JOINT INVENTORY OF ENERGY-SAVING AND RES TECHNOLOGIES WITH BEST COST-EFFECTIVE BUNDLE OF MEASURES FOR SCHOOLS

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Edited by Energy agency of Savinjska, Šaleška and Koroška Region

in cooperation with CertiMaC Scarl

INDEX

1. Energy@school, brief project outline

The building sector has high potential for energy optimization being the most consuming one in EU. In terms of public buildings heritage, energy consumption in schools is the second highest expenditure of Municipalities total running costs. This sector offers potential remarkable achievements in terms of Energy Efficiency (EE), Renewable Energy Sources (RES) application and carbon footprint reduction and several disparities exist among Central Europe countries as for planning and implementing performances of proper sector-based strategies, action plans and managerial capacities.

With reference to the **public stock of buildings and infrastructures**, for sure educational facilities are an important opportunity to achieve substantial energy savings, as they constitute a relevant part of the overall amount of energy consumption and therefore of the expenses paid by the national budgets. Energy consumption in schools is the second most significant expense to total running costs and they account up to 70% of the thermal energy cost of Municipalities. Schools, being such an important line in energy-related budget, represent an important sector of public administration to tackle with reference to buildings' upgrade, retrofitting and renovation. Furthermore, schools are the best environment for behavior change and awareness raising of students and, indirectly, their families because they are the privileged place for the dissemination of culture and information as a whole and therefore also in the field of energy saving and efficiency. Consumption in schools can be quite variable depending on country, climate, building year of construction and type. However considering an average energy use profile, consumes can be roughly divided as follows: 47% heating; 14% lighting; 10% cooling; 9% ventilation; 7% water heating; 4% PC; 2% refrigeration; 1% cooking; 1% office equipment; 5% other. It is estimated that just by making small changes in behavior, schools could save up to 20% of their energy use (and bills). This amount can noticeably increase if energy retrofit interventions are associated to behavioral changes (e.g. around 50% with 0.5 to only 2 years payback period).

Public building sector with reference to schools is therefore one of the main issues and there is concrete need to develop energy-efficient management for schools and strategies on how to improve the energy efficiency. There is also need to raise the awareness of school staff and students, and to involve them in the energy saving activities. People have a crucial role in this process, therefore they need to be supported and provided with the best available solutions.

Main ENERGY@SCHOOL objective is to increase the capacity of the public sector to **implement Energy Smart Schools**, by application of an integrated approach that **educate and train schools staff and pupils to become Senior and Junior Energy Guardians (EGs) who will engage on progressive and sustainable energy efficiency of buildings and an adequate transfer of a correct attitude towards energy consumption ("energy culture").** Thanks to a commitment to high-performance schools, many school districts are discovering that smart energy choices can have lasting benefits for their students, communities, environment. The key idea is to provide concrete technical Tools and Devices and specialized trainings for School Planning Managers on financing opportunities, designing, operating & maintaining energy solutions. The innovative character lies in the active involvement of employees, experts, students, teachers, families in the process of transforming the school into an energy smart school through specific and targeted training and education activities.

The project will therefore address common barriers associated with energy smart-school management, it will develop and provide a Methodology & Approach usable and replicable within other school buildings, together with the necessary Tools, Devices & Protocols. In this way all parties involved in the energy decisions of a public school (technicians and ICT professionals, administrators, school employees Energy managers) can face in a coordinated manner the issue of Energy Efficiency by implementing effective and validated solutions.

The project will deliver:

⇒ 1 Common/Transferrable and 8 customized Strategies for Smart Schools,

⇒ 1 joint and 7 customized Energy Smart-school Management Plans,

⇒ 3 smart phones APPs for Energy Guardians,

⇒ 8 tested pilot solutions of EE & RES application in schools under direct contribution of Energy Guardians, in the form of Guidelines, Toolbox, Best Practices as reference documents and experiences to be capitalized far beyond the project end.

⇒ Training & education programs as adaptable & replicable models for capacity-raising and Energy Culture rooting.

ENERGY@SCHOOL expected results:

I. Optimization of energy consumption in schools,

II. Concrete and progressive increase of EE and RES use in schools not only thanks to technical application of smart solutions, but also to non-technical factors such as a better management capacity and responsible behavior toward energy use,

III. Increase of capacity of public sector to deal with increase of EE and RES use in schools thanks to strategy, action plans, tools (methods, approaches), trainings, pilot actions defined and implemented within the project,

IV. Increase in managerial and organizational competences as well as in human resources to ensure the progressive and sustainable energy efficiency and renewable energy se in public schools (trainings),

V. Creation of conditions for new job opportunities (trainings),

VI. Creation of "energy culture", thus responsible attitude towards energy use, thanks to education and raising awareness activities, as it is demonstrated that amount of saved energy can noticeably increase if energy retrofit interventions are associated to behavioral changes.

List of Project Partners

1 Union of Municipalities of Low Romagna Region , Lead Partner – Italy
2 CertiMaC s.c.r.l. - Italy
3 City of Bydgoszcz - Poland
4 ENERGY AGENCY OF SAVINJSKA, ŠALEŠKA AND KOROŠKA REGION - Slovenia
5 City of Karlovac - Croatia
6 University of Bologna - Dept of Industrial Chemistry - Italy
7 Municipality of the CITY Szolnok with County Rank - Hungary
8 Local Government of Town Újszilvás - Hungary
9 City of Stuttgart - Germany
10 Klagenfurt - Austria
11 Graz Energy Agency - Austria
12 City municipality of Celje - Slovenia

Responsible Partner of Thematic Work Package "*Analysis phase and definition of Energy Guardians Smart-school Management Plans*" and the present document: CertiMaC – Research Laboratory -Italy

2. Introduction

"Joint inventory of energy-saving and RES technologies with best cost-effective bundle of measures for schools" contributes to the second output of Energy@school project, which is the Energy Smart-school Management Plan (EGSMP). EGSMP is a comprehensive plan clearly setting technical, management and behavioural virtuous actions to be undertaken by Energy Guardians and the school to progressively achieve higher energy savings.

"Joint inventory of energy-saving and RES technologies with best cost-effective bundle of measures for schools" is a description of relevant retrofitting measures for ES and RES application in schools, that are classified according cost-effective priority. The guide is mainly aimed at creating technical competences of future senior energy guardians, to be able to asses the necessity of certain energy improvements in the school building and to be able to start necessary steps towards upgrading schools in terms of EE and RES applications. Collection of measures is roughly divided in to the following areas of intervention:

- Insulation of thermal envelope
- Windows
- Measures on heat generators
- Measures on domestic hot water preparation systems
- Measures on distribution systems
- Regulation measures
- Measures on ventilation systems
- Measures on lighting systems
- Control and energy management systems

For each area of intervention guide tries to present possibilities for upgrading older but sound systems to make them more efficient, as well as introducing options for complete refurbishment or replacement. The last chapter presents categorization of measures based on expected savings, investment costs and payback period. Which measures can be applied in a specific building in what savings can be expected, however, depends on the construction material, the way energy is used and how the building and its equipment are maintained. This, of course, varies from building to building. Depending on the specific context, the type of buildings and the technology available, some of these measures will be more applicable than others.

Some low-cost of the measures, described in this document, can be implemented without major investment and without major interruption of the building use. There is no or only little planning necessary and no tenders or public procurement processes have to be started. These measures, such as installation of thermostatic valves, piping insulation, installing occupancy sensors etc, can be implemented only with a little assistance or advice of energy experts and with the help of school building manager.

Other more costly and technically complex measures are always planned and implemented by professionals, only after involving all the relevant actors in the process, such as school management and municipal authorities (or building owners) to be able to cooperatively undertake all important steps from energy audit, assessing priorities, deciding upon most cost-effective bundle of measures, researching all possible financial mechanisms and starting procurement proceedures.

3. Approaching energy refurbishment

3.1. Energy management

Energy refurbishment is usually associated with high investment costs, so technical measures must be carefully planned in accordance with the investment funds that are available. Savings when implementing technical measures can be very large, so it is necessary to consult with both the professional as well as financial institutions (in the case of other sources of funding), that will allow quality implementation of investment. It is important to also consider all financing options, including obtaining government grants and EU funds.

The goal when preparing retrofit plan and choosing proper is usually to follow the objective to maximize the energy savings and minimize the payback period for the given initial investment. To be able to achieve that it is necessary to integrate **energy management**, which is a proactive, organized and systematic way of monitoring, controlling and conserving energy in a building or organisation taking into account environmental and economic objectives. There are few basic steps of energy management cycle that should be considered when planning the energy investment:

1. Systematic acquisition of energy data (monitoring)

Energy data needs to be collected in regular time intervals to be able to understand and evaluate energy use. It is important to be able to visualize historic data, trends, daily and seasonal cycles etc. The more you know the better you do. Most of it can be done by energy management software – **energy bookkeeping.** Accurate and correct data collection is the baseline for all the later processing and calculations of EE and RES implementation.

2. Processing and analyzing energy data

Once you know your spend, it is time to target areas for reductions and savings. What's possible? What's reasonable and achievable? Detailed analysis of your energy data reveals opportunities for improvement in your building. **Energy audits** performed by professionals will help identify the list of possible measures of EE and RES to improve energy situation in building.

3. Planning and implementing EE and RES measures

Energy audits are necessary to assess the existing energy consumption and identify the whole range of opportunities to save energy. Furthermore, energy audits allow prioritization or ranking of measures according to the technical and economic justification and available founds. This should then result in proposals of concrete saving measures for the management, public authorities or building owners and implementing the investment.

4. Monitoring and evaluating

It is advisable to monitor the implementation of the measures and the effects after the implementation to see if energy savings are achieved. Quality, precise and detailed evaluation of the success of each measure is the baseline for the continuation of energy-efficient actions.

3.2. Partial and deep building refurbishment

Energy retrofitting can be approached as a partial or deep refurbishment. Partial implementation of measures means deciding on specific measures to be implemented (for example windows or thermal insulation). The positive side is that the costs and payback period will be much smaller. Energy consumption and costs will still be reduced and living environment will be improved, but the result of such partial approach doesn't bring significant energy optimization and is not that sustainable.

Building will still have to undergo additional investment measures in the future and if only 'partial solutions' are implemented, e.g. limited insulation of roofs or walls, it will be more expensive in the long run and perhaps technically impossible to realise the full energy-saving potential at a later date.

Using budget to fund many cheaper, shallow renovations in order to maximize short term savings, may seem more attractive than a deep energy renovation strategy, but it may also fail to achieve long-term energy saving goals. Deep renovation covers energy refurbishment as a whole, improving building structures and modernizing building mechanical systems. It includes measures on building envelope (insulation of external walls and roofs, replacement of windows and doors ect.), measures on building technical systems (energy supply measures in boiler rooms, measures on ventilation, cooling, lighting, heat recovery, insulation of piping), connection to district heating and using renewable energy if possible (RE boiler systems, thermal solar systems, ground water heating pumps in combination with EE measures, photovoltaic systems, wind, hydro power) etc.

Although the negative side are fairly large investment costs and long payback period, the positive side is that the building is thoroughly restored in the long term and significantly reduced operating and maintenance costs can be expected. **With deep renovation 50%-70% savings of final energy can be achieved.** Deep retrofit is the most sustainable approach, but it is also rarely implemented in buildings across EU. More often partial renovation of buildings is adressed, but partial renovation of buildings will likely not deliver to the EU its environmental objectives, since EU has committed to cut 80%-95% of its CO2 emissions by 2050.

European buildings are responsible for 40% of the total EU energy consumption and 36% of CO_2 emissions and that is why EU is prioritising a deep renovation policy. Energy Efficiency Directive (EED) requires EU States *"to establish a long-term strategy beyond 2020 for mobilising investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. That strategy should address cost-effective deep renovations which lead to a refurbishment that reduces both the delivered and the final energy* *consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance".*

4. Inventory of energy-saving measures

4.1. Insulation of thermal envelope

Thermal envelope is a key element to consider when addressing specific energy conservation methods and energy efficiency in general. The efficiency of the thermal envelope has a direct effect on the energy consumption and required capacity of technical equipment for heating and cooling. It`s main purpose is to prevent heat transfer from the interior of the building to the exterior and vice versa and help maintain the desired indoor climate. Along with heat transfer, phase shift and water vapor diffusion are most relevant factors that have an impact on the thermal envelopes efficiency, durability and economy when considering investment measures.

Advanced and efficient insulation systems provide greater thermal comfort to building users which can`t be compensated by other technical investment measures. Thermal comfort is defined as a state in which a person is satisfied with their thermal environment, thus is very subjective in terms that it includes the effects of many environmental and personal factors. **However, in terms of physical properties the factors that have the largest impact are temperature, indoor humidity and indoor air velocity. All of these factors are directly associated with the buildings thermal envelope and must be considered in unison when choosing the appropriate energy renovation scenario.**

Compromised or inadequate thermal insulation is easiest identified by air leaks, making the interior spaces feel drafty, especially during lower temperatures or strong winds. However, since best construction practices create an airtight barrier of the roof, external walls, building fixtures and the buildings foundation, we must also consider the effects on water vapor diffusion. In the heating season, when warm and humid air from indoors permeates through the envelope towards the exterior climate, it will cool down. When it reaches the dew point temperature, the moisture it holds will begin to condense and if this happens within the building structure (interstitial condensation), it can cause wide array of problems (failing of renders, mold, defective thermal insulation, etc.) Therefore in order to avoid such issues and maximize the performance and sustainability throughout the life cycle of the structure, energy renovation measures on the thermal envelope must be thoroughly planned and though through.

We will present the scenarios in which the external walls are load bearing and can`t be replaced entirely (replacement technologies), therefore all of the methods presented in the chapter are focused on adding a new layer of insulation on top of the existing structure.

4.1.1. Thermal insulation materials

Different kinds of insulation materials are used considering their insulative properties and cost. The insulation material itself is only one part of thermal insulation systems, which serve as barrier between internal and external environments of a particular building. They provide protection from external climate conditions as well as lateral and verical strength of the layer. The insulation material itself is ment to provide thermal and acoustic insulation as well as fire resisting properties.

Within the following chapter, thermal insulation materials most commonly used in energy renovations are presented. Each description is followed by a table presenting key properties of the material including thermal conductivity, density and water vapour resistance. Specific values vary by producer, type of panel, method of installation and so on, therefore they represent estimations.

Stone wool

Stone wool is also known as mineral wool or slag wool insulation. It is made by minerals and other raw materials (volcanic basalt, dolomite, slag) which are heated in a furnace through which a current of air or steam is blown or by rotating molten rock at high speeds.

Stone wool insulation is durable and versatilite. It`s permeable to moisture and not negatively effected by it. It`s hydrophobic, meaning it doesn`t absorb water, therefore it maintains it`s thermal resistance when dried if exposed to water or moisture. It`s available in the form of rigid panels or batts. Stone wool can be either specificaly desgined for thermal insulation or soundproofing, but will provide exceptional insulative and sound barier properties in any case. An additional advantage of mineral wools in general is that their fibers are non-combustible, with maximum working temperatures around 750°C and the melting temperature over 1000°C, therefore their use also improves fire safety of the building and it`s souroundings. Mineral wool is also sustainable in the sense that it`s largerly produced from recycled materials and the energy that is required for their production is quicly offset by the energy savings achieved when used in energy renovation.

Figure 1: Stone wool
(source: www.hempatia.si)

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.030 - 0.040
Density (ρ) [kg/m^3]	25 - 200
Water vapour resistance factor (μ)	1 - 5

Table 1: Basic properties of stone wool insulation

Glass wool

Glass wool has similar overal characteristics and production methods as stone wool, but is made from quartz sand, limestone and soda ash (recycled glass). It also provides good thermal resistance and fairly good soundproofing capabilities. It`s commonly available in batts and one of the most widely used forms of insulation, due to it`s insulative and sound absorption qualities, high tensile strenght and light weight. Despite it`s generaly resistant to moisture (low absorption rate), thermal resistance value is decimated once wet. It`s resistant to corrosion and rot. It`s inorganic and as such doesn`t encourage growth of fungi and vermin. Although non-toxic glass fibres are volatile and installation can irritate the skin, eyes and lungs. Although it doesn`t offer fire safety characteristics comparable to stone wool, glass wool is also non-combustible, with a maximum working temperature aroun 230°C and a melting point at 700°C. Glass woll insulation is one of the most inexpensive options available with respect to the desired value of thermal resistance achieved after energy renovation.

Figure 2: Glass wool
(source: www.ecvv.com)

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.030 - 0.040
Density (ρ) [kg/m3]	12 - 150
Water vapour resistance factor (μ)	≥1

Table 2: Basic properties of glass wool insulation

Expanded polystyrene

Expanded polystyrene (EPS) insulation is lightweight, rigid, provides minimal water absorption and low vapor permanence. It`s relatively low cost, offers constant thermal resistance and it will not substantially decay over time. Expanded polystyrene is available in several compressive strengths and provides minimal water absorption and low vapor permanence. EPS is chemicaly inert and will not facilitate the growth of bacteria of funghi. It`s long term thermal resistance value will not notably decresse over time.

Figure 3: EPS
(www.finehomebuilding.com)

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.032 - 0.045
Density (ρ) [kg/m^3]	10 - 80
Water vapour resistance factor (μ)	20 - 100

Table 3: Basic properties of EPS insulation

Extruded polystyrene

Figure 4: XPS
(www.adityaenerguard.com)

Extruded polystyrene (XPS) provides higher density and higher thermal resistance compared to EPS, but is more expensive (EPS secures higher thermal resistance per euro spent). It`s very durable and not effected by moisture, thus it also works well belowgrade. There is much debate on which material provides better overal properties in moisture impact and water retention. However in practice it was shown, that XPS has a lower moisture content by volume and holds water for much longer. It was also observed that EPS was much better in terms of retaining it`s thermal resistance in a given time period (thermal drift).

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.025 - 0.040
Density (ρ) [kg/m^3]	15-85
Water vapour resistance factor (μ)	80 - 300

Table 4: Basic properties of XPS insulation

Polyurethane

Polyurethane (PUR) or spray Polyurethane Foam (SPUF) is formed by mixing two substances (an isocyanate and a polyol blend) onsite, creating a rigid foam matrix when hardened. Polyurethane is a lightweight material with excelent thermal insulating characteristics. It acts a both a vapour and air barrier.

Figure 5: Polyurethane
(eggenergysystems.com)

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.022 - 0.035
Density (ρ) [kg/m^3]	30 – 160
Water vapour resistance factor (μ)	50 - 100

Table 5: Basic properties of PUR insulation

Cellulose

Cellulose is made from recycled newsprint treated with non-toxic borate compounds. The chemical treatment makes the paper resistant to fire, insects and mould. The material is hygroscopic, meaning it soaks up and reains liquid water and is as such very sensitive to moisture. Celullose has a high thermal resistance value and it also provides excelent resistance to air leackage. It can either by blown into position (dry cellulose fiber is blown through a hose into open attics or into enclosed walls, floors or roof framing cavities) or sprayed into open wall cavities (sprayed or dampened cellulose is sprayed directly into open wall cavities between studs, providing a solid and airthight filler) in new construction or comprehensive retrofit.

Figure 6: Cellulose
(www.izoliraj.me)

Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.038 - 0.040
Density (ρ) [kg/m3]	30 – 70
Water vapour resistance factor (μ)	2 - 3

Table 6: Basic properties of cellulose insulation

Polyisocyanurate

Polyisocyanurate or polyiso foam panels (PIR) are produced in the form of a closed-cell foam with an injected gas trapped within the closed cells. Polyisocyanurate insulation is in essence a thermoset plastic, chemicaly similar to polyurethane. It is used primarily as thermal insulation and vaport restistance in all phases of construction. It has superior fire resistance qualities and good thermal insulation properties. Contrary to other materials presented in this chapter it performes better at higher temperatures, while it`s performance is severaly imparied at freezing levels.

Figure 7: PIR
(www.finehomebuilding.com)

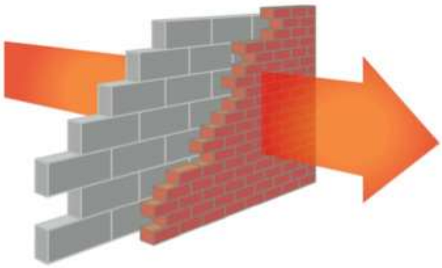
Property:	Value:
Thermal Conductivity(λ) [W/mK]	0.025 - 0.040
Density (ρ) [kg/m3]	28 - 40
Water vapour resistance factor (μ)	50 - 100

Table 7: Basic properties of PIR insulation

4.1.2. Insulation of external walls

Exterior walls (in contact with the outside climate) are one of the most important energy conservation measures to consider when addressing heat loss of any building. There are several options available that vary in cost and performance with respect to the type of wall construction. The following section will present some of the more frequent options to consider. In most cases, the insulation systems are applied directly on top of the existing structure (in some situations preparatory work is required on the surface, such as cleaning, removal of clading or existing thermal insulation, etc.). **External insulation is considered the preferred method for adding insulation to existing buildings** because of many advantages, such as:

- Thermal bridges and moisture are addresed comprehensively (for e.g. if insulation is not installed continusly on the entire surface of the wall, it can lead to cold bridging between floors)
- No loss of interior space
- Less disruptive (can be installed while building is in use)
- Thermal accumulation in walls



Nevertheless there are situations when external thermal insulation is hard/impossible to implement, for e.g. when it transforms the visual appearance of the building (historical buildings, „street side“ facades,etc) or when the implementation would require a comprehensive addaptation of exterior elements of the buildings (shelves, eaves, verges and other details, etc.) that would make the measure un-economical. For the purposes of this report the focus will be put on implementing external wall insulation. There are three main categories of thermal insulation systems on the external wall:

In addition to internal or external insulation, one approach is also cavity wall insulation, which is based on blowing insulation material such as mineral wool fibres, bonded polystyrene beads, and foam into the wall cavity. Cavity walls are common in the United Kingdom and the Netherlands, but not for Central Europe.

- External thermal insulation composite systems
- Ventilated façades
- Thermal Insulating mortars and plasters

External thermal insulation composite systems

External thermal insulation composite systems (ETICS) also known as applied render contact façade systems are the most commonly used approach in energy renovation accros Europe. The system consists of insulating material, a reinforcement layer and a finishing layer. The insulation layer is attached to the wall either by an adhesive, by mechanical fixings or both. The top layers with rendering, reinforcement and surface treatment are applied directly on the insulation layer without any air cavities in between. The insulating materials used within these systems (presented above) are attached to the existing structure either by bonding, mechanical fixings or a combination of these two.

Figure 8: External thermal insulation composite systems

Ventilated façades

Ventilated façades are constructed by a layer of thermal insulation and external cladding. It`s a dry mounted system, meaning that the conections are mechanical (screwed/bolted into place). Ventilated façades allow for faster instalation (less surface preparation, factory made modules), more cost effective insulation, several options for external finishes and significantly reduced risk of condensation to name a few.

Figure 9: Ventilated facade
(www.sto.si)

Thermal insulating mortars and plasters

Insulating mortars and plasters can provide thermal insulation to existing structures (historic buildings with load-bearing masonry) and improve localy present irregulatiries and defects (thermal bridges). The material is sprayed directly to the existing structure and can easily be applied to irregular or complicated walls. The material (usually lime-plaster or mortar with binders and special additives, mixed with EPS beads) is mixed on site and sprayed directly onto the wall in multiple layers. The surface layer is then leveled and a coating layer is applied on top of it. Paint is applied to the coating layer for finishing touch. The coating layer is then finished with paint.

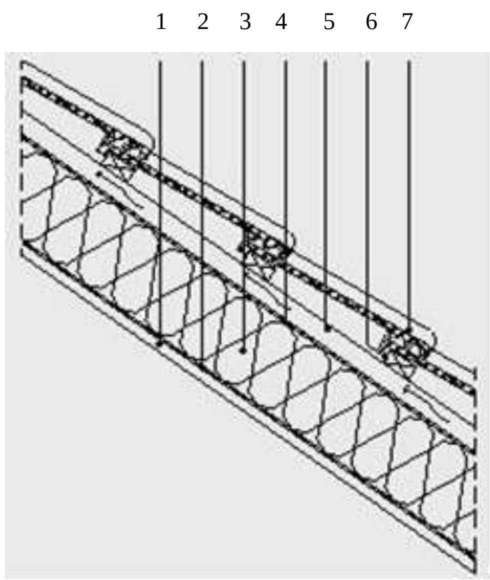
Figure 10: Thermal insulating mortars and plasters
(www.poraver.com)

4.1.3. Roof and attic insulation

Thermal insulation of the roof decreases heat loss through the ceeling of the living spaces below. The method and type of insulation that can be used depends on a number of factors, some of which include space availability, acces, pitched or flat roof and whether the attic is to be used as a living space or not. **It`s estimated that a quarter of heat loss in an average building is incured thorugh the roof** while at the same time, the conservation measure is often much easier to implement, both from a technical and investment perspective, when compared to thermal insulation of external walls.

Pitched (sloping) roofs

With pitched (sloping) roofs we generally have to choose between **a warm and a cold roof concept**. If we intend to use the attic as a living space, than the insulation is installed directly under the roof within the plane of the roof slope. Insulation is therefore implemented between (and on top if required) roof framing (rafters – angled beems supporting the roof), meaning that the space below is enclosed in the thermal envelope and thus kept warm.



1 – wooden lining

2 – vapur barrier

3 – glass wool

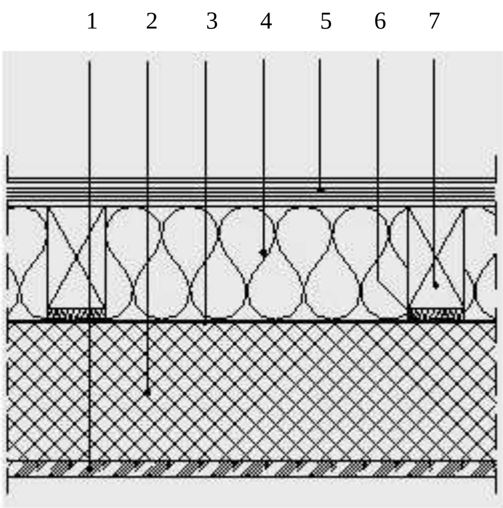
4 - vapour-permeable roof foil

5 – transverse wooden slats

6 – roofing tiles

Figure 11: Thermal insulation in between rafters

If the attic will not be used as living space, then we consider the cold roof option, where the thermal insulation is installed directly above the ceiling, leaving the space above the insulation not heated. Insulation is therefore applied between and over the joists (horizontal beams along the floor of the attic). This option is in most cases less expensive, because there is more available space and therefore more cost-effective insulation materials can be applied.



1 – lime plastering

2 – concrete plate

3 – polyethylene foil

4 – glass wool

5 – wooden floorboards

6 – joist underbase

7 – wooden joists

Figure 12: Thermal insulation in joists

Flat roofs

Flat roofs are more chalenging to insulate and waterproof properly, therefore the carefull selection of materials and methods is required. In general there are 6 main elements that must be included in a flat roof assembly: **the wear course** (protects the roofing from wind forces and mechanical abrasion), **the drainage layer** (permits the flow of water to the drains), **the roofing membrane** (waterproofing of the roof), **thermal insulation**, **vapor retared** (impedes the passage of water vaport into the roofing assembly) and finaly **the roof deck**. The exact order of elements depends on which method of construction is applied. There are several options available, for example:

- Warm roof (warm deck) – thermal insulation is applied above the roof deck
- Cold roof (cold deck) – thermal insulation is instaled below the roof deck
- Inverted roof – thermal insulation is instaled above the waterproofing layer

Usually flat roofs are either a concrete slab or timber construction with several available roof coverings rangin from felt, aspahlt, EPDM rubber to GRP fibreglass and single ply membranes. Applicable methods and choice of materials will depend on the specific type of the existing roof, however the main thing to conisder is the issue of **condensation**. For example, if the renovation measure of adding or upgrading the thermal insulation alters a warm roof to a cold roof, it`s most likely required to implement an additional ventilation layer, so that cold and moist air can escape from the roof space and doesn`t cause decay of the roofing materials.

4.2. Windows

In the winter, when premises need to be heated, our goal is that energy losses are reduced as much as possible. In comparison heat loss due to heat transfer through different parts of the building envelope (walls, roof, floors, windows), proportion of loss through windows is very large.

An average unisolated building loses around 45% of its heat through external walls, around 31% through the roof, 10% through floors and 14% through windows. If the building is insulated, the largest share of the transfer of heat losses are now carried out through the windows, which is 40%. The share of heat loss through external walls and roof are significantly reduced – heat losses through externall walls now amount to 32% and heat losses through roof up to 13%.

Similarly, in the summer, poor windows allow the solar energy and heat to penetrate through the windows and heat the space. The incoming solar radiation consists of infrared (IR), ultraviolet (UV), and visible waves. The IR radiation, which is also called heat radiation, heats the space excessively and adds to the air conditioning in the summer time.

Heat transfer through the building envelope depends on the thermal transmittance of each element, its surface area and climatic conditions. Thermal transmittance, also known as **U-value**, is the rate of transfer of heat through one square metre of a structure, divided by the difference in temperature across the structure. It is expressed in watts per square metre kelvin, or W/m^2K. The better-insulated a structure is, the lower the U-value will be.

4.2.1. Window replacement

Windows lose heat in a number of ways. Around 2/3 of the energy lost from a standard window is through **radiation through the glazing**. After radiation, **air leakage** is probably the biggest contributor to heat loss from existing windows, particularly in older or badly installed windows, but also with new windows. Workmanship and installation standards can strongly affect the thermal transmittance. If insulation is fitted poorly, with gaps and cold bridges, then the thermal transmittance can be considerably higher than desired (*RAL Installation guideline* today presents a benchmark on the field of window installation). A considerable amount of energy is also lost through **window frame**. Thermal transmittance (U-value) is governed by the frame material – in general, timber frames perform better than metal in this respect. When deciding upon replacing windows, it is important to take all those aspects in to consideration.

4.2.1.1. Glazing

One of the most important parts of the window is window glazing or glass, since it greatly influences the heat loss, noise protection, light transmission and solar radiation. With glazing the heat transfer depends on the number of glass layers, special coatings on them, the width of inner space and the type of gas between the panes.

Energy-efficient glazing is the term used to describe the double glazing or triple glazing used in modern windows. Unlike the original single glazing or old double glazing, energy-efficent glazing incorporates coated (low-emissivity) glass to prevent heat escaping through the windows and on top of that the space between the panes is filled with inert gas (most commonly argon or krypton) that has a higher resistance to heat flow than air. **In comparison to old double glazed windows, that usually have U-value around 3 W/m²K, new energy efficient windows achieve U-value 1,1 W/m²K or lower, which means heat loss through window glass is reduced by two thirds.**

Double glazed windows have two sheets of glass with a gap with gas in between, usually about 16 mm, to create an insulating barrier that keeps heat in. Triple glazed windows have three sheets of glass, but aren't always better than double glazed windows. You have to be wise when choosing the most energy efficient window and also consider other factors, such as window orientation, climate and building design. You may even want to choose different types of glazing for different windows throughout the building.

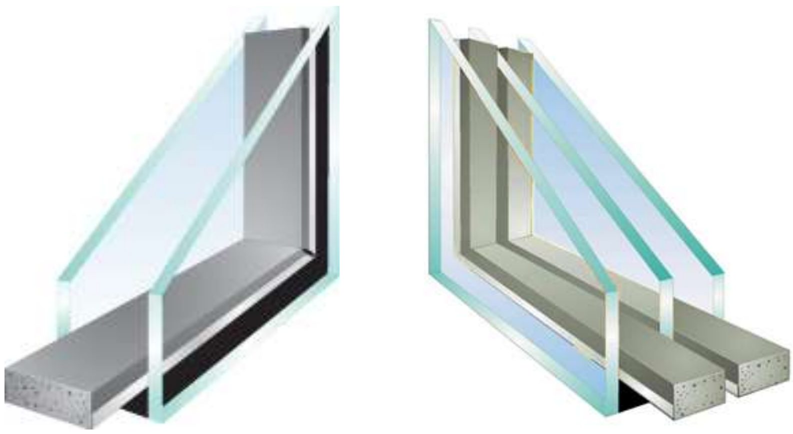


Figure 13: Double and triple glazed window (www.fibertec.com)

For **thermal insulation** we will in any case chose glazing with low-emission coating and gass filling. Low-emissivity (low-e) coatings on glass control heat transfer through windows with insulated glazing. A low-e coating is a microscopically thin, virtually invisible, metal or metallic oxide layer deposited directly on the surface of one or more of the panes of glass. The low-e coating lowers the U-factor of the window. Different types of low-e coatings have been designed to allow for high solar gain, moderate solar gain, or low solar gain. Windows manufactured with low-e coatings typically cost about 10% to 15% more than regular windows, but they reduce energy loss by as much as 30% to 50%.

If our main priority is **protection from solar radiation**, your option is glazing with special coatings and films, that reflect part of the sunrays and protect the area from overheating, glare and ultraviolet radiation. Reflective coatings usually consist of thin, metallic layers, and come in a variety of colors, including silver, gold, and bronze. Reflective coatings block more light than heat, but unfortunatelly also reduce light transmission, which, especially in the winter, reducess the possibility for using daylight and passive solar energy (solar gains).

If **sound insulation** is a one of the main priorities, the most widely used glazing configurations for sound dampening include laminated glass with varied thickness of the interlayer and thicker glass. Acoustically insulating glass cuts out excess sound and the harmful effects of noise and is particularly effective in buildings near to high streets, urban traffic, motorways, train stations and airports.

4.2.1.2. Frames

Improving the thermal resistance of the frame can contribute to a window's overall energy efficiency, particularly its U-factor. **There are advantages and disadvantages to all types of frame materials, but vinyl, wood, fiberglass, and some composite frame materials provide greater thermal resistance than metal (aluminium).** Usually, when considering thermal transmittance of frames, the best solution is wood, followed by artificial materials. Metal (most commonly aluminium) is in the last place with very poor insulating characteristics.

When considering maintance and durability, the order is reverse. Aluminium is considered to be maintanance free and can practically last forever. Frames from artificial materials are also almost maintanance free but are certainly less durable than aluminum. Wood on the other hand requires regular painting and care and it is also quite prone to deformations.

Wood frames

Wood window frames insulate relatively well, but they also expand and contract in response to weather conditions. Wood frames also require regular maintenance, although aluminum or vinyl cladding reduces maintenance requirements.

Composite frames

Composite window frames consist of composite wood products, such as particleboard and laminated strand lumber. These composites are very stable, they have the same or better structural and thermal properties as conventional wood, and they have better moisture and decay resistance.

Aluminium or metal frames

Although very strong, light, and almost maintenance free, metal or aluminum window frames conduct heat very rapidly, which makes metal a very poor insulating material. To reduce heat flow and the U-factor, metal frames should have a thermal break an insulating plastic strip placed between the inside and outside of the frame and sash.

Fiberglass frames

Fiberglass window frames are dimensionally stable and have air cavities that can be filled with insulation, giving them superior thermal performance compared to wood or uninsulated vinyl.

Vinyl frames

Vinyl window frames are usually made of polyvinyl chloride (PVC) with ultraviolet light (UV) stabilizers to keep sunlight from breaking down the material. Vinyl window frames do not require painting and have good moisture resistance. The hollow cavities of vinyl frames can be filled with insulation, which makes them thermally superior to standard vinyl and wood frames.

4.2.2. Measures on existing windows

Windows provide light, warmth, and ventilation in the building, but they can also negatively impact a building's energy efficiency. Energy costs can be reduced by installing energy-efficient windows in the building, but if the budget is tight and replacing windows is not an option, improvements to existing windows can also help.

4.2.2.1. Caulking and weatherstripping

Caulking and weatherstripping can reduce air leakage around windows considerably. Caulking is one of the easiest and most economical projects to tighten a building against air leakage and, in turn, energy wastage. Caulking should be used wherever two different materials or parts of a building meet at a **stationary joint**. It is used for for stationary cracks, gaps, or joints less than half a centimeter wide. Caulk should be applied to cleaned and dry surface, with no chipping or flaking paint, dirt and deteriorated caulk. Various types of caulk are available, so determine carefully which type is best for the specific application.

Figure 14: Caulking window
(www.delfera.com)

Figure 15: Weatherstripping window
(www.berwickelectric.com)

Weatherstripping seals **movable joints** on windows and doors. There are several types of weather stripping, each with its own level of effectiveness and durability. It is important to choose a type of weatherstripping that will withstand the friction, weather, temperature changes, and wear and tear associated with its location. Weatherstripping in a window sash must accommodate the sliding of panes - up and down, sideways, or out. When installed correctly, the weatherstripping should create a tight seal when you close operable windows and exterior doors, but allow it to open freely.

4.2.2.2. Light shelves

Figure 16: Ligh shelf
(www.tubeliteinc.com)

You can make tall windows effective sources of daylighting by using light shelves. Light shelves are made from aluminium, or another reflective material. **Their purpose is to capture natural light and effectivly distribute it throughout the room.**

Light shelves do not increase the amount of light in a room, but they do help to spread it more easily into the space and permit daylight to enter deep into a building. They provide the unique advantage of shifting the daylight so that it comes from a more overhead direction, improving the quality of illumination.

The light shelf itself is a simple device that is easily installed inside the window. As a result it provides a opportunity to reduce the use of electricity for lighting and takes advantage of healthy day lighting. A serious disadvantage of light shelves is that only the portion of windows that face towards the sun and are above head height is usable for daylighting. Light shelves also require periodic cleaning, which is easy to neglect.

Tinted or reflective glazing may greatly reduce the potential benefit of light shelves, or make them uneconomical. These types of glazing typically block about 70 to 80 percent of incoming sunlight.

4.2.2.3. Solar shadings

Solar shading affects energy use in a building by reducing solar gains and by modifying thermal losses through windows. **Southern, eastern, and western exposures of your building will all derive benefits from solar shading. Northern exposures however do not require solar shading and no energy benefit can be gained from shading north facing windows.** The southern exposure is the easiest to shade and provides the greatest energy savings.

Shading devices influence daylighting levels in a room, the view to the exterior and occupants' visual and thermal comfort. Shading is also closely connected with energy use in buildings for heating, cooling and lighting. Both energy use and comfort are crucial issues. Window coverings, however, aren't effective at reducing air leakage or infiltration. You need to caulk and weatherstrip around windows to reduce air leakage.

Louvers

Figure 17: Louvers
(inhabitat.com)

A louver is a window blind with horizontal slats. Slats are angled, so that they can admit light and air, but keep out rain and direct sunshine. The angle of the slats may be adjustable. We can decide upon **interior or exterior louvers.** Slats offer flexibility especially in the summer, when you can adjust them to control light and ventilation. They can also be adjusted to block and reflect direct sunlight onto a light-colored ceiling that will diffuse the light without much heat or glare. Because of the numerous openings between the slats however, in the winter it is difficult to control heat loss through interior window louvers.

Exterior louvers are usually made of wood, steel, aluminum, or vinyl. They're mounted above the window and are lowered and raised with the help of side channels. When you lower louvers completely, their slats meet and provide shade. If partially raised, the blinds allow some air and daylight to enter through windows.

While horizontal louvers are primarily used on south façade, an option are also a vertical exterior louvers, that are useful both for east and west exposures.

Sunshades or overhangs

Overhangs or sunshades are placed horizontally in front of the window, in various ways to shade it from the sun. Depending on sun conditions their type, shape, heigh and depth can differ. This is desirable in order to reduce glare or solar heat gain during warm seasons as much as possible. Properly sized and installed roof overhangs can **most effectively shade south-facing windows from the summer heat.**

In climates, where there are warm and cool seasons, it is often desireable to shade a window during summer months but to allow sunlight to shine through a window in the winter to help warm a building. Because the sun is higher in the summer than the winter, it is possible for a properly oriented overhang to accomplish both summer shading and winter sunlight admission.

Construction and orientation of an overhang is not easy, because it has to consider many passive solar design considerations, such as window size and type, climate, latitude, solar radiation transmittance, illuminance levels ect.

Figure 18: Overhangs
(www.h-hmetals.com)

4.3. Measures on heat generators

4.3.1. Upgrading old heat boiler

Between 50-70% of the energy use in schools is for space heating. Space heating is usually from a central boiler which provides heat to radiators. Heat boilers can be retrofitted to increase their efficiency to improve the safety and efficiency of older systems. The costs of retrofits however should be carefully weighed against the cost of a new boiler.

Burner replacement

The vast majority of older boilers can be retrofitted with new burners. Burners are designed to maximize combustion efficiency while minimizing the release of emissions. An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. Many burners do not hold their air-to-fuel settings over time and often inconsistencies in the burner performance are compensated with high levels of excess air. A boiler will run only as well as the burner performs, that is why it is recommended to replace inefficient burners with new efficient low-excess air burners. **Burner replacement has the potential of reducing fuel use in boilers by several percent.**

Boiler interlock

Boiler interlock is a wiring arrangement to prevent the boiler firing when there is no demand for heat. Where the system has a thermostat that measures the temperature, it will activate the boiler interlock so that the boiler will stop functioning when the room achieves a certain temperature. If there is no thermostat, a boiler interlock can be created by using motorized valves or a boiler energy manager. Traditional radiator controls cannot prevent the boiler from releasing heat the same way that boiler interlock can.

Controls are central to effective performance of any boiler – old or new, as they ensure that the boiler operates at its highest efficiency level. Controls can be added to old boilers, though new boilers often have some controls already incorporated.

Burner control

The objective of boiler burning control is to control the burner to maintain the desired boiler flow (outlet) temperature. Burner control thermostats and sensors must be located in the boiler outlet. Burners can be on/off, high/low or modulating. On/off and high/low/off burners are controlled by thermostats and give some variation in flow temperature due to the thermostat switching differential necessary for stable control. Modulating burners are controlled via temperature sensors and controllers, and provide near constant boiler flow temperatures.

Weather compensation

Weather compensation seeks to match the performance of the heating system in relation to outdoor temperatures. It reduces boiler water temperature for space heating according to external air temperature and should increase the efficiency of condensing boilers by reducing the average water temperature of the system. Simple systems will just measure the outdoor temperature and the flow temperature of the heating system, more complex system may include monitoring of indoor temperatures as well.

Boiler sequence control

A sequence control device for a boiler has a number of benefits over the more traditional style which simply put the boiler through its motions at a regular pace. By controlling when your boiler comes on, and when it moves to the next phase of heating, you can control energy waste. Using a sequence control on a single boiler can be useful, as it allows the user to fire up the boiler at the optimum time, ensuring that the energy use is the most efficient possible.

Sequence control is particularly useful where there is more than one boiler working at a time. Many facilities have more than one boiler for redundancy/reliability, such as schools and hospitals. Boiler sequence control enables only the number of boilers that are actually required to meet the system demand and avoids firing up all of the boilers when that is not necessary. It enables the burners progressively with increasing system demand and disables them with decreasing system demand.

4.3.2. Heat boiler replacement

A 5 to 10 year old boiler operates at around 70% efficiency whilst one that is over 15 years old drops down to 50%. Replacing old boiler can therefore bring considerable savings. As a general rule, building managers should look to replace any boiler over 10 to 15 years old with a high efficiency, **fully-modulating condensing boiler**, which should always be considered as first choice in any application. Condensing boiler can be both combi or heat-only boiler. It can be either gas or oil fired.

In a conventional heating system (gas boilers for example) most of the combustion products (heated gases) pass through the boiler's heat exchange surface, passing the generated energy to the heat distribution system - underfloor heating, radiators. Afterwards, the combustion gases are released into the atmosphere through the boiler's flue. Thus, a certain amount of heat is lost, because together with the gases, a considerable amount of steam that forms during the burning process (due to the water contained in the natural gas in its initial state) is being pushed out. The released steam carries an untapped amount of evaporation energy, that conventional boilers are unable to make use of. Condensing boilers do not only optimally utilise the supplied energy, but compared to conventional heaters, they are also able to use this latent heat from water vapour, which is otherwise lost through the chimney and recycle the heat back into the heating system. **Condensing boiler is thus typically at least 25% more efficient than a non-condensing model.**

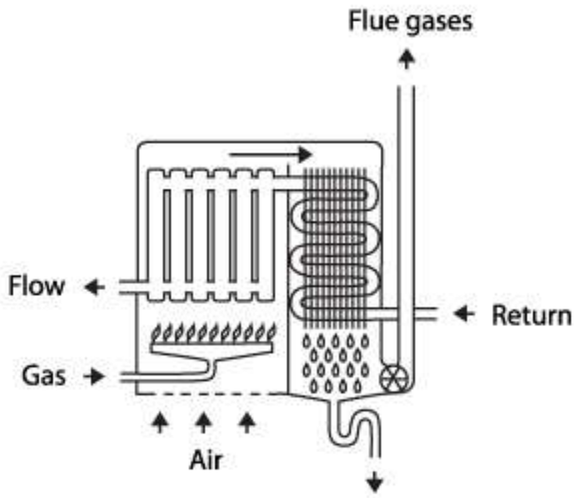


Figure 19: Condending boiler - how does it work?
(http://www.combi-care.co.uk)

To achieve the greatest reduction in energy bills and emissions and the fastest payback, the accepted advice is to replace old existing boilers with a modern **condensing gas boiler**. Natural gas produces the lowest CO_2 emissions per unit of heat delivered and also offers low running costs for a wide range of dwellings. LPG boilers are similar in design and efficiency, but the fuel is considerably more expensive.

4.3.3. Installing heat pumps

When considering heat system refurbishment a common option is also to replace old boiler with heat pump. **Heat pumps can provide heating, cooling and preparation of hot water in one integrated system.** Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature location to a warmer location, making the cool space cooler and the warm space warmer. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances. There are three most common types of heat pumps based on if they collect heat from the air, water, or ground outside the building to concentrate it for the use inside:

- Air source heat pump
- Water source heat pump
- Ground source heat pump

Air source heat pump is the most common type of heat pump. It transfers heat between the building and the outside air, but can also use energy in exhaust-air for heating, cooling and preparation of hot water. Air source heat pumps are relatively easy and inexpensive to install.

Figure 20: Air source heat pump
(www.kra-technical.com)

Water source heat pumps use energy stored in ground, surface or sea water. Water source heat pumps work on basically the same principle as air source heat pumps, but they extract heat from a body of water rather than the air. They do this by cycling water through a system of pipes that is laid out at the bottom of a body of water. Water source heat pumps profit from particularly high efficiency due to excellent temperature characteristics of water as energy carrier.


Figure 21: Water source heat pump

Ground source heat pumps typically have higher efficiencies than air source heat pumps. This is because they use constant temperature of the earth as the exchange medium which has a relatively constant temperature all year round below a depth of 9 m instead of the outside air temperature. They extract heat from the ground either by a vertical or horizontal collector.

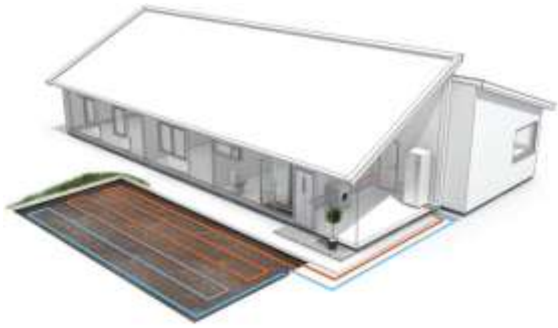


Figure 22: Ground source heat pump
(michaelmagson.co.uk)

The advantage of a heat pump system is that it incorporates free energy and transforms it to a higher temperature. These systems are much cheaper to run than those fueled by natural gas (for example condensing boiler). **It is said, that an air source heat pump will typically produce around 3kW thermal energy for every 1kW of electrical energy consumed.**

The disadvantage is that heat pump systems have a high startup cost and installation process will mean significant work and disruption to building area (except for air source heat pump, which only takes a few days to install). For running electricity is required, which in comparison to gas prices can fluctuate considerably. That also means that heat pumps will never be entirely carbon neutral. The heat pump technology may have low CO_2 emissions if the efficiency is high and if the electricity is produced with a large part of renewable energy.

An air source heat pump will typically produce around 3kW thermal energy for every 1kW of electrical energy consumed, which is often translated as having “efficiency” of 300% (in comparison to condensing gas boiler, which has around 90%-96% efficiency). It is thermodynamically impossible to have an efficiency of more than 100%, as this implies that more energy is being produced than is being put in. For this reason the performance is expressed as a **Coefficient of Performance (COP)** rather than an efficiency. The above example would be expressed as having a COP of 3. The reason that it appears that more energy is being produced than is consumed, is because the only “valuable” energy input is electricity used to drive the compressor and circulating pumps. The remainder of the energy is simply transferred from a heat source that would otherwise not be used (such as the ambient air, ground or a river) so is not considered as an energy input.

4.4. Measures on domestic hot water preparation systems

In most cases domestic hot water supply is combined with space-heating, but usually room heating needs more energy than hot water production, so it does not make sense to optimize combination devices (heat boilers etc.) especially for hot water production in the months, when room heating is not needed. This is why hot water preparation is supplemented with hot water heaters.

Domestic hot water systems can be divided into centralised and localised.

- A localised system is one in which the water is heated locally to its needs, e.g. a single-point heater located above a sink. It may be chosen where a long distribution pipe would mean an unnecessarily long wait for hot water to be drawn off at the appliance. The advantage is that it may be fitted close to the fittings being supplied, but the disadvantage is that a separate gas or electricity connections are required for each heater.
- A centralised system is one in which the water is heated and possibly stored centrally within the building, supplying a system of pipework to the various draw-off points. The advantages of such centralized system are that it requires less maintenance than several units and that a cheaper fuel can be used.

4.4.1. Improving existing water heaters

Water heating systems should be effectively controlled so as to ensure the efficient use of energy by limiting the provision of heat energy use to that required to satisfy user requirements. The most common improvements are time and temperature controls that allow setting the time period required for water heating and the temperature to which water is heated. This means that water need not be heated for longer or to higher temperatures than required.

Timers

Timers allows scheduling operating time for water heater, according to specific needs, and it turns it off automatically when hot water is not needed (weekends etc.). A 7-day programmable timer allows the heating system to be set to match occupancy patterns on a daily and weekly basis. The separation of space heating and domestic hot water controls into zones allows each zone to operate for required periods only.

Cylinder thermostat

A cylinder thermostat regulates the temperature of the water in the hot water cylinder. Once the water reaches the set temperature, the supply of heat from the boiler for the water is switched off. This reduces excessive water heating and, as a result, reduces the heating bill.

The temperature of the hot water should be set at least to 60 degrees to kill off any harmful bacteria that may be present in the water such as legionella. It should be set at a temperature no greater than 65 degrees to prevent water being overheated as this might cause scalding.

4.4.2. Installing new water heaters

Whilst the provision of domestic hot water in EU building stock is still largely based on the use of fossil fuels or electricity, the EU has been progressively strengthening its measures to increase the use of high efficiency renewable technologies such as heat pumps and solar thermal systems.

Gas water heater

A gas water heater uses the heat from burning a fuel (usually natural gas) to heat water, while an electric water heater uses electric resistance coils. Gas water heaters are less energy efficient than electric heaters, but the cost of electricity itself makes the running costs of an electric heater higher. Gas water heaters also have a much faster recovery rate, which makes them a convenient option compared to electric heater, that have high installation costs. However, in EU heat pump is usually a prioritized and recommended solution.

Heat pumps

Heat pumps are often used for both room heating and domestic hot water production. Still there are devices which only produce hot water. Because heat pumps are using renewable energy, they are safer and cleaner to run than fossil fuel burners and can **lower C02 emissions by up to 70% (compared to gas and diesel burners).**

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. Therefore, the amount of power they consume is significantly smaller than the amount of heat energy they produce. They can be two to three times more energy efficient than conventional electric resistance water heaters.

Solar water heating

Solar water heating is the conversion of sunlight into heat for water heating using a solar thermal collector. A variety of configurations are available at varying cost to provide solutions in different climates and latitudes. Solar water heating systems usually cost more to purchase and install than conventional water heating systems. However, a solar water heater can usually save you money in the long run.

How much money you can save depends on several factors:

- The amount of hot water building uses
- System's performance
- Geographic location and solar resource
- The cost of conventional fuels (natural gas, oil, and electricity)

Solar water heating systems almost always require a backup system for cloudy days and times of increased demand. Conventional storage water heaters usually provide backup and may already be part of the solar system package.

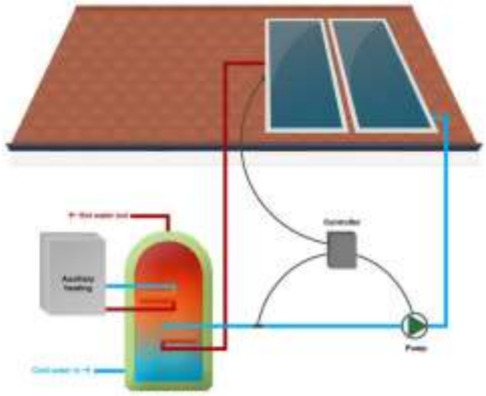


Figure 23: Solar water heating
(www.emeraldenergync.com)

4.5. Measures on distribution systems

4.5.1. Renovating domestic hot water piping system

Domestic hot water piping systems are designed to deliver hot water from a central source to the outlet (faucets). The piping design must account for the source pressure and the design flow rate to ensure an adequate supply of hot water volume to the outlet. These design constraints directly influence the energy loss of the piping system. For example, in long plumbing runs, the pipe size may be increased to reduce flow losses leading to larger volumes of hot water in the piping and increased energy losses, which leads to quicker cooling of the water in the pipes.

Heat loss from distribution pipes depends on several factors including the **diameter and length** of the pipe, the **water temperature** inside the pipe, the **air temperature** surrounding the pipe, and the **length of piping** and time that the pipe is carrying hot water. Another factor that appears to influence the pipe losses is the **material** used for the piping. Metal pipes (copper) have a higher heat loss coefficient than plastic pipes. Based on the characterization study, plastic piping materials result in a reduction of pipe losses from 27% to about 13% over metal piping. If it is time to replace the plumbing, it is important to consider all of those factors.

There are also other advantages of plastic pipes, such as higher possible temperature loads, longer lifetime, better flexibility, smaller water resistance and no risk of corrosion. Plastic pipes are also almost maintanance free and have better acoustic properties (they transmit less noise from water flow and thermal expansion).

4.5.2. Insulation on domestic hot water distribution systems

Since reduction of the length of piping or pipe replacement is not always an option and reduction of diameter of the pipe can result in pressure drop, a most commonly suggested solution for reducing losses in the hot water system is to use **insulation around the pipes.**

It’s surprising how much heat an uninsulated pipe gives off. Insulating your hot water pipes reduces heat loss and can raise water temperature 1°C–2°C hotter than uninsulated pipes can deliver, allowing you to lower your water temperature setting. You also won't have to wait as long for hot water when you turn on a faucet, which helps conserve water. Pipe insulating materials are selected based on where the pipes are located, maximum temperature of the water and the insulating value of the material. All pipe insulation materials are flexible or semi-rigid except for those that are enclosed in a protective jacket. This makes them easy to install in tight locations.

Figure 24: Pipe insulation
(www.barbourproductsearch.info)

Due to the low service temperature, polyethylene materials are fine for use in domestic hot water systems but should not be used where the boiler water is greater than 100°C. All other materials can withstand higher temperature. All piping should have at least 2 centimeters thick insulation. **Payback for pipe insulation will be 1-2 years.**

4.5.3. Insulation on heat distribution systems

Pipe insulation can also be performed on heat distribution pipes. When insulating distribution pipes, however, it is important to not forget about all the other components of distribution systems, such as valves, strainers, pressure regulators, etc. If you can walk into a mechanical or boiler room and see bare steel on operational heat distribution equipment components, then thermal energy is being wasted. The lack of proper insulation of all distribution system’s components wastes energy, creates a health and safety issue (i.e., hot components can cause burns), produces unnecessary carbon dioxide emissions, and, in unventilated mechanical rooms, the resulting high air temperatures create a stressful work environment. Thermal energy waste can be corrected simply by insulating all bare components. **The boiler itself should be wrapped in insulation as well.**

It is recommended that mechanical designers and facility owners/operators learn to survey their mechanical rooms and boiler rooms for bare pipe components and equipment. Although conventional, permanent types of insulation work well, they do not normally provide easy accessibility for maintenance personnel. It is recommended to use removable/reusable insulation blankets for these components. **Insulation of pipes and other heat distribution components can save up to 5 % of heating energy, with a payback period 1-2 years.**

4.6. Regulation measures

Besides insulating pipes for heat distribution, mentioned in previous chapters, there are other low cost ways to save money whilst reducing heating energy use and maintaining comfort.

Some of the measures don't even require any kind of investment:

- Turn down the radiators in the corridors and toilets to low setting. These are areas of low occupancy so temperatures can often be reduced without causing discomfort.
- Radiators which always remain cold at the top are probably air locked, and can easily have the air bled off. The school should be able to do this themselves.
- Learn to ventilate the clasrooms correctly and ensure all windows are closed at the end of each day to retain heat for the following day.
- Tilted windows don't provide fresh air, but are just cooling the wall and unable thermostatic valves placed on radiators under the windows to not sense the right room temperature. Always air with windows wide open for a short period of time.

4.6.1. Thermostatic valves (TRV)

Every degree less saves 6% of the heating energy. The best temperature in classrooms is 20°C. In other rooms, corridors, on staircases and the gym it can be even less. The easiest way to regulate the room temperature is to use thermostatic valves.

Thermostatic valves are a local regulating element for the temperature in the room. They contain a temperature sensor that opens and closes the valves depending on the surrounding temperature. If the thermostatic valves stand in the middle position, most commonly on 3, the temperature will reach 20°C. If the sun is shining into the room or a large number of people heat up the room, the thermostatic valves detects the higher temperature and closes the hot water influx. If the temperature sinks, the valve opens again. Putting the thermostatic valve up or down one digit, the temperature changes by 2 degrees.

Figure 25: Thermostatic valve
(www.ecopagent.si)

As the TRV opens to allow more hot water from the boiler though the radiator, more heat will be given out by the radiator. As the TRV closes and restricts the flow through the radiator, less heat will be given out by the radiator, however, please note that the TRV does not switch the boiler on/off, it only regulates the flow of the available hot water. TRV's are designed with a range of temperature settings to allow individual rooms to be maintained at different room temperatures and even allow unused rooms to be switched off, to save energy. However, the TRV can only provide heat to the radiator if the boiler is providing hot water.

The TRV can only work to the temperature which it can sense so, if it is covered (by courtains, cabinets, furniture or some sort of protective panel/grill), it cannot sense the room temperature properly and may underheat or overheat the room. The alternative may be to install a remote sensor on a standard TRV head. This works by monitoring the room temperature via a 2 or 5 metre capillary connected to the sensing thermostat which can be mounted in an area more representative of the room. **Installation of thermostatic valves on the radiators can save up to 15% of heating energy.**

4.6.2. Hydraulic balancing

The so-called hydronic balancing makes sure that every radiator gets the necessary amount of hot water. It is the process of optimising the distribution of water in a building's heating system by equalizing the system pressure. The flow in the whole system (through the component terminal lines, distributing lines and main distributing lines) should correspond to the flow rates that were specified for the design of the system. If the correct balancing of the system is not established, this will result in unequal distribution of the flow so that there will be a surplus effect in some of the terminals, whereas the effect will be inadequate in others. This does not only mean energy wastage and increased heating costs but the living comfort is influenced, too. You may also notice, that with correctly performed hidraulic balance flow noises from the pipes and the valves should be completely eliminated, since all components like radiators, thermostatic valves, pumps and pipes are coordinated and aligned by the hydronic balance.

Hidraulic balancing is a one time measure, that reqires a proffesional. Only a correct set of balancing valves, installed in the boiling room can ensure the correct distribution of the flow in the system. Hydraulic balancing offers energy saving potential that is often overlooked. **A well-regulated heating system saves up to 20% heating energy, so the visit of the expert pays off quickly.**

4.6.3. Installing new circulation pumps with frequency converters

Heating circulaton pumps are used to circulate water in pipeline of the heating system. In conventional designs pumps are oversized to ensure they can handle the maximum expected load or accommodate any future increase of system capacity. These pumps typically run at fixed flow rates using less than optimal electrical consumption. By using a circulation pump with frequency converter, motor speed can be adjusted to match the system's actual operating requirements and continuously adapt circulator performance to the changing needs of the hydronic heating system. When rooms are heated to the certain temperature, the pump automatically reduces the power for its operation and can operate only with the power of 3W, which is significantly less compared to older pumps, which consume from 60W to 90W power under the same conditions. **Improved circulating pumps with frequency converters can consume up to 80% less electricity than conventional models.**

4.7. Measures on ventilation systems

Ventilation systems in buildings replace used air with fresh air from outside. The quality of indoor air has a significant impact on health and comfort. Inadequate ventilation can make a room stuffy and uncomfortable. Among the main factors that affect the indoor comfort are temperature, humidity and air velocity and movement. With quality ventilation systems we take care of all these factors, as well as minimazing exposure to indoor pollutants such as mold, radon, secondhand smoke, pressed wood products (that may contain formaldehyde), and other materials that can lead to health effects. Moisture buildups can also lead to structural damage to the building. There are two basic types of ventilation - **natural** and **mechanical:**

- ### Natural ventilation

  Natural ventilation is undoubtedly the most environmentally friendly form of ventilation. It does not simply mean »opening a window«, but a design feature, where a ventilation system rely on pressure differences to move fresh air through buildings. Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or differences in humidity. In either case, the amount of ventilation will depend critically on the size and placement of openings in the building (ventilation grills ect.).

  These systems are incredibly low cost, however they depend entirely on natural forces, making them less predictable in certain climatic circumstances. It is difficult to control where air enters a building and how it gets distributed. Other downsides are also, that natural ventilation allows outdoor air inside unimpeded, bringing in outdoor contaminants easily as well. On particularly hot or humid days, natural ventilation also can't reduce the indoor temperature enough to make it comfortable indoors.

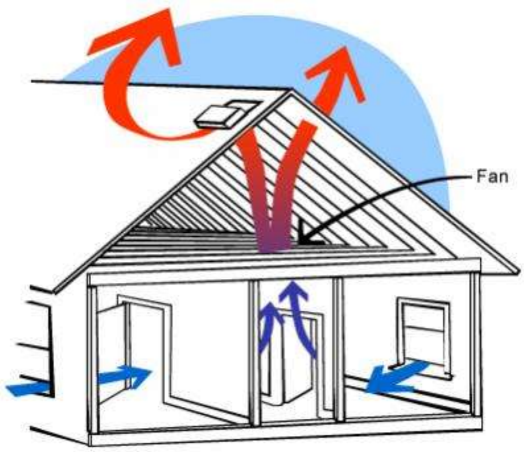
- ### Mechanical ventilation

  Natural ventilation is usualy not a reliable source of adequate amounts of air to maintain good air quality. This is why controlled mechanical ventilation brings certain benefits. Mechanical ventilation systems circulate fresh air using fans and other mechanical means, rather than relying on airflow through building openings. Since it is mechanicaly controlled, it provides proper fresh air flow along with appropriate distribution throughout the building. Mechanical ventilation systems can also provide filtration, dehumidification, and conditioning of the incoming outside air, assisting in controlling the humidity, contaminants, air borne particles, and general air quality.

Many studies in the field have shown that ventilation in classrooms is too poor. One reason is that often schools do not have mechanical ventilation system to compensate for natural and furthermore, when mechanical systems are installed, often their bad control leads to very expensive operation, so managers are discouraged to use them.

4.7.1. Improving existing mechanical ventilation system

Mechanical ventilation consumes energy when unconditioned, outside air must be heated or cooled as it replaces conditioned, indoor air that is being exhausted. This is done using ventilation units that consist of fans, motors and electronic controls and are connected to buildings by air inlets and outlets or ventilation ducts. **Ventilation units consume more than 2% of all electricity in the EU**, and are amongst the biggest consumers of indoor electricity (after heating and lighting). With quality ventilation system or energy efficient measures on older systems we can contribute to lowering energy consumption and also achieve savings in heating.



Sensor and control systems

Sensor and control systems can provide ventilation only where and when it's needed, based on occupancy, building purpose and internal activities. Significant efficiencies could be gained if ventilation systems provided only the fresh air needed to maintain required levels of carbon dioxide (CO_2) and other compounds. In many cases ventilation systems in bathroom areas can also be regulated by timers and occupany sensors to reduce energy consumption.

Installing variable frequency drive (VFD)

Most older ventilation systems adjust flow rates only by turning motors off and on or by using dampers. With variable frequency drive the speed of the electric motor can be adjusted according to the building occupancy or weather changes, which results in a lower motor speed and an energy savings. **The VFD upgrade automatically reduces the speed of the supply air fan when the unit is not conditioning indoor air, reducing the energy use of the fan by 60-80%.**

4.7.2. Replacing existing ventilation system

Installing heat recovery ventilation system (HRV)

Standard mechanical ventilation is a one-way system that simply pulls indoor air into vent ducts and exhaust it outdoors as an exhaust-only system. This system does have its drawbacks. As stale air is removed, fresh air may not enter the building in adequate volume to replace it. When sufficient fresh replacement air doesn't flow in, the building is depressurized and air from elsewhere — like the attic — infiltrates to equalize the pressure differential. Air quality suffers and the building becomes unpredictable to heat or cool and keep comfortable.

The one-way approach to mechanical ventilation has been updated in the recent years with so-called **balanced ventilation systems**. One of them is heat recovery ventilation (HRV), an energy recovery ventilation system using equipment known as heat exchanger, which in the winter uses the heat in stale exhaust air from the building to preheat incoming fresh air. HRV ventilation systems induct fresh, filtered outdoor air into the building while exhausting stale, polluted indoor air at exactly the same rate. Outgoing air and incoming air never mix in the heat recovery process; they simply pass in separate channels in the ventilator core, allowing an exchange of heat through conduction.

Heat recovery ventilation has many benefits. Because the exhaust and intake volumes are balanced, indoor air pressure remains neutral, not depressurized as with conventional exhaust ventilation. **HRV also recovers to 90% of heat from the building that would normally be wasted to heat incoming air and thus help reduce your heating requirements by up to 25%.** HRV is a fully controllable system with manual or remote controls, that allows balanced heat and fresh air distribution throughout the whole school building.

How does HRV work in summer moths? During summer, outdoor heat in the incoming air stream is extracted by the heat exchanger and added to the exhaust stream. As much as 85 percent of the heat is removed from outdoor air, vastly reducing the impact on your air conditioner.

Installing Heating, ventilation and air conditioning System (HVAC)

HVAC refers to heating, ventilation, and air conditioning. It defines the system as a whole that also provides conditioning of the air within the building. While HRV systems recovers and transfers heat only with filtration of air removing dust and pollutants, there is however no direct transfer of moisture. **The objective of HVAC is to control the temperature of air along with effective control of other parameters in the air, such as control of moisture (humidifying and dehumidifying) or CO_2 levels.** HVAC systems is also actively cooling the incoming air in the summer with cooling generator, and not only by extracting heat as in HRV systems. HVAC systems are thus generally more appropriate for medium to larger buildings, such as schools, that have higher cooling and air conditioning requirements.

Installing hybrid HVAC system

One increasingly popular option is also hybrid ventilation. A relatively modern concept, **hybrid ventilation takes advantage of both natural and mechanical systems.**

Hybrid ventilation solutions will use a mixture natural and mechanical ventilation, but utilises the natural ventilation as much as possible, as it is based on the principle of providing healthy indoor climate and comfort, delivered with minimal energy consumption and at minimal cost. Hybrid ventilation, also known as *mixed mode ventilation*, therefore utilises natural ventilation during favourable conditions, and then uses mechanical, low-powered fans to distribute the fresh air when the natural ventilation proves less effective. For example, in periods of low wind, mechanical ventilation systems will take over in order to maintain the internal temperatures and to ventilate the spaces. Hybrid ventilation is normally operated automatically, using sensors to identify when a natural ventilation system needs assistance. The system will then switch to a mechanical system, and back again when wind and other natural forces pick back up.

4.8. Measures on lighting system

Lighting accounts for nearly 50% of the electric bill in most schools. Installing energy efficient lighting is a simple way for schools to reduce their energy consumption.

With that in mind it is important to also follow few important guidelines, to achieve maximum savings and maintaing lighting levels. Without this, light levels can fall by 20% – 30% in 4 years.

- Keep lamps, luminaires and sensors free from dust and dirt.
- Keep windows clean and blinds open whenever it is practical to do so.
- Replace flickering, blackened, dim, or failed lamps and lamps at the end of their useful life, e.g. when tubes start to flicker or lighting levels drop.

4.8.1. Installing energy efficient lighting

You have many choices in energy-efficient lighting, but the most common light bulbs available are fluorescent lamps and light-emitting diodes (LEDs). Although they can initially cost more than traditional incandescent bulbs, during their lifetime they save you money, because they use less energy. **Compared to traditional incandescents, energy-efficient lightbulbs typically use about 25%-80% less energy than traditional incandescents, saving you money, and can last 3-25 times longer.**

Fluorescent lighting

A fluorescent lamp or a fluorescent tube is a low pressure mercury-vapor gas-discharge lamp that uses fluorescence to produce visible light. A fluorescent lamp converts electrical energy into useful light much more efficiently than incandescent lamps. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt, several times the efficacy of incandescent bulbs with comparable light output, which means **fluorescent lamps use 25%-35%**

of the energy used by incandescent products to provide a similar amount of light. They also last about 10 times longer (7,000-24,000 hours).

The two general types of fluorescent lamps are:

- Compact fluorescent lamps (CFLs) - used mostly in household fixtures
- Fluorescent tube and circline lamps – used in bigger buildings and for lighting large areas

Figure 28: CFL bulb
(fire9prevention.wordpress.com)

Figure 27: Circline lamp

Figure 26: Fluorescent tube lamp
(http://www.electronicecircuits.com)

Fluorescent lighting systems are already the most prevalent sources of general illumination in schools, but old and outdated T12 fittings are not to be mistaken with newer energy efficient flourescent T8 and especially T5 fittings. Modern fluorescent systems (T5 lamps with electronic ballasts) can provide low cost, long life, high efficacy, good color, low levels of noise, and flicker. T5 (16mm) tubular fluorescent lamps are the recommended choice for schools as they only work with high frequency control gear and are appropriate for lighting larger areas.

But especially considering dillemas that derive from the usage of flourescent lights in the last years, they might not be better solution in oppose to LED lights. Flourescent lights for example contain mercury, a dangerous chemical which is toxic to humans and the environment. They also emit infrared heat which increases the temperature in a room, thus causing the cooling system in a facility to work harder. In general flourescent lights, based on modern studies, might not be the best solution for learning environment since they emit waves of pronounced color spikes that can lead to the inability of the brain to process colors properly or make eyes very sensitive to artificial light sources.

LED lighting

LED (light-emitting diode) is one of today's most energy-efficient and rapidly-developing technologies. A type of solid-state lighting consisting of semiconductor devices that transmit light when a current is run through them. While LEDs are more expensive than other types of lighting, a well-designed **LED illumination performs better and consumes less power (emits more lumens per watt), requires less maintenance, lasts longer and is more environmentally friendly (no mercury, gases, or UV or IR rays) than incandescent, fluorescent and neon lighting.** LED bulbs have many benefits:

- They last up to 10 times as long as compact fluorescents, and up to 25 times as long as typical incandescents (50,000 plus operational hours).
- They use up to 75% less energy than incandescent lighting.
- They work well indoors and outdoors because of their durability and performance in cold environments (fluorescent lamps on the other hand operate best around room temperature. At much lower or higher temperatures, efficiency decreases).
- They do not cause heat build-up.
- Because they emit light in a specific direction, they do not need diffusers or reflectors that trap lights. (Fluorescent bulbs is non-directional light source. When a fluorescent bulb is lit, it gives off lighting in 360 degrees.)
- Provides more of a comfortable light, which helps students see better without glare and eye strain.

Figure 29: LED bulb
(http://www.solarsystems-usa.net)

LED alternative is thus in many ways a better option in comparison to flourescent lighting. It can **deliver up to 50 percent energy savings and with maintanance costs close to zero, LED retrofit usually pays itself back within 1 to 3 years.**

4.8.2. Lighting controls

Lighting controls help save energy even more and enhance occupants' comfort by using light when and where it is needed most. This lighting control enhancements can be incorporated separately, but this makes adjustmens a lot harder. To adjust the time delay for an occupancy sensor or light level for a daylight sensor, contractors or building owners would have to visit each room and make adjustments at each sensor. This makes it difficult to verify that all sensors have the correct adjustments.

Today lighting control enhancements have been improved in a way they all can be integrated in a networked lighting control system that constantly feeds data about the electricity usage of lighting fixtures for the entire school back to a central processor. The facility manager can receive real time updates on electricity usage instead of waiting for monthly electric bills or even a full calendar year to benchmark results. System changes become easier, too, since settings for occupancy and daylight sensors can be adjusted from the central processor instead of a technician manually resetting every single switch in the entire facility.

Occupancy Sensors

Occupancy sensors detect indoor activity within a certain area. They provide convenience by turning lights on automatically when someone enters a room, and save energy by turning lights off soon after the last occupant has left the room. Time delay of turning off can be adjusted to maximize energy savings even more. Occupancy sensors must be located where they will detect occupants or occupant activity in all parts of the room. In schools occupany sensors are most useful in toilet areas, hallways and outdor school areas.

Daylight controls and manual dimmers

Daylight controls or daylight harvesting systems use daylight to determine the amount of electric lighting needed to properly light a space, in order to reduce energy consumption. Daylight harvesting systems use a photosensor to detect the prevailing light level, luminance or brightness and are used to adjust electric lighting based on the available daylight in the room. When lightbulbs are dimmed, it reduces their wattage and output, which helps save energy. This also increases the service life of lightbulbs significantly.

Manual dimmers are also a very good and inexpensive option and can provide some energy savings when lights are used at a reduced level. However, manual dimming is based on personal feeling only. Considering **EU directive recommends illuminance levels of 300 lx** in classrooms dimming the light manually can not achieve recommended values in a constant manner.

Daylight automatic controls are thus the best solution to achieve a healthy learning environment by maximizing the advantage of natural light and balance it with artificial light when needed. This provides great visual comfort. With automatic dimming or daylight harvest as the sun gets stronger, the artificial lights gradually dim to maintain a consistent light level (300 lx) within the classroom. If

Dimming fluorescent lights is more tricky than dimming incandescent bulbs or LED lamps. When dimming fluorescents it is impossible to create a smooth transition, because bulbs work in different ways. In fluorescents light is generated by a discharge through gas, and that is why there will always be a "jump" in light level when the tube initially strikes. Fluorescent fixtures can be dimmed using a special dimmable ballast, but always remember when dimming fluorescents, performance will not be the same as a traditional, dimmable, incandescent lamp.

a cloud passes overhead and blocks out the sun, the classroom lights automatically increase their output to again maintain the consistent light level. The brightening or dimming of the lights is typically so subtle that teachers and students rarely notice, but school administrators definitely notice the savings on their electric bill.

4.8.3. Replacing light ballasts and diffusers in fluorescent lighting fixtures

In a fluorescent lighting fixtures there is fluorescent lamp and a ballast. The ballast regulates the current to the lamps and provides sufficient voltage to start the lamps. It also limits its current at the same time, so that a fluorescent lamp connected directly to a high voltage power would not overheat and burn out within a second.

Replacing standard fluorescent lamps (T12) with high-efficiency fluorescent lamps (T8 or T5) saves energy and money; replacing ballasts can result in even greater savings. Although ballasts are expensive, and retrofitting may not occur immediately, standard ballasts should be replaced with energy-efficient ballasts upon burn-out. Also, if existing ballasts are reaching the end of their rated life (15 to 20 years), now is a good time to replace them as a group.

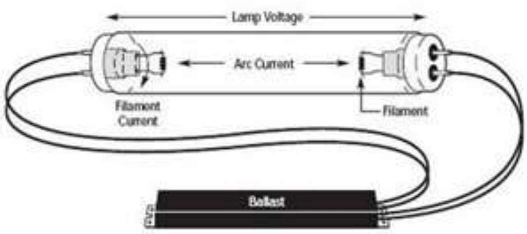


Figure 30: Ballast in fluorscent light fixture (www.ies.org)

When replacing the ballasts in your fluorescent fixtures, consider using one of the improved varieties. **These fluorescent ballasts, called improved electromagnetic ballasts and electronic ballasts, raise the efficiency of the fixture 12%–30% in comparison to early versions of electronic ballasts.** They operate at a very high frequency that eliminates flickering and noise. Some improved electronic ballasts even allow you to operate the fluorescent lamp on a dimmer switch, which usually is not recommended with most fluorescents.

A ceiling light diffuser is a light panel or cover that diffuses light within a room. It works by scattering and dispersing light from fluorescent light bulbs, creating softer, less harsh lighting, as oppose to direct light coming from one concentrated source. Older types of opal plastic diffusers become discoloured with age, and can absorb more than 50% of the light output from the tubes. Replace old diffusers with prismatic UV stabilised diffusers, that have far better light transmittion and UV resistance.

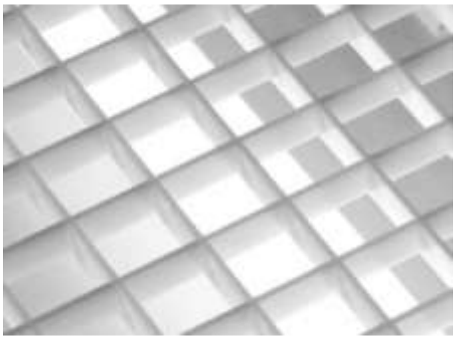


Figure 31: Light diffuser

4.9. Control and energy management systems

Building automation and controls are most effective to enable energy savings in the building sector. Individual low-cost sensors and controls expand opportunities for individuals to have greater control of the thermal and lighting conditions, but lighting, HVAC equipment, water heaters, and other building equipment today are starting to be equipped with smart controllers and even wireless communications capabilities. Controlled subsystems open many opportunities for improving building efficiency, managing peak loads, and providing services valuable to controlling the cost of large utility systems.

4.9.1. Lighting control system

There are various types of lighting control systems available depending on specific needs. Lighting control systems are employed to maximize the energy savings from the lighting system, and may include several diffrent controls, such as relays, occupancy sensors, photosensors, light control switches, etc. Different to individual lighting controls, a lighting control systems connects all controls and sensors in one centralized intelligent networked system, that allows you to have control of the lights in the whole building. Adjustment of the system occurs both at device locations and at central computer locations via software programs or other interface devices, but ability to control individual lights or groups of lights from a single user interface device gives lighting control system a major advantage over stand-alone lighting controls.

Wireless lighting control systems provide additional benefits including reduced installation costs and increased flexibility over where switches and sensors may be placed. This type of system is easy to install, affordable, and is a better option for retro-fit projects because of the reduced need to run wires. All of the dimmers and switches communicate wirelessly to the processor which is why this system is less expensive and requires less installation.

4.9.2. Heating and hot water control system

The installation of effective control system has a major impact on the energy consumption of heating and hot water systems. Effective controls will increase operating efficiency, particularly when updating older systems, and will lead to energy savings, reduced running costs and lower CO_2 emissions.

A control system will ensure that the boiler or heater does not operate unless there is a demand, and it must only provide heat when and where it is required, so as to achieve the required temperatures. Controls usually include weather or load compensation, optimum start, night setback ect.

Central heating control system ensure that each heated space is heated to its ideal temperature without overheating the area, which wastes fuel. It connects to your boiler and your existing radiators to be able to control the entire heating system through a central console. Controls allow different areas of the building to be heated to different temperatures at different times.

Adequate heating controls also help a building manager to accurately match space heating and hot water schedules to the working patterns at the building and determine periods of heating spaces and water, just before students come to school and just after everyone has gone home.

4.9.3. Building energy management system

While individual subsystems such as lighting, can contribute to energy efficiency of the buildings, the building as a whole will perform most efficiently if all the building systems are controlled as a part of an integrated system. Automatic centralized monitoring and control of a building's heating, ventilation and air conditioning, lighting, domestic hot water, energy consumption and other systems through a central building management system can have considerable benefits.

One main characteristic of the technology is that it is capable to provide real-time and extensive data on energy consumption to the facility operator. This information can be used to increase energy efficiency of the overall system, since it is possible to manage and control the operation of different subsystems (lighting, heating, cooling ect.) through a central system.

Additionaly the technology today can also monitor and control the environmental conditions in the buildings. This capacity of the technology has the potential to make the workplace or school environment healthier, since the technology can monitor factors such as air quality and water quality and can react when value thresholds are crossed. For instance, the system can increase ventilation when the carbon monoxide levels in a facility increase above a level considered safe.

Proper operation of a building energy management system can achieve energy savings of 15-20% for heating, cooling, ventilation while energy savings for lighting can be as high as 50-60%.

5. Categorization of measures

The following chapter is a categorization of measures described in previous chapters based on expected savings, costs and payback period. What savings can be expected from a specific measure however, depends on the building itself - from factors such as construction material, the way energy is used, how building and equipment is maintained etc. For that reason it is not possible to provide more specific categorization than the one presented below.

When reading the categorization before you it is important to realize, that the savings deriving from specific measures are not cumulative - the table shows the potential impact on energy use by carrying out only individual measure. That means for example, when implementing several measures at once, such as windows that bring 25% savings on heating, roof insulation that brings 35% savings on heating energy and insulation of external walls that can also bring up to 35%, that doesn't mean you can expect 95% reduction of energy currently used for heating. That would mean, you can turn an old building in to a zero energy house. The math is not that simple however, since we need to consider technical interactions between different measures and systems.

Nevertheless, when planning energy retrofit the goal is to maximize the number of implemented measures, because implementing individual and partial measures consequently decreases the potential for more comprehensive energy reconstruction and savings that could derive from more complete renovation plan. Implementing partial measures is more expensive in the long run and perhaps it will be technically impossible to realise the full energy-saving optimization of a specific building at a later date.

Measure	Expected savings	Investment cost	Payback period
Insulation of thermal envelope			
Insulation of external walls (ETICS and ventilated facades)	Up to 35% heating energy	high	high
Insulation of external walls (thermal insulating mortars and plasters)	Up to 10% heating energy	high	high
Ceiling insulation between conditioned space and unconditioned attic	Up to 15% heating energy	high	high
Roof insulation	Up to 35% heating energy	high	high
Windows			
Window replacement (U lower than 1,1 W/Km^2)	Up to 25% heating energy	medium	high
Caulking and weatherstripping	Up to 20% heating energy	low	low
Solar shadings	Up to 25% electrical energy	medium	high
Measures on heat generators			
Burner replacement	Up to 5% heating energy	low	low
Boiler interlock and boiler controls (burner control, weather compensation, sequence control etc.)	Up to 20% heating energy	medium	low
Heat boiler replacement	Up to 20% heating energy	high	high
Installing heat pumps	Up to 45% heating energy	high	medium

Measures on domestic hot water preparation systems			
Installing heat pumps for hot water preparation	Up to 75% energy for hot water preparation	medium	low
Solar water heating	Up to 60% energy for hot water preparation	medium	medium
Measures on dystribution systems			
Pipe insulation on heat and water distribution systems	Up to 5% heating energy	low	low
Regulation measures			
Installing thermostatic valves	Up to 15% heating energy	low	low
Hydraulic balancing	Up to 20% heating energy	medium	medium
Installing new circulation pumps with frequency converters	Uses up to 80% electrical energy less compared to conventional models	low	low
Measures on ventilation systems			
Installing HRV system	Up to 25% heating energy	high	high
Installing HVAC system	Up to 50% heating energy	high	high
Measures on lighting system			
Installing energy efficient lighting	Up to 30% - 50 % electric energy	low	low
Installing lighting controls (occupancy sensors, daylight controls, etc.)	Up to 50% electric energy used for lighting	low	low
Replacing light ballasts	Up to 30% electric energy per fluorescent fixture	medium	low
Control and energy management systems			
Building energy management system	15%-20% energy for heating and cooling 50%-60% of energy for lighting	high	medium