School of the Future




BUILDING CONSTRUCTION ELEMENTS

Guidelines for energy retrofitting – Towards zero emission schools with high performance indoor environment

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Front page illustrations

Top and bottom from left:

Tito Maccio Plauto Scuola, Cesena, Italy.

Solitude Gymnasium, Stuttgart, Germany.

Brandengen skole, Drammen, Norway.

Hedegårdsskolen, Ballerup, Denmark.

INTRODUCTION

OBJECTIVES

One of the purposes of the School of the Future project is to provide designers and planners with retrofit guidelines for concepts and technologies to obtain energy efficiency and good indoor environment quality in school buildings – ranging from simple, but significant energy reduction and indoor environment improvements to the final target: Zero emission schools.

The objective of these guidelines to develop an overview of the available building and system retrofit technology for energy efficient school buildings including their impact on energy performance and the indoor environment quality as well as their economic feasibility. The intended audience for the guidelines are designers and planners of school buildings. The idea is that municipalities all over Europe can use the guidelines and find technologies useful for their specific school buildings. In addition, the work constitutes background knowledge for further work in the "School of the Future" project, especially the extension of the information tool.

In an earlier EU project: "Bringing Retrofit Innovation to Application in Public Buildings" (http://brita-in-pubs.eu) retrofit design guidelines for public buildings have been developed on certain specific innovative technologies and design strategies. These design guidelines has been used as the basis and inspiration for the School of the Future guidelines and are still relevant to consider when designing building energy renovation projects. The following BRITA in PuBs guidelines exist concerning building construction elements:

- Innovative Insulation
- Advanced Windows
- Passive Solar Heating
- Reduction of Overheating
- Daylighting Improvements

The energy efficient building has many benefits with regard to indoor conditions and comfort, besides the obvious benefit of low energy consumption if it is designed carefully. These benefits relate to the thermal and acoustic indoor climate as well as indoor air quality.

When a building has to be retrofitted due to age and wear, it will most likely be economically favourable to include energy measures. The maintenance interval is often 20–40 years, so if energy measures are not included, another 20–40 years will pass before energy upgrading becomes relevant again.

"SCHOOL OF THE FUTURE" PROJECT

"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 the focus of the project. The energy and indoor environment performance of 4 demonstration buildings in 4 European countries and climates will be greatly improved due to a comprehensive 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 can have a knock-on effect on other schools and on the residential sector, since

the pupils can act as communicators to their families. Tailored training sessions are aimed at improving user behaviour and the awareness of energy efficiency and the indoor environment.

Zero emission buildings are a main goal for various country roadmaps of 2020. The demonstration buildings within the project may not completely reach this level as the aim of the EU 7FP Call is cost efficiency and knock-on effect potential. The retrofit concepts will, however, result in buildings with far lower energy consumption than with regular retrofits with high indoor environmental quality - thus leading the way towards zero emission. They may 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 on 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 and the resulting high interest caused a consortium to be formed that included well-known partners from the building industry.

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
	Danish Building Research Institute (SBi), Aalborg University Copenhagen
	Ballerup Kommune
	Saint-Gobain Isover a/s
	Schneider Electric Building Denmark AS
Norway	Stiftelsen SINTEF
	Drammen Eiendom KF
	Glass og Fasadeforeningen

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SUMMARY

This guideline on Building Construction Elements is one of four guidelines produced by the School of the Future project. The other three guidelines cover: Building Service Systems, Improved Indoor Environmental Quality and Concepts for Zero Emission Schools.

This guideline begins with a general chapter on how to start up and manage an energy retrofit project. The importance of team work and follow-up on quality control are stressed.

Then follows a chapter on the insulation of the building envelope, external walls and roof, including replacement of windows. A number of examples from the four School of Future demonstration projects illustrate this chapter. The chapters also covers other glazing elements, i.e. double skin facades and solar shading devices – again illustrated with an example from one of the schools retrofitted in the School of the Future project.

The next chapter introduces the need to also consider interior building elements – mainly in relation to the indoor environment including acoustics.

The final chapter presents the results of a technical and financial screening of four energy retrofitting measures for building construction elements: Additional wall, roof and floor insulation plus the replacement of windows. This screening was carried out for one climate in Denmark, Germany and Norway and three climates in Italy. The results presented are Net Present Value (NPV), simple payback time, reduced CO_2-emissions and energy savings. As the reference situation, the climate, costs of the measures and the energy prices vary from country to country it is very difficult to draw general conclusions. The reader is advised to study the part that is relevant for his/her situation.

Based on the work undertaken within the School of the Future project and the experience gained by the partners of the project, some general recommendations are highlighted below:

For any building renovation project a holistic point of view should be taken. This includes considering which part of the renovation should to be carried out for other reasons than energy savings, wear and tear (deterioration) as the most likely reason. **The need for renovation anyway ("anyway measures") greatly influences the costs** which should be assigned to the energy-related retrofit and thus the NPV and simple financial payback of the investments. Therefore one of the first activities in any renovation project is to identify anyway measures.

Secondly, as early in the renovation process as possible, co-benefits such as a significant improvement of the indoor environment or greatly increased service life of lamps should be identified and kept in focus to make sure that these co-benefits are becoming results of the renovation. It may even be possible to assign an economic value to them – easy enough for the lamps, but also possible for other co-benefits. A recent report from the US Rocky Mountain Institute provides an introduction and practical guidance on how to calculate and present value evidence in support of a retrofit capital decision [21].

A closing remark as a warning: When retrofitting the construction elements of a building, new materials are installed and sometimes old materials are hidden or exposed. This may have a significant impact on the humidity accumulation in the construction elements and/or on issues of fire-safety - and special considerations need to be given to these matters!

STRATEGIES FOR ENERGY EFFICIENCY

Reducing energy demand and providing good indoor climate is fundamental when retrofitting school buildings.

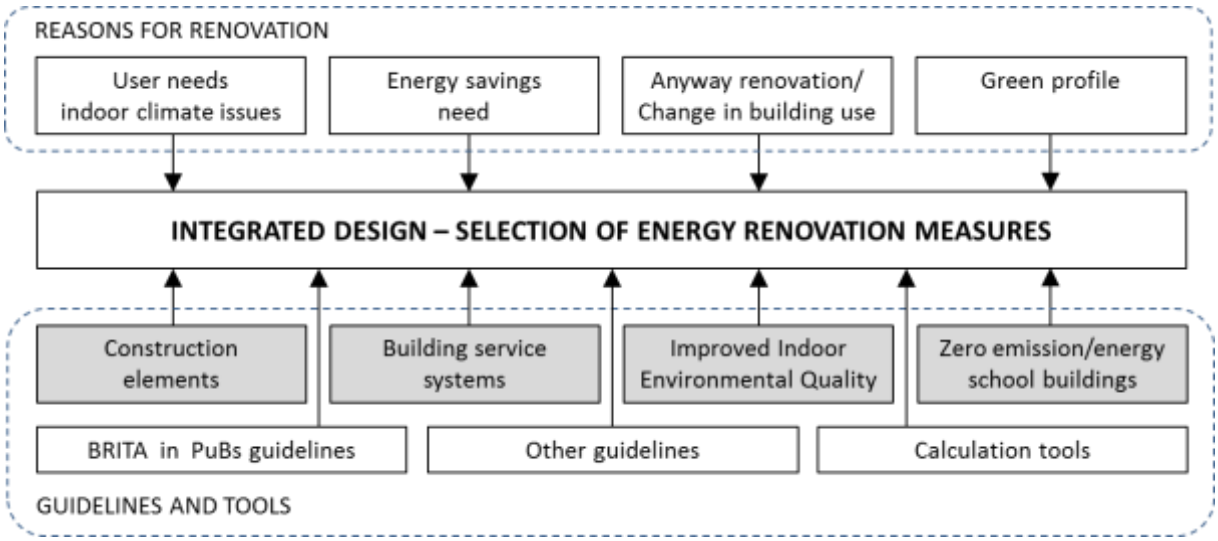
Planning and design process

A preliminary study of the building to be retrofitted should uncover characteristics and conditions of building elements. The year of construction and previous retrofitting can be helpful when mapping the state of materials and details. Airtightness testing and thermography will show the quality of previous work.

The building's location and layout may influence the energy consumption. When it comes to retrofitting, however, the options for changing are limited. Anyhow, location and layout are important parameters regarding the choice of measures.

For listed buildings there are specific limitations. The historical look of the building might not be allowed to change, and new measures must not, of course, damage old constructions, i.e. by unintended humidity fluctuation.

After analysing the actual state of the building, the measures should be listed according to ambitions and economy. The flowchart below illustrates the complete energy renovation planning and design process and the following paragraphs describe each step of this process in more detail.



Energy renovation integrated design process.

Goal setting

It is essential to consider sustainability and energy efficiency at the very start, to establish the key targets. Ambitions and intentions should be stated in the building programme, containing a finite number of clear and manageable high level objectives. Objectives regarding building suitability, energy demand and building materials should be emphasised and put into specific terms. To avoid goals from being left out due to pressures from budget or work schedule, they should be deeply rooted within the building owner's organisation.

Example: Goals for the demonstration schools in the SoF project
The success of the retrofits is measured by the realisation of the following goals:

- Reduction of the total energy use > factor 3, verified through monitoring
- Reduction of the heating energy use > 75 %, verified through monitoring

Improvement of the indoor environment quality (air, daylight, acoustic, thermal comfort) with impact on the pupils' performance to be analysed by short-term measurements and questionnaires. These ambitious goals have an impact on construction elements, building service systems and energy supply.

Early intervention

The professional knowledge of architects and engineers is to be combined in the design phase, estimating how different building structures and envelope designs influence the indoor climate and energy use for heating, cooling, ventilation and lighting. Climatic analysis will reveal the potential for utilising available solar, light and wind resources. Concepts should be tested by means of sketch models to assess the design and adjust it to the situation, before gradually developing the final design.

Previously the tendency was to do environmental simulation of building performance at the end of the design process. Any weak points in the performance of the design could then be 'fixed' by adding heating, cooling, shades, vents, fans, panels, etc. However, at the end of the design process it is too late to incorporate various passive techniques, which should be considered in the early, most conceptual stages of the building design process.

Team work

Essentially, an interdisciplinary planning process is based on the idea of optimised team work, which should start in the pre-project stage to make a clear definition of goals. Furthermore, there should be a qualified design process management, and tools for analyses and assessments should be applied, taking into account a variety of options from the very start. The knowledge of different specialists should be introduced at an early stage.

New concepts and new technology applications are challenging for building owners, architects and consultants. If the design team lacks knowledge of environmental issues or if the performance goals are especially challenging, an external process facilitator should be added to the team. The facilitator will have the task to raise performance issues throughout the process and bring specialised knowledge to the design team.

Several teams have today an appointed environmental co-ordinator, who has a specific responsibility to ensure that the goals are followed up through the various project phases.

Energy design in several steps

In the design phase, a wide number of parameters are to be optimised at the same time. Also in an existing building it might be possible to have different building layouts, structures and envelope designs, which will, in different ways, influence the indoor climate and energy use for heating, cooling, ventilation and lighting.

In aiming to reduce the energy consumption, a five-step strategy is generally recommendable:

1. Reducing heat losses and cooling demand
2. Reducing electricity consumption

3. Utilising passive solar gain
4. Controlling and displaying energy use
5. Selecting energy sources, preferably renewables to a large extent

In other words: the starting point is the application of energy efficient measures to reduce energy demand, and then supply the remaining demand with an energy supply system utilising renewable energy sources.

Step 1. *Reducing heat losses and cooling demand* generally has to do with insulation of the building envelope. A well-insulated and airtight envelope with a minimum of cold bridges, plus efficient heat recovery of ventilation air is crucial for the reduction of heat losses. Window size and orientation, shading systems, thermal sinks, plus possibilities for cross ventilation are crucial for the reduction of the cooling demand. Building shape, zoning of room categories and area efficiency might also be considered in existing buildings.

Step 2. *Reducing electricity consumption* generally deals with exploitation of daylight, and low pressure drops in the ventilation system. Furthermore, energy efficient lighting and equipment are obvious measures.

Step 3. *Utilising passive solar gain* generally has to do with optimum window size and orientation, thermal mass activation, and possibly sun spaces and atria.

Step 4. *Controlling and displaying energy use* generally has to do with smart house technologies; i.e. demand control of heating, ventilation, lighting and equipment, and feedback to users on consumption, in order to assist their manual control.

Step 5. Selecting energy sources generally has to do with applying renewable energy sources in order to minimalise purchased energy. Various sources might be applied, depending on natural resources and national policy, for example solar collectors, geothermal heat, firewood or biogas for heating, and photovoltaic or wind for electricity production.

Regarding the three first steps; examples of energy efficient measures are shown in the following chapters.

Following up on the environmental ambitions

In general, when ambitious objectives are set at the beginning of a planning period, caution should be taken to fulfil the objectives. Professionals with different competences, as well as users, should be involved in the conceptual phase, and the building's environmental footprint should be assessed throughout the design process. To have sufficient time for further consideration is often an essential factor, which is easier to handle when the ambitions are deeply rooted among the decision makers.

Measures must be balanced in relation to several goals

Designers should repeatedly estimate how different a plan lay-out, structure and envelope design influence the indoor climate and energy consumption. One major challenge is handling goal conflicts. Measures must be balanced to reach several goals, e.g.:

- Exploitation of daylight benefits user satisfaction and well-being. At the same time, exploitation of daylight reduces the consumption of electric power for artificial lighting. On the other hand, an extended use of glazing may cause a higher demand for heating and possibly cooling energy.

- Air quality and comfort temperature benefit user satisfaction and well-being. A high performance ventilation system is thus required. On the other hand, the energy consumption of the system should be kept as low as possible.
- Adequate acoustics benefit user satisfaction and well-being. The desired reverberation time varies according to functions, and there may be contradictory considerations to take into account regarding multi-functional space. The placement of absorbers must be considered in relation to the benefit of thermal mass stabilising internal temperatures.

Different solutions have different strengths and weaknesses, and the project team has to optimise the solution as a whole, and not on a component-by-component basis. From the assessment of different solutions, the project team identifies parameters that make a difference, and gain an increasing awareness of the environmental impacts of the design. The success criteria should be related to achieving the objectives and intentions stated in the programme.

Tendering and contracting – ensuring the implementation of intensions

Objectives and solutions developed during the planning and design periods should be discussed with the contractor to ensure a mutual understanding of the building quality. Objectives and solutions should further be communicated to the craftsmen, as their knowledge and motivation are key factors when aiming for a high quality building.

Motivation and control

It can be useful to hold a seminar for craftsmen and construction managers before starting the construction. Review of objectives and solutions can help to create an understanding of the accuracy and care for details necessary to achieve high energy and environmental performance. Included should be information and discussion about the practical execution of critical points such as thermal bridges, airtightness, and integration of technical installations. Information about details to be tested, for example pressure drop testing and thermography can create an understanding of the great importance of craftsmanship.

When following up during the construction phase, a quality assurance plan is an important tool. What is to be controlled should be specified in the plan, and further, when to control, and how to do it. The workers should be informed about what, when and how the work will be quality controlled, and they will hopefully perceive the control as positive and want to contribute to a good result.

Following up on the construction site

Technical construction review, airtightness measurement, and thermography should be done at an earlier stage. Function control of the ventilation and heating systems, and the management and visualisation systems are part of the commissioning, but not a topic for this guideline. Regarding construction elements, the «as built» values should be documented in order to compare them with design parameters. A recent review and adjustment of energy calculations with «as built» values could be done, especially if calculated energy consumption is compared with actual consumption.

Example: Commissioning standard in Denmark

During the last year, a team representing Danish Standard has been working on a new standard for commissioning of buildings in Denmark. The new Danish standard was published in 2014 [DS 3090:14] (Commissioning-processen for bygninger - Installationer i nybyggeri og større ombygninger) (The Commissioning process for buildings – Installations in new buildings and major retrofit constructions) and indicates a process for commissioning, which would work under Danish conditions. The aim of the standard is to encourage the Danish building industry to include a systematic commissioning process between construction and operation of the building. An analysis is under way that investigates how great a potential for energy savings there is in the commissioning process.

BUILDING ENVELOPE – NON TRANSPARENT PART

Reducing energy demand requires a well-insulated and airtight envelope with minimum cold bridges. In a renovation process additional insulation may be placed on the external walls, roof and/or floor. This chapter covers these elements and presents examples of different solutions.

Additional insulation

Heat and humidity fluctuations change when adding insulation to an existing construction. What is possible or not possible differs from construction to construction, i.e. inside or outside insulation, or blowing insulation into cavities. But the principal rule is common: air and vapour barrier on the inside, efficient insulation, and vapour permeability to the outside.

For some historical buildings, analyses might show that additional insulation of facades brings a risk of damage by moisture, because the rule of a vapour barrier and vapour permeability cannot be satisfied. In these cases, one has to look for other energy measures as a trade-off for poorly insulated solid walls, for example better roof and basement insulation, and very high performance windows.

Inside or outside insulation

Additional outside insulation of existing façades reduces possible problems with thermal bridges and does not lessen the usable floor area. However, outside insulation may not always be possible, for example if the façades are to be kept for historical or esthetical reasons, the roof overhang is too shallow, or the dimensions of the building plot are exceeded. If so; internal insulation might be an option.

When adding internal insulation, the temperature on the construction parts outside the insulation layer decreases, resulting in lower temperature in the old construction, less drying-out, and, in a cold climate, possible frost penetration. Additional internal insulation has, in some cases, caused frost penetration in wet brick walls, and in other cases caused fungal growth on facades, because the facades do not dry up like before, when they get less heat gain from the building.

Insulation materials

Air encapsulated in small enclosed spaces is the main principle of insulation materials. As heat is transported through three mechanisms – convection, conduction and radiation – the challenge is to find the right balance between material volume and pore volume. A too large pore volume creates large inner convection, and too much material creates too much heat conduction.

The most common insulation materials are mineral wool (stone or glass wool) and plastic foam insulation (EPS, XPS, PUR). They all fulfil the requirement of a thermal conductivity below 0.05 W/mK. The insulation can be applied as board plates or as loose infill. Of the insulation materials based on mineral oil (plastic foams) EPS and XPS are mostly used only as ground insulation and in some façade systems. PUR has a relatively low thermal conductance and is often used in heavy constructions to avoid large thickness, e.g. in concrete sandwich elements, and occasionally also as roof insulation. Cellulose-based insulation (paper wool) is also used to a less extent. Special focus should be put on the fire protection of the construction when using plastic or cellulose-based materials [8].

So far, mainly traditional mineral wool insulation has been used in Nordic countries. A few projects have applied a small amount of transparent insulation materials, but these products are not readily available on the market. The interest in vacuum insulation panels is growing, in particular for the renovation of existing buildings. The interest is spurred by the wish to have thinner walls, but so far vacuum insulation panels have only been applied in a few demonstration projects. Wall thickness is an important topic, as thicker walls are «steeling» valuable area, indoors or outdoors.

Several research institutes are aiming for inventing and developing innovative and robust highly thermal insulating materials. New concepts are introduced, such as vacuum insulation materials, gas insulation materials, nano insulation materials, and dynamic insulation materials. Some of the insulation materials are described in table 1.

Table 1: Brief description of insulation materials, utilisation and barriers

Insulation material	**Utilisation and barriers**	**Reference**
Mineral wool	Mineral wool is a non-combustible product with unique properties for fire protection. The λ-values range from 0.03 to 0.042 W/mK depending on application and product.	
Polystyrene insulation (EPS)	The λ-values of extruded polystyrene currently range from 0.029 to 0.045 W/mK. EPS is highly combustible and a flame retarder must be added if used above ground level.	
PUR/PIR	In spite of being higher priced PUR/PIR can be an interesting choice where thickness is critical, because of its very low λ-values. Some producers attempt to price their PUR/PIR products to achieve the same “U-value” price as that for mineral wool products.	
Filling compound	Granulated extruded concrete or foam glass is often used instead of gravel under foundations and around pipes. This is both practical and gives extra insulation.	
Aerogels	With a thermal conductivity down to 0.013 W/mK for commercial products aerogels show remarkable characteristics compared with traditional thermal insulation materials. Also the possibility of high transmittances in the solar spectrum (allowing daylight) can be interesting.	[2]
Vacuum insulation panels (VIPs)	VIPs are regarded as a promising high performance thermal insulation solution as their thermal performance typically range 5–10 times better than traditional insulation materials. However, the VIPs have several disadvantages such as the risk of puncturing by penetration of nails and that they cannot be fitted at the construction site. Degradation of thermal performance due to moisture and air diffusion through the panel envelope is also a crucial issue for VIPs	[5, 15, 13]
Gas-filled panels (GFPs)	With their thermal conductivity down to 0.010 W/mK, GFPs are regarded as possible high performance thermal insulating solutions for building applications. However, only thermal conductivities of 0.046 and 0.040 W/mK have	[3]

(cont.)

Insulation material	Utilisation and barriers	Reference
	so far been achieved for prototype air-filled and argon-filled panels. The application of a low-conductive gas and reflective barriers may have a potential in the development of new high performance thermal insulation materials.	
Nano insulation materials (NIMs)	Right now a NIM solution represents one of the best high performance, low conductivity thermal solutions. A new nanofoam insulation material with a λ-value of 0.015 W/mK has been developed by Swedish researchers at the University of Stockholm.	[15, 22]
Dynamic insulation materials (DIMs)	With DIMs, it is possible to control and regulate the thermal conductivity in the materials from highly insulating to highly conducting. If robust and practical DIMs can be manufactured, they have great potential.	[15]

References are given for readers who want to get more information about the various alternatives.

When choosing insulation material, special consideration should be given to its fire resistance capabilities. A study [24] comparing thermal insulation products showed that during fire polyisocyanurate (PIR) and polyurethane (PUR) produce the most toxic smoke due to high yields of hydrogen cyanide while phenolic foam and expanded polystyrene (EPS) produce a moderately toxic smoke. Stone wool and glass wool both showed no significant toxic smoke in the tests. The study also showed that the fire toxicity of PUR and PIR foam increases dramatically when the fire changes from a well-ventilated fire to an under-ventilated post-flashover fire. An increase in toxicity was also observed for EPS and phenolic foam.

As the development and improvement of insulation materials is a fast moving research and development area, this list cannot in any way be complete and the reader is encouraged to seek further information.

Vapour barrier and vapour brake

For walls with moderate insulation thickness, a rule of thumb says that at least ¾ of the insulation thickness should be placed outside the vapour barrier [20]. Moisture condenses on cold surfaces, and that is why vapour in indoor air must be prevented from getting out in the cold parts of the structure.

Concrete and dressed masonry might act as a quite effective vapour brake. But that is not the case for brick façades, which, in fact, might be vapour open constructions. In addition, brick façades have low insulating property. If un-rendered brick façades get additional inside insulation, vapour from the inside must be prevented from penetrating the insulation. If not, moisture might condense on the cold parts of the structure and result in moisture damage. Summer condition might lead to moisture penetration in reverse order. Hard, lashing rain can force humidity into the wall. If the temperature outdoors is higher than indoors, moisture diffuses through the wall and condenses on the vapour barrier. If this phenomenon, called summer condensation, is likely to arise, a vapour brake should be considered, instead of a vapour barrier. An expert in building physics should be consulted when planning inside insulation of un-rendered brick facades.

Additional insulation of external walls

Light constructions

So-called light constructions or multi-layer constructions are common in some parts of the Nordic countries. Exterior walls and roofs are constructed of several layers, where each layer has its own function: Rain-protection, wind-tightness, insulation, load bearing, air-tightness/ vapour barrier and coating. In very low energy buildings with such wall types, the insulating layer is usually made of several layers, typically 2–4 layers. Studs are placed both horizontally and vertically, in order to minimise the effect of wall studs as thermal bridges [6]. Retrofitting light constructions might bring along the opportunity for additional insulation to increase the energy performance of the building envelope.

In some situations, a heavy wall or part of a heavy wall can be replaced by a light wall-construction and thereby create space for the placement of an additional layer of insulation. This has been done in the example given below.

Example of retrofitting part of a heavy wall with a light wall construction:

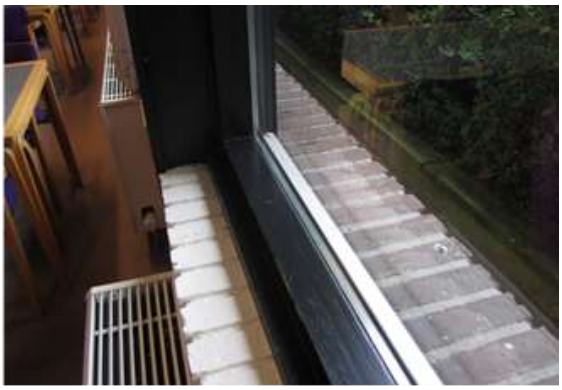
Hedegaards School, Denmark

Hedegaards School is located in Ballerup 15 kilometres west of Copenhagen. The school consists of a number of buildings and it was built in the early seventies. Due to the age of the construction and the actual energy performances, one part of the school has deteriorated to a state where it needs in-depth energy retrofit. In the context of the School of the Future project, a renovation plan was worked out for this part of the school.

The energy retrofit will greatly reduce the thermal losses of the building envelope. In 2012, an average 250 mm of insulation was added on the roof, so the average thickness is now 450 mm. All the exterior walls were replaced by new highly insulated external cladding and all the windows replaced by new windows with 3 layers of glass and a frame system with very low thermal transmittance.

The existing wall had an external brick layer and a cavity insulation of 70 mm of mineral wool.

The renovation work was started by dismantling the outer part of the existing wall - the external brick layer and the insulation. The insulation in the façade had to be installed, taking into account the uneven external side of the inner brick wall. Therefore it was decided to divide the insulation in two – an external mat of 95 mm mineral wool and an internal 230 mm granulated mineral wool. Granulated mineral wool usually comes with a λ-value of 0.038 W/mK and the mat with a λ-value of 0.034 W/mK. However, a granulated wool product was found with a λ-value of 0.034 W/mK – allowing for a total λ-value of 0.034 W/mK for the whole layer of 325 mm insulation. Finally a thin covering sheet of fibre cement was mounted outside which makes room for the added insulation. The U-value of the external wall then becomes as low as 0.1 W/m²K.



Window sill

Existing steel frames

The old external brick layer and insulation dismantled from the facade

Renovation of the facade under-way. The insula-tion is covered by a wind barrier.

After that a ven-tilation space is made, before the cover plates are mounted.

Figure 1: Illustrations showing different steps of the facade insulation process.

Figure 2: The U-value of the external wall becomes as low as 0.1 W/m²K after renovation as a result of using insulation material with low λ-values.

Heavy constructions

Heavy or massive constructions are common in European countries. Masonry walls or concrete elements are the most common of these constructions. Some traditional building materials such as brick have very poor thermal insulation, while more porous materials such as lightweight concrete and expanded clay have a somewhat better insulating capacity.

However, to reach the insulation level needed for very low energy buildings, the masonry walls of all kinds have to be supplemented with an insulating material, or sandwich solutions with two load-bearing layers and an insulating layer in between. Convectional insulating materials can be used in such constructions, for example mineral wool or polystyrene or polyurethane materials. Some other very porous mineral based materials also exist, both as loose infill, (e.g. perlite) and as boards. The «problem» with these materials with less insulating capacity than e.g. conventional mineral wool (0.035 – 0.040 W/m K) is that the thickness of the construction gets bigger [8].

Example of retrofitting a heavy wall construction: Tito Maccio Plauto School, Italy

The Italian demo school has a facade made of a double brick layer and a reinforced concrete bearing structure facing the interior. It is a typical example of the Italian construction technology during the 60s and 70s. The original walls are shown in figure 3, left. In order to improve the energy performance of the buildings, a 12 cm external insulation was installed on the school facades. The initial U-values were calculated to be between 1.8 and 2.8 W/m2K for the current facade and the concrete pillar and beams respectively; the final average U-values was designed to be 0.28 W/m2K. The facade after the renovation is shown in figure 3, right.

Figure 3: Tito Maccio Plauto School facade before and after the building renovation.

Additional roof insulation

Example of retrofitting a light roof construction: Brandengen School, Norway

Heat leakage from the roof of Brandengen School in Drammen has caused icicles in winter. Icicles have to be removed because they can harm people when falling down, and they can also harm the rain gutters if they are allowed to gain weight. Removing icicles from poorly insulated buildings has cost the municipality a lot in previous winters.

When retrofitting the building, one task was to avoid heat leakage from the roof. The wall between the mansard windows, and the floor in the attic, got additional insulation of 30 cm mineral wool. Vents were installed to provide outdoor air to flow into the attic; to cool the attic and to remove moisture. In 2001–2003, a ventilation system was installed and ventilation ducts were placed in the attic. These ducts were not so well insulated. In the autumn of 2011, a layer of 10 cm additional insulation was wrapped around the ducts. See figures below.

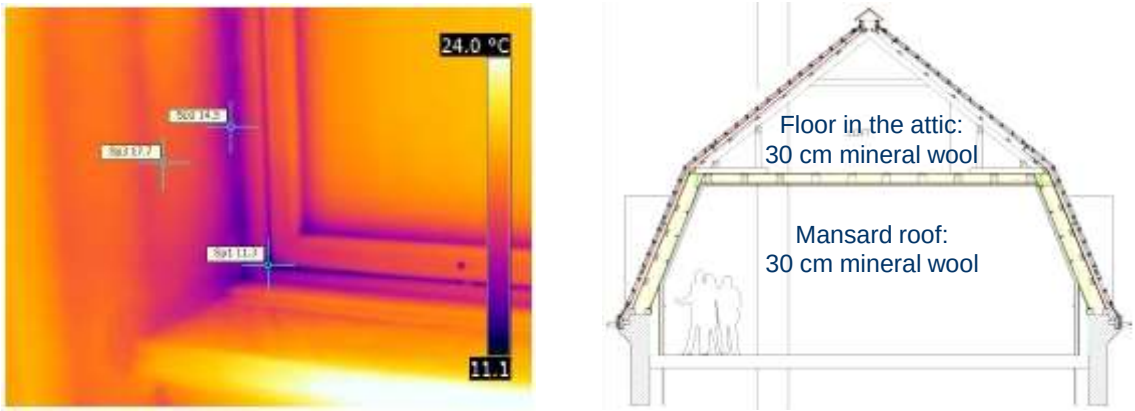


Figure 4: Left: Thermal photography of window in the mansard roof before retrofitting. Photo: H. Masch. Right: Cross-section showing additional insulation of the mansard roof and the floor in the attic.

Figure 5: Left: Attic with ventilation ducts before additional insulation. Right: Attic with ventilation ducts after insulation. Photo: J. Seehusen. May 2012.

Example of retrofitting a heavy roof construction: Solitude Gymnasium, Germany

In the German School of the Future case study "Solitude-Gymnasium" in Stuttgart, built between 1966 and 1991, all five building parts had a flat roof made of concrete with limited insulation, water proofing and gravel on top before the renovation. The U-values differed between 0.67 W/m²K and 0.96 W/m²K. The roofs of the main building and the gym had dome lights.

Figure 6: Aerial photography of the 5 school buildings.

For improving the thermal quality of the building envelope, 14-22 cm of expanded polystyrene with a thermal conductivity of 0.035 W/mK were mounted on the roofs after removing the existing insulation. The resulting U-values were calculated to be between 0.15 W/m²K and 0.20 W/m²K.

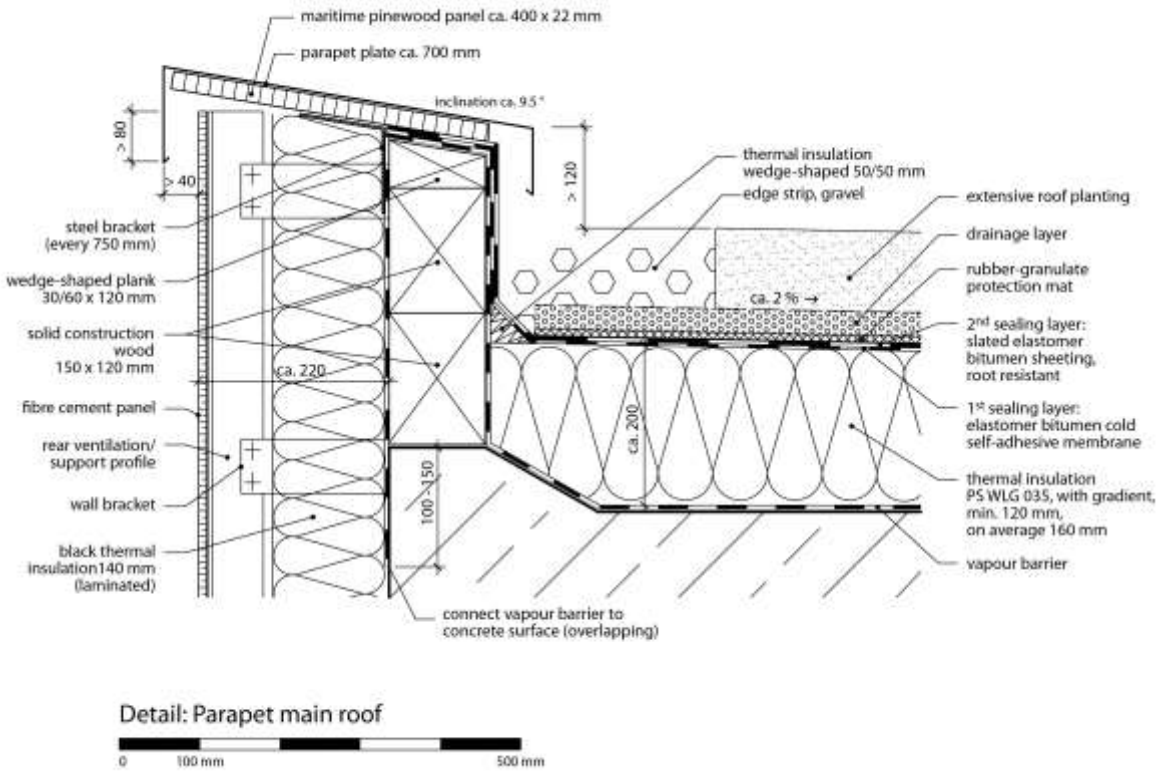


Figure 7: Architectural/principle drawing of the retrofitted roof of the big pavilion that includes the construction of the new parapet.

Figure 8: Photo of the construction work on the roof of the building for science classes (left) and completed renovation of the big pavilion building including the new parapet (right).

Avoiding air leakages

Planners and entrepreneurs have to focus on details to reduce air leakages. Significant development work has been dedicated to finding good solutions to reduce the air infiltration through the building envelope. Construction details and special products for airtightness (e.g. special tape products) have been developed, lab tests have been carried out, and pilot buildings have been constructed. Also, simplified equipment for measuring air leakage during construction, have been developed. Buildings with measured air leakage numbers between 0.2 and 0.6 ACH at 50 Pa have been demonstrated. Main remaining challenges include developing a greater variety of standardised construction details and testing the longevity of the solutions.

There are several brands in the marked, but documentation regarding durability is lacking for some of them. Among the wind blocker tapes only a few have technical approval.

Prefabricated sleeves for lead-in pipes are recommended, especially for round pipes and ventilation channels.

The airtightness of the construction can be tested using a so-called blower door, see figure 9. The blower-door creates an under- and over-pressure within the building to be tested and the airflow in and out of the building forced by this pressure is measured. By calculation, this is then converted to an air exchange at standard conditions.

Figure 9: Blower-door measurements at the Solitude-Gymnasium.

Minimising thermal bridges

A thermal bridge is a part of the construction which conducts more heat than the surrounding areas, for example due to thinner insulation along slab edges and load bearing elements, and beams sticking out through the envelope. Especially thermal bridges are a challenge for interior insulation and crossings between structural components.

Thermal bridges should be minimised in order to reduce heat losses and to avoid too low local temperatures on the internal surface of the envelope. Local cold surfaces can increase the risk of mould growth and even condensation, which decrease indoor air quality.

Example of reducing thermal bridges: Tito Maccio Plauto School, Italy

Original characteristics of the Plauto School in Cesena, Italy, required a special focus to reduce thermal bridges. The external insulation of the facades minimised the thermal bridges due to the exposed bearing concrete structure, as inferred from figure 10. Specific solutions were studies for the installation of new windows, see cross section in figure 10, left. An insulation layer of 3 centimetres is placed on the horizontal and vertical intradoses of the window as inferred from figure 10, right. The new sill (layer 2, in green in figure. 10, left) is made of a 4 cm insulation layer encased in aluminium. With this configuration, the new window sash is not in contact with “cold” surfaces but with the insulation only.

Figure 10: Cross section of a typical window on the left, with details of insulation layers to minimise thermal bridges. Detail of the north-oriented window with insulation layers mounted on the wall and the new insulated aluminium sills. The beige element next to the window is insulation - XPS.

WINDOWS

Windows provide view and daylight. They contribute to heat losses and solar gains. And they might be used for ventilation purposes. Replacement of old windows with new ones is known as a common and effective way to improve the performance of a building, regarding energy efficiency and thermal comfort.

Energy issues

Glazing is an essential component for energy efficiency, related to both thermal and lighting energy demands. Appropriate choice of glazing requires balancing heat gains and losses as well as daylight issues.

Heat losses and solar gains through windows are influenced by window size, orientation and the quality of the glazing unit. Heat losses are also be influenced by frames and spacers, as well as air leakage.

Three properties are used to characterise the energy performance of a window: The U-value, which corresponds to the U-value of other building elements. It is also referred to as heat-loss factor. The daylight transmittance and the g-factor are coefficients used to measure the light transmittance and the solar energy transmittance of glass. For example g = 0.50 means a solar energy transmittance (gain) of 50%.

Table 2: Centre U-value of glass units. Examples. Table showing typical centre U-values for different glass units [Glass og Fasadeforeningen].

Glass unit	**Typical U-values W/m^2 K**
Single	5.8
Double	2.8
Double Low E	1.4
Double Low E with Argon filling	1.1
Triple Low E with Argon filling in one cavity	1.0
Triple Low E with Argon filling in both cavities	0.7–0.5

Today, high performance windows are available on the market, i.e. windows with insulated frames, multiple glazing, low-e coatings, insulating glass spacers and inert gas fills. Low energy windows bring low heat losses and thermal comfort. Quadruple-glazed windows with U-value of 0.6 W/m² K, g-factor of 0.45 and daylight transmittance of 59% are available. Triple-glazed windows with a U-value of 0.7 W/m² K, g-factor of 0.50 and daylight transmittance of 71% are available. Quadruple-glazed windows are rarely used. Windows in low energy buildings are mostly triple-glazed. In Mediterranean Europe, double-glazed units perform well because of low delta T, outdoor/indoor temperature difference, and high solar gains. Double–glazed units have higher solar factor (g=0.63-0.75) than triple-glazed units (g=0.51). The U-value for double-glazed units is U=1.1 W/m² K.

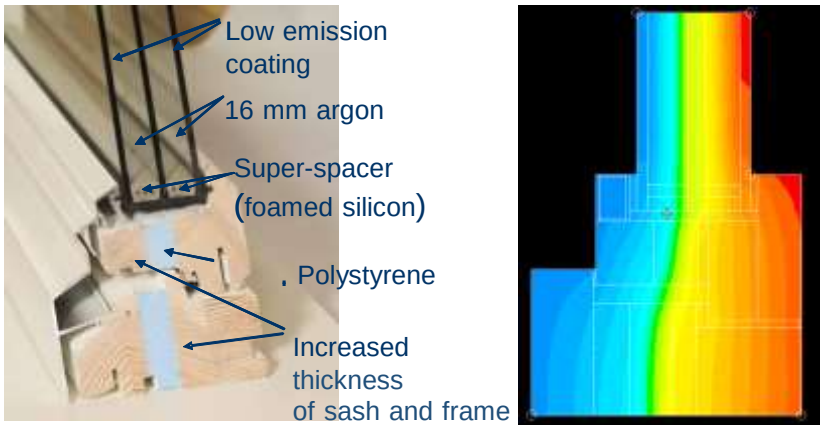


Figure 11: The Norwegian window manufacturer NorDan has developed a passive house window with a total U-value of 0.7 W/m^2 K [NorDan].

Frames and spacers

Over the past years, the window industry has, developed windows with very low U-values. Windows with U-values down to 0.8 W/m2K, or better, are available on the market.

Better insulation properties in thermal bridges have been developed for aluminium windows. PVC windows have got more chambers to reduce the heat-loss, and also polyurethane as insulation in the chambers is used. Regarding wooden windows; the total thickness of sash and frame has increased from approximately 90 mm up to 115 mm, and some producers also use laminated wood with a layer of polyurethane. Passive house standard (better than 0.8 W/m2K) is available for windows within all this framing materials.

Between the glass panes, aluminium and steel spacers are replaced by spacers with better insulation properties, e.g. spacers made of very thin stainless steel, butyl, fiberglass or PVC, and silicon. These spacers reduce heat loss in the edge area and thus cause less condensation.

Daylight indoors

Some countries have requirements for daylight in buildings as a percentage of the external light, described as daylight factor. For example in Scandinavia, the average indoor daylight is required to be 2% of the external light. To fulfil this requirement the glass area in windows should be approximately 10% of a room's floor area. This rule of thumb is based on windows that are not shaded by the surroundings, and have a visual light transmission (VLT) of the glass unit of 80%, corresponding to a double-glazed unit with 2 panes of 4 mm clear glass.

If the glass is tinted and coated to get better U-value, such as low energy glass (LE-glass) and solar control glass, the glass area has to be increased to compensate for the lower light transmission. See the following table.

Table 3: Visual light transmittance related to glass area in per cent of floor area. Table showing correlation between visual light transmissions and glazed areas [Glass og Fasadeforeningen] as a rule of thumb.

Visual light transmittance % of external light	Correction factor *	Minimum glass area % of floor area
80 (reference)	1.00	10.0
75	1.06	10.6
70	1.14	11.4
65	1.23	12.3
60	1.33	13.3
55	1.46	14.6
50	1.60	16.0
45	1.78	17.8
40	2.00	20.0
35	2.20	22.0
30	2.67	26.7
25	3.20	32.0
20	4.00	40.0

* Simplified correction factor to compensate for reduced visual light transmission

Due to low energy coating, the light transmission is 1–10% lower for a double-glazed unit than for clear glass, depending on the type of coating (VLT 79–70%). For a triple-glazed low energy unit, the light transmission can be reduced to VLT 70–57% (units with U-value 0.5 W/m2 K).

Increased daylight requirements may occur in the future. In Italy a daylight factor of 3% is already indicated in a National decree for school buildings issued 1975. In Germany, Denmark and Norway an average daylight factor of 2% is required but a new requirement of 3% is under consideration for the Danish Building Regulations.

For further reading about daylight the reader is referred to the guide on Indoor environmental quality in schools of the School of the Future project:

http://www.school-of-the-future.eu/index.php/project-results

Solar control glass

Solar control glass may be considered if indoor temperatures are too high due to solar gain. In such cases, solar control glass may prevent demand for cooling. As a rule of thumb, permanent structural shading should be avoided in northern latitudes. But as external, movable shading might be very undesirable in school buildings, due to tear and wear, solar control glass may be an option. However, as solar control glass gives lower solar gain also in winter, which is a relevant energy input in southern Europe. A calculation of the total energy demand should be performed in order to assess the best solution for the specific project. Solar control glass has the same range of U-values as Low-energy glasses.

The light transmission of the glass is linked to the solar energy transmittance. Optimal solar control glass let in light/heat at a ratio of 2:1. For example a glass package with description code 70/35 lets in 70% visual light and 35% energy (g-factor 0.35). The table below shows values for different types of solar control glass.

Table 4: Solar control glass. Examples. Table showing correlation between light transmission, U-value and g-factor for different types of solar control glass [Glass og Fasadeforeningen/Pilkington].

Description code	Double	Triple	Light trans. %	U-value $W/m^2 K$	g-factor
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	27	0.6	0.16

As solar glass lets in light/heat at a ratio of 2:1, the light conditions must be analysed before deciding which glass can be used. For example if the demand for light transmission is 80%, the best possible g-factor will be 0.4 (40%).

Double glazed solar control glass that lets in 70% of the daylight is available on the market. This solar control glass lets in only 35% of the heat (g-factor 0.35).

Solar control glass with light transmission around 60% may give sufficient daylight in classrooms, depending on glass area. Such glasses can be delivered with U-values down to 0.7 W/m2 K for the window and 0.5 W/m2K for the glass package. These kinds of windows save energy, and also provide a good indoor climate close to the windows in wintertime, even with rather high windows.

Solar control glass with light transmission around 60% has a g-factor 0.3, which is very low compared with a normal double-glazed unit with g-factor 0.82 or a normal double-glazed unit of LE-glass with g-factor 0.65.

When the light transmission is 60%, the glass area should be 13.3% of the floor area to satisfy a daylight factor of 2%.

Low-E glass

A normal triple-glazed unit with LE-coating lets in 70% of the daylight and 65% of the heat. Also Low-E glasses have a slight form of solar control, especially glasses with the lowest U-values in triple-glazed units. See table below.

Table 5: Low-E glass. Examples. Table showing correlation between visual light transmission, U-value and g-factor for different types of solar control glass [Glass og Fasadeforeningen/Pilkington].

Description Glass code	Double	Triple	Light trans. %	U-value W/m^2 K	g-factor
Hard coated 75/74	x		75	1.6	0.74
		x	69	1.1	0.67
		x	63	0.8	0.58
Soft coated 80/63	x		80	1.1	0.63
		x	73	0.9	0.57
		x	72	0.6	0.51
Soft coated 71/49	x		71	1.1	0.49
		x	65	0.8	0.46
		x	57	0.5	0.36

Key figures for double glazed unit. Examples

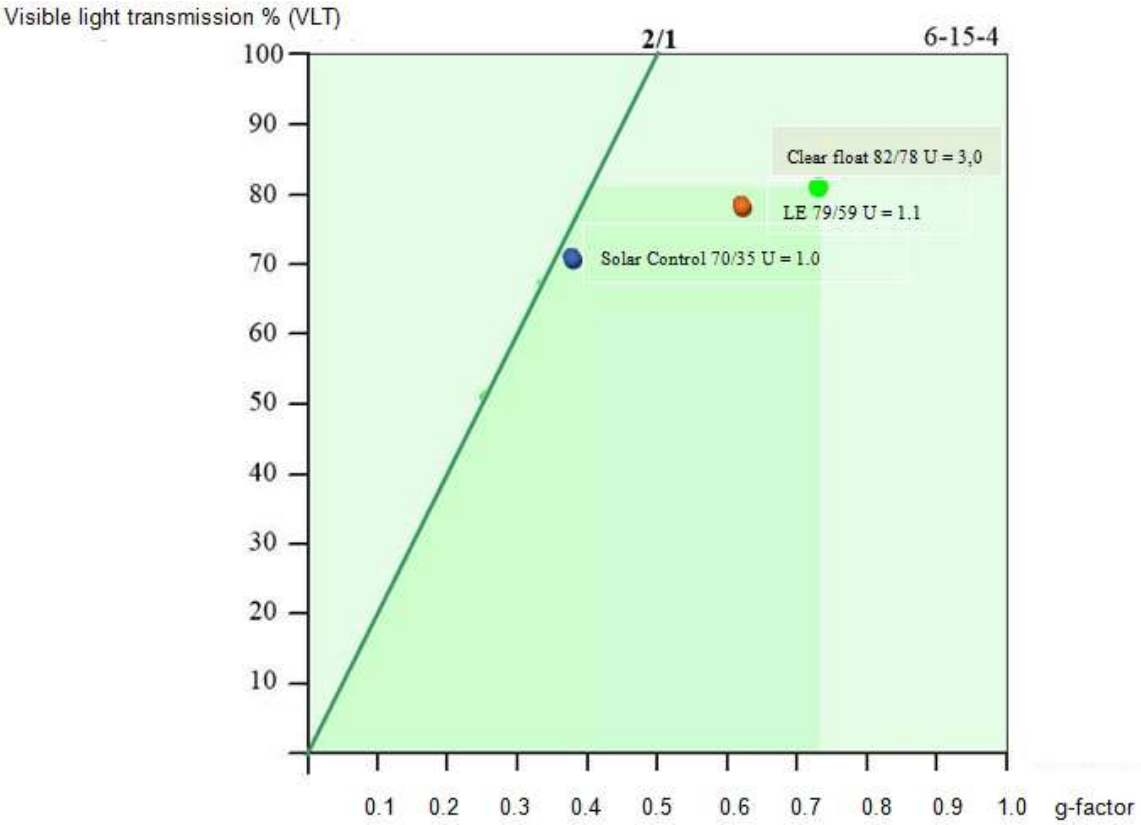


Figure 12: Correlation between light and heat transmission in three different types of double-glazed units [Pilkington].

Electrochromic glass

The latest development for solar control glasses are electro-chrome glasses. They can be delivered with U-values from 0.4 W/m2K to 1,1W/m2K and light transmission and g-factor regulated between the values shown in the table below. Electrochromic glass might be considered to be too expensive for most school budgets, at the time being.

Table 6. Examples of key figures for electrochrome glass for visual light and solar energy transmission [Glass og Fasadeforeningen, N].

Type of glass unit	Light and heat transmissions	Overcast sky	Sunshine
Electrochrome glass	Visual light transmission	60%	2%
	Solar energy transmission, g-factor	0.40	0.06

Figure 13: Unique possibilities with electrochromic glass. Grundschule Hohen Neuendorf and Science College Overbach, Germany.

External condensation

Well-insulated glass has a low temperature on the external side due to low heat flow through the glass unit. This may cause condensation on the external pane in cold weather with high relative humidity (occurs especially at night). Normally this problem is solved by the diffuse radiation of the daylight in the morning and the sun at dawn.

In order to reduce this condensation problem, the glass producers started in 2012 to deliver glass with an external hard-coat, low-E coating, which increases the temperature on the external glass pane. Self-cleaning panes also reduce external condensation.

Light wedges

Joints between windows and walls are also subject to interior daylight level, especially regarding thick walls. A higher level of daylight can be obtained by expanding light wedges towards the external surface.

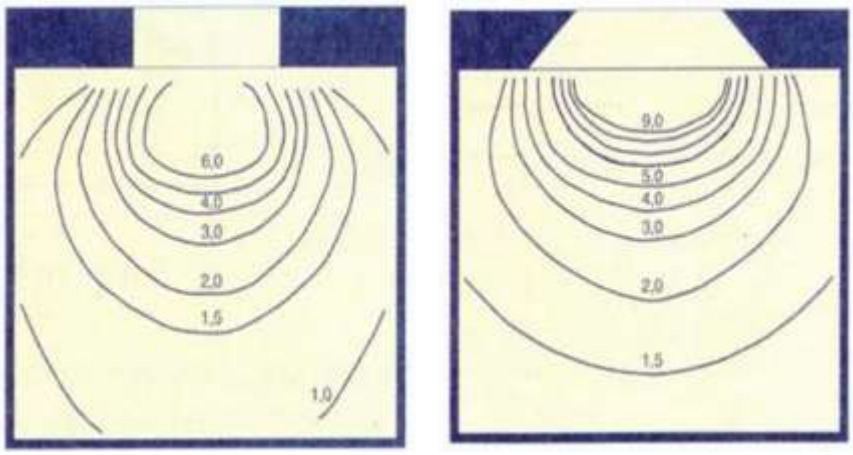


Figure 14: Sloped light wedges give a higher level of and a more even indoor daylight than angular wedges. Reference: Ø. Aschehoug, NTNU.

Thermal comfort

Temperature of the inner glass surface relates to U-value and external temperature. Draught of cold air is related to the temperature of the inner glass surface and height of the glass. Cold draught can be eliminated either with a heating element under the window, or with high temperature on the inner pane, due to low U-value of the glass unit. If the temperature of the inner pane is so high that it eliminates cold draught, it also eliminates cold radiation.

- Draught of cold air is a function of glass U-value, height, and surface temperature. Temperature difference between glass surface and room should not exceed 5–6 ^{o}C.
- Radiation is a function of glass U-value, height, and surface temperature. Temperature difference between glass surface and room should not exceed 8–10 ^{o}C.

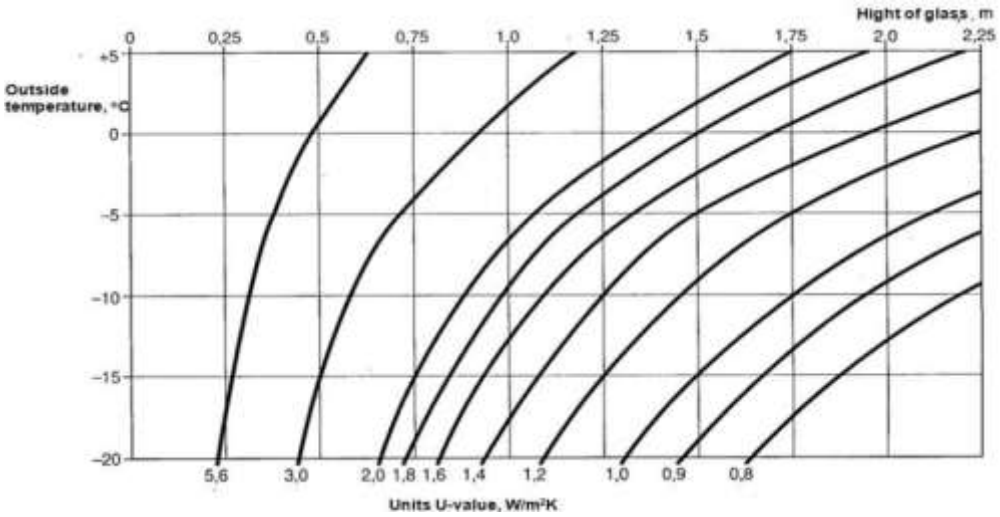


Figure 15: The critical temperatures for cold draught for different U-values and heights of the glass [Pilkington].

Increasing the height of the glass has a dramatic influence on cold draught. For a 1.25 m high window with U-value 1.2, cold draught starts at -15 oC. Increasing the height by 0.5 m to 1.75 m, the cold draught will start at -5 oC.

Heat loss as a function of wind speed and temperature

The challenge is to find the optimal U-value of the glass unit according to the local conditions. The calculated U-values in accordance with EN 673 are based on 4.0 m/s wind outside, 0 ºC temperature outside and 20 ºC inside. If wind speed increases the temperature gets lower, the U-value will increase due to the convection of the air/gas between the panes. The U-value will increase much more for a double-glazed unit than for a triple-glazed.

U-values for double and triple Insulating Glass Units

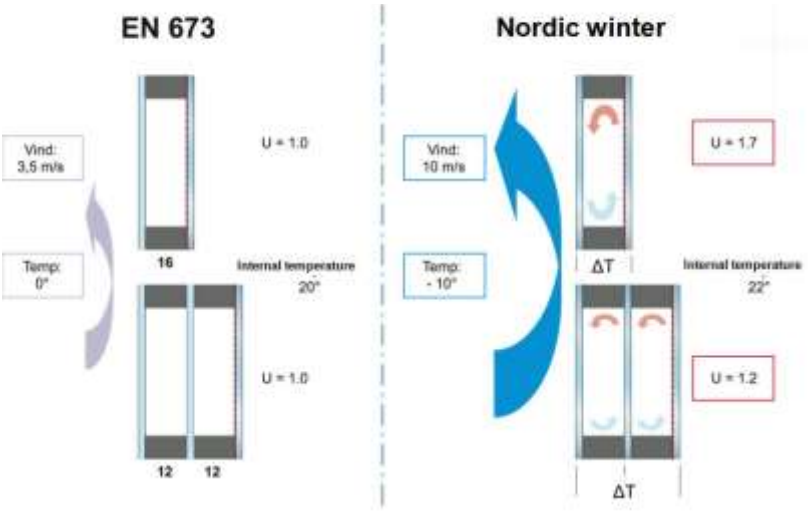


Figure 16: Standard input data for calculation of U-values after EN 673 to the left, and the conditions that most often appear in a Nordic winter situation, where also the indoor temperature is higher than what is used for the standard calculations, to the right. The result of this is a much higher heat loss for the two-layer window than that of the triple-layer window in reality [Glass og Fasadeforeningen/ Pilkington].

Example of window replacement: Brandengen School, Norway

Brandengen School, located in Drammen, has historically valuable buildings from 1914. The municipality emphasised renovation in accordance with the expectations of the conservation authorities. The overall aim was to achieve future high performance building levels when renovating the buildings, i.e. low energy consumption and good indoor climate conditions. The school is a demonstration building within the EU project «School of the Future» (7FP). More information: www.school-of-the-future.eu.

The windows had been replaced at different times since 1965. As the windows had caused high heating costs and not contributed to an optimal indoor climate, the municipality decided to replace all windows installed after 1965, aiming for new high performance windows, which would also respect to the historic aspects of the buildings' aesthetics. Existing original windows from 1914 were refurbished. Most of the original windows are located along corridors, where the indoor temperature requirements are not as strict as in classrooms. The search for modern high performance windows was based on the following criteria and compliance was required:

- Looking similar to the original windows from 1914
- Long life expectation
- U-value $\leq$ 0,8 W/m^{2}K (at affordable price)
- Affordable operational and maintenance costs

«Passive house» windows are now installed. As these windows substantially decrease heat losses, they contribute to better indoor thermal comfort as well as reduced energy bill. Thanks to the glazing's low solar energy transmittance (g-factor = 0.27 on south and west façades), the exterior sunscreens could be removed from the façades, in order to restore the façade aesthetics as close as possible to the original look.

Figure 17: Photos showing south façade of the main building. Left: Before retrofitting, June 2011. Note the shading devices. Photo: S. Tangen. Right: After replacement of windows and roof cladding, May 2012. Photo: S. Røgeberg.

Figure 18: Left: Façade segment showing new passive house windows from NorDan. Middle: Close up photo of new window. Photos: S. Røgeberg. Mai 2012. Right: Vertical section. Note the insulated frames.

Table 7: Glazing properties of new windows at Brandengen School. Table showing characteristics of glazing types. Note that solar glazing is applied on south and west façades. Window manufacturer: NorDan, Norway.

Glazing specifications	U-value W/m^2 K	Visual light transmission %	g-factor
Ground floor with exterior security glazing: Lam m/energi 2s VKS/Ar 6,38ES+16G+4+16G+ES6	0.53	56	0.35
Solar glazing on south and west façades: SKN165 m/Energi VKS/Ar 6*-14G+4+16G+ES4	0.58	48	0.27
Other windows have standard glazing: Energi 2s VKS/Ar 4ES+16G+4+16G+ES4	0.53	58	0.37

Other glazing elements – double skin façades

The double skin is a system involving the addition of a second, glazed skin installed at a distance from the main façade. The intermediate space that is created provides additional insulation and can be heated by solar radiation.

In summer, the double façade can reduce solar gains as the heat load against the internal skin can be lessened by the ventilated cavity. Shading systems placed within the cavity are protected from the weather. A natural stack effect often develops in a solar heated cavity, as absorbed solar radiation in the glass, the structure and blinds is re-radiated. In winter, the double façade acts as a buffer zone between the building and the outside; minimising heat loss, and improving U-values.

For existing buildings double-skin façades can be used to retrofit façades that have deteriorated.

Example of retrofitting with double-skin façade: NTNU University, Norway

An example of retrofitting with a double-skin façade from the Norwegian University of Science and Technology (NTNU) is shown below.

Figure 19: Office building with new skin layer of glazing and PV. BP Solar Skin, NTNU, Trondheim, Norway, 63 ºN. Renewal design: SINTEF/NTNU. Photo: SINTEF Byggforsk.

Figure 20 Left: SINTEF researcher Inger Andresen in front of the retrofitted façade at NTNU. Right: Principle sketch of the double-skin façade by Anne G. Lien, SINTEF. The intermediate space acts as a buffer zone that creates opportunities for improving energy performance. The BP Solar Skin has multiple functions: it is a new building skin, which produces electricity, provides extra insulation and air-tightness to the building envelope, provides a stack effect for ventilation air, gives a view and daylight and gives a more aesthetic façade than the old one.

Solar shading devices

Shading, an essential part of good building design, is applied:

- to reduce solar heat gain in rooms
- to prevent direct sun radiation on persons
- to reduce glare

Solar shading systems for the east, south and west facing windows are often needed to avoid high indoor temperatures during spring, summer and autumn. The systems can be e.g. solar control glass, as referred to in a previous chapter, overhangs, or a variety of different movable systems, for example Venetian blinds for installation inside, outside or between the panes. To reduce heat gain, solar shading is most efficient if installed on the outside. Broadleaved trees may provide some shading in the warm season.

Fixed solar shading is not suitable in most situations. In the long twilight time in winter, as much daylight as possible is wanted. In the long periods with low solar angles, it is a challenge to avoid solar radiation without blocking views to the outside. Moveable sun shading is therefore recommended. Shading devices should preferably be controlled individually for each room.

Figure 21: Left and middle: Windows in east and west facing façades are divided in two heights. Through the lower part it is possible to view the surroundings, while the upper part is shaded by Venetian blinds. Schule Weiler in Vorarlberg, Austria. Architect: Dietrich Untertrifaller Architekten. Photo: SINTEF Byggforsk. Right: North facing windows need no shading. Library in Brekkåsen skole in Melhus, Norway. Architect: Lusparken Arkitekter AS. Photo: The Architect

Example of solar shading: Tito Maccio Plauto School, Italy

Classrooms, offices and laboratories were originally equipped with internal shading devices. The objective was mainly related to glare and visual comfort, overheating being a relevant problem in a non-insulated building. Conversely, overheating may occur in a tight and insulated school after renovation. External shadings are mounted in classrooms and labs to prevent these risks, as inferred from figure 22.

The lamellae have a 50% luminous reflectance; the glazing plus shading system has 15% diffuse light transmittance at the cut-off angle to ensure adequate daylighting when the solar protection is activated. The shading system is motorised and operated by individuals when needed for thermal and visual comfort. Calculation demonstrated that with the activation of the solar protection will ensure adequate comfort levels during the operating hours of the building.

Figure 22: External Venetian blinds of the south-oriented windows.

Interaction of shading with daylight

The shading devise should prevent direct solar radiation without blocking daylight. Horizontal blinds function most effectively on the south-oriented façades, vertical blinds on the east- and west-oriented façades.

Sunlight reflected to the ceiling can be obtained by means of horizontal blinds, preferably with adjustable sloping of lamellas. The sunlight reflected to the ceiling, functions as a secondary light source for the room beneath. With a light coloured ceiling, the room may appear as light, high, spacious and friendly, with a nice and sometimes exiting visual expression. An alternative to a blind system is a light deflecting foil or panel fixed to the glazing. Actually there are two

products that can be used in buildings: laser-cut panels, called Edmond's panels and Serra Glaze foil. Both products can be pasted directly to the glazing [Matusiak].

To diffuse the sunlight thin curtains or rolling curtains with a light transmittance of 10–25% can be used. The curtains can be used as an operable system inside the building. The objective is to admit the light from the sky and the sunlight from very low elevation angles, especially during the dark part of the year. The sunlight will be diffusely distributed in the room as a comfortable and warm, diffuse light.

Example of solar shading device interacting with daylight: Solitude-Gymnasium, Germany

In the Solitude-Gymnasium in Stuttgart, the renovation included the replacement of all windows and with the new mostly triple-glazed windows a new external solar shading system was also mounted. The chosen shading system ensures an optimal solar protection while supplying the rooms with daylight. A two-section slatted blind allows for excluding or reducing incident light on the lower part and redirecting the light to the ceiling on the upper part. On the one hand, these systems provide sun-free and glare-free zones, on the other hand they grant sufficient luminance. [Erhorn].

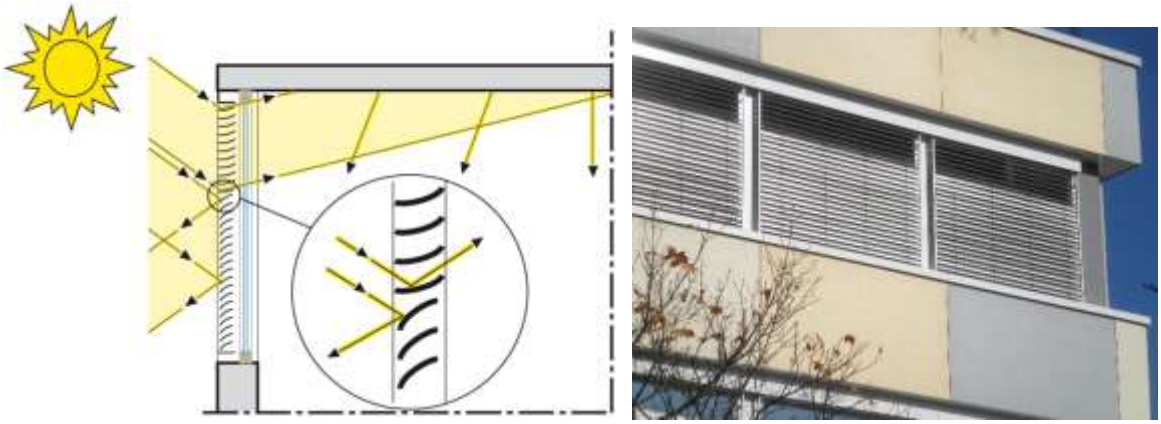


Figure 23: Scheme of blinds with daylight redirection function in the upper part (left) and this kind of shading system installed in the Solitude-Gymnasium in Stuttgart.

Example of solar shading device interacting with daylight: Danish Industry's building

MicroShade® is a new generation of solar shading for glass facades based on "micro lamellas".

Figure 24: Microshade installed at Danish Industry's building in Copenhagen – ref.: Microshade.

MicroShade® solar shading is built into two- or three-layer glazing and comprises a very thin and transparent layer of micro lamellas adapted to the movement of the sun – see figure 24. Sunlight from low angles passes relatively unimpeded between the micro lamellas, while light from higher angles is blocked.

It provides effective solar shading for buildings. It cuts solar radiation and considerably reduces the energy used for cooling and ventilation. At the same time, it improves the indoor climate.

The example shown is the largest glass roof atrium in Scandinavia. The basic challenge was to be able to see the blue sky and at the same time avoid excessive overheating of the building. The roof sections are sloping at different angles and MicroShade with corresponding specifications was built in to ensure optimum shading and performance.

IMPACT OF INTERIOR BUILDING ELEMENTS

The thermal capacity of building structures helps to utilise passive gains that otherwise would have had to be ventilated out of the building, because it would result in too high temperatures. An adequate thermal capacity can store or release heat and thereby reduce temperature swings and also reduce peak heating loads – the latter is sometimes referred to as “peak shaving”. Interior walls, floors and ceilings can be used for placing thermal capacity.

The simplest form of thermal capacity is thermal mass in the form of relatively heavy building materials like concrete or bricks. Another possibility is the use of phase change materials.

The type and nature of internal building elements also have a significant influence on the acoustics, which is part of the perceived indoor environment.

Thermal mass of interior walls, floors and ceilings

The use of thermal mass in the form of exposed heavy construction elements needs to be combined with the acceptance of an interval of the room temperature allowing the air and the structures to heat up and cool down a little. This interval needs to be 4-5 degrees. The required amount of thermal mass is not very high; a solid floor in a lightweight building is sufficient. Regarding heating contribution, mass exposed to direct solar radiation is most effective. Dark colours absorb more energy than light colours. The need for cooling can be reduced by utilising thermal mass in combination with night cooling. The thickness of the mass is also of importance. In general, mass thicknesses beyond 10–15 cm have little effect [Hestnes]. The effect of thermal mass on the energy demand of a building is generally not dramatic, but it may be significant. It does, however, depend on several factors such as the layout of the building, the acceptable temperature range and the amount of acceptable solar energy through the windows. An hourly thermal simulation is needed to identify the energy-saving potential of thermal mass. Thermal mass can also bring along a higher level of indoor comfort as it helps reduce the temperature swings due to free heat gain.

Acoustics

WHO recommends noise levels lower than 35 dB in classrooms. Recent studies have shown that actual noise levels in classrooms are 65 dB! According to WHO, at 65 dB the risk of heart attack increases [23]. A US study found that 50% of teachers had suffered irreversible damage to their voice and a study of primary schools in Spain, the Netherlands and the UK found that a 20dB increase in traffic or aircraft noise could delay a 9-10 year old’s reading age by up to eight months!

When planning energy retrofit (or renovation in general), it is of great importance also to consider options for improving the acoustic performances and to take into account both sound reflection and sound absorption by the exposed surfaces. An expert in acoustics needs to be consulted.

Phase change materials

Another solution for storing and releasing heat within a certain temperature range is based on exploiting latent heat to stabilise temperatures and cut energy consumption. This is done by using phase change materials (PCMs). Such materials raise the building inertia and stabilises the indoor climate. The actual impact is dependent on the same factors as mentioned for the thermal mass, except that the PCMs function at lower acceptable temperature intervals, i.e. 19-21 °C [4]. Again a detailed simulation is needed to identify the energy-saving potential for a specific situation.

Example of the use of phase change materials

One example of PCM in building materials on the market is a gypsum plate that incorporates phase change material. This product provides the benefits of thermal mass at a fraction of the weight of conventional methods – two layers of this board achieve the same thermal capacity as a 100 mm of concrete wall.

Consisting of microscopic glass balls filled with wax, heat energy is absorbed as the temperature rises so that the wax changes from a solid to a liquid state within the glass balls, so that the room will stay at a comfortable temperature range. When the room cools down at night, the wax turns back into a solid, releasing heat back into the building.

ENERGY, ENVIRONMENTAL AND FINANCIAL ANALYSES

Cost considerations are often an important part of the decision-making process concerning energy retrofitting projects. A proper financial calculation presents the Life Cycle Cost (LCC) in the form of the Net Present Value of the individual energy-saving measures conducted over its estimated lifetime. Furthermore, the environmental benefits in the form of reduced CO_2-emissions should also be considered.

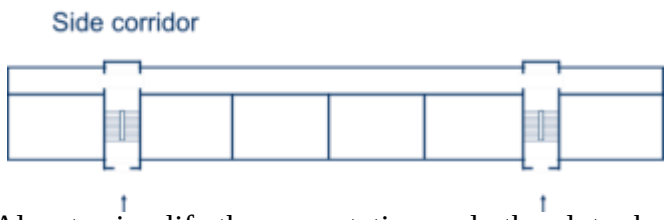
Energy and financial screening of energy retrofitting measures

Within the School of the Future project, a number of energy retrofitting measures/technologies have been «screened» by performing an energy and financial calculation for each measure for three typical school typologies in Denmark, Germany, Italy and Norway. For Italy, the analysis comprised three climate zones – for the other countries only one representative climate zone was used.

The three typologies were: Side Corridor, Central Corridor and Compact Plan. The calculations resulted in four plots presenting the results for each measure, typology and climate. The four plots were:

1. Simple pay-back and physical life time
2. Net Present Value (NPV) and investment
3. CO_2-reduction
4. Saved energy

The Side Corridor type school is considered the most common type of school in all the four countries. Therefore the results selected for presentation in this report cover the Side Corridor school typology:



Also, to simplify the presentation, only the plots showing NPV and investment are presented - the other 3 plots are summarised in words for each technology.

The complete screening reports for all four countries can be found by following this link: http://www.school-of-the-future.eu/index.php/project-results/technology-screening

In finance, the net present value (NPV) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows of the same entity. In the case when all future cash flows are incoming and the only outflow of cash is the purchase price, the NPV is simply the PV of future cash flows minus the purchase price. The cash inflows have to be discounted to present the value of money today from the value of the money in the future, taking inflation and returns into account.

Results of Life Cycle Cost (LCC) Analyses

Covered energy retrofitting measures for building construction elements

The screening analysis covered a number of different energy retrofitting measures. Of these, the following four relate to building construction elements:

- Additional wall insulation
- Additional roof insulation
- Additional floor insulation
- New low-energy windows

Therefore, results for these four technologies are presented and commented on the following pages. The results for the other technologies are presented in the other Design Guidelines of the School of the Future project covering: Building Service Systems, Improved Indoor Environmental Quality and Concepts for Zero Emission Schools.

General observations

It is very difficult to make general conclusions across the countries, because of the following factors that differ considerably from country to country:

- Climate - affects energy savings and then the NPV
- The reference U-value - affects energy savings and then the NPV
- The cost of Investment - affects the NPV
- Energy prices - affects the NPV

A few general observations can be made concerning the school typologies, and for some of the technologies applied to roof, walls and windows. Also for the three Italian climates it is possible to make some general conclusions as the investments and energy prices are the same.

These general findings are presented below before the detailed presentation of the analyses.

For the typologies, it can be seen that a type (typology) of school with relatively more façade (e.g. Side Corridor) than another type school (e.g. Compact Plan) can get the wall improved for a relatively bigger area and therefore get a higher NPV (if the NPV [€/(m²-facade)] is positive) or will have a worse NPV (if the NPV [€/(m²-facade)] is negative).

The same is observed for a type of school with a bigger roof area (e.g. Compact Plan.

For the windows the screening results show that the choice of a 2-layer energy glass results in a better NPV than the choice of a 3-layer glass in Denmark, Norway and Germany, because of the lower cost of the 2-layer window.

In Italy, the investments are almost equal and therefor the NPV is better for the best window, except for the Taranto climate, where the building consumes more energy for cooling.

In all cases: **The need for renovation anyway ("anyway measures"- see page 7) greatly influences the costs.** As this is something that must be individually established in each case the screening performed based on standard cost assumptions without taking this into account. Thus when the costs of an anyway measure has been established this can be added to the NPVs shown below. This may have a very large effect on insulation of the walls as scaffolding and weather proofing constitute a big part of the costs, so if these are to be held anyway **the NPV of additional insulation may turn from negative to positive**.

Insulation of the external walls and roof

Better insulation of the walls has a big influence on the NPV due to the high costs of the investments. The NPV is only positive if the U-value for the reference building is poor and the costs of investments are not too high. This observation is valid for all three typologies and climates.

If the NPV is positive, there will be an optimum point of thickness beyond which thicker insulation will decrease the NPV.

In general, insulating the roof instead of the external wall shows better LCC results. This relates to the fact that the differences in investments typically are so high that is has a bigger effect on the NPV than the energy savings.

This underlines the very fundamental recommendation that energy efficiency should always be considered and optimised in connection with a building renovation project, where the external walls – for example – have to be renovated anyway.

Observations for Italy

The costs of investments, the starting point of the U-values of the building elements, the type of schools and the energy price are identical for the three climates, so only the energy savings are different in the three climates. As the energy savings are bigger in Turin than in the two other cities/climates, the NPVs for the different measures are highest for Turin.

Importance of the size of the initial investment and “anyway measures”

A general observation is that the initial investments are high, because the implementation of the measure is not straightforward. External insulation of the facades is good example. If the existing facades have to be renovated because of wear and tear, most of the investment in the façade renovation will have to be made anyway and the additional insulation can easily be placed and the cost is a marginal cost in relation to the overall renovation with a dramatic influence on the NPV for this measure.

Other measures for valuing energy retrofits

It may be argued that the NPV of energy retrofits as conducted in this context is a too narrow definition of their value, as it is focused on energy cost savings alone. Other benefits of energy retrofit projects could or should be incorporated as well. The US-based Rocky Mountain Institute has written a guide on “How to calculate and present deep retrofit value - A guide for owner occupants” [21], which explains that “a retrofit project can decrease company and property operating costs, increase company revenues, and help manage enterprise risk, all of which lead to higher property and company value”, provides a list of these costs, etc.:

- Retrofit Development Costs
- Non-Energy Property Operating Costs
- Retrofit Risk Mitigation
- Health Costs
- Employee Costs
- Promotions and Marketing Costs
- Customer Access and Sales

- Property-Derived Revenues
- Enterprise Risk Management/Mitigation

and guidance on how to calculate them and incorporate them in the overall value of the energy retrofit project.

Results for Denmark

Reference building

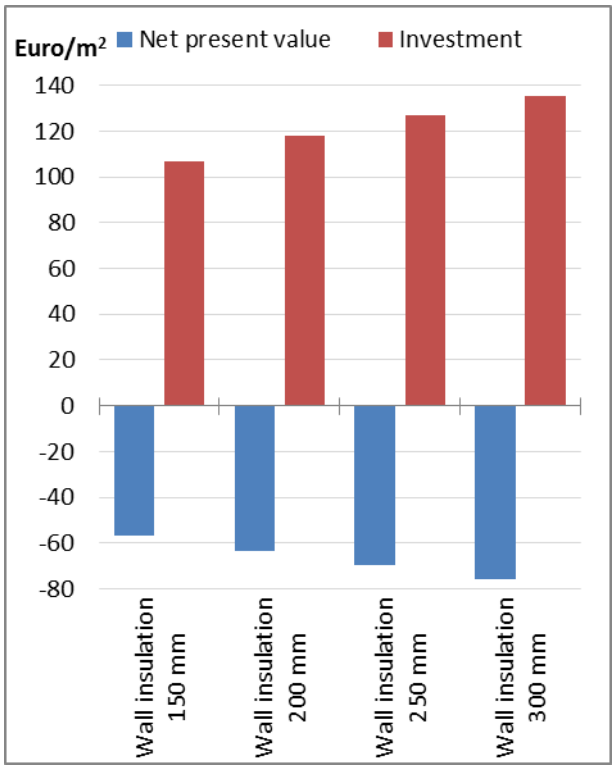
The reference school building is from the 1950s, so it has poor insulation in the walls and the construction is medium heavy. There is natural ventilation and no cooling. The basement is not heated. The heat supply is an older gas boiler, the hot water is used for a school with gym, and radiators with thermostats are used to heat the building. There is no building energy management system (BEMS) installed. The period of use is 201 days a year from 8 am to 5 pm.

The reference building consumes 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).

Additional wall insulation

Four different additional thicknesses of external wall insulation were analysed:

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



Compared with the starting point U-value = 0.57 W/m^{2}K.

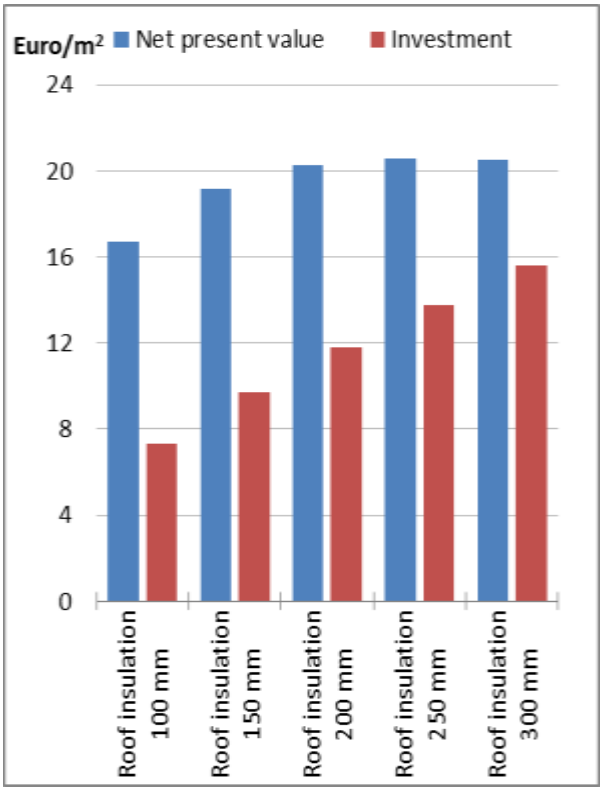
Extra wall insulation involves high investments and mainly therefore the NPV is negative for all four thicknesses despite the energy savings. This also means that the simple payback time is 50 years or more.

CO_2 reductions range between 3.6 and 4.5 kg/m^2/year and the energy savings between 17 and 22 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation

The starting point for these calculations was a roof with a U-value = 0.40 W/m²K. Five different thicknesses of additional insulation were analysed:

- 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)



In all cases, the NPV is higher than the investments corresponding to payback times of less than 10 years.

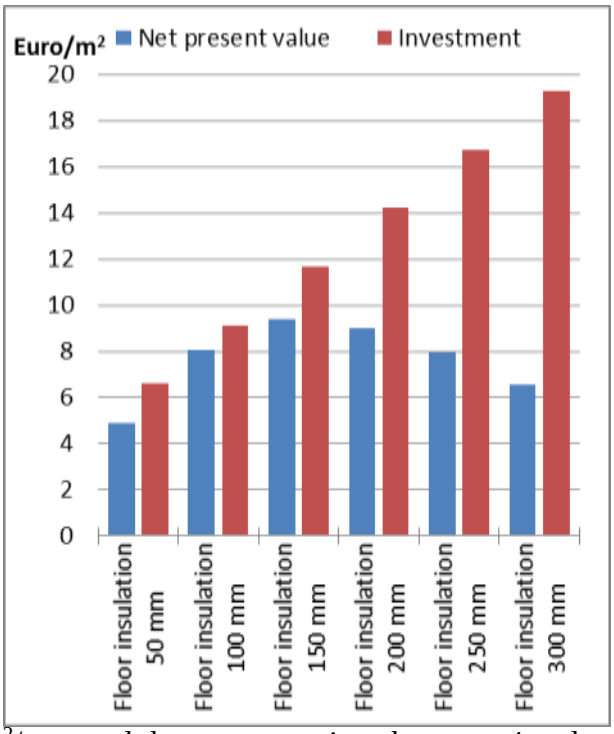
Note that the NPV decreases with insulation thicker than 250 mm, so this is the financial optimum in this case.

CO_2 reductions range between 1.7 and 2.6 kg/m²/year and the energy savings between 8.5 and 12.5 kWh/m²/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional floor insulation

Six different thicknesses of additional insulation levels of floor insulation were analysed starting with the 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 prices for the floor insulation used were for a school, where there is easy access to insulating the floor from beneath through crawl space or basement. In all cases, a positive NPV is achieved. For insulation thicker than 150 mm the NPV decreases, but stays positive. Payback times are between 13 and 17 years.

The CO_2-reductions is between 0.8 and 1.8 kg/m²/year and the energy savings between 4 and 9.5 kWh/m²/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

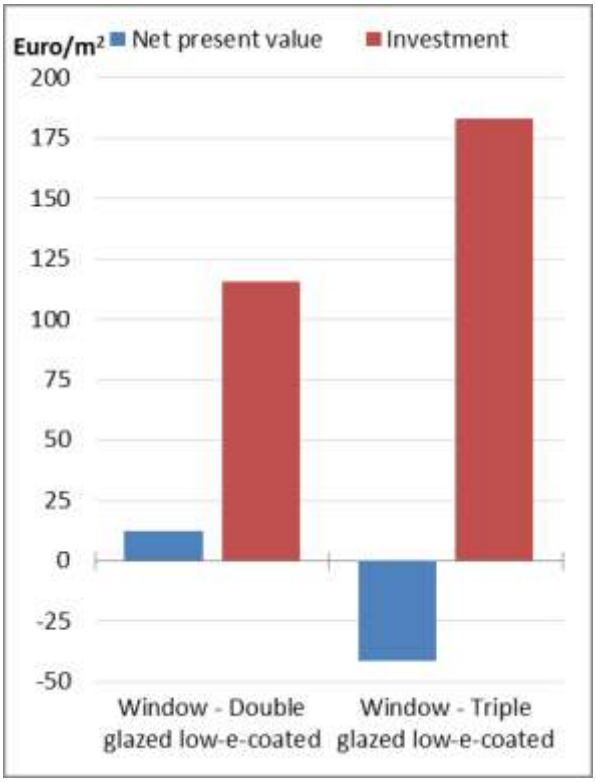
New low-energy windows

Two types of replacement windows were analysed and compared with the starting point window, which is a double-glazed window with a U-value = 3.1 W/m^{2}K:

- 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)

Due to the fact that the investment for a triple-glazed window is considerably higher, the NPV is negative for that and it has a longer payback time than the double-glazed window. Payback times are 30 and 21 years, respectively.

CO_2 reductions range between 9.5 and 11 kg/m^2/year and the energy savings between 49 and 56 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.



Summary for energy retrofit of building construction elements in Denmark

The conducted screening analyses show that insulating roof and floor and changing to low-energy windows have a positive NPV. The replacement of windows results in the biggest CO_2-reductions and energy savings. This relate to the change in U-value from 3.1 to 1.2 W/m²K, which in absolute value is much higher than the change of U-value for the roof or floor.

It should be noted that the NPVs cannot be added, because the energy savings stemming from the implementation of each technology is affected and reduced by the energy savings of the other technologies.

Whole concepts have been analysed as part of the School of the Future screening work and results for whole packages of technologies can be found in the screening reports. However, if the NPV – values are negative, they remain negative and ways should be sought to reduce the investment costs to reach a positive NPV.

It may also be considered that positive NPV values can outbalance negative values resulting in financially justifiable energy retrofit project.

Results for Germany

The school typology Side Corridor is investigated for the period 1969-1978, when it is assumed that there was poor insulation in the walls and that the construction was 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 is used for a school without gym, and radiators with thermostats are used to heat the building. There is no building energy management system (BEMS) installed.

Period of use is 200 days a year and from 8 am to 3 pm.

The reference building consumes 164.0 kWh/m^2 year of heating and 11.0 kWh/m^2 year of electricity (including electrical light, pumps and fans).

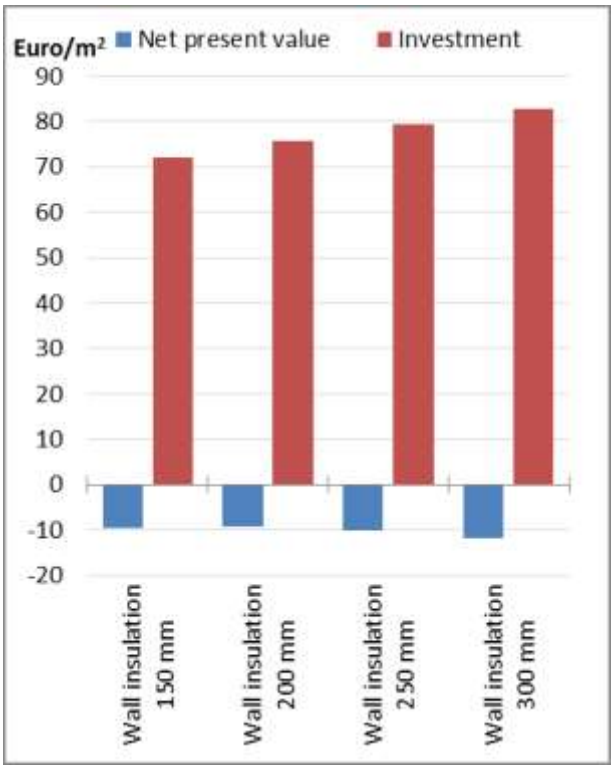
Additional wall insulation

Starting point: U-value = 0.87 W/m^{2}K

- 150 mm (U_{Wall} = 0.19 W/m^{2}K)
- 200 mm (U_{Wall} = 0.15 W/m^{2}K)
- 250 mm (U_{Wall} = 0.13 W/m^{2}K)
- 300 mm (U_{Wall} = 0.11 W/m^{2}K)

The investments are high and mainly therefore the NPV is negative despite the high energy savings.

The payback times of extra wall insulations are lower than the physical lifetime, but still quite high: 26-27 years.

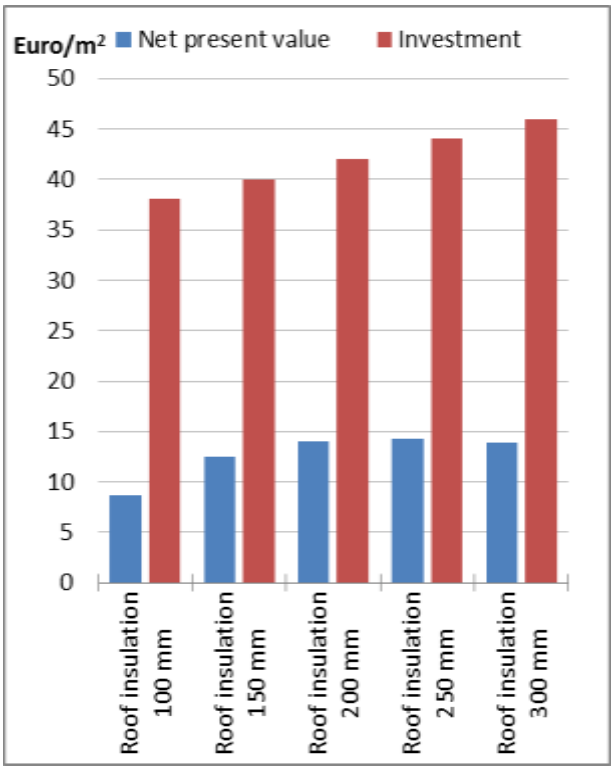


CO_2 reductions range between 6.7 and 7.5 kg/m^2/year and the energy savings between 25 and 28 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation

The starting point for these calculations was a roof with a U-value = 0.80 W/m²K. Five different thicknesses of additional insulation were analysed:

- 100 mm (U_{Roof} = 0.25 W/m^{2}K)
- 150 mm (U_{Roof} = 0.19 W/m^{2}K)
- 200 mm (U_{Roof} = 0.15 W/m^{2}K)
- 250 mm (U_{Roof} = 0.12 W/m^{2}K)
- 300 mm (U_{Roof} = 0.11 W/m^{2}K)



In all cases, the NPV is smaller than the investments corresponding to payback times of 17-19 years.

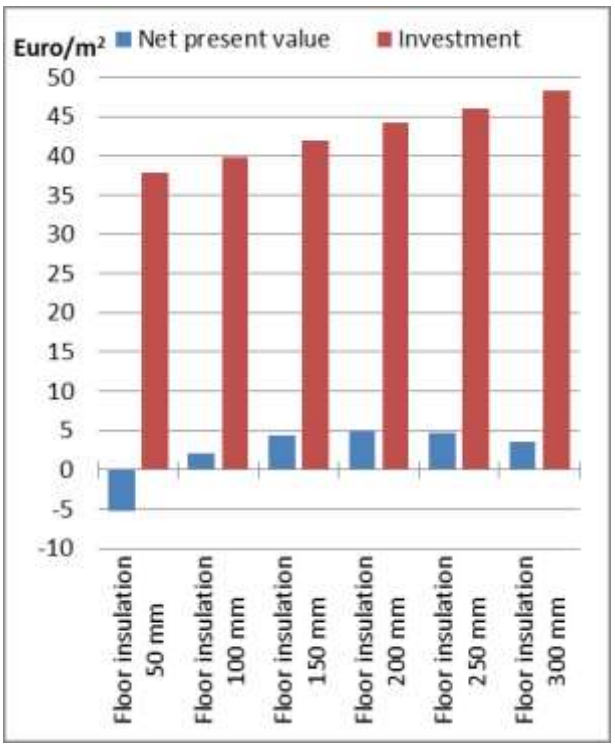
Note that the NPV decreases with insulation thicker than 250 mm, so this is the financial optimum in this case.

CO_2 reductions ranges between 5 and 6.3 kg/m^2/year and the energy savings between 18 and 24 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional floor insulation

Six different thicknesses of additional insulation levels of floor insulation were analysed starting from the U-value = 1.0 W/m^{2}K:

- 50 mm (U_{Floor} = 0.43 W/m^{2}K)
- 100 mm (U_{Floor} = 0.27 W/m^{2}K)
- 150 mm (U_{Floor} = 0.20 W/m^{2}K)
- 200 mm (U_{Floor} = 0.16 W/m^{2}K)
- 250 mm (U_{Floor} = 0.13 W/m^{2}K)
- 300 mm (U_{Floor} = 0.11 W/m^{2}K)



The prices for the floor insulation used were for a school, where there is easy access to insulating the floor from beneath through crawl space or basement. In all but the first case, a positive NPV is achieved. For insulation thicker than 200mm, the NPV decreases but stays positive. The simple payback time is between 21 and 27 years.

CO_2 reductions range between 3.5 and 5.5 kg/m^2/year and the energy savings between 13 and 21 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

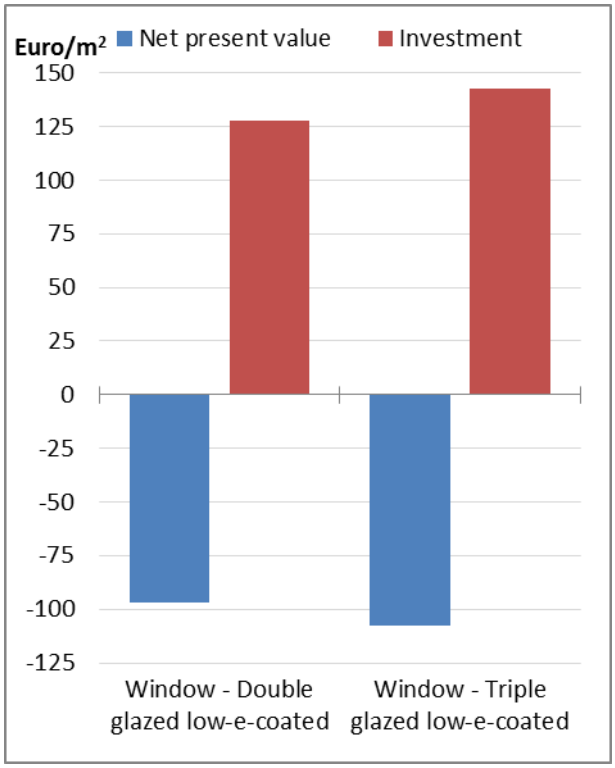
New low-energy windows

Two types of replacement windows were analysed and compared with the starting point window, which is a double-glazed window with a U-value = 2.7 W/m^{2}K:

- Double-glazed low-e-coated (U_{Window} = 1.2 W/m^{2}K
- Triple-glazed low-e-coated (U_{Window} = 0.9 W/m^{2}K)

Due to the fact that the investments for a new low-energy window are high, the NPV is negative. The payback times are also very high: About 100 years.

CO_2 reductions range between 3.2 and 3.8 kg/m^2/year and the energy savings between 14 and 16 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.



Summary for energy renovation of building construction elements in Germany

The conducted screening analyses show that insulating roof and floor has a positive NPV except for the smallest level of additional floor insulation. The initial conditions for both the roof and floor were rather poor, so the additional insulation means a significant improvement. Both the insulation of the facade walls and the replacement of windows result in negative NPV. Additional wall insulation results in the biggest CO_2 reductions and energy savings.

It should be noted that the NPVs cannot be added, because the energy savings stemming from the implementation of each technology is affected and reduced by the energy savings of the other technologies.

Whole concepts have been analysed as part of the School of the Future screening work and results for whole packages of technologies can be found in the screening reports. However, if the NPV – values are negative, they remain negative and ways should be sought to reduce the investment costs to reach a positive NPV.

It may also be considered that positive NPV values can outbalance negative values resulting in financially justifiable energy retrofit project.

Results for Norway

The Side Corridor school investigated is from the 1970s, and it is assumed that there is low insulation in the walls and the construction is medium heavy.

The school is ventilated by mechanical exhaust air without cooling. The school is electrically heated, but in the results in this report the electricity for heating are shown separated from the energy consumption by other electrical installations (e.g. fans, pumps and electrical lighting).

The electrical radiators have integrated thermostats, and the hot water consumption is for a school with a gym. The basement is not heated. The period of use is 201 days a year and from 8 am to 5 pm.

The reference building consumes 169.1 kWh/m^2 per year of electricity, where 149.2 kWh/m^2 per year is used for heating.

Additional wall insulation

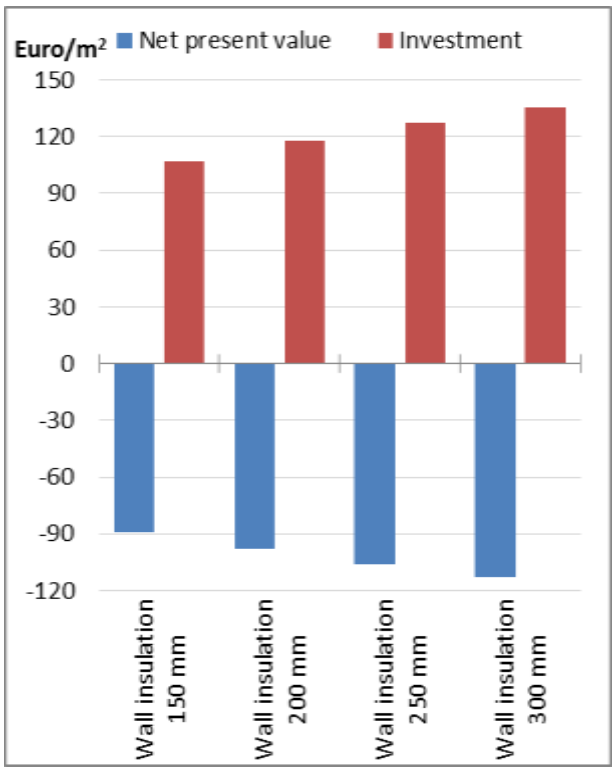
Four different thicknesses of additional insulation were considered starting with an U-value = 0.37 W/m^{2}K:

- 150 mm (U_{Wall} = 0.15 W/m^{2}K)
- 200 mm (U_{Wall} = 0.12 W/m^{2}K)
- 250 mm (U_{Wall} = 0.11 W/m^{2}K)
- 300 mm (U_{Wall} = 0.09 W/m^{2}K)

The investments are high and mainly therefore the NPV is negative despite the high energy savings. The highest investment gives the worst NPV, even though the energy savings are highest.

The payback times of the extra wall insulation are higher than the physical lifetime (40 years) about 140 years.

CO_2 reductions range between 2.8 and 3.6 kg/m^2/year and the energy savings between 21 and 26 kWh/m^2/year.

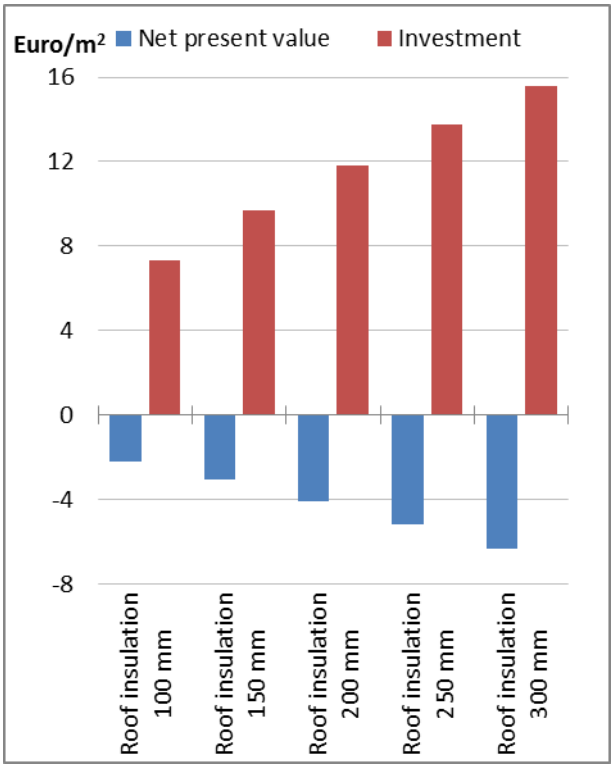


Additional roof insulation

The starting point for these calculations was a roof with a U-value = 0.20 W/m²K. Five different thicknesses of additional insulation were analysed:

- 100 mm (U_{Roof}= 0.13 W/m²K)
- 150 mm (U_{Roof}= 0.11 W/m²K)
- 200 mm (U_{Roof}= 0.10 W/m²K)
- 250 mm (U_{Roof}= 0.09 W/m²K)
- 300 mm (U_{Roof}= 0.08 W/m²K)

Because of the relative good starting point the energy savings are modest, which results in negative NPVs and long payback times: 34-39 years. The CO_2 reductions are correspondingly small – ranging from 0.8 to 1.5 kg/m²/year. The energy savings are low: 2.2-4.2 kWh/m²/year.

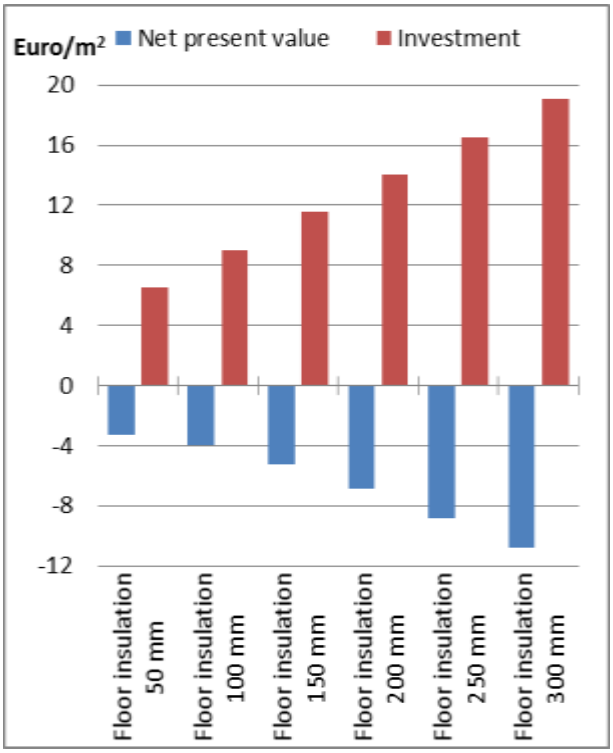


Additional floor insulation

Six different thicknesses of additional insulation levels of floor insulation were analysed starting with the U-value = 0.3 W/m²K:

- 50 mm (U_{Floor}= 0.21 W/m²K)
- 100 mm (U_{Floor}= 0.17 W/m²K)
- 150 mm (U_{Floor}= 0.14 W/m²K)
- 200 mm (U_{Floor}= 0.11 W/m²K)
- 250 mm (U_{Floor}= 0.10 W/m²K)
- 300 mm (U_{Floor}= 0.09 W/m²K)

Prices for the floor insulation used were for a school, where there is easy access to insulating the floor from beneath through crawl space or basement. In all cases, a negative NPV is achieved. Again this relates to a relatively good starting point – energy savings are moderate to small. The simple payback time is between 41 and 55 years.



CO_2 reduction ranges between 0.5 and 1.3 kg/m²/year and the energy savings between 1.5 and 4 kWh/m²/year.

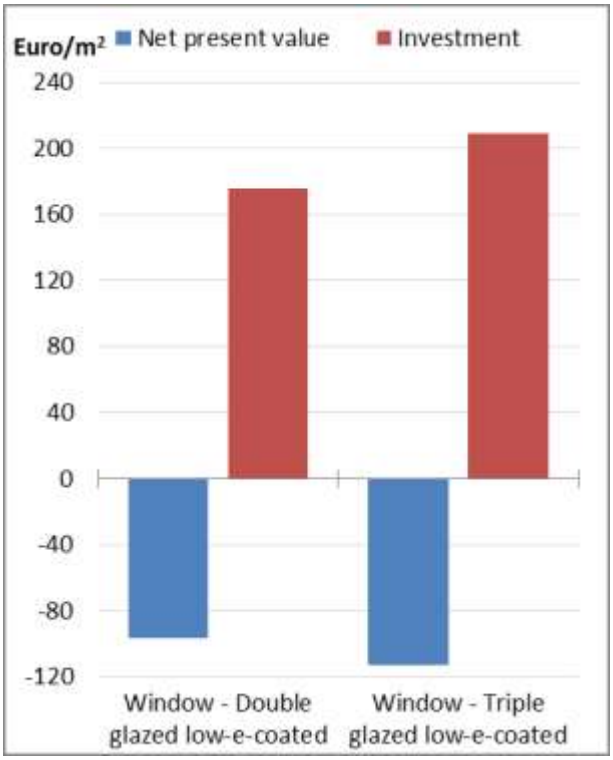
New low-energy windows

Two types of replacement windows were analysed and compared with the starting point window, which is a double-glazed window with a U-value = 2.9 W/m^{2}K:

- 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)

Due to the fact that the investments for a new low-energy window are high, the NPV is negative. The payback times are also very high: A little over 50 years – compared with a lifetime of 20 years.

CO_2 reductions range between 12.5 and 15.5 kg/m^2/year and the energy savings between 40 and 50 kWh/m^2/year.



Summary for energy retrofit of building construction elements in Norway

The conducted screening analyses show that the energy retrofitting of all the building construction elements resulted in a negative NPV. This is partly due to the fact that the reference school building for Norway is relatively well insulated and to the low energy prices in Norway.

The replacement of windows results in the biggest CO_2 reductions and energy savings. This relates to the change in U-value from 2.9 to 1.2 or 0.7 W/m²K, which in absolute value is much larger than the change of U-values for the wall, roof or floor.

It needs to be kept in mind that for Norway the CO_2 emissions from electricity production are arbitrarily set equal to those of Denmark.

It should be noted that the NPVs cannot be added, because the energy savings from the implementation of each technology is affected and reduced by the energy savings of the other technologies.

Whole concepts have been analysed as part of the School of the Future screening work and results for whole packages of technologies can be found in the screening reports. However, if the NPV – values are negative, they remain negative and ways should be sought to reduce the investment costs to reach a positive NPV.

Results for Italy

Climatic conditions

The Italian territory is characterised by a wide climatic variety. As an example there are municipalities with less than 600 degree days (base 20°C) and others with more than 5000 degree days. This complexity has led to the definition of six climatic zones: they are defined for the heating season only and are summarised in the next table. The table also shows the distribution of the population by climatic zone.

Table 8: Italian climatic zones

Climatic zone	Degree days [°C day]	Population distribution [%]
A	<600	0.04
B	>600 - <900	5.6
C	>900 - <1400	21.5
D	>1400 - <2100	26.0
F	>2100 - <3000	44.2
F	>3000	2.7

Some zone aggregation was decided in order to limit the number of simulations and outputs, and provide a clearer picture of the screened technologies. Three localities were selected as those with degree day values closer to the average of the aggregated zones weighted in relation to the population. The localities are:

- Turin (zone E+F) - typical northern Italian climate.
- Terni (zone D) – typical central Italian climate
- Taranto (zone A+B+C) – typical southern Italian climate

Table 9: Italian climatic zones data

	Turin	Terni	Taranto
Degree Days	2617	1650	1071
Lat	45°7’	42°33’	40°27’
Long E	7°43’	12°38’	17°14’
Design Ext Temp	-8°C	-2°C	0°C
Tint - Text	28°C	22°C	20°C
Heating season	183 days	166 days	137 days

Economic parameters

The specific parameters taken into account for economic calculations in the ASCOT calculation program are shown in Table 10.

Table 10: Economic parameters

Economic parameters	
Discount rate	4.7%
Tax of interest income	0.0%
Inflation of energy	4.3%
Inflation of maintenance	2.8%
Expected economic lifetime	30

Envelope components

For all the climatic zones, the same structural components and their thermal characteristics are shown in Table 11. For the roof and the windows, two calculations were made for two different references: Existing and already renovated.

Table 11: Envelope thermal characteristics

Envelope structures	U_{value} W/m^2K	
	Existing	Already renovated
External Wall	1.16	-
Floor	1.10	--
Roof	1.00	0.55 – 0.42
Windows	6.0	3.30

The following presentation of results is divided into three parts according to the different climatic zones.

Turin climate

The reference U-values and the U-values for the assumed renovations appear in table 12.

Table 12: U-values of reference and renovated construction elements.

TURIN			
Extra Wall insulation	U ref	U opt	
+ 80 mm insulation – U-value → National Code	1.16	0.33	
+100 mm insulation – U-value → Extra	1.16	0.28	
Extra-Roof insulation			
Roof not insulated + 90 mm insulation – U-value → National Code	1.00	0.31	
Roof not insulated + 120 mm insulation – U-value → National Code	1.00	0.25	
+ 90 mm insulation – U-value → National Code (already 0.06 insulated)	0.42	0.21	
+120 mm insulation – U-value → Extra (already 0.06 insulated)	0.42	0.18	
Extra-Floor insulation	U ref	U opt	
+ 90 mm insulation – U-value → National Code	1.10	0.32	
+120 mm insulation – U-value → Extra	1.10	0.25	
Windows	U ref	U opt	t
U-value → National Code (already insulated) t=0.75	3.3	U=1.7	0.70
U-value → Extra (already insulated) t=0.75	3.3	U=1.2	0.70
Reference Windows t =0.80	6.0	U=1.7	0.70
Reference Windows t =0.80	6.0	U=1.2	0.70

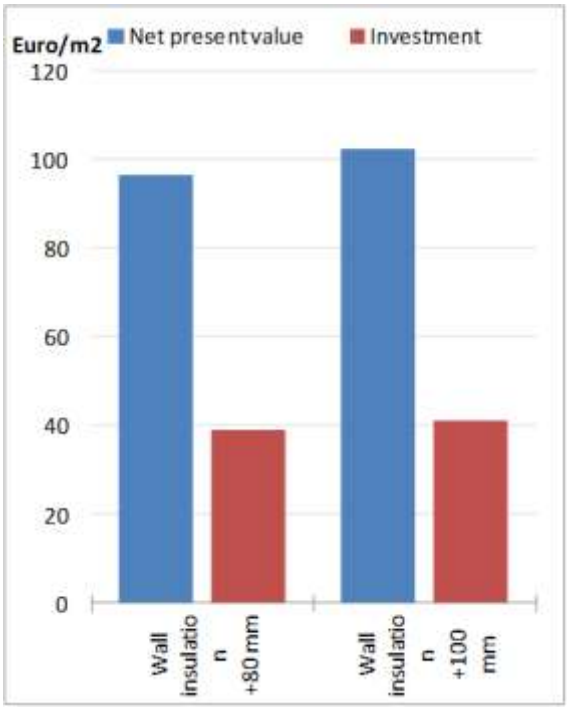
Additional wall insulation

Two different thicknesses of additional insulation were considered as shown in Table 12.

The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

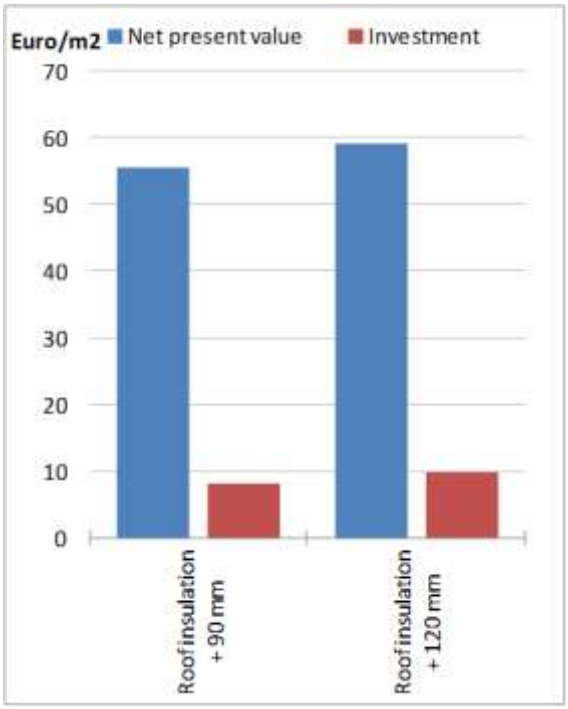
The simple payback times of the extra wall insulation are as low as 8 years in both cases.

The CO_2 reduction is around 11 kg/m^2/year and the energy savings lie between 51 and 64 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.



Additional roof insulation (reference)

Two different thicknesses of additional insulation were considered as shown in table 12.



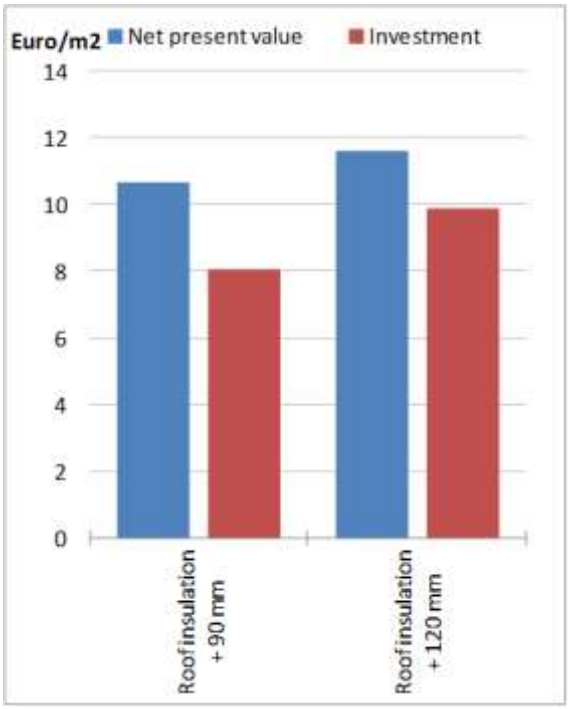
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulation are as low as 3-4 years.

The CO_2 reduction is 5-5.5 kg/m^2/year and the energy savings lie between 24 and 26 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation (already renovated)

In this case, the roof had already been insulated to a U-value of approx. 0.5 W/m^{2}K. Again two different thicknesses of additional insulation were considered as shown in table 12.



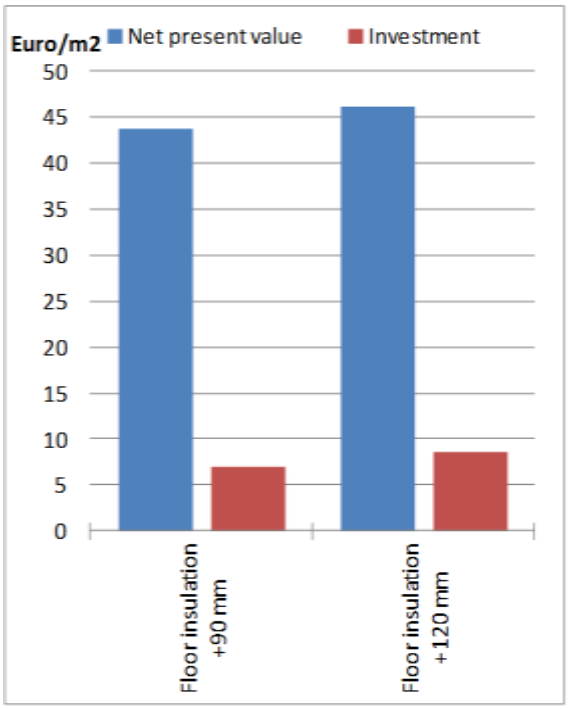
The NPV is still higher than the investments even if it shows that this intervention is considerably less profitable than in the reference case. The highest investment also results in a higher NPV, so it still appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulations are now 13-14 years.

The CO_2 reduction is 1.4-1.7 kg/m^2/year and the energy savings lie between 7 and 8 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps that transport the hot water for the heating system.

Additional floor insulation

Two different thicknesses of additional insulation were considered as shown in table 12.



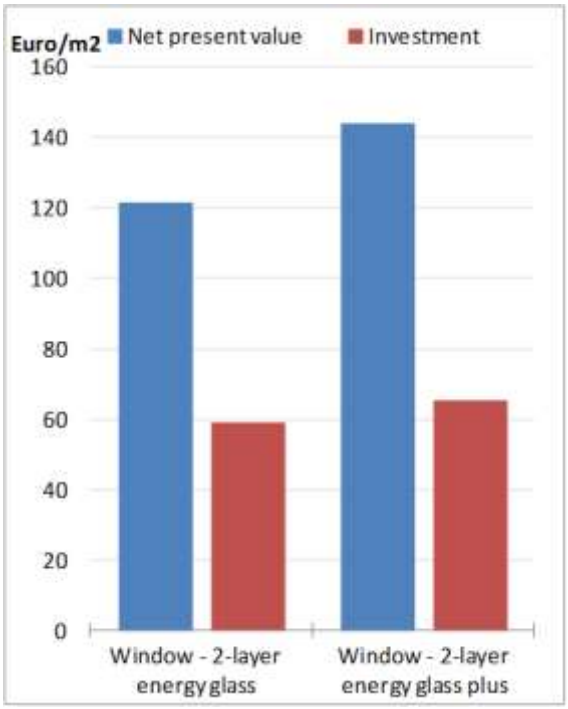
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulation are as low as 4-5 years.

The CO_2 reduction is 4-4.3 kg/m^2/year and the energy savings lie between 19 and 21 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (reference)

Two different energy qualities of new energy windows were considered as shown in table 12.



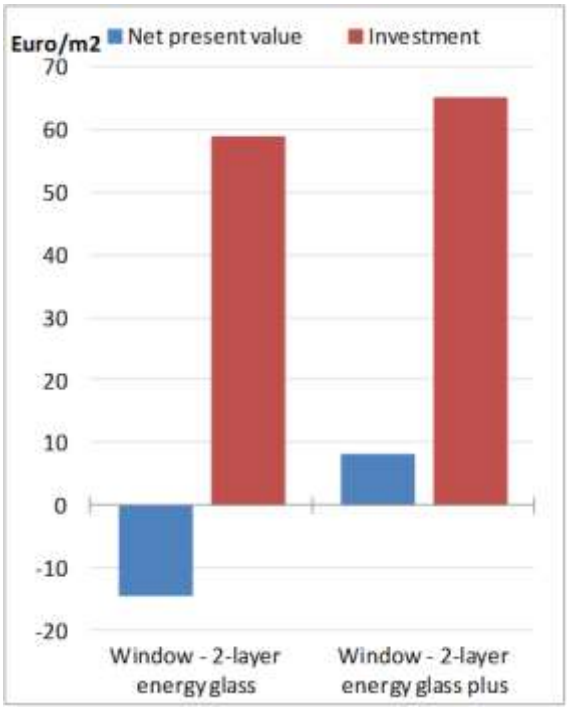
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the new windows are 8-9 years.

The CO_2 reduction is 14-16 kg/m^2/year and the energy savings lie between 70 and 80 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (already changed)

In this case the windows had already been changed earlier, so the initial U-value was 3.3 W/m^2K instead of 6 W/m^2K like in the reference case. Again two different energy qualities of new energy windows were considered as shown in table 12.



The NPV has now become negative for the standard 2-layer energy glass window but still positive for the energy glass plus window. This is due to the relatively low energy savings. The simple payback times of the windows are over 25 years. The CO_2 reduction is 3.5-6 kg/m^2/year and the energy savings lie between 17 and 28 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Terni climate

Reduction of losses regarding the envelope components

The first step considers the upgrading of the envelope according to the requirements fixed by the national building code. A more efficient step is taken into account, with the thermal transmittance of the envelope components reduced by 15/20% with respect to the actual standards.

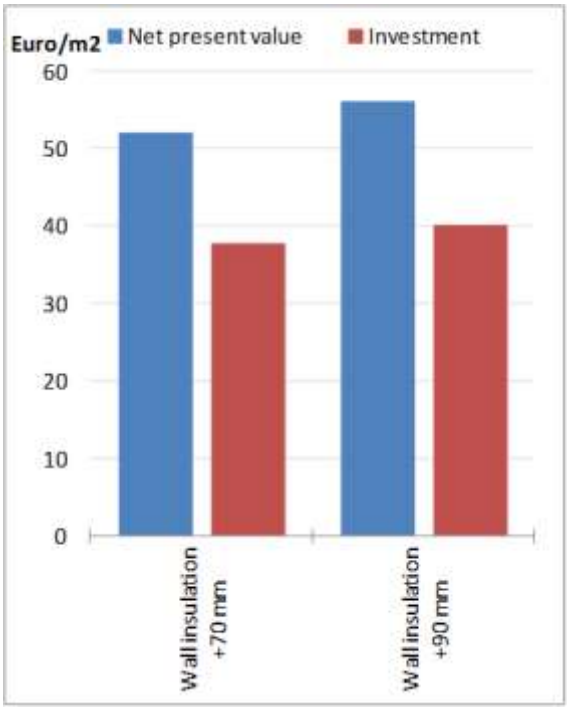
The thermal characteristics of the reference building structure vs renovated ones are shown in Table 13: the best performance of renovated components resulted by adding an insulation material (λ= 0,036 W/mK) to the existing masonry.

Table 13: Envelope renovation characteristics

TERNI			
Extra Wall insulation	U ref	U opt	
+ 70 mm insulation – U-value → National Code	1.16	0.36	
+90 mm insulation – U-value → Extra	1.16	0.30	
Extra-Roof insulation			
Roof not insulated + 90 mm insulation – U-value → National Code	1.00	0.31	
Roof not insulated + 120 mm insulation – U-value → National Code	1.00	0.25	
Roof already 0.04 insulated + 90 mm insulation – U-value → National Code	0.55	0.23	
Roof already 0.04 insulated +120 mm insulation – U-value → Extra	0.55	0.20	
Extra-Floor insulation	U ref	U opt	
+ 90 mm insulation – U-value → National Code	1.10	0.32	
+120 mm insulation – U-value → Extra	1.10	0.25	
Windows	U ref	U opt	t
U-value → National Code (already insulated) t=0.75	3.3	U=2.0	0.70
U-value → Extra (already insulated) t=0.75	3.3	U=1.5	0.70
Reference Windows t =0.80	6.0	U=2.0	0.70
Reference Windows t =0.80	6.0	U=1.5	0.70

Additional wall insulation

Two different thicknesses of additional insulation were considered as shown in table 13.



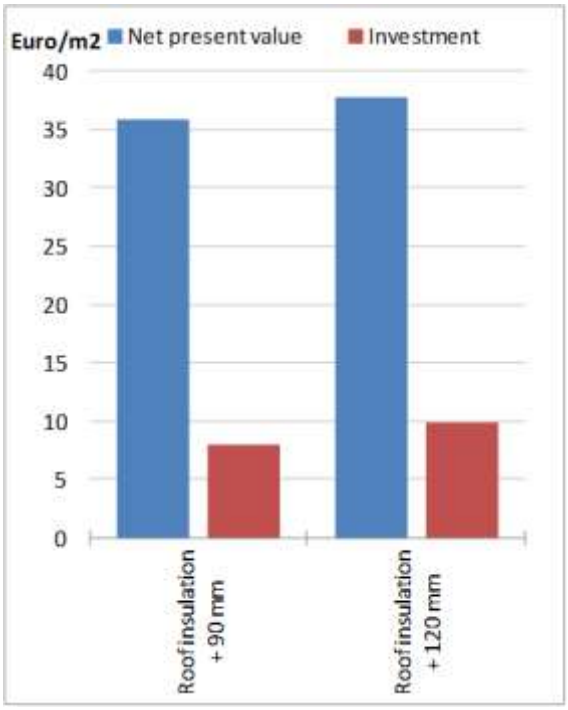
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback time of the extra wall insulations is 12 years in both cases.

The CO_2 reduction is around 7 kg/m^2/year and the energy savings lie around 35 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation (reference)

Two different thicknesses of additional insulation were considered as shown in table 13.



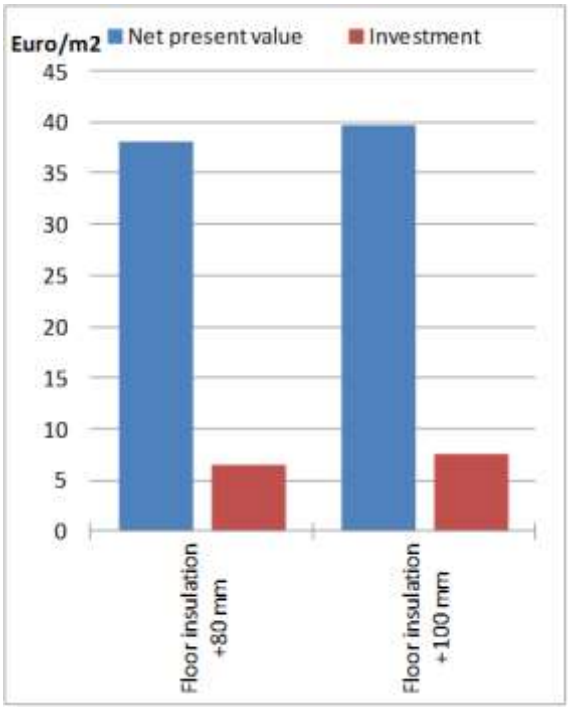
The NPV is quite high compared with the investments due to the high energy savings and relatively low cost. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback time of the extra roof insulation is as low as 5 years in both cases.

The CO_2 reduction is 3.5-3.7 kg/m^2/year and the energy savings lie between 17 and 19 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation (already renovated)

In this case, the roof had already been insulated to an U-value of 0.55 W/m^{2}K. Again two different thicknesses of additional insulation were considered as shown in table 13.



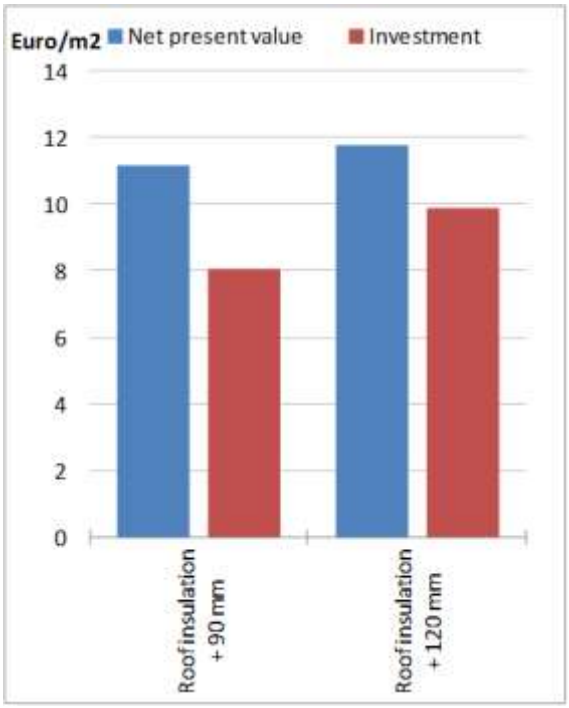
The NPV is still higher than the investments even if it shows that this intervention is considerably less profitable than in the reference case.. The highest investment also results in a higher NPV, so it still appears to be a good idea to invest in the thickest insulation level.

The simple payback time of the extra roof insulation is now 12-13 years.

The CO_2 reduction is 1.5-1.7 kg/m^2/year and the energy savings lie between 7 and 8 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional floor insulation

Two different thicknesses of additional insulation were considered as shown in table 13.



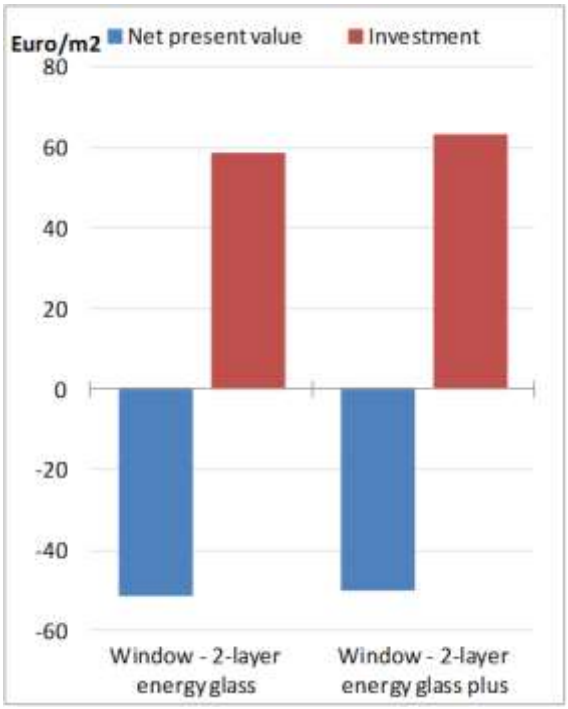
The NPV is quite high compared with the investments due to the high energy savings and relatively low cost. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulation are as low as 4-5 years.

The CO_2 reduction is 4.2-4.6 kg/m^2/year and the energy savings lay around 17 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (reference)

Two different energy qualities of new energy windows were considered as shown table 13.



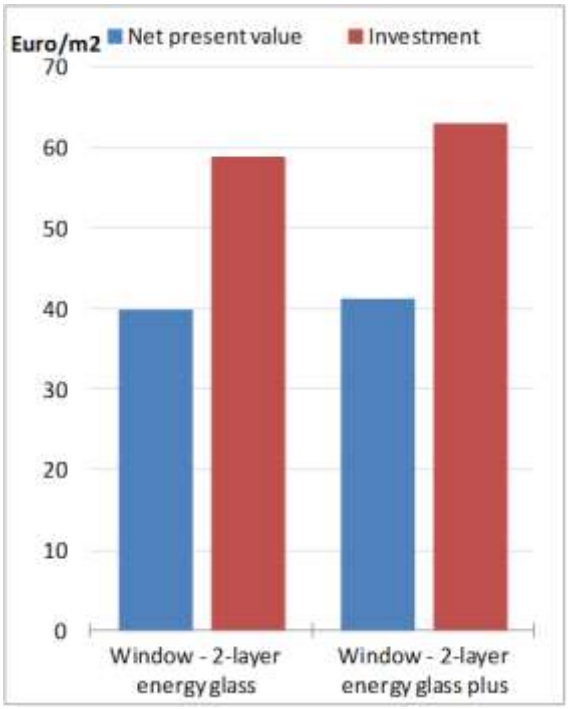
The NPV is positive in both cases – but lower than the initial investments. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback time of the new windows is around 17 years.

The CO_2 reduction is around 8 kg/m^2/year and the energy savings lie around 40 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (already changed)

In this case, the windows had already been changed earlier, so the initial U-value was 3.3 W/m^{2}K instead of 6 W/m^{2}K as for the reference case. Again two different energy qualities of new energy windows were considered as shown in table 13.



The NPV is in this case negative for both types of new windows. This is due to the relatively low energy savings and quite high costs.

The simple payback time of the windows is more than 100 years.

The CO_2 reduction is 0.6-1 kg/m^2/year and the energy savings lie between 4 and 6 kWh/m2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Taranto climate

Reduction of losses regarding the envelope components

The first step considers the upgrading of the envelope according to the requirements fixed by the national building code. A more efficient step is taken into account, with the thermal transmittance of the envelope components reduced by 15/20% with respect to the actual standards.

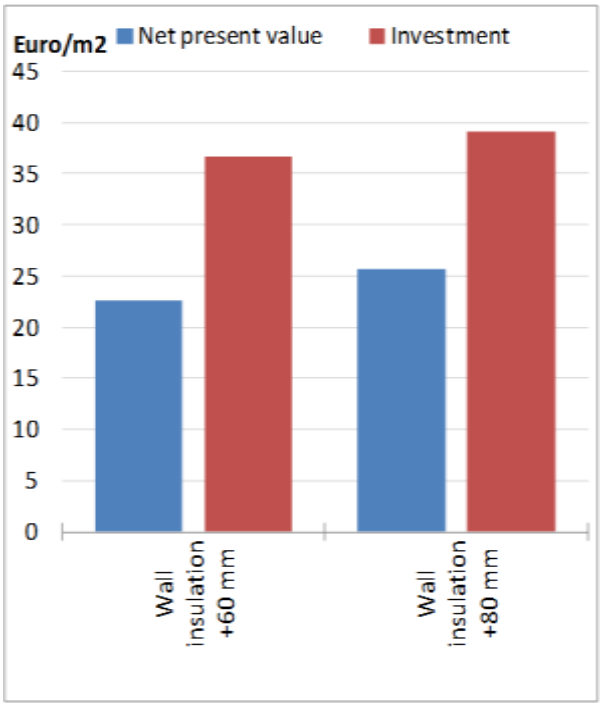
The thermal characteristics of the reference building structure vs renovated ones are shown in Table 14 the best performance of renovated components resulted by adding an insulation material (λ = 0,036 W/mK) to the existing masonry.

Table 14: Envelope renovation characteristics

TARANTO			
Extra Wall insulation	U ref	U opt	
+ 60 mm insulation – U-value → National Code	1.16	0.39	
+ 80 mm insulation – U-value → Extra	1.16	0.33	
Extra-Roof insulation			
Roof not insulated + 70 mm insulation – U-value → National Code	1.00	0.37	
Roof not insulated + 90 mm insulation – U-value → National Code	1.00	0.31	
Roof already 0.04 insulated + 70 mm insulation – U-value → National Code	0.55	0.26	
Roof already 0.04 insulated + 90 mm insulation – U-value → Extra	0.55	0.23	
Extra-Floor insulation	U ref	U opt	
+ 70 mm insulation – U-value → National Code	1.10	0.36	
+ 90 mm insulation – U-value → Extra	1.10	0.30	
Windows	U ref	U opt	t
U-value → National Code (already insulated) t=0.75	3.3	U=2.5	0.82
U-value → Extra (already insulated) t=0.75	3.3	U=1.4	0.70
Reference Windows t =0.80	6.0	U=2.0	0.70
Reference Windows t =0.80	6.0	U=1.5	0.70

Additional wall insulation

Two different thicknesses of additional insulation were considered as shown in table 14.



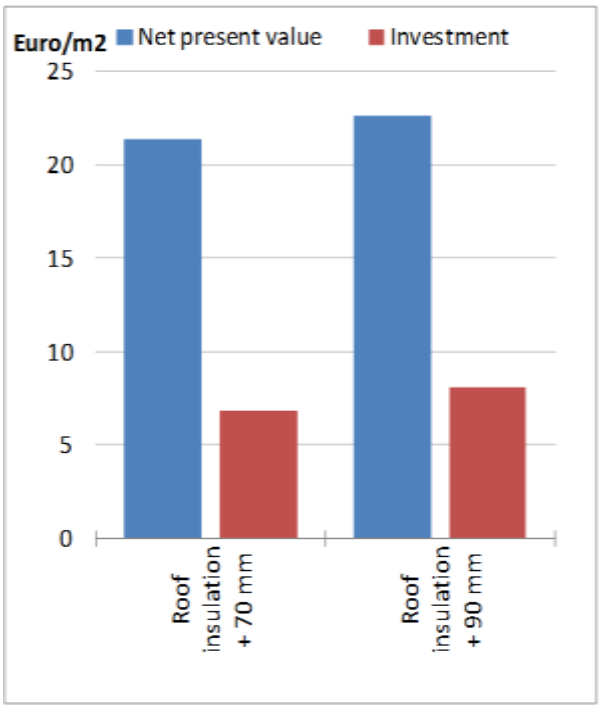
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback time of the extra wall insulation is as low as 8 years in both cases.

The CO_2 reduction is around 11 kg/m^2/year and the energy savings lie between 51 and 64 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation (reference)

Two different thicknesses of additional insulation were considered as shown in table 14.



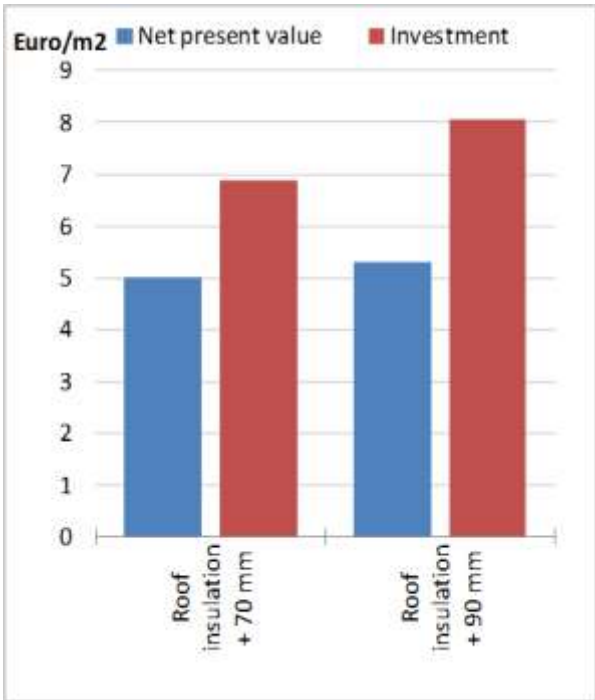
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulations are as low as 3-4 years.

The CO_2 reduction is 5-5.5 kg/m^2/year and the energy savings lie between 24 and 26 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional roof insulation (already renovated)

In this case the roof had already been insulated to an U-value of approx. 0.5 W/m^{2}K. Again two different thicknesses of additional insulation were considered as shown in table 14.



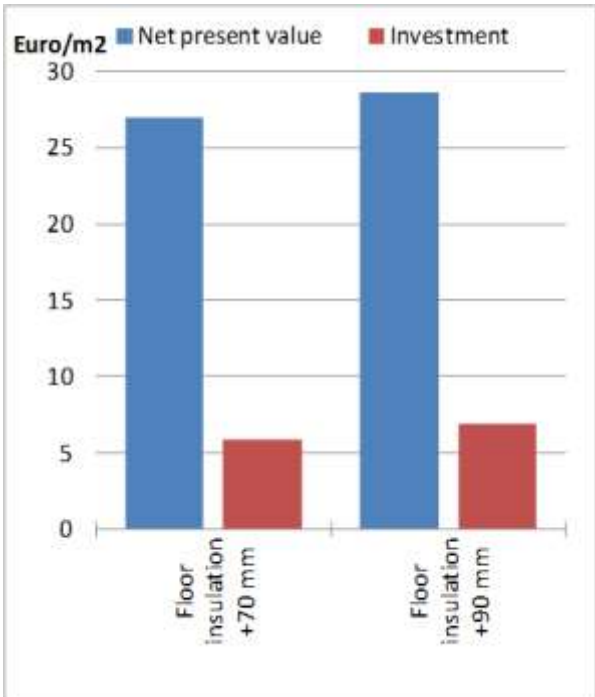
The NPV is still higher than the investments even if it shows that this intervention is considerably less profitable than in the reference case. The highest investment also results in a higher NPV, so it still appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulations are now 13-14 years.

The CO_2 reduction is 1.4-1.7 kg/m^2/year and the energy savings lie between 7 and 8 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Additional floor insulation

Two different thicknesses of additional insulation were considered as shown in table 14.



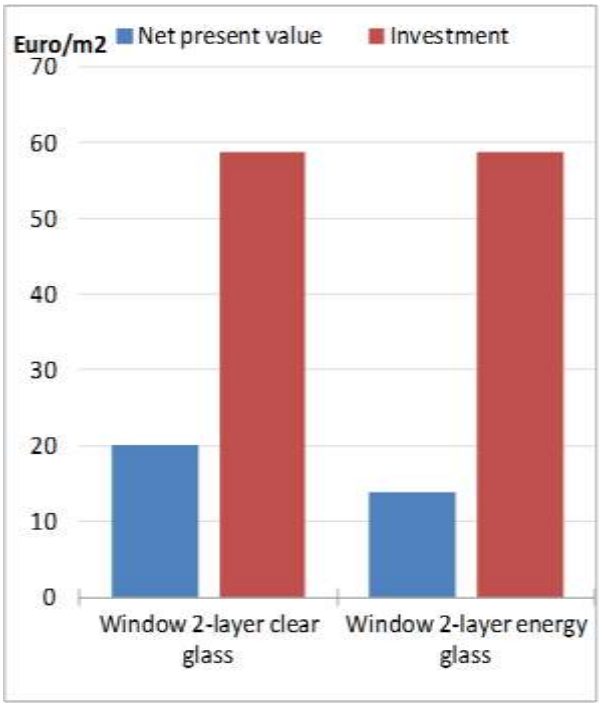
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulation are as low as 4-5 years.

The CO_2 reduction is 4-4.3 kg/m^2/year and the energy savings lie between 19 and 21 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (reference)

Two different energy qualities of new energy windows were considered as shown in table 14.



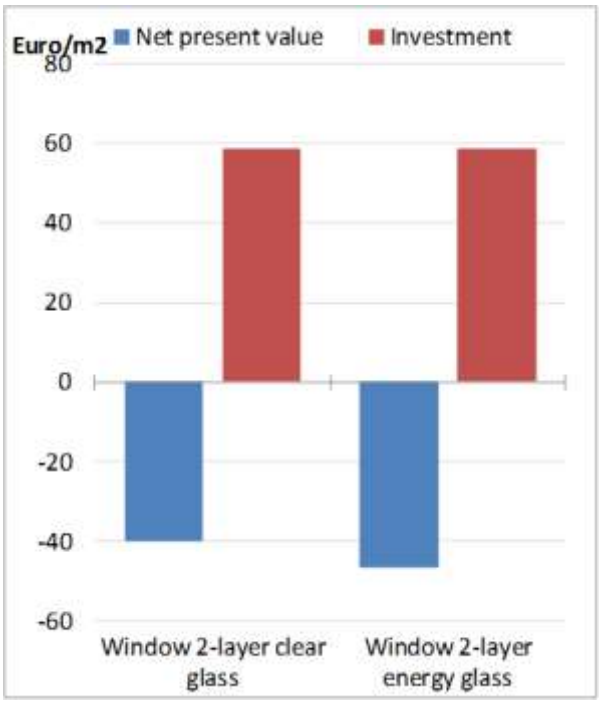
The NPV is quite high compared with the investments due to the high energy savings. The highest investment also results in a higher NPV, so it appears to be a good idea to invest in the thickest insulation level.

The simple payback times of the extra roof insulation are 8-9 years.

The CO_2 reduction is 14-16 kg/m^2/year and the energy savings lie between 70 and 80 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

New low-energy windows (already changed)

In this case the windows had already been changed earlier, so the initial U-value was 3.3 W/m^{2}K instead of 6 W/m^{2}K as for the reference case. Again two different energy qualities of new energy windows were considered as shown in table 14.



The NPV has now become negative for the standard 2-layer energy glass window but still positive for the energy glass plus window. This is due to the relatively low energy savings.

The simple payback time of the windows is over 25 years.

The CO_2 reduction is 3.5-6 kg/m^2/year and the energy savings lie between 17 and 28 kWh/m^2/year – including a small reduction in the consumption of electricity due to less use of the pumps to transport the hot water for the heating system.

Summary for energy refit of building construction elements in Italy

The conducted screening analyses show a strong dependence on the climatic conditions in Italy.

Turin has a continental climate and the impact of insulation measures for all the envelope components show high energy savings and NPVs. This also depends on the poor energy performance of the reference building configuration, which has no insulation. It is to be noted that windows have high NPVs with higher initial investments. The additional roof insulation presents NPVs slightly higher than the investment costs, which makes this measure less profitable; the window replacements were also tested in the case of a previous replacements: the results show negative NPVs in case of an efficient energy windows and slightly positive for energy plus windows, in both cases the measure is not effective when compared with the initial costs.

Terni has the typical climate conditions of the centre of Italy, with milder winters compared with Turin. In general, this means that energy and financial savings due to energy conservation measures are lower. Valuable measures are the insulation of roof and floor for non-insulated buildings, the insulation of façades and the additional insulation on the roof give NPVs higher than the initial investment, but the measures are less effective than the previous ones. Windows replacement is not very effective, because of high initial costs and moderate energy savings, depending also on the properties of existing windows and characteristics of those available on the market; in case of new windows, replacing already changed ones, the NPV is negative.

Taranto has a typical Mediterranean climate with mild winters and warm summers. The results are in this case in line with those achieved for Terni, but with lower *intensities*. This implies that effective measures are the insulation for roof (if not previously insulated) and the floor. Wall and extra roof insulation still provide positive NPVs, but the energy savings are so low that they are lower than the initial investments. Windows replacement is not an effective solution for this building configuration.

It should be noted that the NPVs cannot be added, because the energy savings stemming from the implementation of each technology is affected and reduced by the energy savings of the other technologies.

Whole concepts have been analysed as part of the School of the Future screening work and results for whole packages of technologies can be found in the screening reports. However, if the NPV – values are negative they remain negative and ways should be sought to reduce the investment costs to reach a positive NPV.

It may also be considered that positive NPV-values can outbalance negative values resulting in financially justifiable energy retrofit project.

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