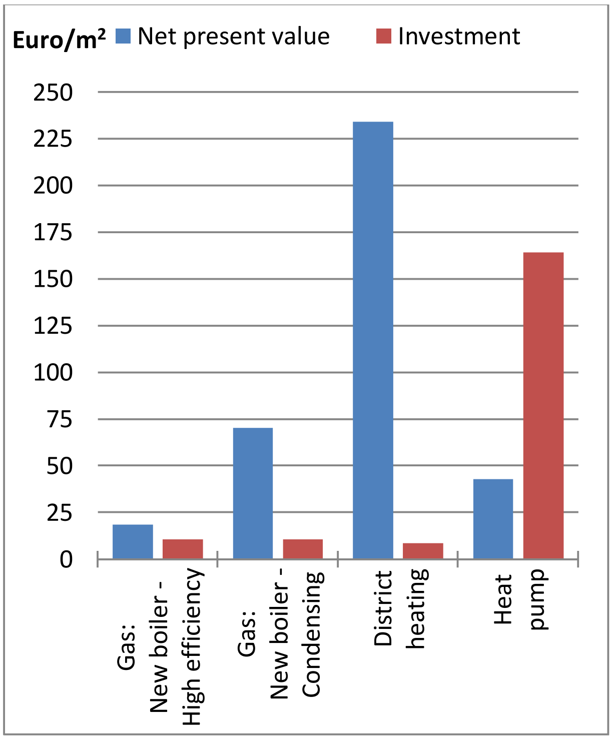


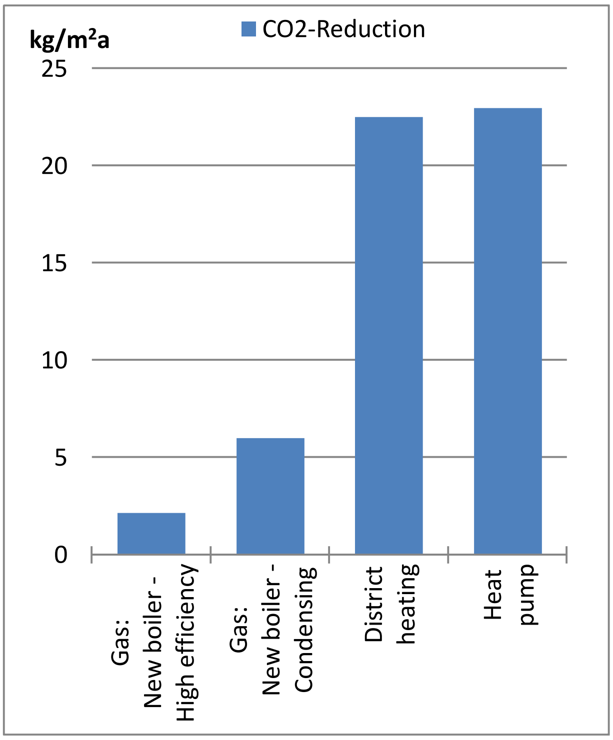
Heat supply – [Starting point: Gas: Old boiler (efficiency = 0.75)]

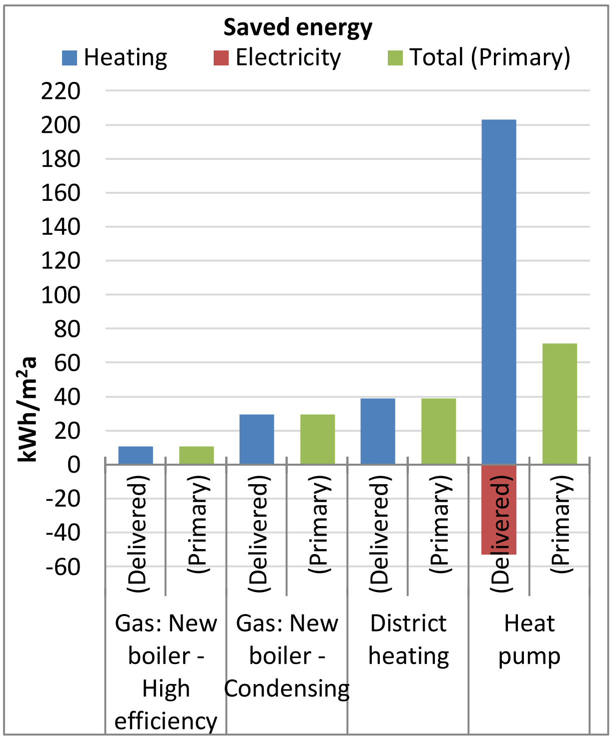
- Gas: New boiler high efficiency (eff. = 0.83) / Gas: New condensing boiler (eff. = 1.02) / District heating (eff. = 1.0) / Heat pump (COP = 3.2)

In the calculations it is assumed that the pipes in the building and the radiators are not replaced when changing the heat supply. Heat pump: includes pipes in the ground and depends of the power demand of the building. That is why the district heating system has the cheapest investment, best NPV and shortest payback, but the heat pump results in a higher amount of saved energy although it consumes electricity.





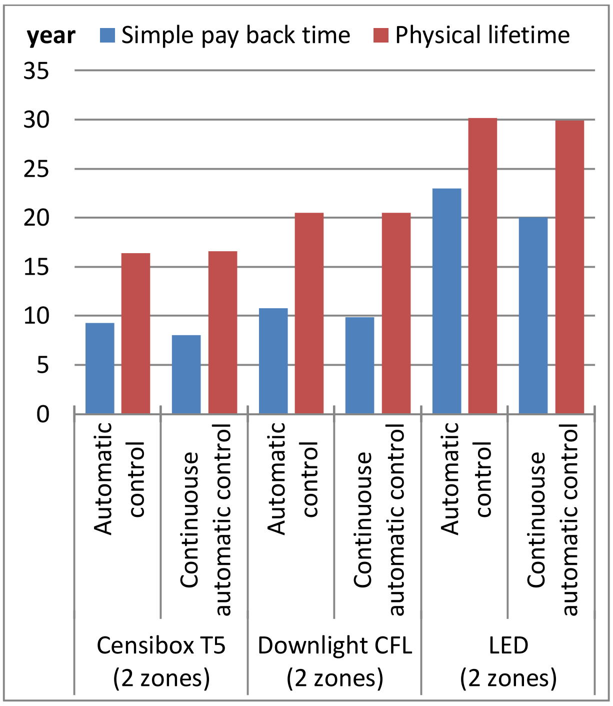


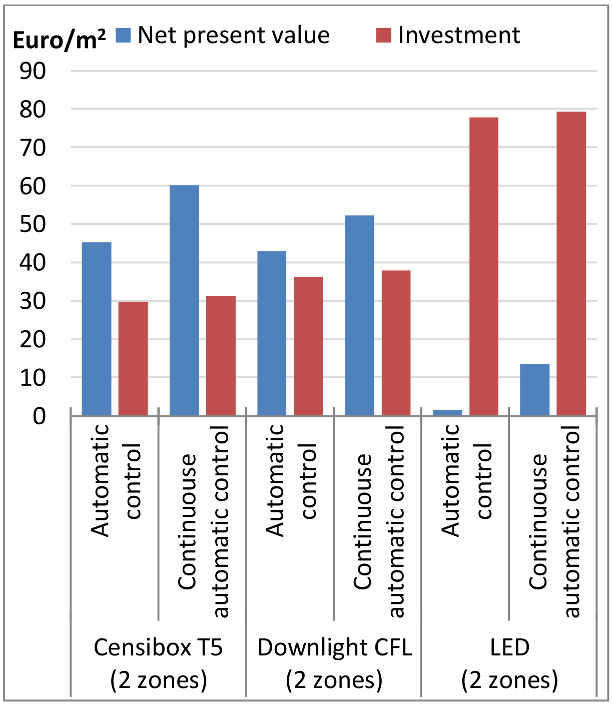


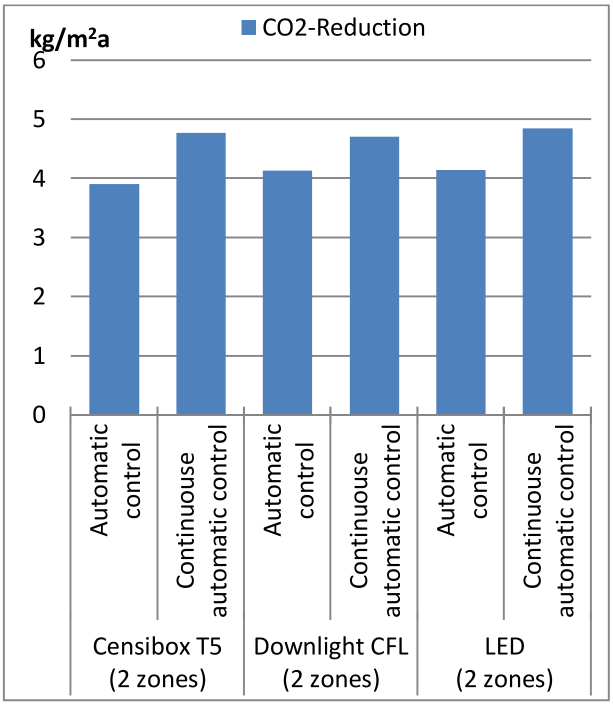
Illuminance and control – [Starting point: Censibox T8; max power: 14 W/m²; manually control (1 zone)]

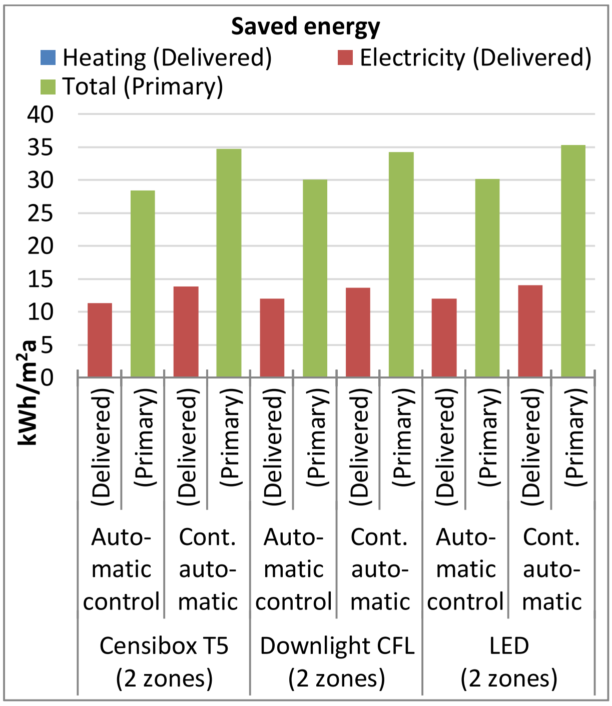
- Censibox T5 rectangular 142x1515 (max power = 0.80 W/m^2) / Downlights (CFL) (max power = 0.34 W/m^2) / LED Circular 450 (2012) (max power = 0.34 W/m^2) with automatic control or continuous automatic dimming control.

The NPV of the LED is low because the investment is high. It is expected that the future developments of LED will lower the price of LED in the future. We assume that the classroom has already the Censibox-system with T8 installed. A big amount of the energy saving and CO_2-reduction is also caused by the optimized control system. The advantage of fewer replacements for LED-fixtures during the period of analysis is not included in the NPV which would give a more equal NPV for the three different luminaires.





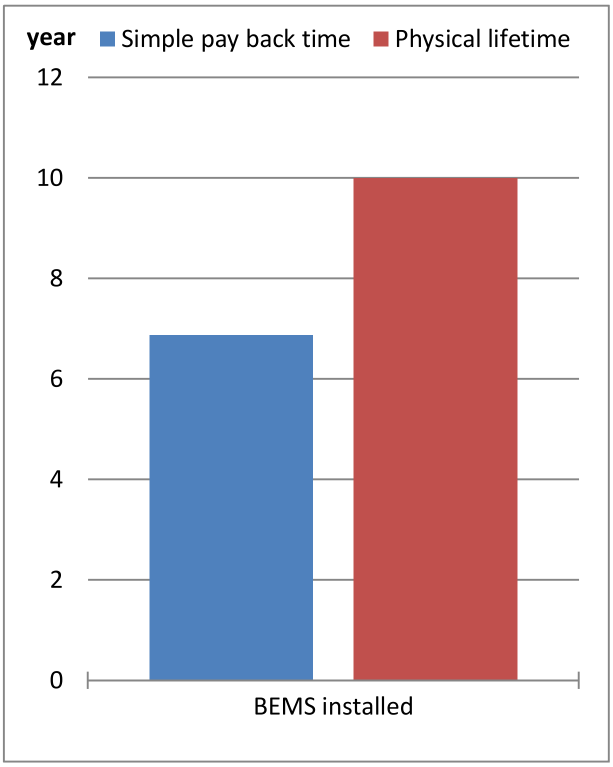


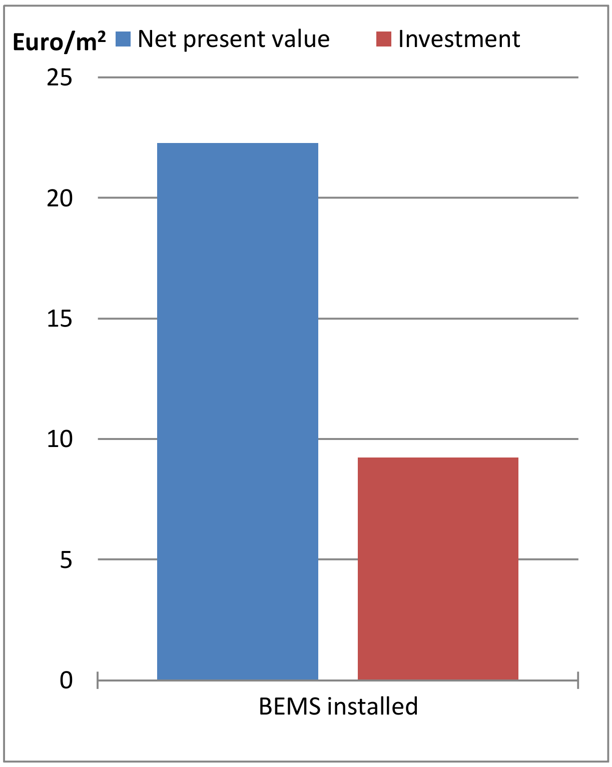


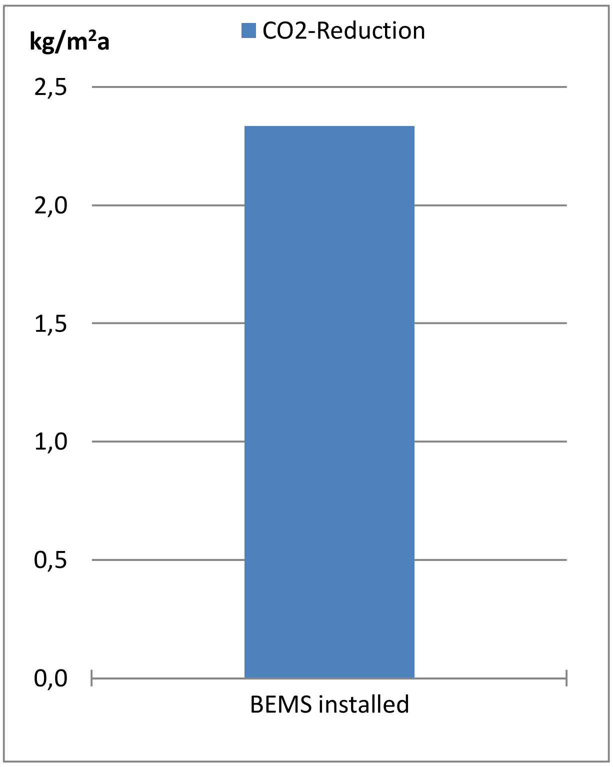
BEMS – Building energy management system [Starting point: none]

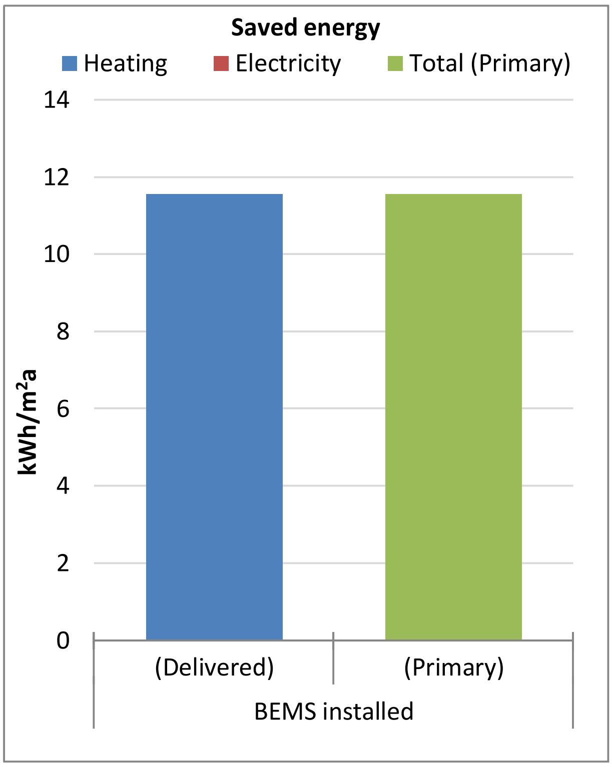
- Installed (50% reduction)

The energy consumption of the school is reduced with the installation of a BEMS and the NPV is high.





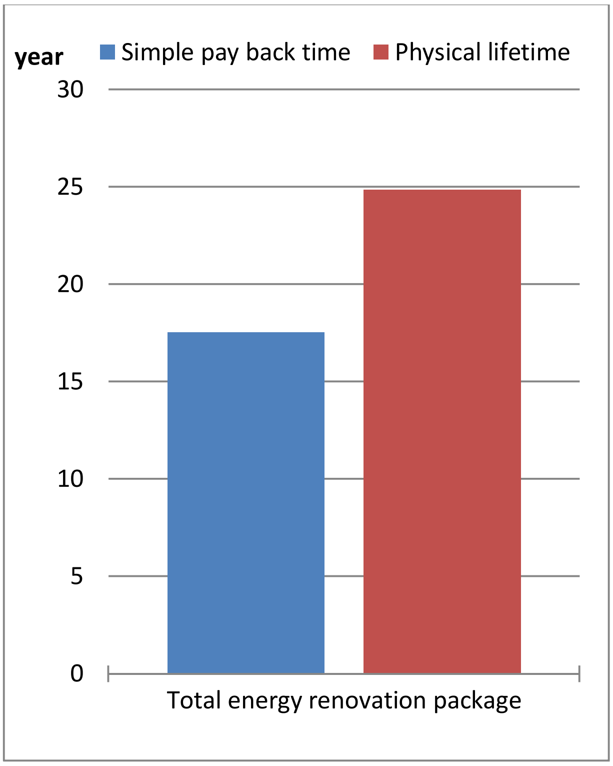


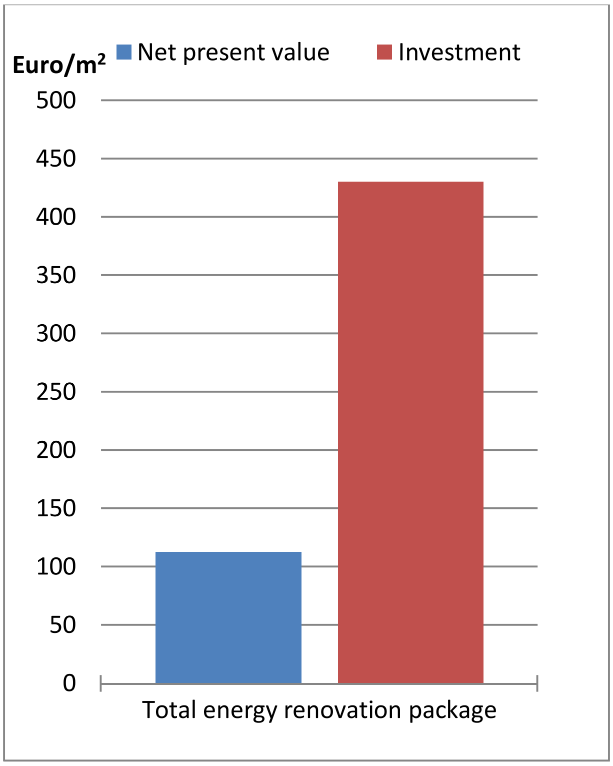


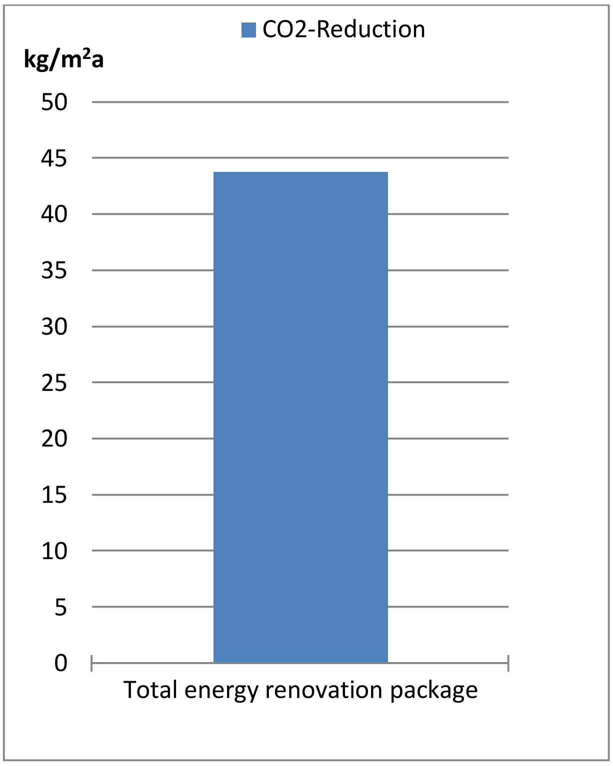
Total energy renovation package

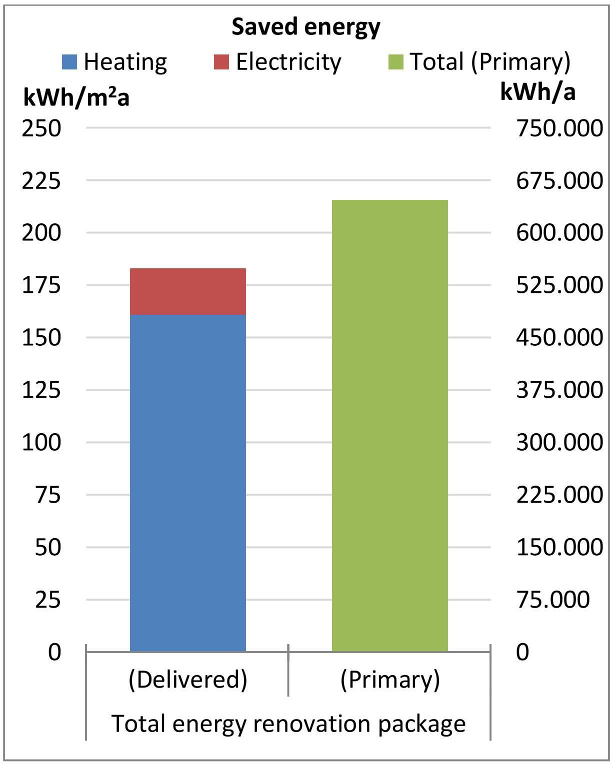
For each technology is it generally the option with the best NPV that has been chosen for the total renovation concept. If it's not, an option with reasonably energy saving or good economy was chosen. The payback time is lower than the average lifetime and the NPV is positive, but not high. Much energy is saved and the emission of CO_2 is much reduced compared to the starting point.

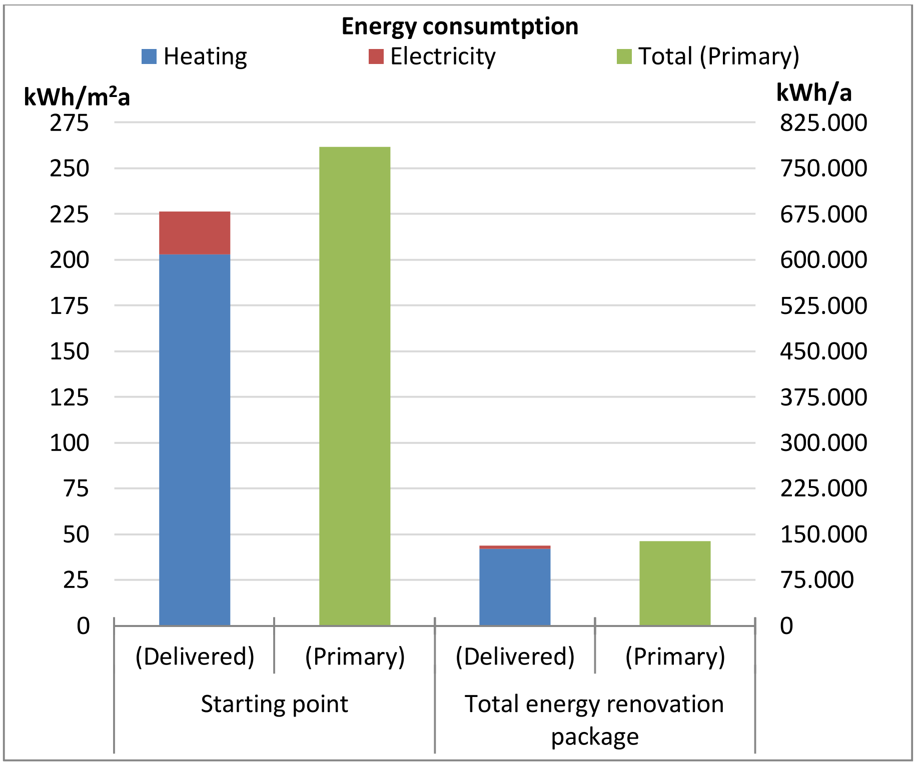
Total energy renovation package	**Chosen technologies**
Solar thermal heating	13 m^2
Photovoltaics (120 m^2)	Monocrystalline
Extra external wall insulation	+ 200 mm
Extra floor insulation	+ 200 mm
Extra roof insulation	+ 200 mm
Windows	Double glazed (low-e-coated)
Ventilation system	Mechanical vent. with good system effeciency
Heat supply	District heating
Illuminance	Downlights (Compact Fluorescent Lamps)
Control	Continuous automatic dimming control
BEMS – Building energy management system	Installed






CO2-Reduction
kg/m²a
50
45
40
35
30
25
20
15
10
5
0
Total energy renovation package


Saved energy
Heating
Electricity
Total (Primary)
kWh/m²a
kWh/a
250
225
200
175
150
125
100
75
50
25
0
750.000
675.000
600.000
525.000
450.000
375.000
300.000
225.000
150.000
75.000
0
(Delivered)
(Primary)
Total energy renovation package


Energy consumtption
Heating
Electricity
Total (Primary)
kWh/m²a
kWh/a
275
250
225
200
175
150
125
100
75
50
25
0
825.000
750.000
675.000
600.000
525.000
450.000
375.000
300.000
225.000
150.000
75.000
0
(Delivered)
(Primary)
(Delivered)
(Primary)
Starting point
Total energy renovation package

Yearly energy consumption	Heating [kWh/m²a]	Electricity [kWh/m²a]	Total (Primary) [kWh/m²a]	Total (Primary) [kWh/a]
Starting point	203,2	23,4	261,7	785.100
Total energy renovation package	42,1	1,7	46,4	139.050
Energy saving	161,1	21,7	215,4	646.050

8. RESULTS OF INDOOR ENVIRONMENT CALCULATIONS FOR DENMARK

8.1. COPENHAGEN

8.1.1. Reduction of losses from the building envelope

Besides the original aim of reducing heat losses, an improved insulation for windows and the outer wall has also a positive effect on thermal comfort during cold seasons.

Better insulation standards result in higher surface temperatures and less down draught on windows (see Figure 8.1 and Figure 8.2). The effect from the improved windows is much higher than the effect from additional wall insulation, because the reference is worse and improving steps are bigger. The down draught at the windows directly influences the draught risk. Values should, at the best, not be higher than 0.15 m/s.

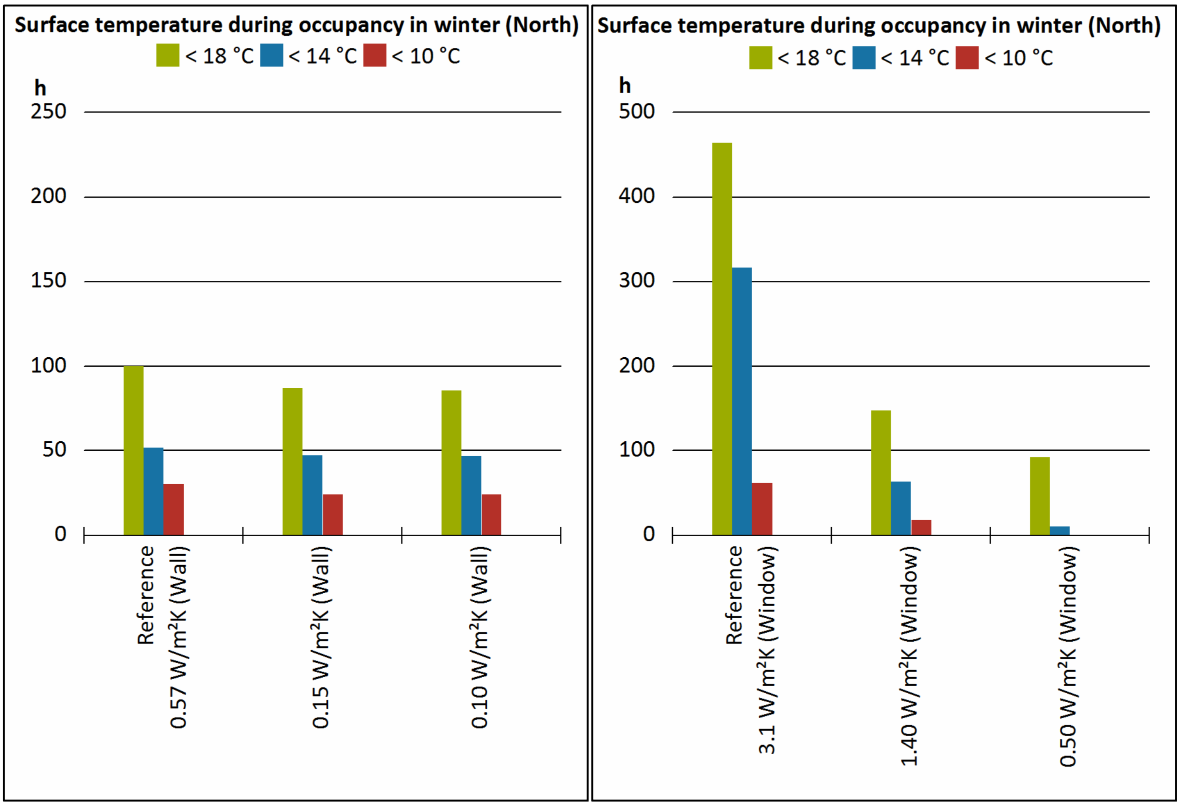


Figure 8.1: Frequency of surface temperature undershooting at the outer wall and windows with different insulation standards

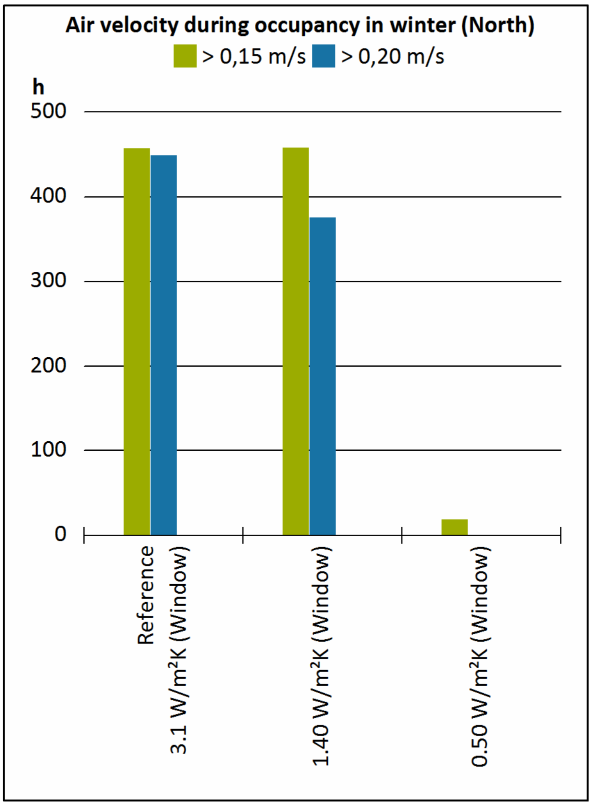


Figure 8.2: Frequency of down draught near the windows with different insulation standards

Besides these results, it should be mentioned, that only changing windows in an old building without improving the outer wall at the same time, might cause mould problems, if the air change rate is considerably reduced.

Both, surface temperature and down draught, have a direct impact on thermal comfort. The surface temperature influences radiant heat exchange between the human body and the wall. The effect of the different measures on the mean radiant temperature and therefore thermal comfort can be seen in Figure 8.3. The higher the radiant temperature is, the lower the air temperature can be with the same thermal comfort. It should be kept in mind, that the area of the outer wall in the simulated case is quite small, compared the area of windows. In a corner room the influence of wall insulation will be higher. This effect can be translated also to floor and roof insulation. The bigger the area connected to outdoor conditions is, the higher is its effect on the radiant temperature in the room.

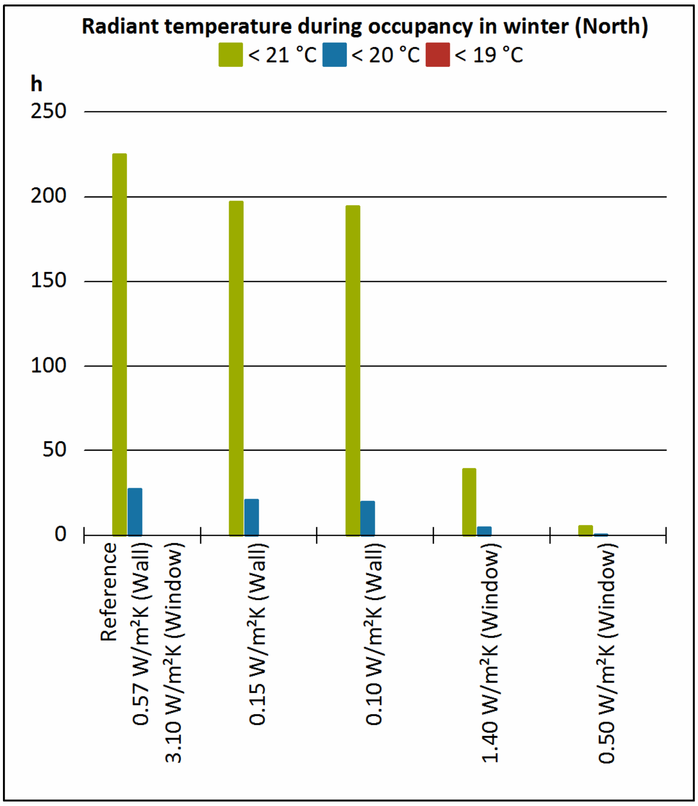


Figure 8.3: Frequency of mean radiant temperature undershooting with different insulation standards at the outer wall and windows

Besides the effects seen for winter, the improved insulation also has an effect in summer (see Figure 8.4). The room is not able to cool down at night as much as with low insulation standards and the risk of overheating rises. For the same reason like in winter, the effect of improved windows is more visible than for improved wall insulation with also the same restrictions like explained for winter conditions. The overheating effect has to be compensated either with reducing gains or with systems for passive or active cooling. It should be mentioned that the calculated improved windows do already have a lower g-value for less solar heat load (see Appendix 2).

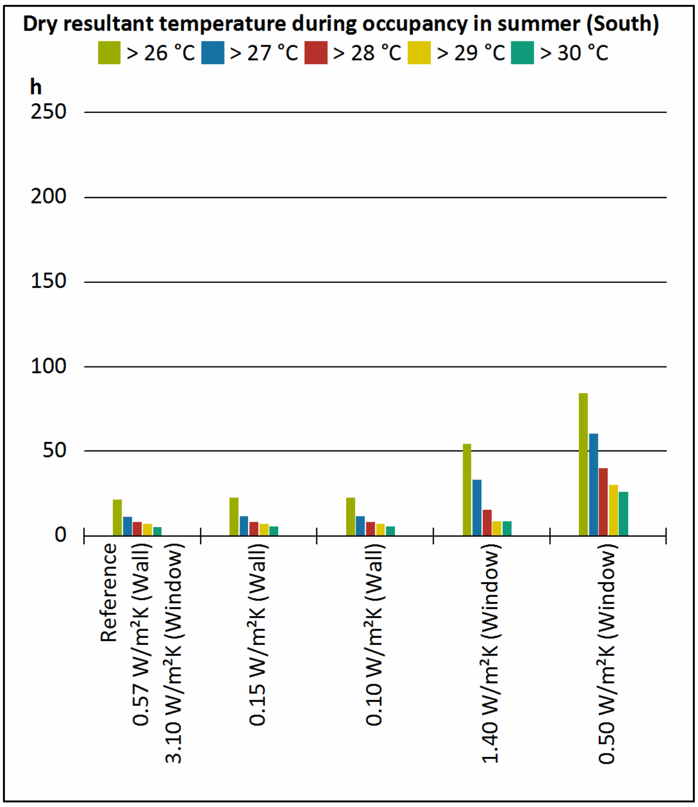


Figure 8.4: Frequency of dry resultant temperature overshooting with different insulation standards at the outer wall and windows

8.1.2. Ventilation

Manual window ventilation normally is substituted in schools first to improve indoor air quality in winter and second to save energy demand through ventilation heat losses. The improvement of indoor air quality can be guaranteed by several systems (mechanical ventilation in different variations and automated window ventilation), if designed in a proper way (see Figure 8.5). The second effect of not using natural pulse ventilation in winter is that indoor temperature stays constantly over 20℃ (see Figure 8.6) and draught risk, caused by fully opened windows, is avoided.

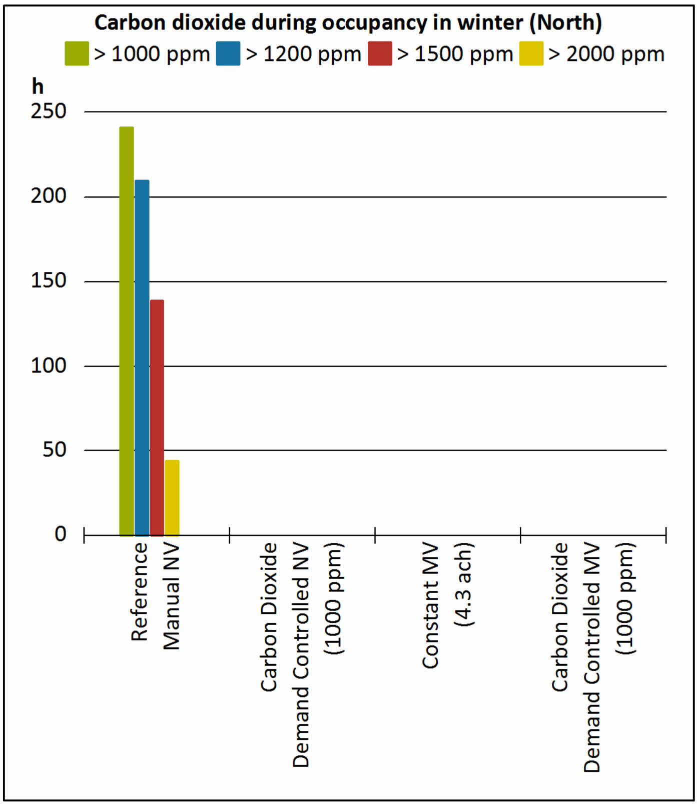


Figure 8.5: Frequency of carbon dioxide overshooting in winter with different ventilation systems

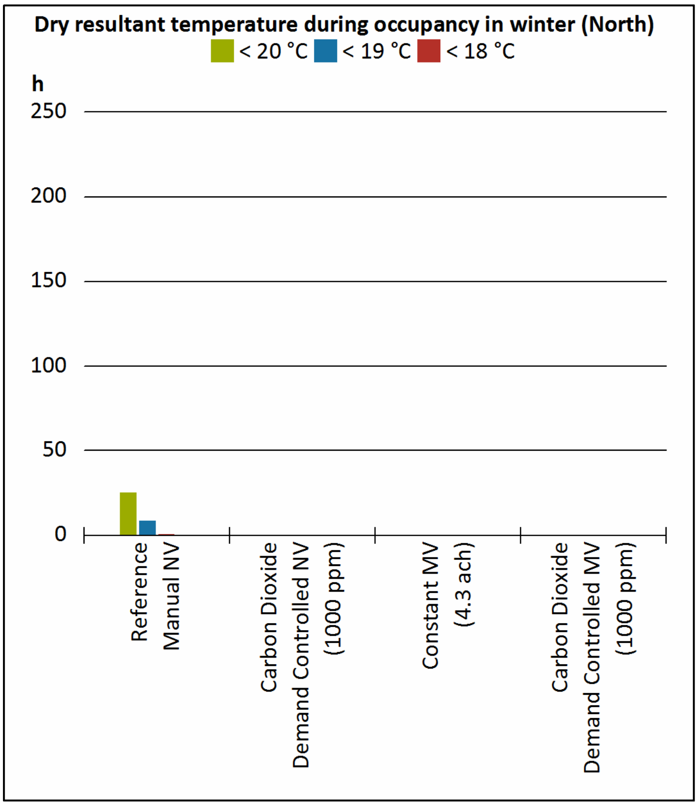


Figure 8.6: Frequency of dry resultant temperature undershooting in winter with different ventilation systems

The situation is different for summer seasons. As demonstrated in Figure 8.7, the restricted flow rate of mechanical ventilation, especially when only carbon dioxide is the only control issue, causes more overheating hours. This effect appears even with a low insulation standard and would be worse with a high insulation standard, when rooms can't cool down through surfaces in the night. Particularly because it is no problem to control indoor air quality without negative draught effects, natural ventilation (controlled manually and automatically) can provide a higher cooling effect through higher ventilation rates in summer. Using only mechanical ventilation in summer, the ventilation rate has to be increased (passive cooling) or supply air has to be precooled (active and passive systems) according to the heat loads inside.

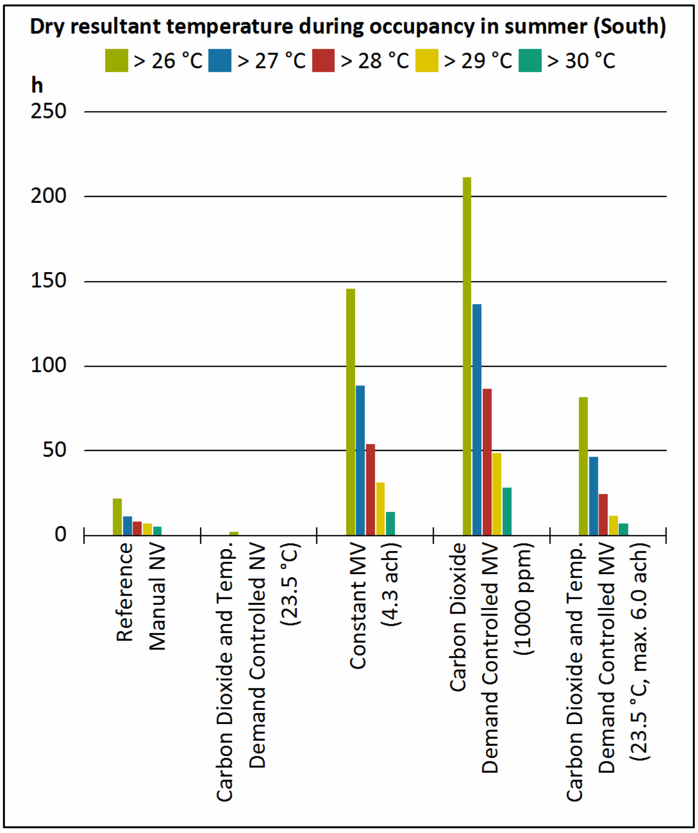


Figure 8.7: Frequency of dry resultant temperature overshooting in summer with different ventilation systems

8.1.3. Reduction of gains

Reducing gains is one possibility to avoid or reduce overheating in summer, but the effect of lower heat emission from electric lighting is small (see Figure 8.8). A significant effect can be seen by using flexible blinds on the outside instead of inside. Here the effect would be even bigger for situations with reduced heat removal caused by a higher insulation standard or a restricted air flow rate.

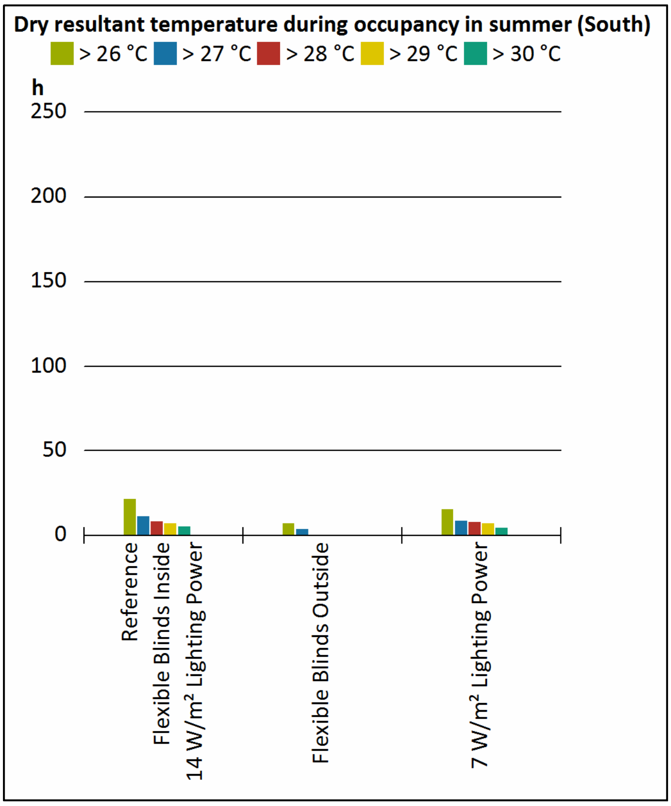


Figure 8.8: Frequency of dry resultant temperature overshooting in summer with different measures reducing gains

8.1.4. Passive cooling

Although an increased ventilation rate during occupancy could also be assigned to passive cooling practices, its effects were already shown in chapter 8.1.2. That was done, because it is difficult to separate effects from combined control issues especially in natural ventilation. Temperature control influences carbon dioxide levels and carbon dioxide control influences indoor temperature.

In this chapter effects from passive cooling through night flushing and ground air ducts are shown, both methods for cooling without a cooling unit. With night flushing both mechanical ventilation and natural ventilation through clerestory windows show a similar effect for reducing the overheating hours. But also both systems might make more sense in combination with systems creating a bigger overheating problem than natural day ventilation, for example when mechanical ventilation has to be used due to traffic noise issues (see Figure 8.9).

Using ground ducts for precooling supply air in summer for mechanical ventilation creates a significant improvement in overheating hours compared to mechanical ventilation without ground ducts. But compared to natural ventilation the overheating is worse. So, if mechanical ventilation has to be used for other reasons like noise or outside air quality, ground ducts can be a reasonable alternative to an increased air flow or mechanical cooling (compare Figure 8.9). The system could also be combined with night ventilation.

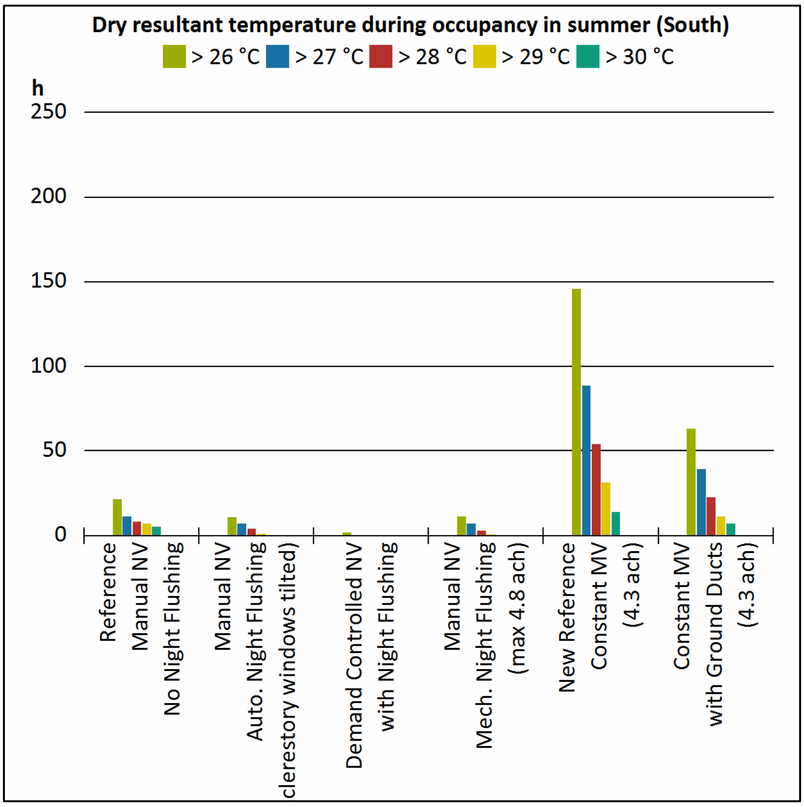


Figure 8.9: Frequency of dry resultant temperature overshooting in summer with night flushing systems and ventilation through ground ducts

9. APPENDIX 1. TECHNICAL AND ECONOMIC INPUT DATA FOR THE CALCULATIONS FOR DENMARK

ASCOT

All costs in EURO

INSULATION STANDARD		No insulation	BR61 (Construction period)	BR77	BR77	BR95 + BR-S98	BR08 (New build)	BR10 (New build)
External wall (light construction)	W/m²K	1,10	0,50	0,30	0,30	0,20	0,20	0,15
External wall (heavy construction)	W/m²K	1,60	0,60	0,40	0,40	0,30	0,20	0,15
Floor	W/m²K	0,40	0,40	0,30	0,30	0,20	0,15	0,10
Roof	W/m²K	1,90	0,40	0,20	0,20	0,15	0,15	0,10
Windows and doors	W/m²K	3,10	3,10	2,90	2,90	1,80	1,50	1,40
Windows g-factor		0,75	0,75	0,75	0,75	0,75	0,63	0,63
Losses foundations	W/mK	0,50	0,30	0,25	0,25	0,25	0,15	0,12
Losses around windows	W/mK	0,10	0,10	0,10	0,10	0,10	0,03	0,03
Air tightness, 50Pa	l/sm²	4,0	4,0	4,0	4,0	3,0	1,5	1,5

SOLAR HEATING per housing unit	Renovation	Life-time	Area	VSOL	ηo	a1	a2	Pump	Maintenance
Unit	€	years	m²	m³	–	W/m²K	W/m²K²	W	€/year
Solar-DHW central	12.203	20,0	13	0,6	0,80	2,48	0,016	3,80	138
Solar-DHW central	17.124	20,0	20	1,0	0,80	2,48	0,016	3,44	140

Photovoltaic (costs per kWp)	Renovation	Life-time	Area	Efficiency	Wpeak	kWpeak	Maintenance
Unit	€/kWp	years	m²	-	W/m²	kWp/school	€/year
Amorphous	2.327	25,0	120,0	0,80	80,0	7,68	0
Poly-crystalline	2.302	25,0	120,0	0,80	134,0	12,86	0
Mono-crystalline	2.297	25,0	120,0	0,80	150,0	14,40	0

Photovoltaic (prize for electricity at 100% usage of own production)	
Unit	€/MWh
Purchase prize (electricity)	280
Contribution for usage of own production	0
Total prize (savings)	**280**

Ventilation	Renovation	Life-time	SEL	Efficiency	qm	qi ref	qi opt	Maintenance	COP
Unit	€/m²	years	kJ/m³	-	l/s/m²	l/s/m²	l/s/m²	€/year	-
Natural ventilation	0,00	40,0	0,00	0%	1,63	0,28	0,28	0	0,0
Mechanical exhaust air	40,00	20,0	1,50	0%	1,63	0,28	0,28	1.200	0,0
Mechanical exhaust air, HP	80,00	20,0	1,50	0%	1,63	0,28	0,28	2.400	3,2
Balanced mechanical ventilation	120,00	20,0	2,30	0%	1,63	0,28	0,28	3.600	0,0
MVHR average system efficiency	150,00	20,0	1,50	75%	1,63	0,28	0,28	4.500	0,0
MVHR good system efficiency	170,00	20,0	1,20	90%	1,63	0,28	0,28	5.100	0,0

HEAT SUPPLY	Renovation	Life-time	Fullload efficiency	Correction	Part load efficiency	Correction	Idle running losses Factor	Losses to room	Output	Circ. pump	Losses from pipes		Price €/MWh
Unit	€	years	-	-	-	-	-	-	kW	-	kWh/m² year	CO_2/kWh [kg]	€/MWh
District heating	33.503	20,0	1,00	0,000	1,00	0,000	0,000	1,00	457	1,0%	10	0,20	80,67
N-gas: old furnace high efficiency		20,0	0,87	0,001	0,86	0,002	0,015	0,85	457	1,0%	20	0,21	116,00
N-gas: new furnace high efficiency	41.679	20,0	0,91	0,001	0,91	0,001	0,007	0,80	457	1,0%	20	0,21	116,00
N-gas: new furnace condensing	41.679	20,0	0,96	0,003	1,06	0,003	0,007	0,80	457	1,0%	20	0,21	116,00
Heat pump	604.134	20,0	1,00	0,000	1,00	0,000	0,000	0,80	457	1,0%	20	0,60	280,00
Heat pump		**20,0**	**COP**	**tc**	**te**								
Heat pump			3,2	42,5	-1,5								

Prices €/MWh	Constant	Variable	Total
Reference			
Electricity	0,00	280,00	280,00
District heating	26,67	80,67	107,33
N-gas	0,00	116,00	116,00
Heating oil	0,00	106,67	106,67

BEMS	Renovation	Life-time	Reduction
Unit	€	years	%
No	0	0,0	0%
Yes	27.680	10,0	50%

Extra wall insulation	Renovation	Life-time	λ	Thickness
Unit (Cost per component area)	€/m²	years	W/mK	m
+150 mm insulation	296,82	40,0	0,040	0,150
+200 mm insulation	327,22	40,0	0,040	0,200
+250 mm insulation	352,93	40,0	0,040	0,250
+300 mm insulation	375,44	40,0	0,040	0,300
Extra roof insulation	**Renovation**	**Life-time**	**λ**	**Thickness**
Unit (Cost per component area)	**€/m²**	**years**	**W/mK**	**m**
+100 mm insulation	22,03	40,0	0,040	0,100
+150 mm insulation	29,10	40,0	0,040	0,150
+200 mm insulation	35,44	40,0	0,040	0,200
+250 mm insulation	41,30	40,0	0,040	0,250
+300 mm insulation	46,80	40,0	0,040	0,300
Extra floor insulation	**Renovation**	**Life-time**	**λ**	**Thickness**
Unit (Cost per component area)	**€/m²**	**years**	**W/mK**	**m**
+50 mm insulation	20,83	40,0	0,040	0,050
+100 mm insulation	28,83	40,0	0,040	0,100
+150 mm insulation	36,83	40,0	0,040	0,150
+200 mm insulation	44,83	40,0	0,040	0,200
+250 mm insulation	52,83	40,0	0,040	0,250
+300 mm insulation	60,83	40,0	0,040	0,300

Windows (cost per sqm. Window)	Renovation	Life-time	U-value	g-factor	Light tranmittance	A-factor	Barrier	
Unit	€/m²	years	W/m²K	-	-	-	-	
Average area pr. window							0,8	
2-layer energy glass	463,05	20,0	1,20	0,63	0,65	0,8	0,8	0,40
3-layer energy glass	732,69	20,0	0,70	0,53	0,62	0,8	0,8	0,34

Air tightness	Renovation	Life-time	qi
Unit	€/m²	years	l/s/m²
Passiv house	20,00	20,0	0,60

ILLUMINATOR CLASSROOM	Renovation	Life-time	Power level min.	Power level max.	Lightlevel min from illuminator	Lightlevel max from illuminator
Unit	€/m²	years	W/m²	W/m²	Lux	Lux
Censibox T5 rectangular 142x1515	23,94	14,7	0,80	4,0	43	216
Downlights (CFL)	35,00	20,00	0,34	6,00	21	300
LED Circular 450 (Estimated for 2012)	72,06	30,7	0,34	3,4	21	207

ILLUMINATOR CONTROL CLASSROOM	Renovation	Life-time	Effect in use	Stand by power use for lighting non-usage time
Unit	€/m²	years	W/m²	W/m²
Automatic	4,65	20,0	0,045	0,037
Continuously automatic	6,97	20,0	0,053	0,037

ILLUMINATIONZONES CLASSROOM	Renovation	Life-time	Zones
Unit	€/m²	years	-
2 zones	6,53	25,0	2

ILLUMINATOR CORRIDOR/STAIRCASE	Renovation	Life-time	Power level min.	Power level max.	Lightlevel min from illuminator	Lightlevel max from illuminator
Unit	€/m²	years	W/m²	W/m²	Lux	Lux
Censibox T5 rectangular 142x1515	23,94	14,7	0,80	4,0	43	216
Downlights (CFL)	24,00	20,00	0,11	2,00	10	100
LED Circular 450 (Estimated for 2012)	72,06	30,7	0,34	3,4	21	207

ILLUMINATOR CONTROL CORRIDOR/STAIRCAS	Renovation	Life-time	Effect in use	Stand by power use for lighting non-usage time
Unit	€/m²	years	W/m²	W/m²
Automatic	4,65	20,0	0,045	0,037
Continuously automatic	5,11	20,0	0,053	0,037

Dimensioning temperature		
Dim. indoor temperature	20	℃
Dim.outoor temperature	-12	℃
Dim. temperature difference	**32**	**℃**

ASCOT

All costs in EURO

INSULATION STANDARD		No insulation	BR61 (Construction period)	BR77	BR77	BR95 + BR-S98	BR08 (New build)	BR10 (New build)
External wall (light construction)	W/m²K	1,10	0,50	0,30	0,30	0,20	0,20	0,15
External wall (heavy construction)	W/m²K	1,60	0,60	0,40	0,40	0,30	0,20	0,15
Floor	W/m²K	0,40	0,40	0,30	0,30	0,20	0,15	0,10
Roof	W/m²K	1,90	0,40	0,20	0,20	0,15	0,15	0,10
Windows and doors	W/m²K	3,10	3,10	2,90	2,90	1,80	1,50	1,40
Windows g-factor		0,75	0,75	0,75	0,75	0,75	0,63	0,63
Losses foundations	W/mK	0,50	0,30	0,25	0,25	0,25	0,15	0,12
Losses around windows	W/mK	0,10	0,10	0,10	0,10	0,10	0,03	0,03
Air tightness, 50Pa	l/sm²	4,0	4,0	4,0	4,0	3,0	1,5	1,5

SOLAR HEATING per housing unit	Renovation	Life-time	Area	VSOL	ηo	a1	a2	Pump	Maintenance
Unit	€	years	m²	m³	–	W/m²K	W/m²K²	W	€/year
Solar-DHW central	12.203	20,0	13	0,6	0,80	2,48	0,016	3,80	138
Solar-DHW central	17.124	20,0	20	1,0	0,80	2,48	0,016	3,44	140

Photovoltaic (costs per kWp)	Renovation	Life-time	Area	Efficiency	Wpeak	kWpeak	Maintenance
Unit	€/kWp	years	m²	-	W/m²	kWp/school	€/year
Amorphous	2.327	25,0	120,0	0,80	80,0	7,68	0
Poly-crystalline	2.302	25,0	120,0	0,80	134,0	12,86	0
Mono-crystalline	2.297	25,0	120,0	0,80	150,0	14,40	0

Photovoltaic (prize for electricity at 100% usage of own production)	
Unit	€/MWh
Purchase prize (electricity)	280
Contribution for usage of own production	0
Total prize (savings)	**280**

Ventilation	Renovation	Life-time	SEL	Efficiency	qm	qi ref	qi opt	Maintenance	COP
Unit	€/m²	years	kJ/m³	-	l/s/m²	l/s/m²	l/s/m²	€/year	-
Natural ventilation	0,00	40,0	0,00	0%	1,44	0,28	0,28	0	0,0
Mechanical exhaust air	40,00	20,0	1,50	0%	1,44	0,28	0,28	1.200	0,0
Mechanical exhaust air, HP	80,00	20,0	1,50	0%	1,44	0,28	0,28	2.400	3,2
Balanced mechanical ventilation	120,00	20,0	2,30	0%	1,44	0,28	0,28	3.600	0,0
MVHR average system efficiency	150,00	20,0	1,50	75%	1,44	0,28	0,28	4.500	0,0
MVHR good system efficiency	170,00	20,0	1,20	90%	1,44	0,28	0,28	5.100	0,0

HEAT SUPPLY	Renovation	Life-time	Fullload efficiency	Correction	Part load efficiency	Correction	Idle running losses Factor	Losses to room	Output	Circ. pump	Losses from pipes		Price €/MWh
Unit	€	years	-	-	-	-	-	-	kW	-	kWh/m² year	CO_2/kWh [kg]	€/MWh
District heating	25.825	20,0	1,00	0,000	1,00	0,000	0,000	1,00	371	1,0%	10	0,20	80,67
N-gas: old furnace high efficiency		20,0	0,87	0,001	0,86	0,002	0,015	0,85	371	1,0%	20	0,21	116,00
N-gas: new furnace high efficiency	32.081	20,0	0,91	0,001	0,91	0,001	0,007	0,80	371	1,0%	20	0,21	116,00
N-gas: new furnace condensing	32.081	20,0	0,96	0,003	1,06	0,003	0,007	0,80	371	1,0%	20	0,21	116,00
Heat pump	492.631	20,0	1,00	0,000	1,00	0,000	0,000	0,80	371	1,0%	20	0,60	280,00
Heat pump		**20,0**	**COP**	**tc**	**te**								
Heat pump			3,2	42,5	-1,5								

Prices €/MWh	Constant	Variable	Total
Reference			
Electricity	0,00	280,00	280,00
District heating	26,67	80,67	107,33
N-gas	0,00	116,00	116,00
Heating oil	0,00	106,67	106,67

BEMS	Renovation	Life-time	Reduction
Unit	€	years	%
No	0	0,0	0%
Yes	27.680	10,0	50%

Extra wall insulation	Renovation	Life-time	λ	Thickness
Unit (Cost per component area)	€/m²	years	W/mK	m
+150 mm insulation	296,82	40,0	0,040	0,150
+200 mm insulation	327,22	40,0	0,040	0,200
+250 mm insulation	352,93	40,0	0,040	0,250
+300 mm insulation	375,44	40,0	0,040	0,300

Extra roof insulation	Renovation	Life-time	λ	Thickness
Unit (Cost per component area)	€/m²	years	W/mK	m
+100 mm insulation	22,03	40,0	0,040	0,100
+150 mm insulation	29,10	40,0	0,040	0,150
+200 mm insulation	35,44	40,0	0,040	0,200
+250 mm insulation	41,30	40,0	0,040	0,250
+300 mm insulation	46,80	40,0	0,040	0,300

Extra floor insulation	Renovation	Life-time	λ	Thickness
Unit (Cost per component area)	€/m²	years	W/mK	m
+50 mm insulation	20,83	40,0	0,040	0,050
+100 mm insulation	28,83	40,0	0,040	0,100
+150 mm insulation	36,83	40,0	0,040	0,150
+200 mm insulation	44,83	40,0	0,040	0,200
+250 mm insulation	52,83	40,0	0,040	0,250
+300 mm insulation	60,83	40,0	0,040	0,300

Windows (cost per sqm. Window)	Renovation	Life-time	U-value	g-factor	Light tranmittance	A-factor	Barrier	
Unit	€/m²	years	W/m²K	-	-	-	-	
Average area pr. window							0,8	
2-layer energy glass	463,05	20,0	1,20	0,63	0,65	0,8	0,8	0,40
3-layer energy glass	732,69	20,0	0,70	0,53	0,62	0,8	0,8	0,34

Air tightness	Renovation	Life-time	qi
Unit	€/m²	years	l/s/m²
Passiv house	20,00	20,0	0,60

ILLUMINATOR CLASSROOM	Renovation	Life-time	Power level min.	Power level max.	Lightlevel min from illuminator	Lightlevel max from illuminator
Unit	€/m²	years	W/m²	W/m²	Lux	Lux
Censibox T5 rectangular 142x1515	23,94	14,7	0,80	4,0	43	216
Downlights (CFL)	35,00	20,00	0,34	6,00	21	300
LED Circular 450 (Estimated for 2012)	72,06	30,7	0,34	3,4	21	207

ILLUMINATOR CONTROL CLASSROOM	Renovation	Life-time	Effect in use	Stand by power use for lighting non-usage time
Unit	€/m²	years	W/m²	W/m²
Automatic	4,65	20,0	0,045	0,037
Continuously automatic	6,97	20,0	0,053	0,037

ILLUMINATIONZONES CLASSROOM	Renovation	Life-time	Zones
Unit	€/m²	years	-
2 zones	6,53	25,0	2

ILLUMINATOR CORRIDOR/STAIRCASE	Renovation	Life-time	Power level min.	Power level max.	Lightlevel min from illuminator	Lightlevel max from illuminator
Unit	€/m²	years	W/m²	W/m²	Lux	Lux
Censibox T5 rectangular 142x1515	23,94	14,7	0,80	4,0	43	216
Downlights (CFL)	24,00	20,00	0,11	2,00	10	100
LED Circular 450 (Estimated for 2012)	72,06	30,7	0,34	3,4	21	207

ILLUMINATOR CONTROL CORRIDOR/STAIRCAS	Renovation	Life-time	Effect in use	Stand by power use for lighting non-usage time
Unit	€/m²	years	W/m²	W/m²
Automatic	4,65	20,0	0,045	0,037
Continuously automatic	5,11	20,0	0,053	0,037

Dimensioning temperature		
Dim. indoor temperature	20	°C
Dim.outoor temperature	-12	°C
Dim. temperature difference	**32**	**°C**

10. APPENDIX 2. TECHNICAL SETTINGS FOR THE INDOOR COMFORT SIMULATIONS

10.1. COPENHAGEN

Table 10.1: Settings for boundary conditions

Boundary conditions	Settings
Weather file	IES VEpro weather file for Copenhagen
Geometry room	9*7*3.2 m
Number of persons	30 + 1
Occupancy	See daily schedule below, typical holidays
Window area per floor area	25 %
Heating system	On with outdoor temperature < 15°C
Control heating	Setpoint 22 °C, night reduction to 17°C
Mechanical ventilation	Supply air temperature heated up to 18 °C in winter

Table 10.2: Window setups for natural ventilation

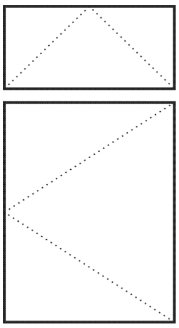
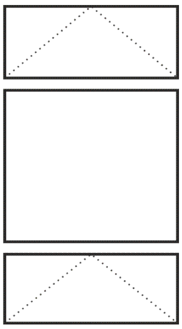
Window type 1	Window type 2
 6 x 0.72 m² tilted; 6 x 1.92 m² open	 6 x 0.60 m² tilted; 6 x 0.60 m² tilted

Table 10.3: Occupancy schedule for a school day

8				9				10				11				12				13				14				15			

Table 10.4: Reference case and variations for measures to reduce losses from the building envelope

Reduction of losses from the building envelope	Reference case	Insulation V1	Insulation V2	Windows V1	Windows V2
U-value outer wall	0.57 W/m²K	0.15 W/m²K	0.1 W/m²K		
U-value window	3.1 W/m²K			1.4 W/m²K	0.5 W/m²K
Air tightness window (50 Pa)	4 l/sm²			1.5 l/sm²	1.5 l/sm²
G-value window	75 %			60 %	52%

Table 10.5: Reference case and variations for measures for ventilation optimization

Ventilation	Reference case	Ventilation V1	Ventilation V2	Ventilation V3	Ventilation V4
Windows	Type 1	Type 2			
Manual natural ventilation (It should be clear, that this is a very idealistic natural ventilation, because real users won't open windows in such a consequent way)	Clerest. windows: Tilted with T_{dr} > 23.5°C, Lower windows: Rushairing between lessons (45 min)				
Automated natural ventilation		Tilted opening only when T_{dr} > 20.5°C			
Mechanical ventilation			Balanced system, 4.3 ach	Balanced system, max 4.3 ach	Balanced system, max 6.0 ach
CO_2-control		Setpoint according to outdoor temperature*		Setpoint 1000 ppm	Setpoint 1000 ppm
Temperature-control		Max opening with T_{dr} > 23.5°C			Max ventilation rate with T_{dr} > 23.5°C

* The opening width of all windows is restricted due to outdoor temperatures, so that no draught risk emerges. This implies to windows located higher in the facade can be opened earlier and wider with low outdoor temperatures.

Clerestory windows: For outdoor temperatures below 10°C the carbon dioxide setpoint for opening is 900 ppm (with a small hysteresis), for outdoor temperatures between 10 and 15 °C the carbon dioxide setpoint is 700ppm and for outdoor temperatures above 15 °C the carbon dioxide setpoint is 400ppm.
Lower windows: For outdoor temperatures above 10°C the carbon dioxide setpoint for opening is 700 ppm.

Table 10.6: Reference case and variations for measures to reduce internal gains

Reduction of internal gains	Reference	Blinds V1	Lighting power V1
Blinds	Inside (F_c=0.6)	Outside (F_c=0.31)	
Manual blind control	With direct solar radiation > 300 W/m²		
Electrical lighting power	14 W/m²		7 W/m²
Manual control	With lighting level < 300 lx		

Table 10.7: Reference case and variations for passive cooling systems

Passive cooling systems	Reference	Cooling V1	Cooling V2	Cooling V3	Cooling V3
Day ventilation setting	Reference ventilation, Ventilation V2	Reference ventilation	Ventilation V1	Reference ventilation	Ventilation V2
Precooling supply air with earth channel (heat exchanger with 30 % efficiency from 10°C to outdoor air)*					Active with T_{dr} > 23.5°C and T_o > 15°C
Automated natural night flushing		Clerestory windows tilted with T_{dr} > 21.5°C	Clerestory and lower windows tilted with T_{dr} > 21.5°C		
Mechanical night flushing				Balanced system, 4.8 ach with T_{dr} > 21.5°C	

*This imitates a ground duct with 50 m length, 3 m beneath the surface.