Energy saving technology screening within the EU-project “School of the Future”

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Abstract

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. The screening will also provide important information about the cost-efficiency of the screened technologies for different climates and school typologies. The intended audiences for this work 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 School of the Future project, especially for the design guidelines to be developed, but also the extension of the information tool and the tailored training.

Keywords: school; retrofit; EU FP7; energy efficiency; renewables; indoor comfort; technology screening; energy savings; CO2-reductions; indoor climate quality; cost-efficiency

1. Introduction

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.

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, cooling, ventilation and lighting systems
- Energy supply/generation systems

The identified measures / retrofit technologies were organized according to these headlines.

The impacts of the different measures has been analysed with calculation (ASCOT) and simulation (IES VE-pro) 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 CO₂-levels down and the light – 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 Toronto).

This paper presents the typologies used for the calculation, the selected technologies and some examples of the results obtained.

2. School typologies

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.

Each school has a threatened floor area of 3000 m² and all classrooms have a distribution of the window/floor-area of 25 %. The compact floor is one floored building with at big roof area and the side and central corridor are three floored buildings with a smaller roof area but with a larger area of facades and windows.

Fig. 1. Floorplans of the three school typologies.
3. Reduction of losses from the building envelope

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

The thermal transmittance of insulation materials are characterised by their $\lambda$-values. In Denmark a $\lambda$-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 $\lambda$-value of 0.04 W/m/K has been used for the screening. The thicknesses used for each country/location appear from the country results reports.

Depending on the geographical location and age of existing school buildings they will have different thicknesses of insulation – from none in Southern Italy to perhaps 100 mm or 200 mm in an already partly renovated school in the Nordic countries. The possibility to add extra layers of insulation will depend on the construction of the roof, floor and walls. In this analysis simple situations are considered; for the roof where insulation can be added from above and for the floor where insulation can be added from underneath. An extra layer of insulation may be added on the inside or on the outside of the walls, the latter being more efficient, but generally also more costly. The inside insulation is however reducing the available floor area.

3.1. Additional roof insulation

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 will vary considerably from country to country.

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

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 will vary considerably from country to country.

3.3. Exterior wall insulation

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.

3.4. Window replacement

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.

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, VLT. One window might for example have a relatively high VLT and relatively low g-value, which can be an advantage when the internal heat gains are high as in offices and schools as it contributes to prevent overheating.

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.
4. Optimal handling of gains

4.1. Reduction of overheating/preventing cooling demand

The idea with windows is to let in the daylight and to look out. It is therefore a good idea to start with the light transmission of the glass. Some countries have a demand of daylight in percentage of external light in their building regulations. In Scandinavia it is 2% in average indoors of the external light. To get this level you must have 10% of a room’s floor area as glass area in the windows. This is based on the light transmission VLT of the glass unit to be 80% (double glazed unit with 2 pcs 4 mm clear glass). If the glass is tinted and coated to get better U-value (LE-glass and solar control glass) one has to increase the glass area to compensate for the lower light transmission according to table

Solar control in the glass is a good idea because it always works even with diffuse radiation. However, the need for g-factor (total solar energy transmission) must be correct as it is linked to the light transmission. The glass package let in light/heat as 2/1. This means that the optimal solar control glass lets in for example 70% light and 35% of the energy (g-factor 0.35). Description code 70/35. In Norway the building regulation from 2010 says that the g-factor should be max 0.15 if there is a cooling system in the building. So now we must take care of the light transmission, the U-value and the g-factor as shown in tab. 2.

We have through the years experienced, that solar control glass with light transmission around 60% normally gives sufficient daylight in the classrooms. They can be delivered with U-values down to 0.7 W/m2K for the window and 0.5 W/m2K for the glass package. This saves energy, and also gives a good internal climate close to the window in wintertime, even with rather high windows. It gives a total energy transmission in the summer with g-factor = 0.3 compared to a normal double glazed unit with g-factor 0.82 or a normal double glazed unit with LE-glass at 0.65. When the light transmission is 60% the glass area should be 13.3% of the floor area to satisfy a daylight factor at 2%.

4.2. Controls: building energy management system (BEMS) and thermostats

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. The impact of installing thermostats is therefore analysed for the Italian schools and climates.

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.

Thermostatic controllers vary in accuracy and speed of reaction. For the calculations two different qualities have been tested.

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%.

The costs for the installation of thermostats are a function of the number of radiators and the quality of the thermostats. Country specific costs are used for the Italian analyses.

5. Heating, cooling, ventilation and lighting systems

5.1. Ventilation

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.

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.

5.2. Electrical lighting systems with controls

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 as 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. The efficient lighting systems considered are new light tubes – T5, compact fluorescent light (CFL) and LED lamps. Controls are manual, continuous dimming and 2 zones versus one in the reference case have been analysed.

6. Energy supply/generation systems

6.1. Integration of photovoltaic cells in the build environment

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. Part 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 have to be taken into account.

The solar cells produce electricity at varying efficiencies depending primarily of the type of cells used. For the screening we have chosen to consider monocrystalline cells, 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. However, most common are the grid connected systems as the battery storage systems are still very costly.

6.2. Solar domestic hot water systems

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.

Solar thermal systems has not been analysed for Germany and Norway. In Denmark 2 system sizes judged reasonable for a 3000 m² school has been analysed: 13 m² and 20 m² collector area.

6.3. Heat supply

For the analyses it has been assumed that the reference buildings have heating supply from an old gas boiler. The different possibilities to improve and replace this system are:

- New high efficiency gas boiler
- New condensing gas boiler
- District heating system
• Electrical heat pump

The technical characteristics of each of the above replacement technologies are primarily efficiencies which represent the best available technologies today. For the heat pump a yearly COP of 3.2 was used.

7. 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.

8. Calculation and simulation programs used for the screening

8.1. Energy calculation tool – ascot

All the calculations of energy savings – and corresponding reduced CO₂-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 economic 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 social or environmental and other external costs incurred by the project (not included in the first prototype but an option that can be added at a later stage)

The ASCOT model allows a comparison between a traditional (reference) building renovation 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 (ISO/DIS 13790), Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies: Heat generation system, thermal solar systems.

8.2. Indoor environment simulations

As for most calculated reference scenarios natural pulse ventilation is used for the ventilation of the classrooms, it is essential to get realistic results for the air change rate. 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. And the classrooms are defined to have only single-sided natural ventilation, so the effect from wind turbulence on air change rate can, esp. in summer, not be neglected.

For these reasons, the indoor environmental simulations were done with the simulation program VE-Pro (version 6.4.0.11, Integrated Environmental Solutions Limited, Glasgow, UK). This program has a very reliable calculation
tool for natural ventilation (MacroFlo), 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.

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

For all of the 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. 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.

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 resultant temperatures in summer (south facing rooms)
- Carbon dioxide level in winter

9. Presentation of the results

For each energy renovation measure the results of the energy calculation screening are presented on 4 plots showing [1]:

- Simple payback time & physical lifetime,
- Net present value & investment,
- CO₂ 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 considerably 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 CO₂-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. Norway has not resolved this issue for its electrical energy distribution and therefore the primary energy factors for Denmark has been used.

The calculated results for extra insulation of the floor in a compact plan school in Denmark:
The result illustrated that the CO₂-reduction, the energy savings and the investment increases together with the thickness of the insulation. Those results are seen in all the graphs with extra thickness of insulation. The net present value is in this case positive and is increasing together with the thickness of extra insulation up to 150 mm where the investment increases more than the amount of energy there is saved and therefore the net present value decreasing. That turnover happens for all of the types of insulations but within different point depending on the investment and the amount of saved energy.

The results also illustrated how the different type of construction of the schools affects the results.
In figure 4 the results for a school in Denmark with compact plan are shown. Compared to the results for a school with a side corridor in the in figure 5, the two types of construction gives two levels of energy savings, but also two levels of investments.

The geometry of the schools makes the difference in the results. A compact plan (figure 4) has only one floor and a side corridor (figure 5) has three plans. The threatened floor area are the same so there for the school in one plan has a three times bigger roof area and a much smaller wall area. In the results above the compact plan have a high net present value for all of the steps of extra insulation, but also a high investment. A bigger investment gives a bigger energy saving and if the investment not is to high the net present value will be higher.

The opposite result will be shown for the result of extra insulation of the walls because the side corridor has a bigger area of wall to insulate and to reduce the energy loss.
The figure 6 illustrated the results for a German school with an old gas boiler as an existing heating supply. By changing to a new gas boiler the energy consumption are reduced, but the net present values are still negative due to the low savings compared to the investments. By changing to a heat pump the energy savings a high for heating, but the electricity consumption is increased and due to the energy primary factor is the primary energy savings less than half of the energy saving for the heating. The NPV value is though the energy savings negative because of the high investment. District heating has a smaller energy saving for the heating than the heat pump, but partly due to the energy factors the district heating have the highest primary energy saving, but not the highest delivered energy saving or the biggest economic savings. The investment for the district heating are lower than the investment for the heat pump and there for is the net present value higher and even positive.

The reduction of CO$_2$ depends on if the saved energy not only are for electrical consumption or for room heating but also if it is gas, oil, district heating or electrical heating.

In this case the conclusion of the best energy saving technology depends on which focus you have and for instance how your central heating plant produces energy. The technology with the highest energy saving of delivered energy is not the same technology there have the biggest CO$_2$-reduction or highest net present value.
10. Conclusion

The calculation tool ASCOT is working well and it is possible to illustrate and compare the effect of many different energy saving technologies. Besides simulating the results for each of the energy saving technologies, ASCOT can simulate the effect of several energy saving technologies on the same school. In the report [1] the screening provides an overview on the available building and system retrofit technologies for energy efficient school building including their impact on the energy performance and indoor environment quality. The report [1] also provide the needed information about the economic result of the retrofitting energy saving technologies so that e.g. municipalities all over Europe easily can use the screening or with ASCOT make a screening of retrofitting energy saving technologies on their own school.

Acknowledgements

The School of the Future project receives funding by the European Commission within the 7th Framework Programme under the contract no. ENER/FP7/260102.

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