RepliCable and InnovaTive
Future Efficient Districts and cities

D2.1: Report on retrofitting of building envelope

WP 2 , T 2.1

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[1] PU = Public

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Abbreviations and Acronyms

AP2BEER	Affordable and Adaptable Public Buildings through Energy Efficient Retrofitting
BAST	Building Added Solar Thermal
BAPV	Building Applied Photovoltaics
BIST	Building Integrated Solar Thermal
BIPV	Building Integrated Photovoltaics
DHW	Domestic Hot Water
EPS	Expanded Polystyrene
ETICS	External Thermal Insulation Composite System
ETP	European Technology Platform
FRP	Fibre-Reinforced Polyester
GE2O	Geo-clustering to deploy the potential of Energy efficient Buildings across EU
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IGU	Insulated Glass Unit
JTI	Joint Technology Initiative
LCC	Life Cycle Cost
Low-E	Low Emissivity
PC	Polycarbonates
PMMA	Polymethyl-methacrylate
PIME´S	CONCERTO communities towards optimal thermal and electrical efficiency of buildings and districts, based on MICROGRIDS
PV	Photovoltaics
RES	Renewable Energy Sources
R&D	Research and Development

SHGC	Solar Heat Gain Coefficients
SI	International System of Units
SME	Small and Medium Enterprises
SRA	Strategic Research Agenda
STC	Solar Thermal Collector
STEEP	Systems Thinking for Efficient Energy Planning
uPVC	unPlasticised Polyvinyl Chloride
XPS	Extruded Polystyrene
3ENCULT	Efficient Energy for EU Cultural Heritage

0 Abstract

Building energy efficiency can be improved by implementing either active or passive energy efficient measures for the retrofitting of the building envelope. Recent years have seen a renewed interest in environmental-friendly passive building energy efficiency strategies as they are being envisioned as viable solutions to the problems of the energy crisis and the environmental pollution, in the line of new social aspirations.

The objective of this deliverable is to provide an advanced catalogue of envelope retrofitting solutions with the identification of the most suitable and replicable on the basis of innovation and cost-effectiveness.

The solutions are divided according to the category of passive and active measures. Firstly, the passive solutions are addressed. In order to provide a more complete approach not only tacking into consideration "technologies", but also "technics", a framework about bioclimatic architecture is proposed in this section. Secondly, active solutions are analysed and next to that, the synergies between different solutions and their integration possibilities are explained.

After the passive and active solutions analysis, a general picture on progresses of several European research projects on this building element, the envelope, are presented, bringing as references some of the most relevant ongoing projects.

Finally, in connection with the theory, the relationship between research and market is presented in Section 7, with the analysis of the information on the existing clusters spread over Europe related to "energy efficient buildings". In this regard, Section 7 presents the envelope retrofitting solutions applicable within the CITyFiED project in the demo sites of Turkey, Sweden and Spain.

It is important to highlight that the main sources of information to develop this deliverable are the references to previous works and experiences of the CITyFiED project partners in other similar approaches, together with the inclusion of data from other relevant European research projects. They are especially relevant:

- AP2BEER (D2.2 "*Technologies and strategies for Public Building and District Retrofitting*") [1]
- PIME´S (D2.4.4 "*Guide for bioclimatic design*") [2]
- STEEP (D3.1 "*Knowledge exchange on technologies"*) [3]
- 3ENCULT (D3.1 "*Report on Energy Efficiency Solutions for Historic Buildings"*) [4]
- GE2O (D2.1 "*Summary of the best practices, lessons learnt and potential barriers"*) [5]
- Technology Map of the European Strategic Energy Technology Plan 2011, by the Joint Research Centre for SET-Plan information system [6]

1 Introduction

WP2 aims to develop a systemic methodology for the renovation of large areas in the cities. The retrofitting actions can contribute to low energy and zero emission cities and urban areas, taking into account the technological availability for building retrofitting, deploying district heating networks and also integrating distributed power generation. Renewable energy sources and waste energy recovery play a key role in this approach towards a clean energy city strategy that reduces drastically the CO_2 emissions and primary energy use.

Under this framework, Subtask 2.1.1 "*Retrofitting of the building envelope – Passive and active solutions"* focuses on the definition of the most suitable and replicable solutions for the retrofitting of the building envelope, on the basis of innovation and cost-effectiveness.

1.1 Relationship with other WPs

Deliverable	Task	Relation
Various	WP1	Model for the evaluation of replication potential.
Various	T2.1	Contribution to the catalogue of solutions regarding the reduction of the thermal energy consumption.
Various	T4.1	Assessment on technical solutions for retrofitting for the Spanish, Turkish and Swedish demo site activities.

Table 1.1: Relationship with other WPs

1.2 Contribution from partners

Partner Short Name	Contributions
ACC	Organisation and structure of the work and the document contents according with the Annex I – "Description of Work" commitments. Development of Sections 2, 5 and 6. Revision of the whole document before its submission.
ITU	Development of sections 3 and 4. Contribution in the overall document revision.
CAR	Quality review and active contributor to the document contents as task coordinator.

Table 1.2: Contributions from partners

2 Bioclimatic and passive solutions for energy-efficient building envelope retrofitting

Bioclimatic design is based on the characteristics of the site in order to minimize the energy needs of the building and to create a more comfortable built environment adapted to the ways and lifestyles of the inhabitants. In addition, special attention is paid to respect the existing landscape and integrate the building within it.

Passive design refers to a design approach that uses natural elements to heat, cool, or light a building. Systems that employ passive design require very little maintenance and reduce a building's energy consumption by minimizing or eliminating mechanical systems used to regulate indoor temperature and lighting.

Different solutions of both related criteria can be applied to the retrofitting of the building envelope, as it is explained in this section.

2.1 The building envelope

The building envelope is the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating internal temperatures and helps to determine the amount of energy required to maintain thermal comfort. Minimizing heat transfer through the building envelope is crucial for reducing the need for space heating and cooling. The overall design can help determine the amount of heating, cooling and lighting a building will require.

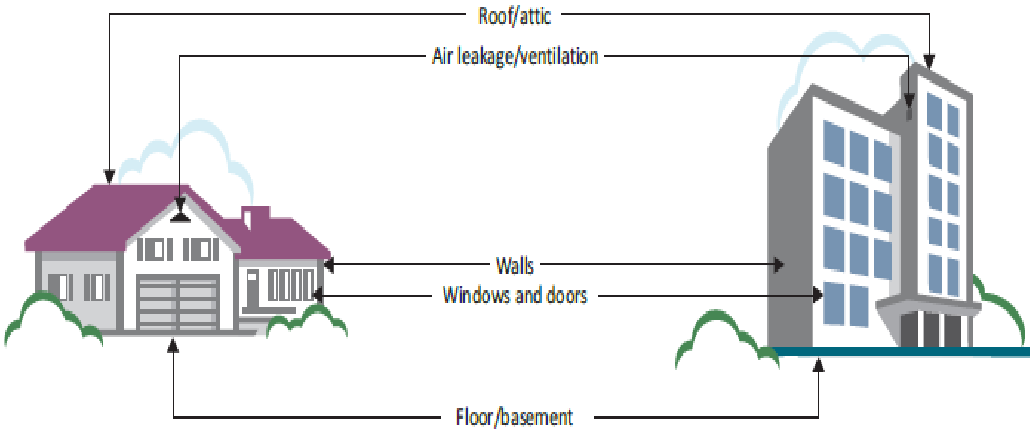


Figure 2.1: Building envelope components
Source: International Energy Agency

A building's envelope is the main responsible for its heat losses and gains. Walls, roofs, windows and floors can be optimized by studying different characteristics:

- Thermal resistance
- Thermal bridging reduction
- Air tightness
- Thermal inertia, energy storage capacity
- Optimization of solar energy gains
- Solar control
- Passive cooling
- Passive thermal gains - e.g. transpired solar collectors
- Natural ventilation
- Natural daylight transmission through glazing

The systems and elements that comprise the building have functional, performance, design and construction relationship to others. Functional performance for the thermal environment, moisture protection, sustainability and durability are shared by all four of our major subsystems: walls, fenestration, roofs and below grade elements. Thus each one has to be designed to contribute to overall functional effectiveness in order to meet the performance requirements for the whole building.

Acoustic performance from the outside is the responsibility of the wall system and, to a lesser extent, the fenestration, while daylight transmission and control is the responsibility of the fenestration.

Natural ventilation, if provided, will be a fenestration design problem but will also have major repercussions on the HVAC design. If the HVAC system employs perimeter heating or cooling this must be integrated with the envelope performance requirements. Interior air quality is primarily an HVAC issue, mainly concerned with outside air supply and filtering. The exterior wall will also have some performance requirements relating to materials and permeability [7].

These relationships and some others are analysed in the next tables that comes from the *Building Envelope Design Guide* written by Chris Arnold [7]. The first table shows the list of basic performance requirements. The next tables show the list of secondary performance requirements (safety, aesthetics, practice and innovation).

	Systems	Walls	Glazing	Roof	Below grade	Comments
BASIC PERFORMANCE REQUIREMENTS	Thermal	X	X	X		Wall and glazing insulation and relative quantities largely determine thermal performance in medium and high rise buildings (small footprint), roof more influential in low rise (large footprint).
	Acoustics	X	(X)			Protection against outside acoustic environment. Walls major determinant, glazing is an influence.
	Light transmission		X	(X)		Glazing major determinant, both quantity and location: roof may be important if skylights are provided.
	IAQ	(X)	(X)			HVAC system is major determinant, together with natural ventilation (operable windows) if provided. Wall openings (grilles) must provide outside air supply to HVAC system.
	Mold protection	(X)	(X)			HVAC system is major determinant, together with natural ventilation (operable windows) if provided.
	HVAC integration	X	X	(X)		Wall and glazing insulation are critical in determining HVAC loads, together with roof if large footprint building.
	Natural ventilation		X			Operable glazing is traditional way of providing natural ventilation, but coordination with HVAC system is essential to ensure energy efficient system.
	Durability	X	X	X	X	All systems contribute to overall durability of building.
	Sustainability	X	X	X	(X)	Materials and performance of walls, glazing and roof have major influence: below grade construction may contribute but few alternatives are available for design and construction.

Note: X, Major determinant or influence; (X), Minor determinant or influence

Table 2.1: Basic performance requirements of the Building Envelope
Source: Building Envelope Design Guide. Arnold, C., 2009 [7]

SAFETY REQUIREMENTS	Systems	Walls	Glazing	Roof	Below grade	Comments
	Fire Protection	X	X	X		Wall, glazing and roof materials are critical and strongly regulated by code. HVAC and fire protection systems are key systems for smoke and fire reduction and elimination.
	Floods	X	(X)		X	Below grade and first floor wall construction are critical but building location is the key determinant. Protection of low level glazing is important.
	High Winds	X	X	X		Building envelope is particularly vulnerable to high winds because wind action attacks the building exterior surfaces.
	Seismic	X	X	(X)	X	Building structure is main defence against earthquakes. Heavy non-structural precast wall panels and glazed curtain walls may need special attachment detailing to structural frames subject to large racking deformations in high seismic zones. Heavy roof materials (tile) are vulnerable and need positive attachment.
	Blast, CBR	X	X	X	X	Building structure is main defence against blast: non-structural wall panels and glazing need special design and attachments to the structure, roof may contribute debris due to suction effect. HVAC main protection against CBR.

Note: X, Major determinant or influence; (X), Minor determinant or influence

Table 2.2: Safety requirements of the Building Envelope
Source: Building Envelope Design Guide. Arnold, C., 2009 [7]

AESTHETIC INFLUENCES	Systems	Walls	Glazing	Roof	Below grade	Comments
	Aesthetic					Aesthetic issues primarily relate to building exterior (public view) and interior of exterior wall (occupant view).
	Color	X	X	X		Related to materials: natural (stone etc) metals (metallic or painted finishes) and availability of a range of alternatives.
	Texture	X	X	X		Smooth (metals), smooth to rough (natural materials, such as marbles, granites etc) and cast textures on concrete.
	Pattern	X	X	X		Primarily related to joints between panels and glazing, and the size and shape of panels.
	Associations	X	X	X		Local context and cultural associations, e.g. natural stone versus stucco.

Note: X, Major determinant or influence; (X), Minor determinant or influence

Table 2.3: Aesthetic influences of the Building Envelope.
Source: Building Envelope Design Guide. Arnold, C., 2009 [7]

PRACTICE CONSIDERATIONS	Systems	Walls	Glazing	Roof	Below grade	Comments
	Cost					Pervades the choice of all materials and systems.
	Material	X	X	X	X	Cost and availability of materials.
	Installation	X	X	X	X	Cost (and time) of installation.
	Life Cycle	X	X	X	X	Evaluation of cost and performance in relationship to owner's (and society's) needs and resources.
	Codes & Standards	X	X	X	X	Pervades the use of almost all materials and systems.

Note: X, Major determinant or influence; (X), Minor determinant or influence

Table 2.4: Practice considerations of the Building Envelope.
Source: Building Envelope Design Guide. Arnold, C., 2009 [7]

	Systems	Walls	Glazing	Roof	Below grade	Comments
INNOVATION	Innovation					Includes the need for innovation and trends in innovation, through research and market forces initiated by codes and regulations e.g. developments in glazing technology to respond to energy conservation codes.
	Performance	X	X	X	X	Performance enhancement is a continuing goal, often related to marketing.
	Costs	X	X	X	X	Strongly driven by competition induced by bidding process.
	Aesthetic	X	X	X		A strong driver for exterior materials and finishes, glazing and steep slope roofing.

Note: X, Major determinant or influence; (X), Minor determinant or influence

Table 2.5: Innovation of the Building Envelope
Source: Building Envelope Design Guide. Arnold, C., 2009 [7]

These relationships mean that the building envelope cannot be designed in isolation. It is a function of design management to ensure that the performance attributes and the physical connections between the envelope and the rest of the building are integrated in concept and execution from the commencement of the design process [7].

2.2 Bioclimatic solutions for energy-efficient building envelope retrofitting

In order to provide a more complete approach not only tacking into consideration “technologies”, but also “technics”, a framework about bioclimatic architecture is proposed in this section.

Bioclimatic design means that a building is designed in such a way that, based on local climate data, environmental elements such as sun, wind, air, vegetation and soil are taken into consideration as much as possible into heating, cooling and lighting to reduce the overall energy consumption of the building and to provide comfortable and pleasant living spaces for the inhabitants.

The main features of bioclimatic design are:

- Proper thermal insulation and airtightness of the external envelope of the building.
- Use of solar energy for heating in winter time. This can be achieved by a proper passive solar heating system

- Removal of the heat from the building by passive cooling systems and natural ventilation
- Protection of the building from overheating by proper shading solutions in summer time.
- The use of solar energy for day-lighting all year round
- Providing a pleasant and comfortable indoor and outdoor environment for the inhabitants.

Bioclimatic design conserves resources and maximizes comfort through design adaptations to site-specific and regional climate conditions. It describes how the building responds to local climate, sun path, prevailing breezes, and seasonal and daily cycles through passive design strategies. For that it is needed: site and climatic analysis; description of internal versus external building loads; and design strategies to reduce or eliminate the need for non-renewable energy resources. Global solutions can be used as a guide but each building or district is different, so, strategies should be specifically shaped to the building plan, section, and massing, placement, orientation, and shading of the building or buildings.

There are several factors that should always be taken into account on bioclimatic architecture to approach any analysis. These factors may be characteristically defined for a certain location and environment. All different data should be collected to provide an effective analysis.

Regarding bioclimatic design, the main characteristics of climate are temperature, sunshine, wind, precipitations and relative humidity:

- There are several techniques available for representing **climate conditions** or data on determined geographical area as maps or climate diagrams. Parameters determining climate conditions are subject of spatial variability (as the influence of astronomical and geographical factors or latitude, which define different climatic zones of diverse extension such as regional, local or microclimates) and variability over time for different periods as annually or longer.
- The **sun** is the main energy source for bioclimatic design. The sun and its incidence over the earth is the main factor determining the temperature on the surface of the earth and by extend the heat gains of buildings too. Radiation, air movement and humidity are determined by the incidence of the sun. In consequence, it is necessary to study the path of the sun throughout the whole year. Thanks to knowledge on solar geometry we can determine the influence of the sun on our buildings, as well as the best orientations and other designing parameters. From the solar geometry we can obtain the shadows that the building will receive and the shades that would be necessary to prevent from undesirable solar gain. In order to find out the altitude and latitude of the solar incidence we may need solar elevation (angle formed on the vertical plane over the horizon) and azimuth (angle between the projected vector of the position of the sun and the North on the reference plane of the horizon). It is important to use local solar time specific to the location when the sun azimuth and elevation is determined. Using solar time, the sun always shows the south at exactly noon.

- Natural ventilation design takes advantage of the movement of the air caused by **wind.** For a proper design the dominant direction, speed and frequency of the wind must be known for the whole year. Modern instruments used to measure wind speed and direction are called anemometers and wind vanes respectively. This data can be collected from weather stations; however local conditions near the building, such as landscape, vegetation and other large objects can affect the air flow, which should also be considered in the design.
- The **temperature of the external air** is an important input data when the heating and cooling system of a building is designed. The temperature of the air is measured by thermometers placed 1.5 - 2.00 m above the ground and exposed to the air but sheltered from direct solar radiation. Daily and monthly mean air temperature data is easily available from weather stations. The temperature of the sky is lower all year long; we may use this fact to reduce the overheating by several bioclimatic strategies which gain thermal exchanges. The ground stores heat energy, which may be both solar gained or geothermal. On the other hand, the temperature of the ground is almost constant. The first layer of 0.20 to 0.30 m deep suffers from day-night temperature fluctuation, whereas from 0.80 to 2.00m deep the variation occurs only on longer periods. The depths of 2.00 m and more are not affected by seasonal differences.
- The **average annual precipitation** is a vital climatic data. Precipitation is measured in units over a given time period. Wind, buildings, trees, topography, and other factors can modify the amount of registered precipitation, so rainfall and snowfall tend to be measured away from obstructions. A thirty-year average of annual precipitation is used to determine the average annual precipitation for a specific place. The amount of precipitation and the number of annual rainy days influence the external air temperature, the relative humidity and the amount of sunny hours. When a rainwater harvesting system is designed, the average annual precipitation is also an important input data.

Improvement of the quality of life appears as a global, all-encompassing and holistic objective, involved in sustainable development. Bioclimatic design principles applied for human comfort within the improvement or adjustment of environmental conditions in the interiors of buildings so that their inhabitants find them comfortable and pleasant:

- **Thermal comfort:** To keep human thermal comfort the body must keep a constant temperature. Exterior climatic conditions should be studied to design the correct protections. Thermal comfort is reached when the heat generated by human metabolism can be dissipated; maintaining a thermal equilibrium with the surroundings and the constant internal temperature. Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Comfort zone is defined by the mentioned factors that keep heat exchange equilibrium. Thermal comfort is related to light clothing, low air flow rates and low humidity. These conditions are ensured by the use of both passive strategies and HVAC technical equipment.

- **Air quality:** For an interior space occupied by human beings, the oxygen consumption and its substitution by carbon dioxide may cause organic disorders that may lead lethal consequences. Breathing and transpiration may cause undesirable odours on interior areas too. Ventilation is a simple way to mend these problems, by the substitution of interior air by fresh air from the exterior. Excessive ventilation leads to an over consumptions in terms of HVAC and the insufficient ventilation is one of the main causes of the so called sick building syndrome.

Nowadays the concept of bioclimatic design is not considered extensive, but it is sufficiently developed form the technical and theoretical point of view. Architects are aware of the influence on, for example, the building orientation, the layout or zone planning or the compactness solutions and measures when planning new buildings. But what happens in retrofitting activities when those solutions are not available because they are already determined? Is bioclimatic design applicable in retrofitting activities?

The answer, of course, is yes. In the next pages we will show some conventional and innovative bioclimatic solutions available for retrofitting activities, most of them related to glazing and thermal mass interventions.

The **glazing** ratio of the façades has a big effect on energetic behaviour of buildings and comfort conditions in the interior. Although small openings allow less solar radiation inside during the summer, this way solar gain is significantly reduced in winter. During the design phase the ratio of opaque and transparent surfaces needs to be established properly, in accordance with local climate conditions. It is recommended to protect the southern areas from sun exposure in warmer climates, while they will not be needed on north-facing facades. Anyway, in many cases a glass surface with a good thermal performance will be worse than an average insulated opaque structure.

Also, an adequate **thermal mass**, which is one of the most important pillars of bioclimatic design, has two main advantages: in winter it stores the solar heat gain collected during the day and radiates it to the rooms at night, while in summer it warms up more slowly than a lightweight structure, provided that proper ventilation during the night exists.

2.2.1 Principles against heat losses in winter: insulation of the building envelope and passive solar heating systems

Thermal insulation materials are specifically designed to reduce the flow of heat by limiting conduction, convection, or both. Radiant barriers are materials that reflect radiation, and therefore reduce the flow of heat from radiation sources. Good insulations are not necessarily good radiant barriers, and vice versa. Metal, for instance, is an excellent reflector and a poor insulation.

The buildings, with their heating systems, form dissipative systems. In spite of the efforts to insulate houses in order to reduce heat losses via their exterior, a considerable amount of heat is lost, which can make the interior uncomfortably cool or cold. For the comfort of the inhabitants, the interior should be maintained out of thermal equilibrium with the external surroundings. In effect, the thermal gradient between the inside and outside is often quite steep. This can lead to problems such as condensation and uncomfortable air currents, which can cause constructive or structural damage to the property. Such issues can be prevented by using insulation techniques for reducing heat loss.

Passive solar heating systems use the energy of solar radiation without involving any mechanical or electrical devices. However, there are so called hybrid systems as well, where an active device is also used, mainly small ventilators, which help to transfer the heated air.

The main features of passive solar systems are:

- Transparent glazed areas in the external walls and roofs, preferably on the southern sides, which collect and let the solar energy gets into the building;
- Internal absorbing surfaces, preferably in dark colour to absorb the solar radiation;
- Internal, preferably heavyweight walls and floors with high thermal capacity to store as much heat as possible;
- Distribution of stored heat by natural ventilation and radiation;
- Properly insulated and air-tight external envelope including opaque and transparent structures to minimise heat loss through the building fabric.

2.2.2 Principles against overheating in summer: passive cooling systems

Passive cooling systems constitute a group of bioclimatic solutions based on the good use or protection from external conditions. Passive design refers to a design approach that uses natural elements to heat, cool, or light a building. The following strategies related to envelop building refurbishment are taken into account:

- Evaporative cooling
- Radiant cooling
- Earth cooling
- Natural ventilation
- Solar shading

2.2.2.1. Evaporative cooling

Evaporative cooling is based on the heat drain of evaporating water. When water evaporates, it draws a large amount of heat from its surroundings and converts into latent heat in the form of water vapour. The intensity of evaporation (and the cooling effect) depends on the humidity and the speed of the surrounding air. Thus, evaporative cooling performs best on hot and dry climates with a lot of wind. However, in most cases evaporative cooling itself is not enough and it should be combined with other cooling methods.

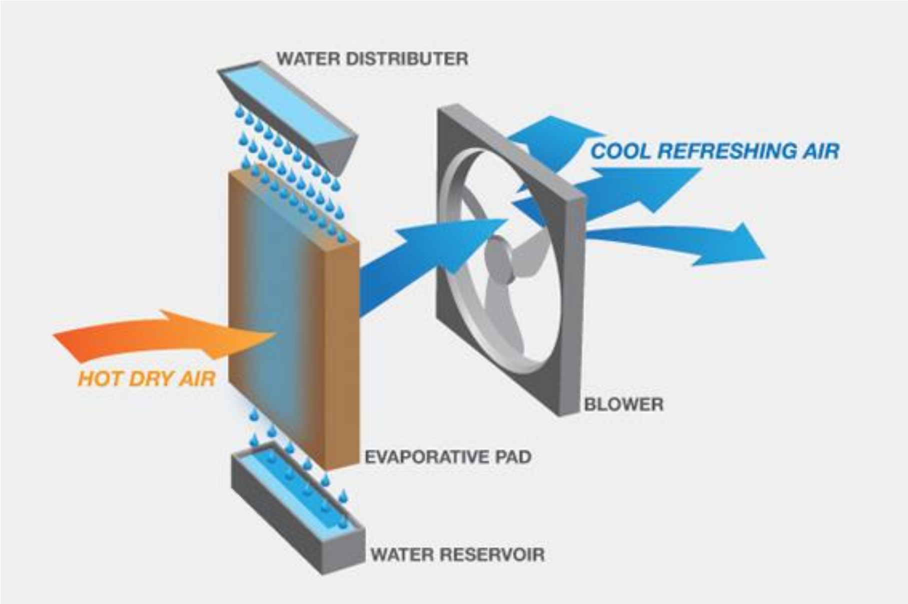


Figure 2.2: Evaporative cooling operation
Source: Temperature Plus

2.2.2.2. Radiant cooling

Radiant cooling is based on the heat emission of the building structures to the night sky. Since the roof has the greatest exposure to the sky, it is the best location for the (generally painted metal) radiator. Since it works during the night, thermal storage mass (e.g. a heavy roof) is required and because of the low cooling effect the whole roof area should be used. In its original way of use it cools only the top story of the building.

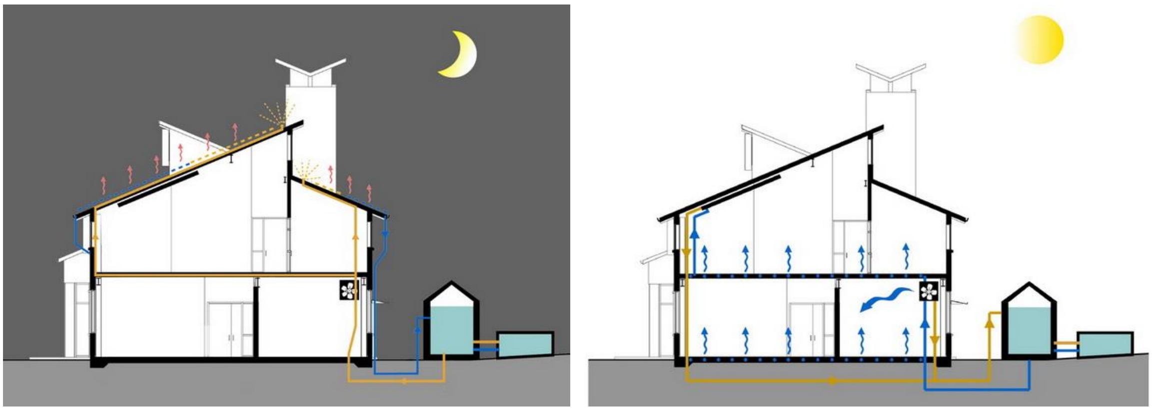


Figure 2.3: Diagram of the use of the tubes in the floor for radiant cooling
Source: American Institute of Architects

2.2.2.3. Earth cooling

Earth cooling is based on the steady state temperature of the deep soil layers. The temperature of the soil near the surface fluctuates widely according to the season. However, the soil temperature fluctuates less and less as the soil depth increases. Under the frost line the summer and winter fluctuations have almost disappeared and the temperature of the soil can be considered steady all year, which is equal to the average annual air temperature.

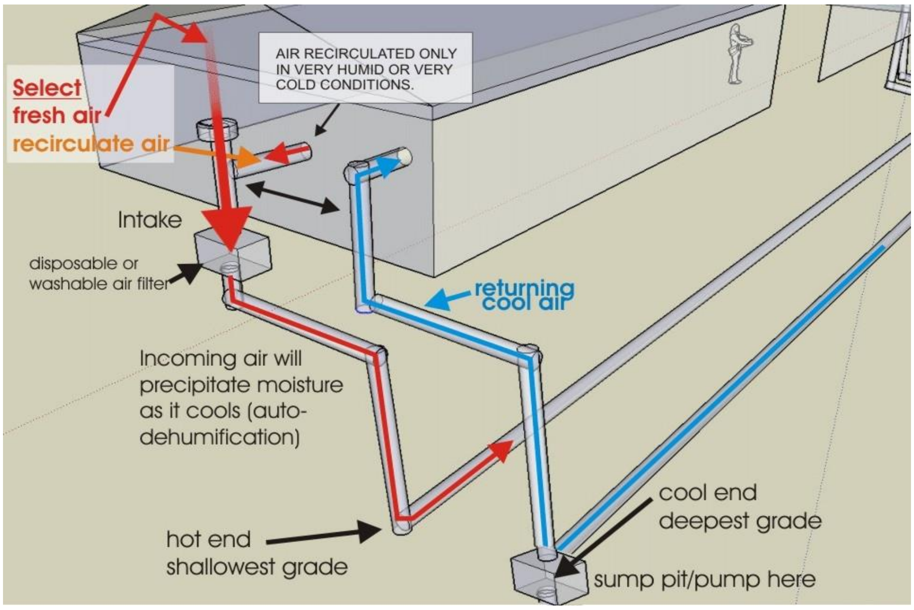


Figure 2.4: Earth tube cooling
Source: Ecotechdesign

2.2.2.4. Natural ventilation

Natural ventilation is the process that exchanges air from the interior of a building to the outside without any mechanical equipment. The air movement is caused by the different pressures due to the temperature differences or to the incidence of wind. Natural ventilation among with insulation, thermal mass and solar protections, may reduce drastically the necessity of HVAC on buildings.

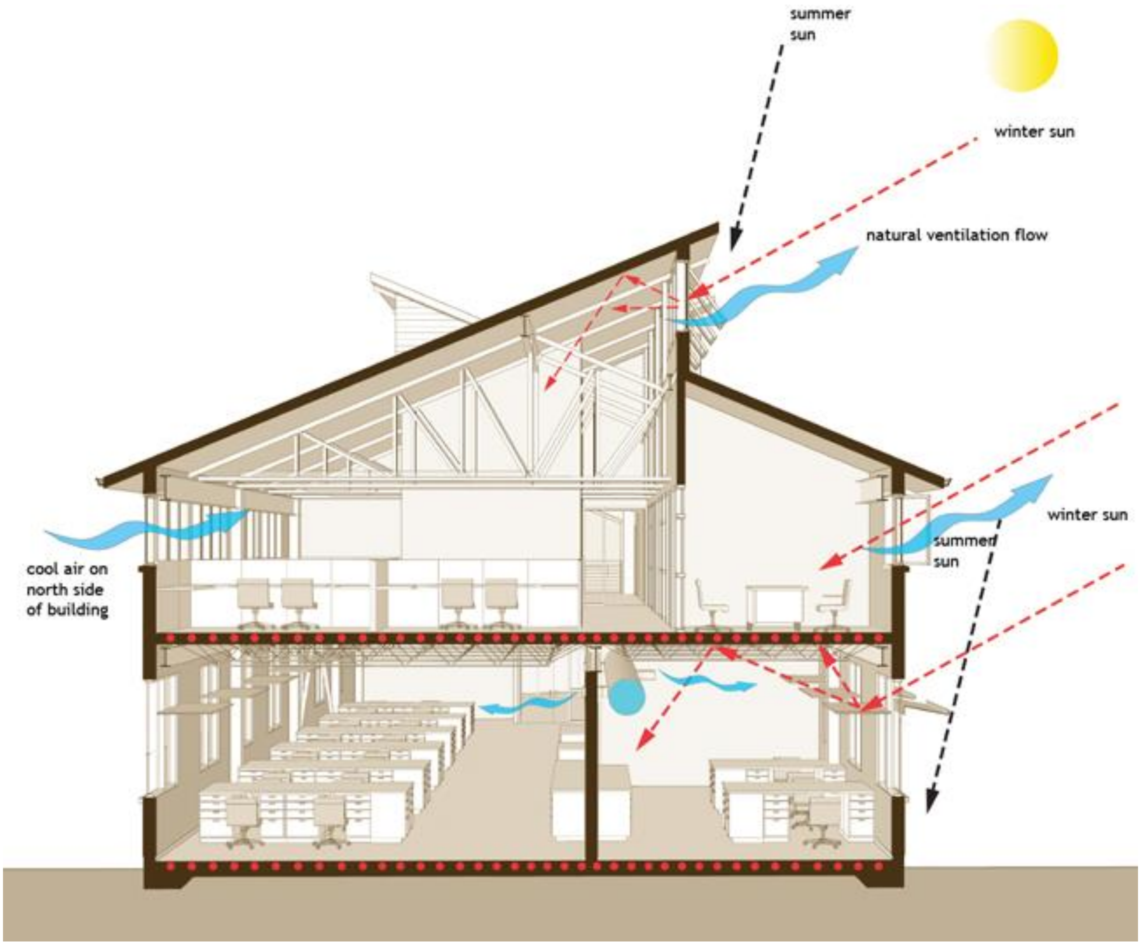


Figure 2.5: Section showing ventilation flow
Source: American Institute of Architects

To obtain the benefits from wind driven ventilation in retrofitting activities the building façades should became permeable and the interior distribution of pressures should be studied. At district level, landscape strategies that may change air movements within the surrounding could be also studied together with building strategies as location and size of the windows and openings or interior openings between different areas of the building.

2.2.2.5. Solar shading

Solar shading, or the process of controlling the sunlight entering a building through the glazing or hitting the external surface of an opaque structure, can be accomplished through a number of methods. The techniques employed generally depend on the climate and the use of the space. For instance, in climates with a high cooling load, sun entering the space or heating the external envelope can increase cooling energy use, whereas in heating climates, the excess sun may be desirable, but glare and high contrast ratios may make it difficult for occupants to work. In either case, properly designed sun shading can enhance day-lighting while reducing uncomfortable glare and unwanted solar gain.

Shading can be accomplished by exterior or interior shading devices, roof overhangs, landscaping or special glazing. Although each has its benefits, a combination of strategies usually works best, because different strategies may be appropriate for each orientation of the building. Effective sun shading is dependent on an understanding of sun angles and solar geometry.

General rules for good solar shading design include:

- The east and west glazing of the building should be minimised as the east and west elevations are both difficult to shade "architecturally".
- Projections and/or reveals should be designed for the south façade.
- If no exterior shading devices are to be used, specify windows with low solar heat gain factors should be specified.
- For occupant comfort, light-coloured Venetian blinds or light-coloured translucent shades should be provided on all windows in occupied areas.

Figure 2.6: Solar shading solutions
Source: Colt International Ltd

2.2.3 Bioclimatic design of a building and its surroundings

The local natural environment can significantly affect the performance of the building. The vegetation, which changes with the season and the daytime, can help to improve the comfort of the users of the building. Without vegetation, a site loses its natural capacity for storm water management, filtration, and groundwater recharge.

Reduced vegetative cover also affects soil health, because vegetation maintains soil structure, contributes to soil organic matter, and prevents erosion. Through evaporation, transpiration, and the uptake and storage of carbon, trees and other vegetation moderate the climate of the world and provide a breathable atmosphere.

The use of the daylight and the influence of colours should also be taken into account. The use of the next strategies is considered in this section:

- Green façades
- Green roofs
- Water surfaces around the building
- Daylight use
- Colours influence

Green façades

The advantage of the deciduous green facades is that they provide proper shading in summer, while in autumn and winter they let through the necessary light and heat of the sun. In summer the vegetation decreases the temperature of the local environment by 1-2°C due to their evaporation, and it also improves the quality of the air by the oxygen emission. The disadvantage of the green facade is the significant requirement of maintenance, and the proliferation of insects. The beneficial effects can be improved, if a space is left between the vegetation and the facade.

Figure 2.7: Bioclimatic green façade
Source: MMA Architectural Systems

Green roofs

Also known as vegetated roof covers or eco-roofs, they constitute thin layers of living vegetation installed on top of conventional flat or pitched roofs. Green roofs protect conventional roof waterproofing systems while adding a wide range of ecological and aesthetic benefits. Furthermore, green roofs provide significant heat attenuation due to their large mass. In addition, the evaporation of the wet soil and plants decreases the temperature of the building environment. Green roofs have proved that they outperform white or reflective roof surfaces at reducing the ambient air temperature.

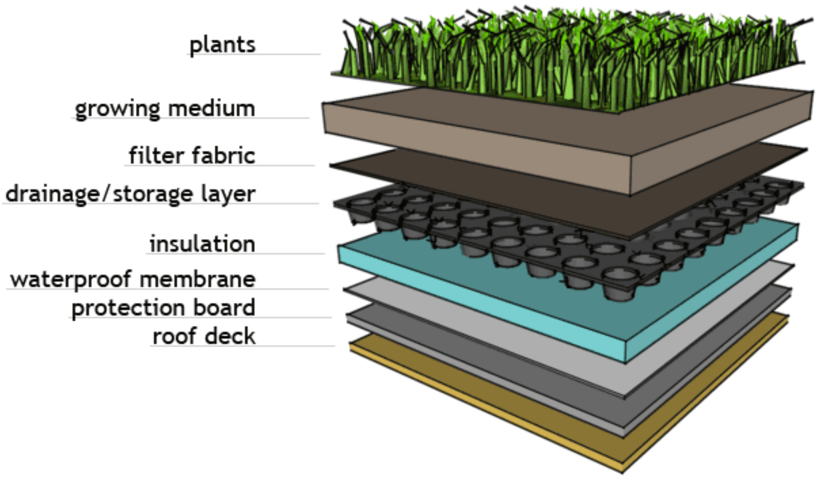


Figure 2.8: Green roof components
Source: DC Greenworks

In order to reduce urban heat island effects, green roofs or vegetated structures like trellises can be used. Moreover non-vegetated surfaces such as walkways, roofs, or parking lots should be considered, and vegetation-based methods should be selected to achieve storm water management goals for the site. As vegetation, especially in summer, lets through scattered light; it can be applied to moderate direct light, which can cause unnecessarily enlightenment bright indoor. Trees and bushes can also be arranged around the building in a way that will lead to improve natural ventilation due to directed wind.

Water surfaces around the building

Water surfaces around the building can reduce, due to their evaporative heat absorption, the air temperature by 2-4°C, improving the micro climate in summer. Artificial water surfaces can be placed inside or outside the building. Big shopping malls often use fountains inside. Water surfaces can also be formed on the roof of the building. It should be noted that water surfaces require additional maintenance and investment costs and they should be properly designed and constructed at a very high level.

Figure 2.9: Roof covered by a water surface
Source: MMA Architectural Systems

Daylight use

Daylight use may be the crucial factor to bioclimatic lighting design. The use and opening hours of the building, as well as the orientation and the glazing areas, the building and interior spaces dimensions (depth versus façade) should be considered. When the problem is caused by the depth of a certain room, daylight conductors may be applied. Daylight may not provide the sufficient luminance it is needed at any time, but its use may suppose important energy consumption reductions. It must always be combined with artificial lighting. There are three main criteria on lighting design: obtain a correct luminance on the surface where it is needed for certain activities; avoid the reflections which may cause dazzle; relate interior to exterior luminance.

Figure 2.10: Daylight use in the Reichstag dome in Berlin, Germany
Source: Foster and Partners

Selection of materials should take into account the reflection properties to make a good use of daylight and an efficient lighting design. Specular materials can be used to redistribute or redirect daylight as used on light tubes and light shelves. A proper use of daylight use should be based on: the election of orientation and the use of shadings, shutters, blinds, or any kind of sun protection; the use of advanced glazing reducing heat transmission and controlling solar gains; a design that should consider the location and size of windows according to the use and proportion of the interior spaces; the use of light colours and reflective materials; the use of reflection to redistribute day light; and glare control both interior and exterior areas.

Colour influence

Additionally, colour is an important factor on the thermal performance of buildings. Colour election according to climatic requirements is important to reduce solar gains in summer or to improve solar gains during winter. It is important to consider that certain colours may cause glare in the exterior and interior areas of the buildings. Colours may also be classified by the field of colour psychology that identifies the associations and effects on human emotions.

Figure 2.11: Colour influence in the façade, MUSAC museum in León, Spain
Source: Mansilla & Tuñón architects

Cool roofs are a form of roof where the materials used are deliberately selected for their high solar reflectance (called albedo) and high thermal emittance. They absorb, and consequently store, less solar energy during the day and thus are not major emitters of heat into the urban atmosphere at night. Cool roofs reach temperatures considerably lower than their low reflectance counterparts. They can extend the lifetime of roof materials by damping the daily temperature range and thus reducing excessive contraction and expansion, and by reducing the absorption of damaging ultraviolet.

2.2.4 Advisable constructive solutions depending on climatic conditions

Constructive solutions should adapt to the climate of the place where a building is located, in order to achieve a good energy performance and accurate comfort conditions. The next table, based on *"Arquitectura y clima: Manual de diseño bioclimático para arquitectos y urbanistas"* by Victor Olgyay [8] points out different strategies to achieve this goal.

CLIMATE	MAIN STRATEGIES	ELEMENT	INTERVENTION
COLD	Due to cold weather conditions, the main strategies to reduce energy demand on buildings are focused on winter periods, and they are: - Increase solar radiation absorption (good-oriented, large and low-e windows). - Reduce heat loss by conduction and evaporation (low U-value of envelope).	**Openings and windows**	Windows shall be small except in south and east façades, where solar gains through them are a very good heat source. Low U-value and airtightness are extremely necessary to reduce heating demand during cold months. In the same way, it´s advisable to install solar protection for summer months.
		Walls	Façades must be highly insulated
		Roof	Roofs must be highly insulated, and the shape shall be pitched roof for evacuate the snow.
		Solar protection elements	Solar protection should not avoid solar radiation during cold months. In south façade, horizontal blinds with nearly 60º of inclination angle are a good solution.
WARM	Both cold and warm periods represent an important part of the year, and therefore, strategies should be possible to reduce or increase heat gains due to solar radiation and convection losses. - Increase solar radiation absorption (good-oriented, large and low-e windows). - Reduce heat loss by conduction and evaporation (low U-value of envelope).	**Openings and windows**	The location of windows shall allow cross ventilation. South oriented windows could be large but shall be protected from solar radiation during summer months with horizontal elements. West oriented windows shall be small and solar protected with operable nearly vertical elements such an awning.
		Walls	North façade must be highly insulated, for the rest of façades there are many possibilities depend on the specific climate.
		Roof	Roofs must be highly insulated for cool months but also they have to allow natural ventilation inside their layers to reduce heat radiation into the building during the summer.
		Solar protection elements	Horizontal protection over south-oriented windows and operable protection on east and west facades. The installation of adjustable vertical blinds on north facades is a good solution to avoid solar radiation during the evening in summer.

CLIMATE	MAIN STRATEGIES	ELEMENT	INTERVENTION
DRY AND HOT	Heat and solar radiation excess are the main negative external conditions, and therefore the main strategies will be: - Reduce solar radiation and convection gains. - Facilitate losses by radiation. - Promote evaporation (evaporative cooling). Although it is not an architectonical strategy, it should be noted that is really important to avoid internal gains, with the use of high performance electrical appliances in the kitchen.	**Openings and windows**	Due to the high level of solar radiation, small windows reduce solar gains. Also, the openings shall be located mainly over east and north facades. The airtightness of the windows during the day is very important to avoid hot air inlet.
		Walls	Walls located on diurnal rooms shall have thermal inertia, however, on nocturnal rooms, walls shall have less capacity.
		Roof	On small buildings, the better solution is a shaded (by trees) and ventilated roof. On medium and high buildings, there is no possibility to shade the roof, therefore a reflexive coating to avoid overheating in combination with a ventilated chamber is the best option.
		Solar protection elements	It is advisable solar protections on east, south and west façades; and they should be separated from the building as possible to eliminate their accumulated heat with the wind convection.
WET AND HOT	High temperatures and high humidity are the main negative external conditions. To fight them, the main strategies are: - Reduce solar radiation. - Increase natural ventilation. - Promote evaporation. - As mentioned in dry and hot climates, avoid internal gains is really important.	**Openings, windows and walls**	The difference between openings and walls disappear, because ventilation is necessary in most of the year. Cross ventilation in the axle E-W is essential. Elements as screens, blinds and jalousies are valid for allow the airflow and simultaneously avoid solar radiation. Windows shall be located on north and south orientation where the solar radiation is low and easy to manage with horizontal elements. Walls mustn´t have neither thermal inertia nor insulation.
		Roof	The biggest heat impact is produced in this element (usually the places have low latitudes and therefore the sun is high on the sky all year). A double skin roof with ventilation between them is the best option, also, the external surface must be reflexive.
		Solar protection elements	It is necessary solar protection in all the orientation, but that protection must allow airflow as mentioned before.

Table 2.6: Advisable constructive solutions depending on climatic conditions
Source: Arquitectura y clima, Olgyay, V., 2014 [8]

2.3 Passive solutions for energy-efficient building envelope retrofitting

The passive design approach can include the structure of the building itself, including building orientation, window placement, skylight installation, insulation and building materials, or specific elements of a building, such as windows and window shades. This section focuses on passive solutions for energy-efficient building envelope retrofitting.

2.3.1 Thermal performance of the building envelope: thermal insulation and radiant barriers

Thermal insulation materials are specifically designed to reduce the flow of heat by limiting conduction, convection, or both. Radiant barriers are materials that reflect radiation, and therefore reduce the flow of heat from radiation sources. Good insulations are not necessarily good radiant barriers, and vice versa. Metal, for instance, is an excellent reflector and a poor insulation.

The effectiveness of insulations is indicated by their R-value, or thermal resistance value. The R-value of a material equals the thickness of the insulation divided by the thermal conductivity. R-values are measured in SI units: m^2K/W.

As the thickness of insulating material increases, the thermal resistance also increases. However, adding layers of insulation has the potential of increasing the surface area, and hence the thermal convection area.

The effectiveness of a radiant barrier is indicated by its reflectivity, which is the fraction of radiation reflected. A material with a high reflectivity (at a given wavelength) has a low emissivity (at that same wavelength), and vice versa. An ideal radiant barrier would have a reflectivity of 1, and would therefore reflect 100% of incoming radiation.

Thermal transmittance or U-value is the rate of transfer of heat through a structure divided by the difference in temperature across the element. It is a measure of how well the building element is insulated and it is expressed in W/m^2K. The lower the U-value is, the better the performance of the element will be.

There are essentially two types of building insulation: bulk insulation and reflective insulation. Most buildings use a combination of both types to make up a whole building insulation system. The type of insulation used is matched to create maximum resistance to each of the three main forms of building heat transfer (conduction, convection and radiation).

Bulk insulators block conductive heat transfer and convective flow either into or out of a building. The denser a material is, the better it will conduct heat. Because air has such low density, it makes a good insulator. Insulation to resist conductive heat transfer uses air spaces between fibres, inside foam or plastic bubbles and in building cavities like the attic. This is beneficial in an actively cooled or heated building, but can be a liability in a passively cooled building; adequate provisions for cooling by ventilation or radiation are needed.

Bulk insulation comes in many shapes, thicknesses and materials and is primarily used in ceilings and sometimes in walls. The most common bulk insulation material is mineral wool or glass fibre. Other materials include recycled and virgin polyester, wool and cellulose fibre. Bulk insulation stops heat flow by trapping air in small air pockets.

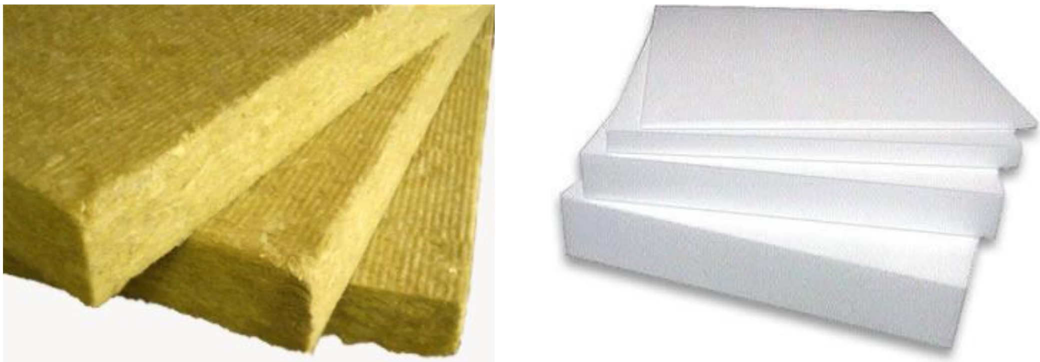


Figure 2.12: Bulk insulation materials: mineral wool and Expanded Polystyrene (EPS)
Source: www.construmatica.com

Radiant barriers work in conjunction with an air space to reduce radiant heat transfer across the air space. Radiant barriers are often used to reduce downward heat flow, because upward heat flow tends to be dominated by convection. This means that for attics, ceilings, and roofs, they are most effective in hot climates. They also have a role in reducing heat losses in cool climates, although much greater insulation can be achieved through the addition of bulk insulators. Some radiant barriers are spectrally selective and will preferentially reduce the flow of infra-red radiation in comparison to other wavelengths. For instance low-emissivity (low-e) windows will transmit light and short-wave infra-red energy into a building but reflect back the long-wave infra-red radiation generated by interior furnishings. Similarly, special heat-reflective paints are able to reflect more heat than visible light, or vice-versa. Thermal emissivity values probably reflect better the effectiveness of radiant barriers, since R-value testing measures total heat loss in a laboratory setting and do not control the type of heat loss responsible for the net result.

Reflective insulation resists radiant heat by reflecting or not emitting heat. It is usually shiny aluminium foil laminated onto paper or plastic. Reflective insulation needs a layer of air between its shiny reflective side and the roof or wall cladding. A film of dirt or moisture can alter the emissivity and hence the performance of radiant barriers.

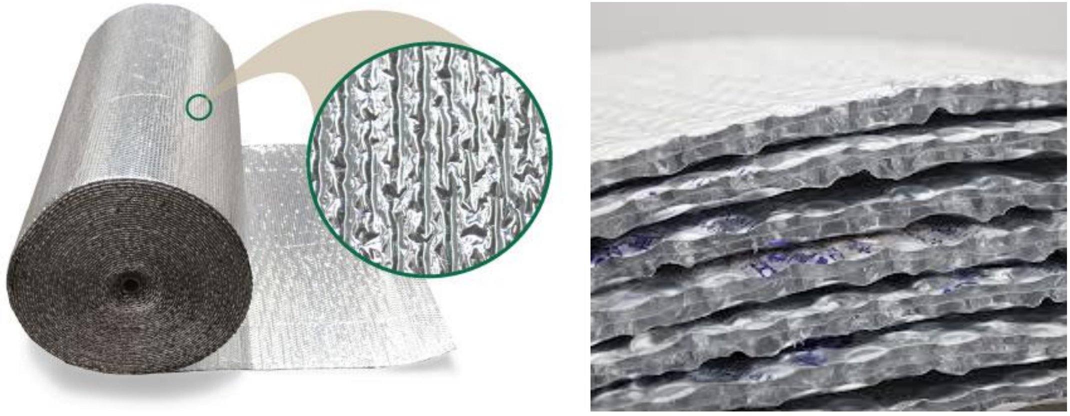


Figure 2.13: Radiant insulation materials: aluminium foil laminated
Source: www.construmatica.com

In cold conditions, the main aim is to reduce heat flow out of the building. The components of the building envelope (windows, doors, roofs, walls, and air infiltration barriers) are all important sources of heat loss. In an otherwise well insulated home, windows will then become an important source of heat transfer. The resistance to conducted heat loss for standard single glazing corresponds to an R-value of about 0.17 m^2K/W, whereas the R-valued for insulated elements reaches about to 2-4 m^2K/W. Losses can be reduced by good weatherisation, bulk insulation, and minimising the amount of non-insulating (particularly non-solar facing) glazing. Indoor thermal radiation can also be a disadvantage with spectrally selective (low-emissivity) glazing. Some insulated glazing systems can double or triple R values.

In hot conditions, the greatest source of heat energy is solar radiation. This can enter buildings directly through windows or it can heat the building shell to a higher temperature than the ambient, increasing the heat transfer through the building envelope. The Solar Heat Gain Co-efficient (SHGC) or G-value (a measure of solar heat transmittance) of standard single glazing can be around 78-85%. Solar gain can be reduced by adequate shading from the sun, light coloured roofing, spectrally selective (heat-reflective) paints and coatings and various types of insulation for the rest of the envelope. Specially, coated glazing can reduce G-value to around 10%. Radiant barriers are highly effective for attic spaces in hot climates, and they are much more effective in hot climates than in cold climates. For downward heat flow, convection is weak and radiation dominates heat transfer across an air space. Radiant barriers must face an adequate air-gap to be effective. If refrigerated air-conditioning is employed in a hot, humid climate, then it is particularly important to seal the building envelope, however dehumidification of humid air infiltration can waste significant energy. On the other hand, some building designs are based on effective cross-ventilation instead of refrigerated air-conditioning to provide convective cooling from prevailing breezes.

Nowadays there are many types of thermal building insulation materials available, which can be classified as follows.

Type	Material	
Insulating concrete forms	Autoclaved aerated concrete	Light weight concrete
Spray foam	Polyuterane foam	Flexible elastomeric foam
	Polyethylene foam	
Plastic foam	Extruded polystyrene	Polyurethane rigid panel
	Expanded polystyrene	
Fiberglass	Glass wool	Rockwool
Natural	Perlite loose-fill	Hemp wool
	Vermiculite loose-fill	Cotton wool
	Expanded clay	Reed panels
	Soft and hard Wood panels	Sheep wool
	Cellulose	Duck feather
	Expanded cork	Straw bale
Aerogel	Air-filled SiO2	Vacuum siO2
Phase-change material (PCM)		
Vacuum insulation (VIP)		
Nanotechnologies		

Table 2.7: Proposed clasification of insulation materials.
Source: AP2BEER Project

2.3.1.1. Opaque envelope elements

The next opaque envelope elements, which are façade, roof and slab constructive systems for buildings, are analysed in this section:

- Solid walls
- Cavity walls
- Double and Ventilated façade
- Roofs and lofts
- Ground floors and basements

Solid walls

A solid wall has no cavity; each wall is a single solid wall, usually made of brick or stone. Both internal and external solid wall insulation substantially reduce a home's heating costs and CO_2 emissions.

Internal wall insulation

- Generally cheaper to install than an external wall insulation.
- Does not alter the appearance of outside walls.
- Slightly reduce the floor area of any rooms in which it is applied (the thickness of the insulation is typically around 100 mm).
- If there are unresolved problems with penetrating or rising damp, these should be resolved before installation.
- There are two main alternatives to insulate a solid wall internally: rigid insulation boards or a stud wall. Before applying internal thermal insulation a full condensation calculation and assessment need to be carried out and the sensitivity of the external wall for colder conditions caused by the internal insulation (e.g. frost resistance) has to be taken into consideration as well.

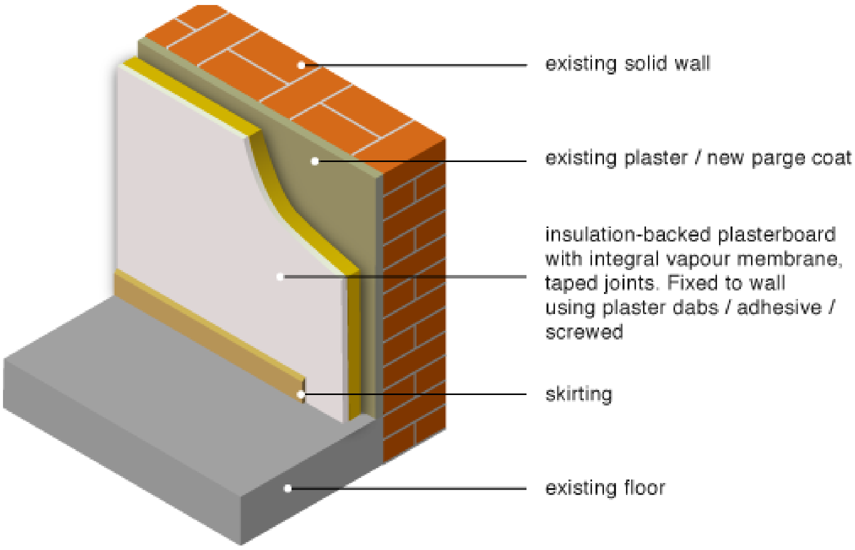


Figure 2.14: Internal wall insulation applied to a solid wall.
Source: www.energysavingtrust.org.uk

External wall insulation

This system is also called External thermal insulation composite system (ETICS). Its main characteristics are listed below:

- It can be applied without disruption to the household and does not reduce the floor area of the building.
- It renews the appearance of ageing outer walls.

- Planning permission may be required.
- This method fills cracks and gaps in the brickwork, which will reduce draughts.
- Increases the lifetime of a home's wall by protecting the brickwork.
- External wall insulation reduces condensation on internal walls and can help prevent damp, although it will not solve rising or penetration damp which must be resolved prior to insulating the walls (however, interstitial condensation can occur in the structure if the external render or cladding has a high vapour resistance). Condensation risk has to be checked in such cases.
- It is not recommended for homes with structurally unsound outer walls that cannot be repaired.
- A layer of insulation material is fixed to the walls with mechanical fixings and/or adhesive then covered with a special type of render (plasterwork) or cladding.
- The finished look can be smooth or textured and painted, tiled, panelled, pebble-dashed (for easy maintenance) or finished with brick slips to provide a real masonry brick finish.
- As they will cover the whole of the outside of the property, any of these finishes are likely to change its appearance – and will cover existing brickwork.

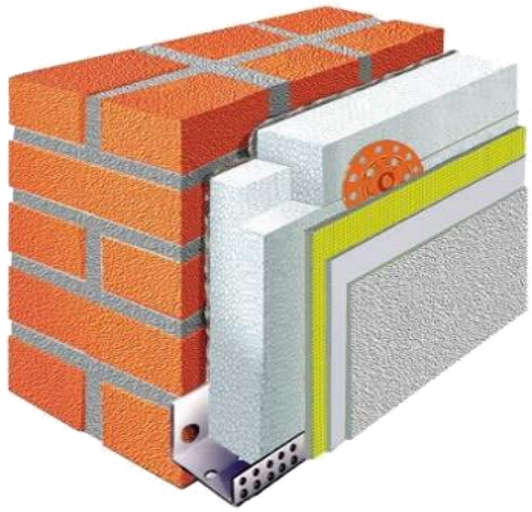


Figure 2.15: External wall insulation applied to a solid wall
Source: www.energysavingtrust.org.uk

Cavity walls

A cavity wall is made up of two walls with a gap in between, known as the cavity; the outer leaf is usually made of brick, and the inner layer of brick or concrete block. Cavity wall insulation fills that gap, keeping the warmth in to save energy. It can also help reduce condensation inside the house if this is a problem on your external walls.

Cavity wall insulation

If a cavity wall has no insulation layer, the cavity can be filled with an insulation material by making small holes around 22 mm in size at intervals of around 1 - 1.5 m from the outside of the building. The insulating material is blown or injected into the cavity through these holes which are subsequently filled to leave no sign of the work that has been carried out. Typically, cavity wall insulation can be made out of mineral wool, beads or granules, cellulose or foamed insulations.

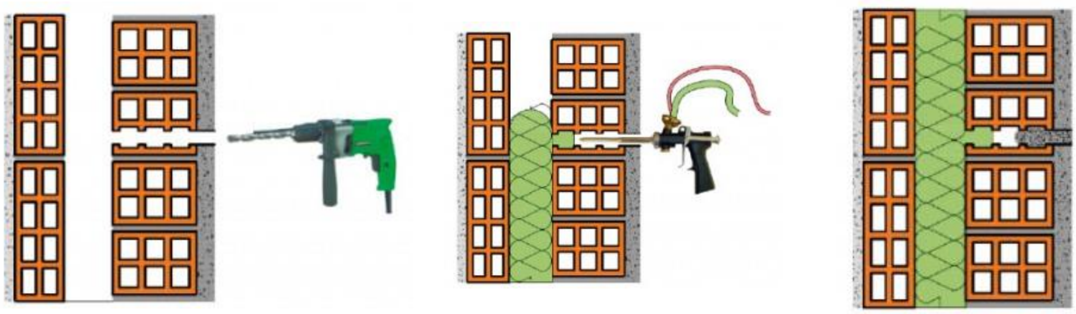


Figure 2.16: Injection of foam insulation into a wall cavity
Source: www.construmatica.com

Double and ventilated façades

The double façades work as greenhouses that can be used as a buffer zone during winter because, thanks to solar gains and the greenhouse effect, the temperature of the chamber will be higher than outdoor; in this way the heat losses through the building envelope can be reduced significantly. In summer to avoid overheating, solar shading and natural ventilation, operable windows, have to be provided.

A double façade or double-skin facade is a façade system that consists of two skins placed in such a way that air flows in the intermediate cavity. Typically, insulated glass units form the inner skin and the outer skins are made of single glass layers but other options are possible. The ventilation of the cavity can be natural, fan supported or mechanical. Apart from the type of ventilation inside the cavity, the origin and destination of the air can differ depending mostly on climatic conditions, the use, the location, the occupational hours of the building and the HVAC strategy.

The Belgian Building Research Institute set, in Ventilated Double Facades [9], set three main criteria for distinguishing between types of double façade systems. The first distinction is between the types of ventilation. Natural ventilation relies primarily on stack effect for air movement, but also pressure differences created by wind. Since no mechanical systems are used to facilitate the air movement, the level of ventilation is dependent on exterior climate and the temperature of the air in the cavity.

Double Façade Systems Ventilation Types	Cavity Partition Types
– Natural – Mechanical	– Ventilated window – Ventilated façade

Cavity Ventilation Types	
Outdoor air curtain	In this ventilation mode, the air introduced into the cavity comes from the outside and is immediately rejected towards the outside. The ventilation of the cavity therefore forms an air curtain enveloping the outside facade.
Indoor air curtain	The air comes from the inside of the room and is returned to the inside of the room or via the ventilation system. The ventilation of the cavity therefore forms an air curtain enveloping the indoor facade.
Air supply	The ventilation of the facade is created with outdoor air. This air is then brought to the inside of the room or into the ventilation system. The ventilation of the facade thus makes it possible to supply the building with air.
Air exhaust	The air comes from the inside of the room and is evacuated towards the outside. The ventilation of the facade thus makes it possible to evacuate the air from the building.
Buffer zone	This ventilation mode is distinctive inasmuch as each of the skins of the double facade is made airtight. The cavity thus forms a buffer zone between the inside and the outside, with no ventilation of the cavity being possible.

Table 2.8: Proposed clasification of double façades.
Source: Ventilated Double Facades and AP2BEER Project

The double façade is based on the notion of exterior walls that respond dynamically to varying ambient conditions, and that can incorporate a range of integrated sun-shading, natural ventilation, and thermal insulation devices or strategies. The next table shows the advantages and disadvantages or these systems.

Disadvantages	Advantages
– Higher construction cost than the single façade. – Higher maintenance, cleaning, inspection, operating and servicing cost than the single façade. – Fire protection. Transmission of smoke from room to room is possible. – Reduction of rentable office space. Depth of the facade varies from 200 mm to several meters what depends on the used system. – Overheating problems in case of bad design. According to the literature solutions are to design minimum 200 mm and appropriate size of ventilation opening. – Increased air velocity between the layers and pressure differences. – Increased weight of the structure comparing to the single façade. – Reduction of light entering the rooms comparing to the single façade. – Acoustic problems in case of bad design.	– Lower construction cost than the electro-chromic, thermo-chromic or PV panels. – Acoustic insulation protects the office buildings from outdoor source of noise like e.g. heavy traffic. – Thermal insulation is greater both during winter and summer due to the outer skin – During the winter if the intermediate space partially or completely is closed the heat loss in smaller than in single skin. – During the summer it is possible to extract the air from the cavity by natural or mechanical ventilation. – Burglar proof. – Energy savings when properly designed on cooling. – Minimizes solar loading. – Protection of shading and lighting devices which are placed on the inner side of outer layer. – The glazed spade can be used as a fire escape. – Low U-value and g-value.

Table 2.9: Advantages and dissadvantages of double façades.
Source: AP2BEER Project

Ventilated façades

A ventilated façade is a double skin façade made up of two layers separated by an air gap. The layers can be opaque or transparent. Ventilated façades are thinner than double façades, ventilation is gained by natural convention, on what is known as stack effect, and no air intake from the chamber is used to condition the interior space of the building. Only exception to this rule are those called Unglazed Transpired Collector which are later described among other renewable energy solar technologies.

A ventilated façade system is composed by four main elements: (i) anchoring system, (ii) substructure, (iii) fixing element, and (iv) finishing cladding.

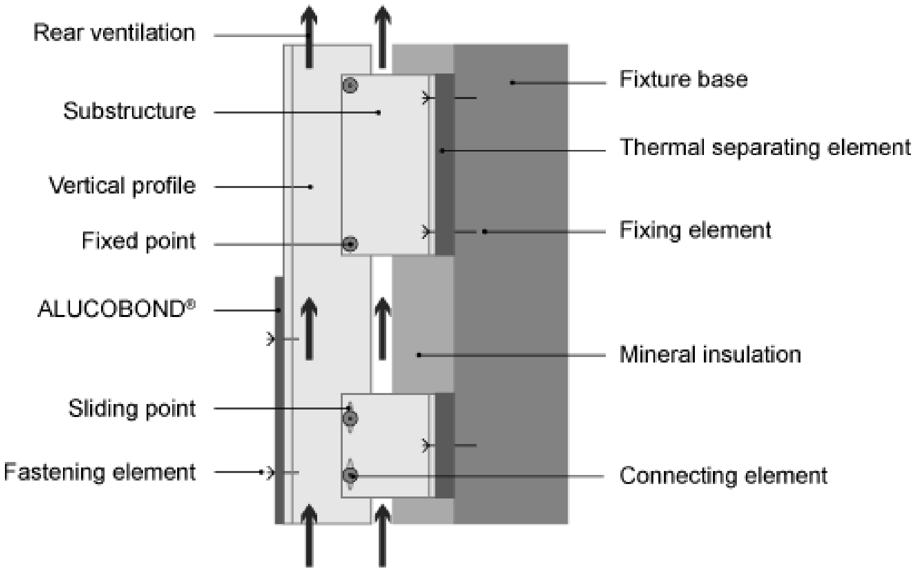


Figure 2.17: Example of ventilated façade.
Source: ALUCOBOND and AP2BEER Project

Thermal insulation normally mineral insulation is usually applied, combining the benefits of ETICS and the effect of the ventilated air chamber. Main benefits are improved thermal and acoustic insulation, elimination of thermal bridges, improved water proofing and fire protection.

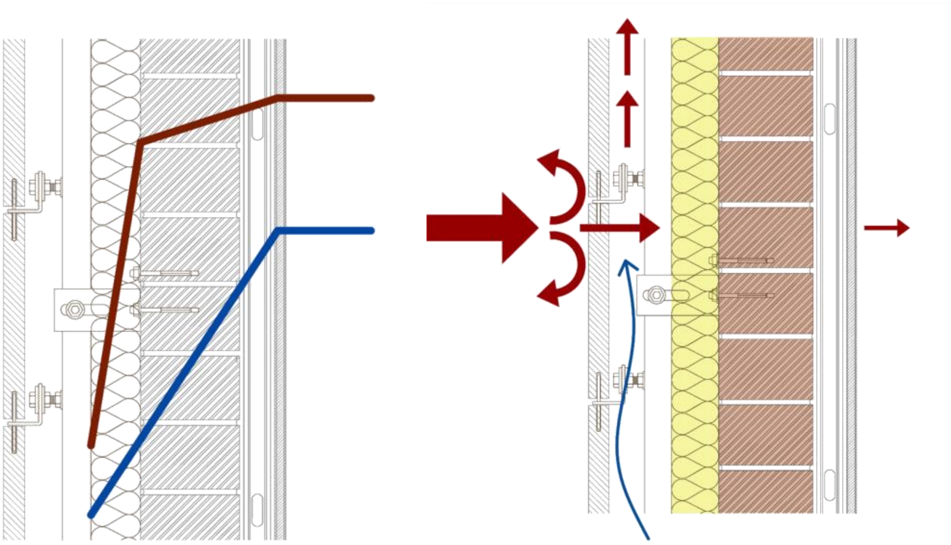


Figure 2.18: Ventilated façade benefits
Glaser diagram (red- saturation pressures and blue curve for partial pressures). Capability to reject extra heat during the summer, due to the stack effect. Source: AP2BEER

This is a state of the art technology with lots of commercial product possibilities, offering a wide range of finishing materials: ceramics, metal, natural or artificial stone and various composite systems. Cost depend mainly on the selected cladding, from approx. 130 €/m^2 for metal, from 110-210 €/m^2 for ceramics, 160-180 €/m^2 for stone and 140-220 €/m^2 for composites.

Best suitable climates are those with cold winters and hot summers, from an energy point of view. Its application is wide extended in countries like the UK due to its water tightness. Energy savings are climate dependent, and vary significantly depending on the existing wall the thickness of both the insulation and the cavity. On our particular experience for Spanish climate the reduction of HVAC demand gained through application of ventilated façades is usually around 15% mainly due to the reduction of air conditioning demand.

Roofs and lofts

There are three main types of roof and loft insulation: quilts (mineral wool and natural wool); blown insulation (mineral wool and cellulose); and boards (expanded/extruded polystyrene).

Loft insulation blankets

Loft insulation blankets Loft insulation blankets, often referred to as quilts are made from glass or rock fibre, some of which will have been recycled. Mineral wool is the most common form, and natural wool is another, which is very environmentally friendly. Basically, the deeper the insulation is in the loft, the less heat will be lost through the roof and the bigger CO_2 and financial savings can be made. Installing 270 mm of insulation in a loft compared with no insulation will save around a tonne of CO_2 per year. Typically, quilts are laid down between the joists and reach the top of the joist. Typically, this will make the insulation around 100 mm to 150 mm deep. More layers should then be added at right angles, to close up any gaps between the joist and the quilt, and to bring the depth to the required value.

Figure 2.19: Loft insulation with mineral wool blankets
Source: www.webstersinsulation.com

Timber floors can be insulated by lifting the floorboards and laying mineral wool insulation supported by netting between the joists. It is advised not to block under-floor airbricks in the outside walls, since floorboards will rot without adequate ventilation.

Blown in insulation

Another type of loft insulation is blow in insulation using special equipment which blows loose, fire-retardant insulation material into the specific, sectioned-off area of the loft to the required depth. It is blown mineral wool or cellulose fibre, which can be made from newspapers.

Figure 2.20: Loft blown in insulation
Source: www.webstersinsulation.com

Rigid insulation boards

If the plan is to convert the space into a living area, then instead of laying insulation between the joists, it is possible to fit rigid insulation boards between the rafters. Rigid insulation boards are made of expanded or extruded polystyrene. Expanded polystyrene (EPS) is polystyrene that's been expanded into foam. Extruded polystyrene (XPS) is similar but a better insulator. If deeper insulation is needed, insulated plasterboards can also be fitted onto the rafters, although this will make the loft space a little smaller.

Figure 2.21: Roof insulation with rigid boards
Source: www.webstersinsulation.com

Ground floors and basements

Heat loss from uninsulated basements may represent up to 50% of a building's total heat loss compared to well-insulated building. Ground floor insulation is used primarily to reduce heating costs and has little or no benefit in lowering cooling costs. It also reduces the potential for condensation and corresponding growth of mould.

Ground floor types are either: full basement, slab-on-ground, or crawlspace. Deep frost lines and low water tables often make a full basement the primary foundation of choice. However, slab-on-ground construction is also common, and home additions often have crawlspace foundations:

- For full basements the basement wall can be insulated either on the internal or external side. Interior insulation can use conventional framing with batt or wet-spray insulation. Rigid foam is also used on basement interiors. Extruded or expanded polystyrene or polyisocyanurate insulation boards can also be used. Fire codes usually require most of these interior insulations to be covered with drywall. Exterior insulation typically uses extruded or expanded polystyrene directly on the exterior of basement walls. Insulation exposed above-grade must be covered to protect it from physical abuse and the damaging effects of the sun.
- In crawlspaces the walls are just short basement walls. Exterior foam and foam-form insulation systems can be used. However, interior crawlspace wall insulation is usually either foam board or draped insulation. If crawlspaces are insulated with fibreglass or mineral wool batts, the batts are usually tacked to the sill plate and draped down and onto the floor. Somewhere a ventilated crawlspace is required to help control moisture; however it is significantly reduced if the floor of the crawlspace is covered with plastic sheeting. The floor over the crawlspace can also be insulated. This raises the thermal envelope from the crawlspace walls to the floor. While this technique offers many advantages, piping must be freeze-proofed, and heating and cooling ducts must also be insulated. In case of slab-on-ground heat loss is greatest at or near the exterior grade. To reduce heating costs and reduce the cold-floor syndrome common to slab-on-ground construction, insulation is critical. Exterior foam insulation works well. Insulation should extend from the top of the slab to the top of the footing. Foam insulation inside the footing is also common.

Innovative thermal insulations

Transparent thermal insulations

Transparent thermal insulation relies on compensating heat loss with solar gains and, in addition, to use these gains for space heating. Transparent thermal insulation materials (versus opaque thermal insulation materials), feature two properties that are highly important with a view to the energy balance of a building:

- Highly efficient thermal insulation (i.e. low values for the thermal conductivity [λ])
- High transmittance for solar radiation (i.e. high values for the total solar energy transmission coefficient [g])

Transparent thermal insulation materials usually consist of translucent plastics, such as polycarbonates (PC) or polymethyl-methacrylate (PMMA), with either tubular or honeycomb structure perpendicular to the wall surface.

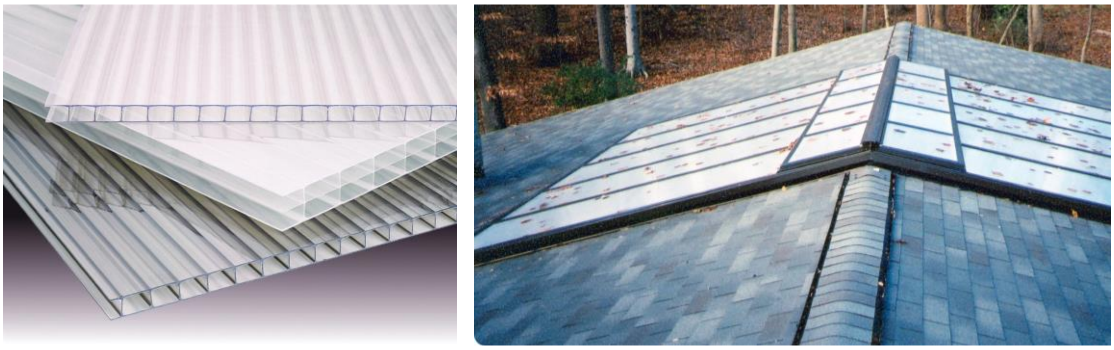


Figure 2.22: Polycarbonate roofing panels and windows
Source: www.solarinnovations.com

Vacuum insulated panels

A vacuum insulated panel consist of a nearly gas-tight enclosure surrounding a rigid core, from which the air has been evacuated. A vacuum insulated panel uses the insulating effects of a vacuum to produce much higher thermal resistance than conventional insulation since there is no heat convection in vacuum.

The thickness of vacuum insulated panel ranges from 1 to 5 cm and the panels have a size of maximum 60 x 100 cm. The most efficient core material is a compressed board made from pyrogenic silica powder. The fill material is surrounded by a gas-tight enclosure. The role of this enclosure is not only to hold the vacuum but it also helps to integrate the panel into the building structure. The enclosures are multi-foil systems from which the aluminium-foil systems are the most suitable for the construction industry.

The manufactured panels with an average internal pressure of 5 mbar have a thermal conductivity of between λ = 0.008 to 0.005 W/mK, depending on the materials used. This value is 5 - 8 times lower than the thermal conductivity of conventional thermal insulations.

The most typical fields of application of vacuum panels are building retrofitting and parapet glazing of curtain walls where only small place is available for the thermal insulation. It is also used where extremely good thermal insulation is required, for example for passive houses.

In addition to the low thermal conductivity, this innovative structure has some other features as well which make them different from other conventional structures, such as: high sensitivity against mechanical damage, strict prefabrication and dimension-coordination rules, more important role and effect of thermal bridges regarding the thermal insulation of the complete structure. These features require different thinking from the designer, from the constructor and even from the user.

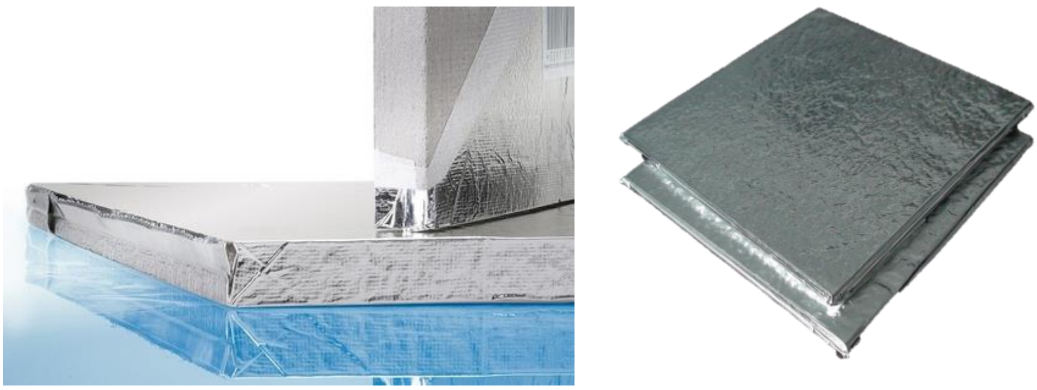


Figure 2.23: Vacuum insulation panels
Source: www.vip-bau.de

2.3.1.2. Translucent envelope elements (glazed areas)

Windows and other glazed external surfaces have a major impact on the energy efficiency of the building envelope. Windows also provide natural daylight, ventilation, noise control, security and allow views connecting interior and outdoor spaces. Glass is a good conductor of heat and also allows radiant heat to pass through freely. Energy from radiation can move into a window in the day time and out of the same window at night.

Heat loss and gain in a well-insulated home occurs mostly through the windows. In summer, the glass in direct sun can allow significant thermal energy in. Solar heat gain through windows can be reduced by insulated glazing, shading, and orientation. Solar heat gain can be significant even on cold clear days, however in winter, losses from a window can be ten or more times the losses through the same area of insulated wall. With good passive design windows can trap warmth in winter and repel summer heat. They admit cooling breezes and exclude cold winter winds. Convective heat transfer through and around window coverings also degrade its insulation properties.

- **Tinted or "toned" glass** is the most common type of absorbent glass. Toned glass acts like sunglasses to reduce the solar radiation entering into the building home, which helps to keep it cool in summer. "Supertoned" glass reduces the transmission of ultraviolet rays which, when combined with heat, are a major cause of fading of furnishings. As a special case, the transparent solar glass modules consist of transparent crystalline photovoltaic cells, or thin film transparent amorphous Si PV. In this case the absorbed light generates electricity.
- **Spectrally selective glazing** is commonly used for cooling climates or for westerly elevations where solar control and natural lighting are a priority. Spectrally selective glazing maximises light transmission while simultaneously reflecting unwanted solar radiation (UV and near infrared). Spectrally selective coatings can also have low emissivity.
- **Reflective glass** has either a vacuum-deposited metal coating or a pyrolytic coating. Vacuum-deposited coatings are soft and must be glazed facing indoors. Pyrolytic coatings are hard and durable and can be glazed facing outdoors.
- **Low emissivity (low-e) glass** has a coating that allows short wavelength energy (daylight) from the sun to pass into the house but reduces the amount of the long wavelength energy (infrared heat) that can escape through the window.
- **Polymers** are used instead of glass in some applications, such as translucent glazing and skylights. Plastic glazing may also be included in composite laminates to improve impact resistance or within double glazing to improve insulation.

All properties lose heat through their windows. Installing energy efficient glazing is an effective way of reducing energy consumption and keeping the building warmer and quieter, and it reduces condensation build-up on the inside of windows. Double glazed windows use two sheets of glass with a gap between them which creates an insulating barrier, whilst triple glazed windows have three sheets of glass. Energy efficient windows are available in a variety of frame materials and styles, and they also vary in their energy efficiency, depending on how well they stop heat from passing through the window, how much sunlight travels through the glass and how little air can leak in or out around the window.

- **Insulated Glass Units (IGUs)** are manufactured with glass in range of thickness from 3 mm to 10 mm or more in special applications. Laminated or tempered glass may also be used as part of the construction. The most energy efficient glass for double glazing is low emissivity (Low-E) glass. This often has an unnoticeable coating of metal oxide, normally on one of the internal panes - next to the gap. It lets sunlight and heat in but cuts the amount of heat that can get out again.

All double glazed windows have pane spacers set around the inside edges to keep the two panes of glass apart. In a more efficient window, the pane spacers contain little or no metal. The maximum insulating efficiency of a standard IGU is determined by the thickness of the space containing the gas or vacuum. Too little space between the panes of glass results in conductive heat loss between the panes (the inside surface of one pane cools the surface of the other pane) while a too wide gap results in convection current losses (gas begins to circulate because of the temperature differences and transfers heat between the panes). Double glazing has a gap of around 12-19 mm.

A practical alternative is to replace the air in the space with a heavy gas that is more viscous than oxygen and nitrogen. Higher viscosity reduces convective heat transfer, as well as reducing the heat capacity portion coming from rotational degrees of freedom. Argon (argon has a thermal conductivity 67% lower than air), krypton (krypton has about half the conductivity of argon) or xenon is used to increase the insulating performance. In general, the more effective a fill gas is at its optimum thickness, the thinner the optimum thickness is.

Regarding IGU frames the uPVC frames are the most common type. They last a long time and can be recycled. Wooden frames can have a lower environmental impact, but require maintenance. Aluminium or steel frames are slim and long-lasting, and they can be recycled, but aluminium is a good conductor of heat and can decrease the insulating value of a window by 20 to 30 percent. Fibre-reinforced polyester (FRP) frames are the most thermally efficient framing materials available. Composite frames have an inner timber frame covered with aluminium or plastic. This reduces the need for maintenance and keeps the frame weatherproof. They insulate about twice as well as standard aluminium frames but they are more expensive. IGU thickness is a compromise between maximizing insulating value and the ability of the framing system used to carry the unit. Issues arise with the use of triple glazing. The combination of thickness and weight results in units those are too unwieldy for most residential or commercial glazing systems.

Thanks to its replacement windows will be more airtight than the original single glazed frames but condensation can appear in the building due to the reduced ventilation. If there is not a sufficient level of background ventilation in the room some replacement windows will have trickle vents incorporated into the frame that let in a small amount of controlled ventilation. Condensation can sometimes occur on the outside of new low-e glazing. This is because low-e glass reflects heat back into the building and as a result the outside pane remains cool and condensation can build up in cold weather.

A standard IGU consisting of clear uncoated panes of glass with air in the cavity has a typical U-value of 2.90 W/m^{2}K. Adding argon gas decreases the value to about 1.90 W/m^{2}K.. Using low emissivity coating on surface #2 will provide a typical U-value of 1.40 W/m^{2}K. Properly designed triple glazed IGUs with low emissivity coatings on surfaces #2 and #4 and filled with argon or krypton gas in the cavities result in IG units with U-values as low as 0.80-1.10 W/m^{2}K..

Large air spaces also improve the noise insulation quality or sound transmission class. Asymmetric double glazing, using different thicknesses of glass rather than the conventional symmetrical systems will improve the acoustic attenuation properties of the IGU at the cost of longevity if the unit is used to separate exterior and interior environments. If standard air spaces are used, sulphur hexafluoride is used to replace or augment an inert gas and improve acoustical attenuation performance. The most widely used glazing configurations for sound dampening include laminated glass with varied thickness of the interlayer and thickness of the glass. Including a structural, thermally improved aluminium thermal barrier air spacer in the insulating glass can improve acoustical performance by reducing the transmission of exterior noise sources in the fenestration system.

Secondary glazing works by fitting a secondary pane of glass and frame, inside the existing window reveal. This is likely to be less effective than replacement windows. The units tend to be not as well sealed, however it is considerably cheaper than double glazing. Curtains lined with a layer of heavy material can further reduce heat loss from a room through the window at night and cut draughts.

Some example of how this combination of possibilities works within heat and light transmission is shown in the next figures:

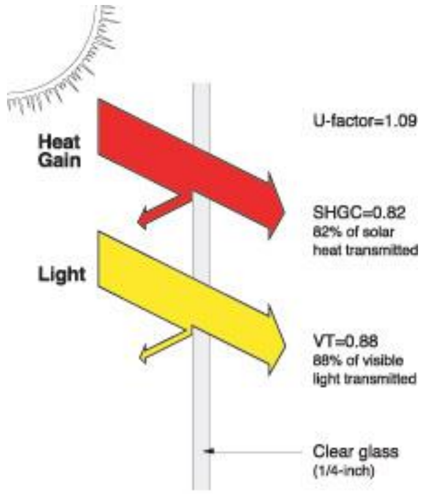


Figure 2.24: Clear Single glazing

The figure illustrates the performance of single glazing with clear glass. Relative to all other glazing options, clear single glazing allows the highest transfer of solar energy while permitting the highest daylight transmission.

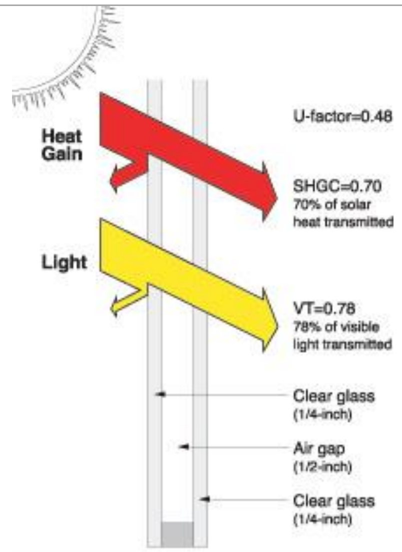


Figure 2.25: Clear double glazing

The figure illustrates the performance of a typical double-glazed unit with two panes of clear glass. The inner and outer panes of glass are both clear, and they are separated by an air gap. Double glazing reduces heat loss (as reflected by the U-factor) by more than 50 percent in comparison to single glazing.

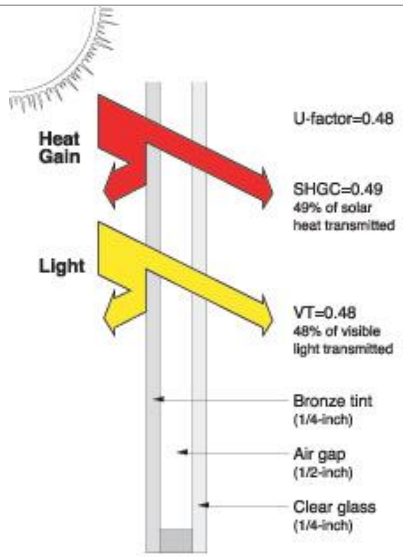


Figure 2.26: Double glazing with bronze-tinted glass on the outside layer

Traditional tinted glazing, bronze and gray, often force a trade-off between visible light and solar gain. There is a greater reduction in visible transmittance than in solar heat gain coefficient.

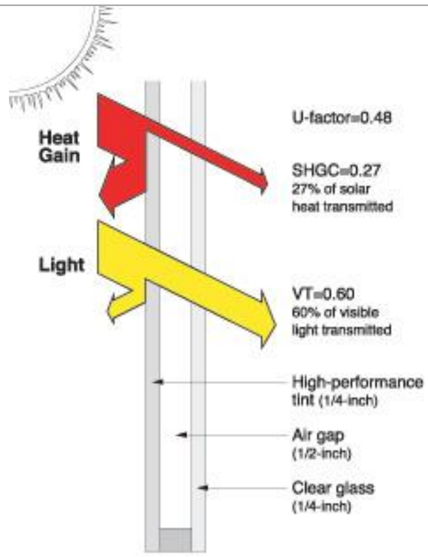


Figure 2.27: Double glazing with high-performance tint on the outside layer

To address the problem of reducing daylight with traditional tinted glazing, glass manufacturers have developed high-performance tinted glass that is sometimes referred to as spectrally selective.

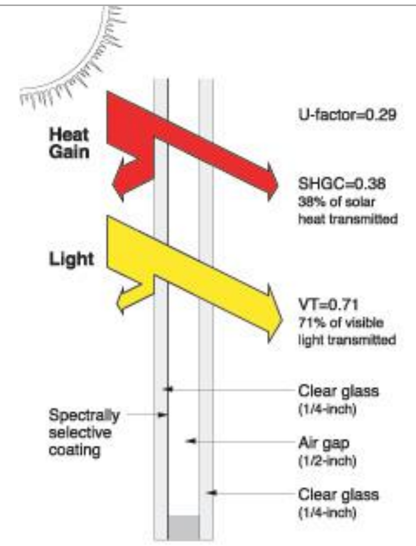


Figure 2.28: Double glazing with clear glass and low-solar-gain low-E coating

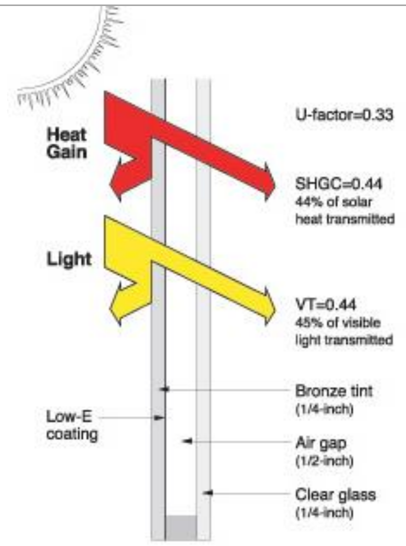


Figure 2.29: Double glazing with bronze tinted glass and low-solar-gain low-E coating

A glazing designed to minimize summer heat gains, but allow for some daylighting, would allow most visible light through.

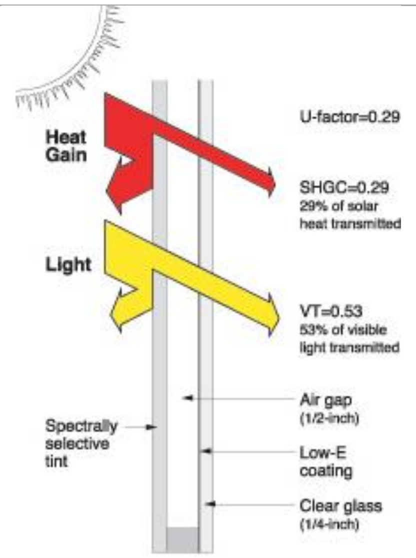


Figure 2.30: Double glazing with low-solar-gain low-E coating on spectrally selective tinted glass

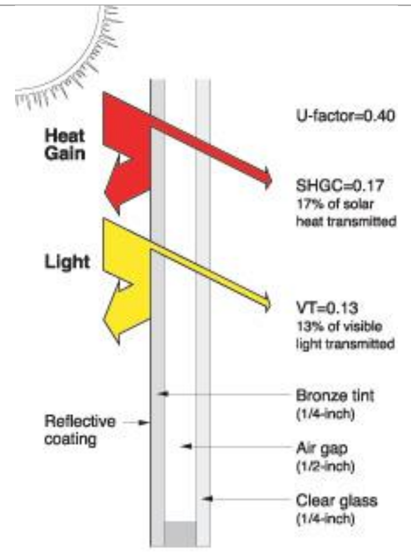


Figure 2.31: Double glazing with bronze tint and highly reflective coating

The same coating on spectrally selective tinted glass. Low-E coatings can be formulated to have a broad range of solar control characteristics while maintaining a low U-factor.

The figure illustrates a highly reflective coating placed over a bronze-tinted, double-glazed unit. The emittance of the coating creates modest changes in the U-factor.

Depending on the climate, the glazed areas should be treated in a different way:

- **Heating (or alpine and cool temperate) climates** are colder climates where most energy is used to heat the home. South facing glazing is ideal for these climates. It is desirable to maximise south facing glazing with solar exposure (especially in living areas). High g-value glazing can be used to maximise solar gains in winter. Summer heat gain can then be controlled with adjustable external shading. Winter heat loss can be reduced using insulating glass and frames, and also with internal insulating treatments such as snug fitting insulating drapes with sealed pelmets or insulating blinds. East and west-facing windows will contribute to overheating in summer if not well shaded. An ideal solution is to use smaller insulating glass units on east and west facades to reduce heat loss in winter. Large areas of north facing glass will allow heat loss but do not allow compensating solar heat gain and should be avoided. Moderate north facing glass areas are required for cross ventilation and daylighting.
- **Cooling (or tropical, subtropical and hot arid) climates** are warmer climates where most energy is used to cool the home. The window's role in a cooling climate is to reduce the amount of heat entering the building without reducing natural light to the extent that artificial lighting is required inside. Low g-value windows are designed to block the sun's heat and are appropriate in cooling climates. Low U-value windows keep hot outside air from entering the house, and are particularly important if the house is air-conditioned. It is advised to use solar control (tinted) glazing to reduce solar heat gain. Tinted windows reflect some heat and absorb some heat, which is then radiated both inwards and outwards. By means of convection, most of the heat gets outside, and windows transmits the rest. In cooling climates, heat radiated inwards can reduce thermal comfort near the window. A double glazed unit provides better performance in a cooling climate because the inner pane blocks some of the heat radiated inward by the outer pane. The best performance is obtained by using a low-emissivity (low-e) glass for the inner pane. Double-glazing also gives a low U-value, reducing infiltration of warm air from outside. However external shading should always be the first solution considered. Advanced glazing options can provide effective solutions on difficult sites where other shading options are not possible.
- **Mixed (or temperate) climates** use energy for heating in winter and cooling in summer. The goal in these climates is to keep heat in during winter and out during summer. During winter, a low U-value and a high g-value are ideal to capture useful solar energy and reduce heat loss. During summer, good solar control and/or shading are required. Good design dictates that windows with good heating performance should be used on the south and north elevations and good cooling performance on the east and west elevations.

For heating energy reduction performance in temperate climates the windows are double glazed insulating units, with either clear glass or low-e glass. With a large number of windows and wide sliding doors, natural light floods the interior of the building. The use of double-glazing provides a benefit in summer by reducing the flow of warm air towards the cooler interior. Correctly sized eaves or other shading should be used to protect south-facing windows. This provides protection from summer heat and glare while still allowing sun penetration in winter.

For cooling energy reduction performance in temperate climates the windows are double glazed for insulation purposes but use adjustably shaded solar control glass to reduce the solar heat gain in summer. The double-glazing reduces conducted heat from high external temperatures entering the cooler interior. The solar control properties of the outer pane of glass reduce some of the unwanted radiated heat gain, especially for westerly orientations. If the toned glass windows have a light transmission of about 60 percent, it does not lead to an increased need for artificial lighting. To eliminate all summer heat gain by solar radiation, the windows would need to be shaded externally. The uPVC window frames do not condense on the inside even in the coldest weather, making them ideal for bathrooms. uPVC frames with double-glazing insulate the unit from the elements and the surrounding wall ensuring that minimal heat, cold, vibration and noise is transferred.

The following table shows several different glazing types and their properties:

Type	Glass composition	U-value [W/m²K]	L.T.	g[2]	Climate orientation	Cost [€/m²]
Double glazing (air filled)	4/16/4	2.7	81	77	Temperate climate	25.00
Double glazing (argon filled)	4/16 argon /4	2.6	81	77	Temperate climate	27.00
Double glazing, Low E Glass (air filled)	4/16/4 low-E	1.4	78	60	Temperate climate	29.00
Double glazing, Low E glass (argon filled)	4/16 argon /4 low-E	1.1	78	60	Temperate climate	32.00
Double glazing, Solar control	6 stopsol/16AR/4 low-E	1.1	36	26	Mediterranean climate	70.00
Triple glazing (air filled)	4/16/4/16/4	1.8	74	70	cold climate	45.00
Triple glazing (argon filled)	4/16argon/4/16argon/4	1.7	74	70	Harsh climate	47.00
Triple glazing, Low E Glass (air filled)	4/16/4/16/4 low-E	1.0	64	47	Harsh climate	51.00

[2] Solar energy transmission coefficient

Type	Glass composition	U-value [W/m^2K]	L.T.	g^2	Climate orientation	Cost [€/m^2]
Triple glazing, Low E glass (argon filled)	4/16 argon/4/16 argon /4 low-E	0.8	64	47	Harsh climate	54.00
Triple glazing, Solar control (air filled)	6 stopsol +16+4+16 + 4 low-E	1.0	30	21	Mediterranean climate	90.00
Triple glazing, Solar control (argon filled)	6 stopsol +16 argon +4+16 argon + 4 low E	0.8	30	21	Mediterranean climate	95.00
Electrochromic and thermochromic glazing (air filled)	6 magnetronic +16+33.1 low-E	1.3	25	17	Mediterranean climate or business buildings	75.00
Electrochromic and thermochromic glazing (argon filled)	6 magnetronic +16+33.1 low-E	1.0	25	17	Mediterranean climate or business buildings	78.00

Table 2.10: Glazing types and properties
Source: AP2BEER Project

The next transparent envelope elements are analysed in this section:

- Shading
- Double skin glazed facades
- Box window façade
- Connected windows
- Corridor facade
- Connected windows with multi-storey shafts
- Innovative glazing systems

Shading

Exterior

The most effective solar shading devices are external to the building envelope. Shades and blinds located inside the building may be effective at controlling glare, but are not effective in reducing the solar gain entering the space. Solar shading is most easily and effectively handled on south and north elevations.

East and west facing windows are the most difficult to shade. A well-conceived shading device must be able to maximize heat gains in winter conditions and to control the radiant heat in summer conditions, as well as to improve visual and acoustic comfort of the interior.

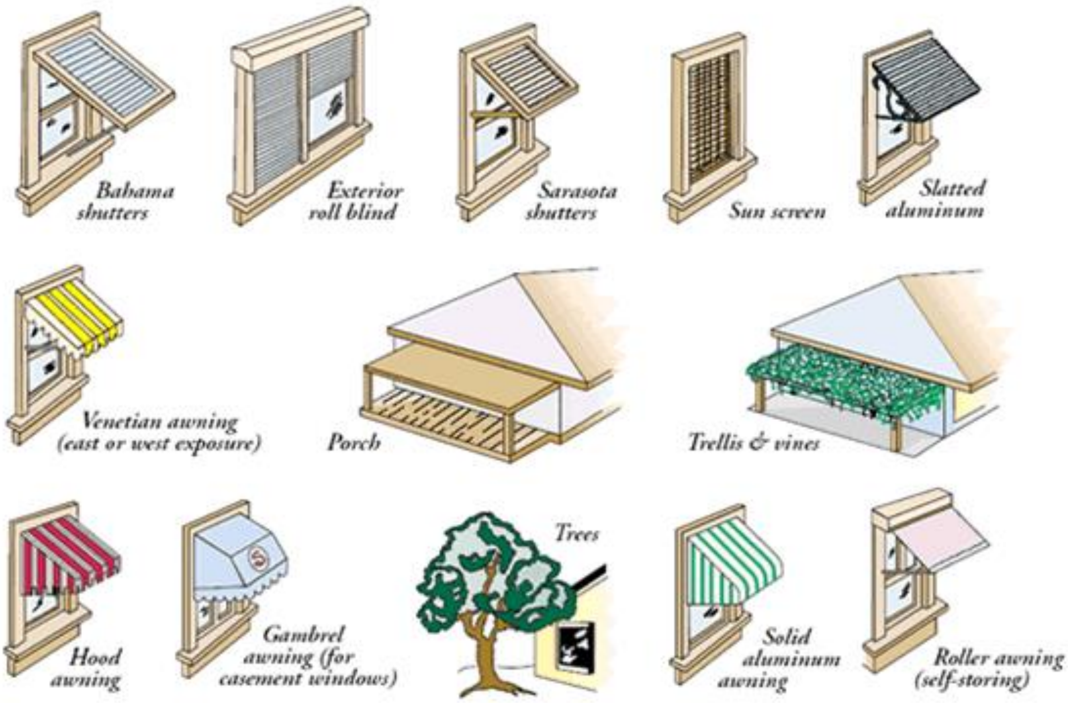


Figure 2.32: Some examples of traditional exterior shading systems.
Source: http://www.fsec.ucf.edu/

Solar screens, also known as solar shades, are usually made from mesh or polymer and are shades that cover the entire surface area of a window. They absorb and reflect the sun's rays instead of letting them penetrate the window, and provide an energy-saving blanket for all seasons. Screen materials include: PVC-coated polyester, PVC-coated fiberglass, and metallized PVC-coated fiberglass

Roll-down blinds provide solar protection and they give pleasant lighting inside as well as visibility to the outside. The fabric is made of polyester fabrics. They characterize by their high durability for the external conditions and deformation of the structure.

Shutters exist in three forms: roller shutters, swing shutters beside the window and fixed shutters. There are three ways of assembling rolling shutters: on the building elevation, near the window left oriented sheeting or right oriented sheeting. The sheeting rolls into the box in case of rolling shutters while the swing and fixed shutters stay all the time visible.

Louvers in a vertical or horizontal configuration can be made of different material like aluminium, textile or glass fins.

Awning is a canvas stretched on a fixed or moveable frame like in a sunshade idea.

Shading devices can be divided into:

- **Fixed Shading** are commonly constituted by a shield of linear panels or slats, mounted in parallel on a fixed or adjustable frame, to form a pattern to intercept the solar radiation. Sunscreens are installed in front of the window with pre-oriented blinds or blades, creating a kind of outer curtain. Generally, the blades are geared according to the sun incidence of the hottest period of the year.

- **Mobile Shading** protects the building from solar radiation, by modifying the blinds or blades angle, allows optimising the amount of natural light. The devices that rely on blinds are installed horizontally to the façade, while those with blades can have a vertical application too. Vertical blades are smaller in size and can rotate. The rotation of the blades allows to shield the radiation and to reflect it into the enclosure by adjusting the flow. This system, usually of significant dimensions, is lacking of the capability to eliminate all the shield obstruction, when not required, since the blades attached to their pivot are not packable. Shadings with horizontal blades have larger dimensions (to resist against the wind). These devices come with various section profiles (the most common is ellipsoidal), with large intersection, and can be automated by light sensors which allow a continuous variation according to the daily sun path.

The shading devices are considered important design parameters in hot climates, and must be carefully designed and oriented, maximizing shading during summer months to reduce solar heat gain, and allowing direct sun into the interiors during winter season to maximize solar heat gain. However, in hot climates the “winter” season generally could be a dry or wet season with warm temperatures. So, the over-heating period is extended, and the need of shading is also present.

Middle panel

Middle pane can provide shading by using glazing with electrochromic or thermochromic layers. The ventilation is provided by small openings in the window frame. In case without the ventilation the frame does not have openings.

One possible solution of combining the glazing with shielding systems derives from the existing Venetian blind systems, with smaller scale blinds to be placed in the cavity of the double glazing. This hybrid system provides a satisfactory level of solar radiation control and represents an efficient alternative to those previously described. The system ensures an adjustable filter to the entrance of sunlight: the amount of light can be adjusted from 80 % total obscuration and instantly adjusting the brightness depending on the demand. The blinds are mounted within two panes of glass, and their scrolling takes place in a sealed chamber. This feature ensures total protection against dust and weather. The solution presents durability and maintenance issues.

Integral venetian are integrated within the cavity of the permanently sealed double glazed units therefore requiring no cleaning and are protected from damage. Ensuring privacy when closed they can also be tilted to provide protection from the heat and the glare of the sun. Blinds units are specifically designed for use in double or triple glazed units.

The raising, lowering and tilting functions are achieved using a rotational magnetic transmission through the glass, guaranteeing the glazed units hermetic seal. Raising and lowering of integrated blinds is achieved with a continuous cord loop that drives the external magnet. The cord is held lightly under tension by a cord tensioner on the glass directly below the external magnet. Alternatively they can be electronically operated via solar control panel and rechargeable battery or mains with a switch or remote control.

Interior

Shades and blinds located inside the building may be effective at controlling glare, but are not effective in reducing the solar gain entering the space.

Shading inside can be provided by: roll-down blinds, vertical louvers/fins with or without ventilation through the frame openings.

Interior shading devices have limited solar control potential and they often depend on user control to function properly. More likely an occupant will set the shading device once and leave it in position for the remainder of the day. When using an interior shade, select a light-colour shade to minimize heat gain. To maintain an exterior view while shading the window, consider fine mesh roll screens that reduce illumination and glare while allowing contact with the view. Another option is to use screens or louvers that operate upward from the window sill. This provides shade near the bottom of the window where it is often first needed while allowing an effective clerestory for daylighting.

Mounting the shade below the top of this west-facing office window allows the occupant to close the blinds to control glare on the work surface while still permitting daylight to enter the space. This strategy also works well when controlling glare from extremely bright exterior surfaces, such as from a nearby parking lot. Light-coloured shades are preferred over the dark shades.

Double skin glazed facades

Double skin façade systems consist of two glass skins (single or double) placed in such a way that air can flow in the intermediate cavity. The distance between the skins usually varies from 0.2 m up to 2 m. For protection and heat extraction reasons solar shading devices are placed inside the cavity. The ventilation of the cavity can be natural, fan supported or mechanical; the origin and destination of the air can also vary depending on the location, the use and HVAC strategy of the building.

The main advantages of double skin façades compared with single skin facades are improved acoustic insulation, protection of shading devices and provision of natural ventilation in the internal spaces. However, energy reduction and provision of an improved indoor thermal environment can also be achieved, when these are designed and integrated properly. Due to the additional skin, a thermal buffer zone is formed which reduces the heat losses and enables passive solar gains. During the heating period, the solar preheated air can be introduced inside the building providing natural ventilation with a good indoor climate retained. Different configurations can result in different ways of using the façade, proving the flexibility of the system and its adaptability to different climates and locations.

Figure 2.33: Photograph of the interior of a double skin glazed façade.
Source: www.frenestrapro.com

One of the glass skins is usually double glazed with noble gas filling and low-emission coating and the other skin is usually single glazing. The position of the glazing is determined by the air flow. If external air flows in the cavity, the internal skin will be double glazed. On the other hand, if internal air flows in the cavity, the external skin will be double glazed. In some cases both skins are double glazed, mainly where high acoustic requirements have to be met.

The ventilation of the cavity can be natural (passive) or mechanical (active). In most cases hybrid systems are used where mechanical ventilation helps the air-flow during those periods when passive ventilation is not possible.

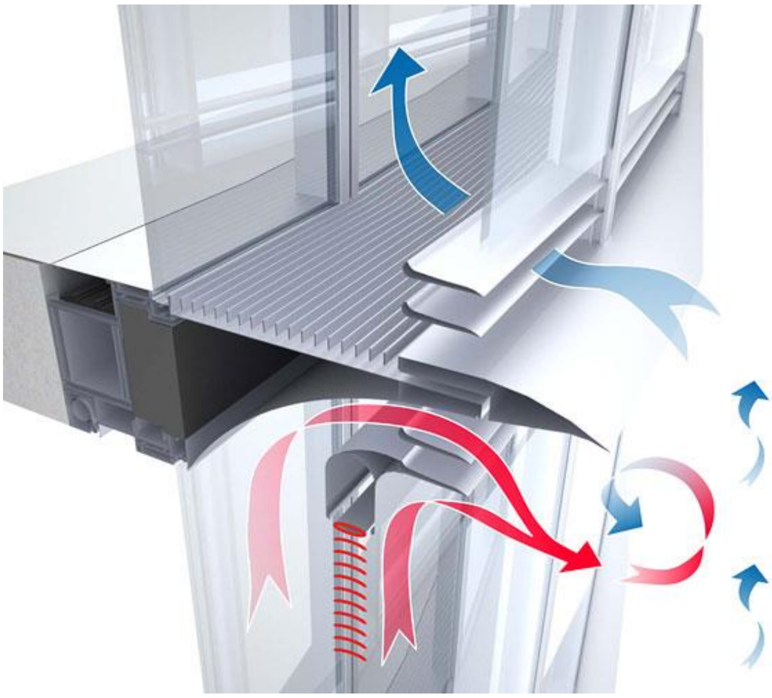


Figure 2.34: Ventilation flow in a double skin glazing façade.
Source: www.architectus.com.au

In winter the façade should be operated as a closed cavity or an internal air-curtain to increase the solar gain and reduce the heat loss due to transmission. To provide the air-change needed, using the pre-heated air from the cavity can significantly reduce the ventilation heat loss. In addition, the thermal comfort level in the interior next to the glazing will be improved due to the higher internal surface temperature.

In the summer months considerations should be taken to avoid overheating. The main goal at this time is the intensive ventilation of the building. For facades with natural ventilation, the stack effect should be increased as the higher the air-flow the more heat can be extracted. The cavity width should be greater than 40 cm and there should be a minimum temperature difference of 5°C between the external air and the air in the cavity to achieve sufficient air movement. The intensity of air flow also depends on the cavity height and it should also be considered that the air temperature is not too warm at the top of the cavity.

In addition to the air movement in the cavity, construction details also determine the operation of the façade. Basically there are two main alternatives: window-type and curtain wall-type installations. The ratio of the openings needed varies in different climates.

Box window façade

The box-window is the oldest form of double façade. It uses isolated cavity volume and outer skin for individual window units. It is mainly used for its higher acoustic performance. It also has some thermal advantages in the winter. Since the cavity height is limited, the risk of summer overheating is high so the ratio of the openings on the external skin should be as large as possible or mechanical ventilation is recommended.

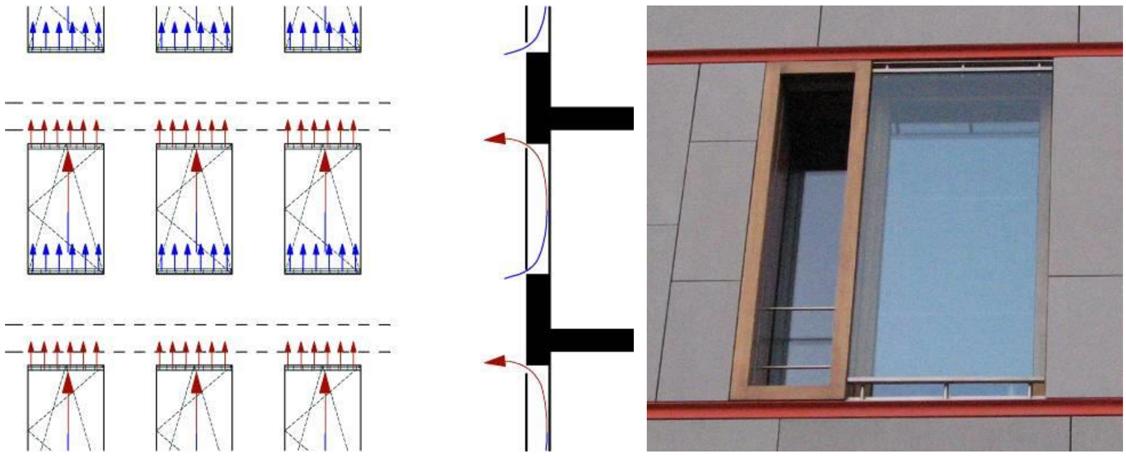


Figure 2.35: Box window façade
Source: EMI-ACC (PIME´s Project)

Connected windows

The cavity behind the external glass sheet is divided horizontally and vertically (at each level and each room). Natural ventilation in the cavity can occur in summer as well. It is a very good solution from acoustic point of view, sound transmittance between rooms is limited. When the ventilation inlet and outlet holes are made, it should be prevented that the fresh and used air are mixed.

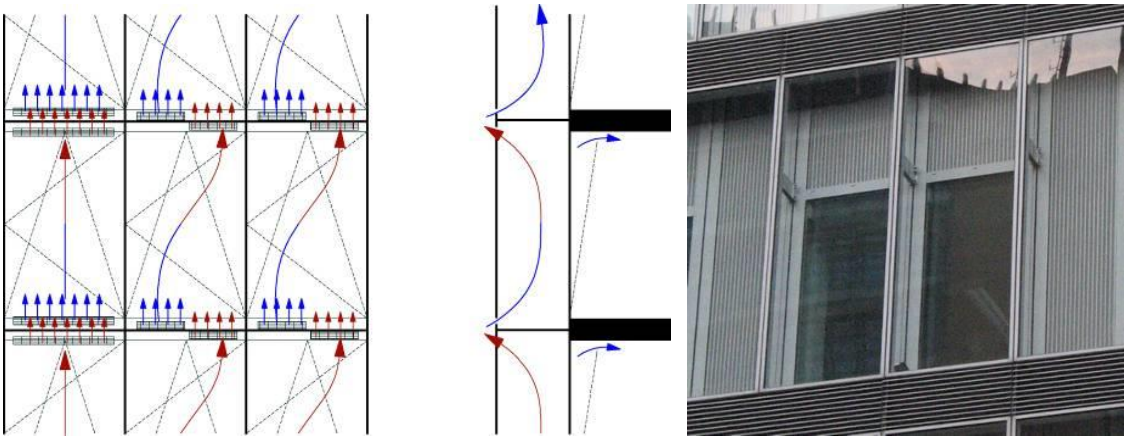


Figure 2.36: Connected window with straight and diagonal air-flow.
Source: EMI-ACC (PIME´s Project).

Corridor facade

The air cavity is divided horizontally at each floor level. There is no vertical separation in the cavity, so more intensive natural ventilation can occur using the advantage of the horizontally continuous cavity and wind conditions around the building. However, it is a weaker solution from acoustic point of view.

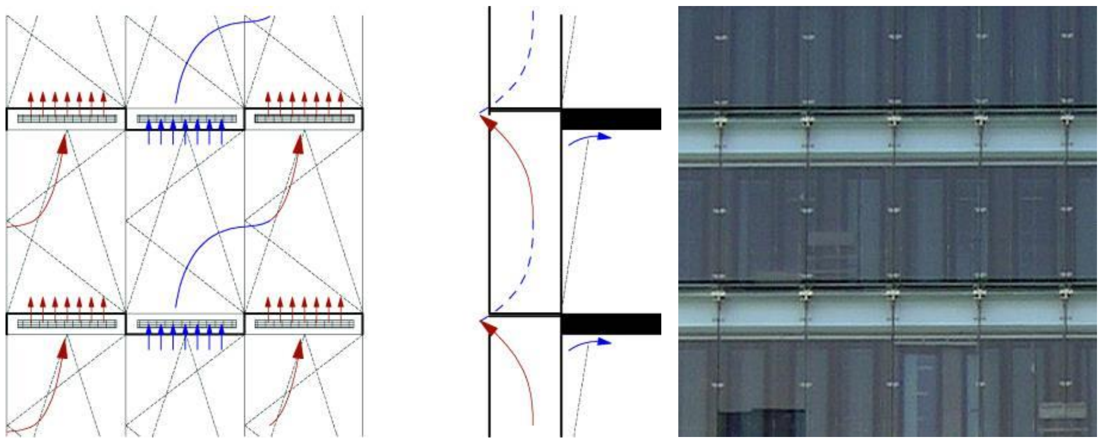


Figure 2.37: Corridor facade with diagonal air-flow.
Source: EMI-ACC (PIME´s Project)

Connected windows with multi-storey shafts

There are multi-storey vertical shafts between the connected window units in which more intensive natural ventilation can occur even when the whole building is not too high and has not too many floor levels. For higher buildings, the height of the vertically ventilated shaft must be limited due to overheating at the higher floor levels.

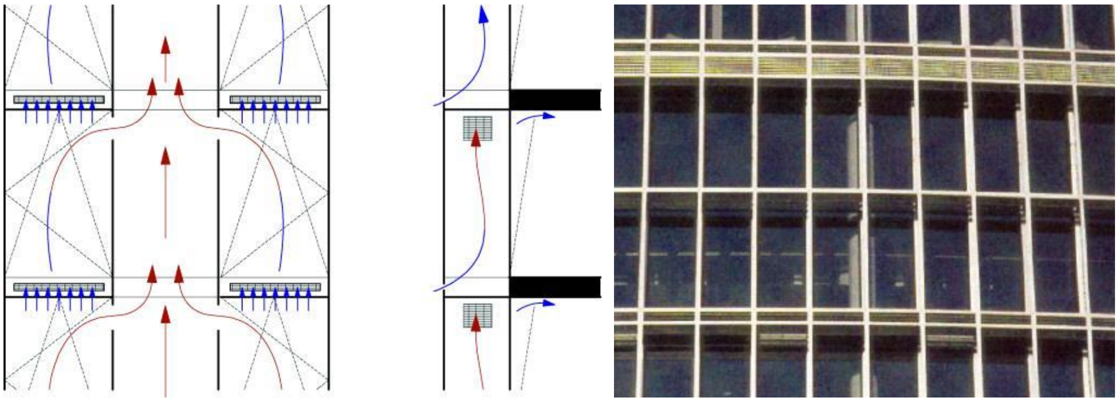


Figure 2.38: Multi-storey vertical shafts
Source: EMI-ACC (PIME´s Project)

Innovative glazing systems

Vacuum Insulated Glass

Vacuum glazing, similarly to vacuum insulated panels, is based on the theory that no convective heat transfer occurs in vacuum. The substance of this method is that the gas filling between the glazings is replaced by vacuum. The production of vacuum glass is quite difficult because a very low (0.001 to 0.0001 mbar) pressure should be achieved to reach the proper insulation ability. Spacer elements are placed to balance the enormous atmospheric pressure without inhibiting the opacity. Vacuum glasses can be recognized by these special items of spacers (1,000 pieces/m^2) and they have a very thin structure (only 7-9 mm) and low weight compared to traditional glasses.

The weak point of this structure is the glass sheet edge because proper air-tightness must be ensured on long therm. Metal sheets are used to close the edges but this solution creates significant thermal bridges. Promising experiments are currently conducted with plastic form to replace the metal parts.

Using this technology an U_g-value of 0.20 W/m^{2}K can be achieved in theory. However, due to manufacturing limits, an U_g-value of 0.50 W/m^{2}K can be achieved in practice for the time being, which is still a very good result.

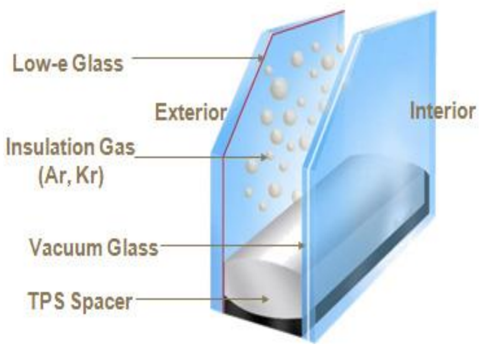


Figure 2.39: Vacuum insulated glass structure
Source: http://www.lghausys.com

GlassX glazing

A recently developed translucent glazing system is capable of storing the solar energy and radiates this energy to the interior when it is necessary. The integrated prismatic glass protects the room against overheating in summer. The special advantage of the glazing that it is a combination of transparent insulation, energy conversion, thermal storage and it can also be used as a protection against overheating.

Summer solar radiation is reflected by the air prism at the outer layer of the multi-layer insulated glass but the sun can pass through in winter time. The recommended glazing layers from outside to inside:

- Safety glass
- Cavity, noble gas filling, prism
- Safety glass, low-e coating
- Cavity, noble gas filling
- Safety glass, low-e coating
- PCM (phase change material) panels between the glass panes
- Safety glass

Different variations of the layers results in various thicknesses and U-values. A triple glazing construction can provide excellent thermal insulation with a U-value of less than 0,5 W/m2K.

A prismatic glass implemented in the space between the panes reflects sun rays with an angle of incidence of more than 40° (in summer, when the sun is high in the sky). On the other hand, the winter sun with an angle of incidence of less than 35° passes through the prism so that the solar energy can be utilized.

The other key element of GlassXCrystal glazing is a heat storage module that absorbs and stores the solar energy and, after a while, releases it again as pleasant radiant heat. PCM (Phase Change Material) in the form of a salt hydrate is used as the thermal storage medium. The heat is stored by melting the PCM, and the heat stored is released again when the PCM cools down. The salt hydrate is hermetically sealed in polycarbonate containers that are painted grey to improve the absorption efficiency. On the interior side, the element is sealed by 6 mm safety glass that can be printed with any ceramic silk-screen print.

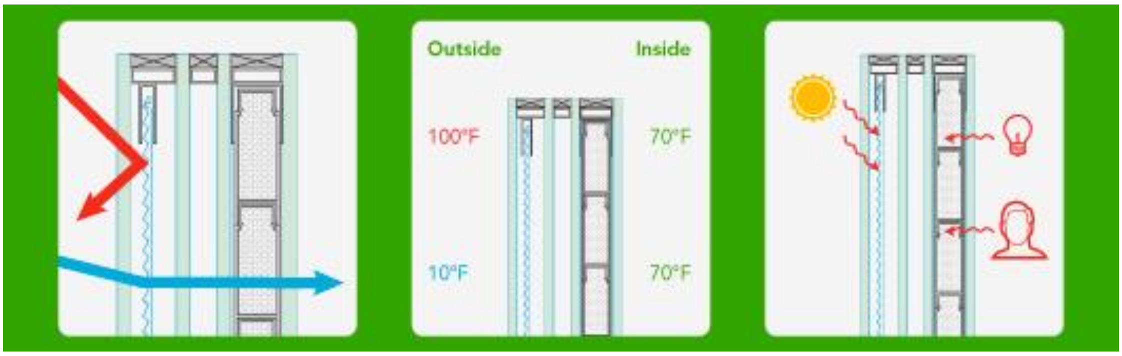


Figure 2.40: Images explaining how GlassX works
Source: www.glassxpcm.com

2.3.2 Characterization of building envelope solutions

Thermal bridges and air-tightness will be studied in detailed in D2.5. *Report on methodologies for natural processes based ventilation systems evaluation and implementation* and in D2.6 *Report on envelopment solutions characterization, diagnosis and optimization in terms of airtightness and thermal bridges*. In this deliverable, a general overview is provided.

2.3.2.1. Thermal bridges

A thermal bridge or cold bridge is a fundamental of heat transfer where a penetration of the insulation layer by a highly conductive or non-insulating material takes place in the separation between the interior (or conditioned space) and exterior environments of a building envelope. Thermal bridging is created when materials create a continuous path across a temperature difference, in which the heat flow is not interrupted by thermal insulation, allowing heat to flow through the path of least thermal resistance created, although nearby layers of material separated by airspace allow little heat transfer. Common building materials that are poor insulators include glass, concrete and metal. A common construction design is based on stud walls, in which thermal bridges are common in wood or steel studs and joists, which are typically fastened with metal. Notable areas that most commonly lack sufficient insulation are the corners of buildings, and areas where insulation has been removed or displaced to make room for system infrastructure, such as electrical boxes (outlets and light switches), plumbing, fire alarm equipment, etc. Concrete balconies that extend the floor slab through the building envelope are also a common example of thermal bridging. Some forms of insulation transfer heat more readily when wet, and can therefore also form a thermal bridge in this state. The larger the difference between the temperature inside and outside the building is, the faster the building gains or losses heat.

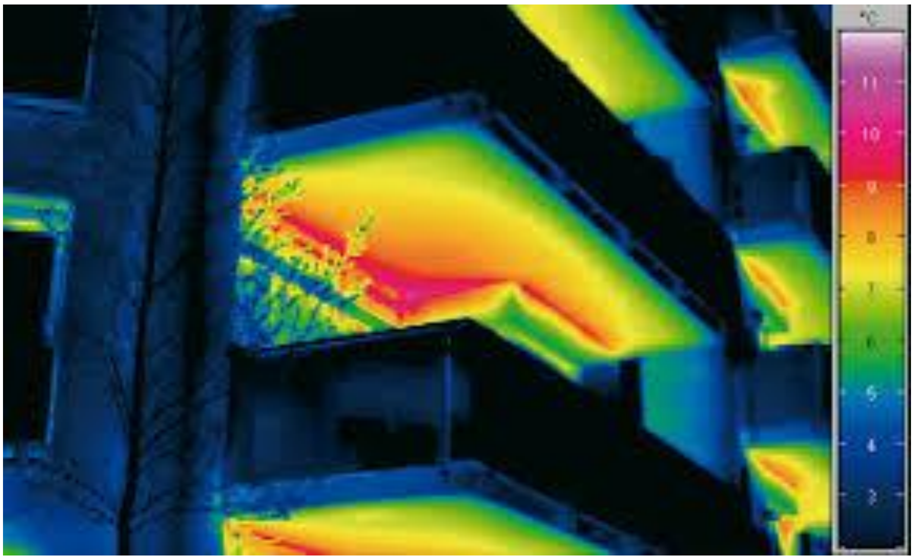


Figure 2.41: Thermography image showing thermal bridges
Source: http://kirhammond.wordpress.com

Insulation around a bridge is of little help in preventing heat loss or gain due to thermal bridging; the bridging has to be eliminated, rebuilt with a reduced cross-section or with materials that have better insulating properties, or with a section of material with low thermal conductivity installed between metal components to retard the passage of heat through a wall or window assembly, called a thermal break. Another solution is to increase the bridge length, or decrease the number of thermal bridges. The heat conduction can be minimized further by the installation of an insulation board over the exterior outside wall, because they cover the most surface area of any building. Currently, the types of insulation that are being used are fibreglass or rock wool insulation, wood fibre board, foam board EPS or XPS, insulating glass or polystyrene rigid board insulation, formed in place polyurethane insulation, cellulose/perlite/vermiculite loose fill, and insulated pre-cast concrete insulation. Each type of insulating material is used most effectively in various parts of buildings including interior walls, exterior envelopes, flooring, roofing, and basements.

2.3.2.2. Infiltration and air-tightness

Ventilation is a way of keeping the air in the building fresh, dry and healthy. Air should move around the rooms, and should be slowly exchanged with fresh air from outside. This stops the build-up of damp and stale air. There are several different types of controlled ventilation:

- Extractor fans: found in kitchens, bathrooms and utility rooms to remove damp air
- Under-floor grills: these help keep wooden beams dry.
- Wall vents: these let small amounts of fresh air into rooms.
- Trickle vents: modern windows often have small vents to let fresh air enter.

Air leakage is a major cause of energy loss, typically around 20% in older houses, from space heating. In modern houses, where heat loss is less through other means, ventilation counts for a higher proportion (estimated at between 35-40%). Draughts occur where there are accidental gaps in the construction of the building, or if doors, windows, keyholes or letterboxes are left open or uncovered.

Draught proofing is one of the cheapest and most efficient ways to save energy in any type of building. Ensuring air-tightness is achieved through careful implementation of strategy throughout the design and construction, an achievable air-tightness performance target have to be defined at the beginning of the design work. The line of the air-tightness barrier has to be designed, which should be simple and buildable. Air testing is carried out when the envelope is complete.

Air barriers must be impermeable to air, continuous, durable and accessible. Internal air barriers need to be airtight, external air barriers need to be wind-tight. The air barriers can be vapour open but require careful specification of adjoining construction and insulation materials. Having made the building airtight, mechanical ventilation is essential.

For windows that open, draught-proofing strips are needed to stick around the window frame. There are two main types: self-adhesive foam strips and metal or plastic strips with brushes or wipers attached. Gunned in compatible sealant is suitable for small joints, but where the openings are larger, a pre-compressed flexible expanding foam strip is necessary. Compatible gunned in sealant should be used to seal joints between door and window frames and the surrounding wall externally. For sash windows brush seals are needed. For windows that do not open silicon sealant can be used.

3 Active solutions for energy-efficient building envelope retrofitting

With the comparison of today's improvement in technology, population growth and industrial activities, new strategies for reducing consumptions and orientation through renewable resource use become more of an issue. As there are many kinds of passive and bioclimatic architectural strategies that can be applied for buildings in order to decrease energy consumption rate, active strategies should also be considered seriously where passive and bioclimatic architectural strategies are not enough for conditioning and comfort demand.

Strategies on active building envelope which builds a boundary for the interior and exterior environment have the main effects on district solutions in terms of sustainability which are mostly related to climatic conditions. Differently from the passive and bioclimatic solutions, active solution technologies are applicable by the use of advanced technology that works co-ordinately with climatic conditions so that natural sources that can be evaluable on site area. Domestic energy consumption in buildings can be categorized in three main categories as they are thermal energy, electrical energy and refrigeration. Suggested technologies are proposed to reduce the energy consumption of buildings.

Within the solutions provided by active strategies for building envelope, there are certain barriers about economical, technical and experimental issues such as higher initial expenses despite their low operation costs, demand for qualified and experienced technical team and wide range of product requirement. To overcome these barriers, it is important to raise public awareness, strength infrastructure of the active market and governmental support with related regulations and laws.

In this report, several technologies that can be applied to envelope components as roofs, façades and windows are defined and evaluated respectively.

3.1 Solar technologies

Main working methodology of the active solar technologies is to take advantage of solar energy as a natural source. In this report, systems applied in building are identified in two main categories as they are:

- Solar thermal collectors
- Photovoltaics

3.1.1 Solar Thermal Collectors

Solar thermal panels are devices that take advantage of the direct sunlight and convert it into heat that can be used in different processes, most commonly for DHW supply. Thus domestic hot water is required during throughout the year, solar thermal panel application to the envelope provides high rate of energy saving.

Solar Thermal Collector technologies

Collector technologies based on capacity can be defined in 2 different types as they are non-concentrating and concentrating solar thermal collectors. Non-concentrating collectors can be divided in three and concentrating collectors can be divided in two groups based on their technologies;

<u>Non-concentrating STC</u>

- Unglazed collectors: Unglazed collectors does not include glazing or insulated collector box. They only consist of an absorber. They are used for low temperature applications most commonly.
- Glazed collectors: Glazed collectors are thermally insulated on their back and edges. They are provided with a transparent cover on the upper surface. They can heat fluid up to 80°C.
- Evacuated collectors: Collector type which is containing a glass tube with vacuum inside that minimizes heat losses to environment. Working temperature of evacuated tube collectors are between 50°C and 200°C which is relatively high when compare with other non-concentrating collectors.

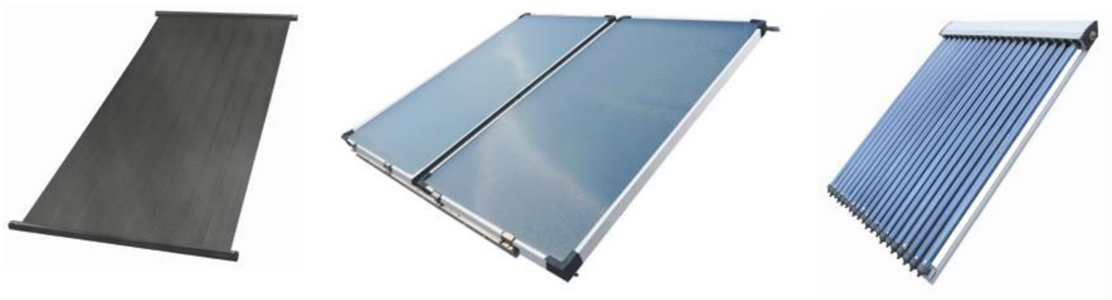


Figure 3.1: Non-concentrating STC types.

<u>Concentrating STC</u>

- Parabolic collectors: Parabolic collectors can be used with both non evacuated flat plate collectors and evacuated tube collectors. PTC collectors are designed for a high concentration ratio. They can heat the working fluid up to 240 °C and they are used for high temperature application.
- High concentrating collectors: High concentrating collectors have sun tracking technology which can generate temperatures high enough to operate a thermodynamic cycle and produce electricity. Additionally, they can be used in (process) heat applications.

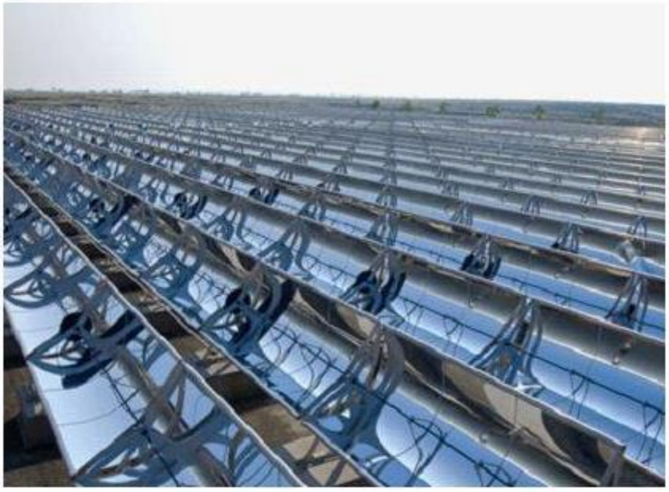


Figure 3.2: Parabolic collectors
Source: www.intechopen.com

Application of solar thermal collector technology is identified under two main categories as they are roof and façade applications.

System components of a solar thermal panel are listed below;

- Collector: Main component of the system which is used to transform solar radiation to heat
- Storage tank: Equipment to store generated heat in collectors. Also important for the heat balance
- Pump and Controller: Pumps move the fluid through piping circuits. Pump operation is controlled by the controllers
- Auxiliary heating system: Supporting system when storage tank cannot provide required temperature to the building system

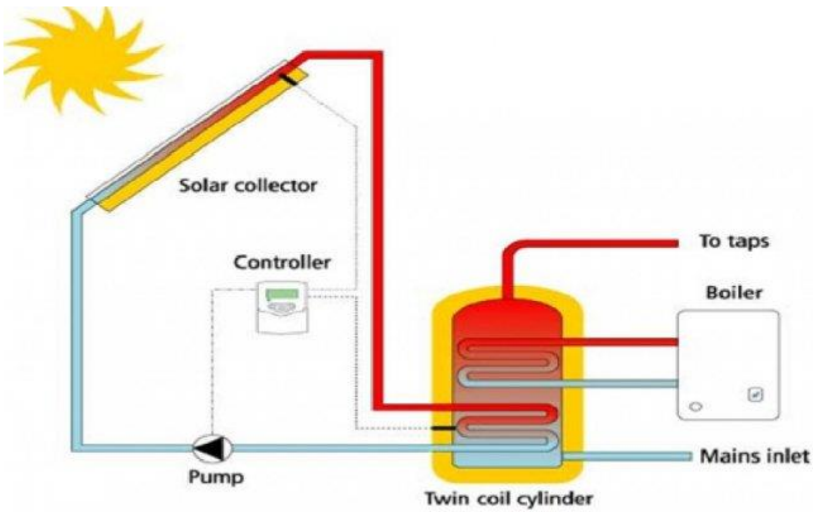


Figure 3.3: Simple application of solar thermal system
Source: www.rentec-renewableenergy.co.uk

Solar thermal panels have additional 3 main targets apart from domestic hot water supply as they are space heating, pool heating and solar cooling. All four applications require various temperature ranges and collector types accordingly to their function.

Domestic water heating system

Domestic water heating system by solar thermal collectors is the most common residential technology that can be applied in order to provide hot water for buildings and districts. STC systems are more efficient in warmer climates thus it has a direct relation with the climatic conditions. Temperature requirement of a domestic hot water is generally below 80°C and system can recover 30% of total energy consumption. Success of the system depends on area of the collector and size of the storage besides climate. In case of optimum conditions are provided, it is possible to satisfy domestic hot water demand at 100% by solar thermal systems. Two main system configurations are used for solar DHW heating systems:

Thermosyphon systems

In thermo syphon systems, water is circulated automatically from solar collector to storage tank by using the density difference between different temperatures of water in different aspects of the system. Thermo syphon systems neither include pump to transfer hot water nor controller due to its self-starting and self-controlling properties. All these characteristics make the system simple and cost effective. This type solar thermal system is better to be used in frost-free climates.

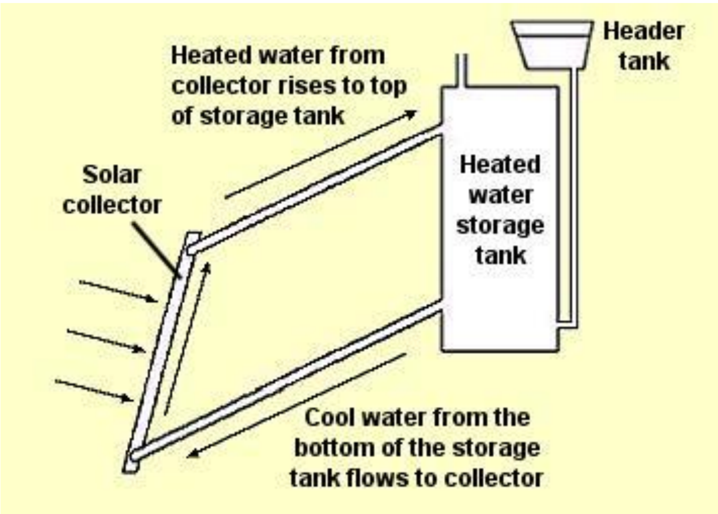


Figure 3.4: Thermo syphon system
Source: http://www.diydata.com

Forced-circulation system

In forced-circulation systems water needs additional mechanical pump to start circulation process in the system. Sensors and controller device are also needed in order to ensure the system. For this reason, forced circulation systems are relatively more complex, energy consuming and expensive. Nevertheless, collected solar energy amount is higher due to the pumping system which is efficient under low solar energy gains as well.

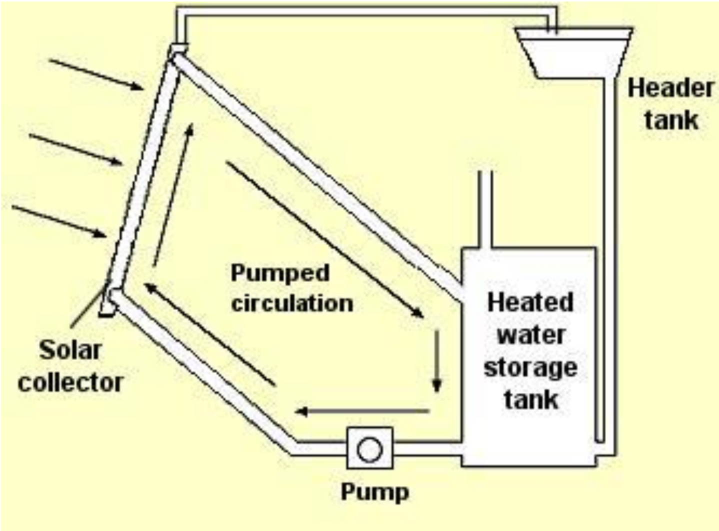


Figure 3.5: Forced-Circulation System
Source: www.diydata.com

Space heating system

Similar with the solar water heating system, space heating is also an applicable energy efficient active solution that can be applied in buildings by using solar thermal collectors. Although their working methodologies are parallel, requirements such as collector size and storage area are larger–so that their control systems are more complex when they are compared. Space heating systems are generally combined with hot water systems.

Figure 3.6: Solar space heating system
Source: http://deepbluenrg.ca

Solar cooling system

Electricity consumption of buildings proceeds from not only heating but also the cooling demand. Solar cooling systems are efficient solutions in order to reduce this consumption by supporting air conditioning and refrigeration systems.

Solar cooling technologies have two main processes;

Closed cycle

Thermally driven chillers produce required water at the appropriate temperature degrees in accordance with the cooling system equipment such as air handling units, fan-coils, chilled beams, etc. Flat plate collectors, evacuated tube collectors, optical concentration collectors can be used for a closed cycle solar cooling technology. Closed cycle system configuration can be seen on the figure below.

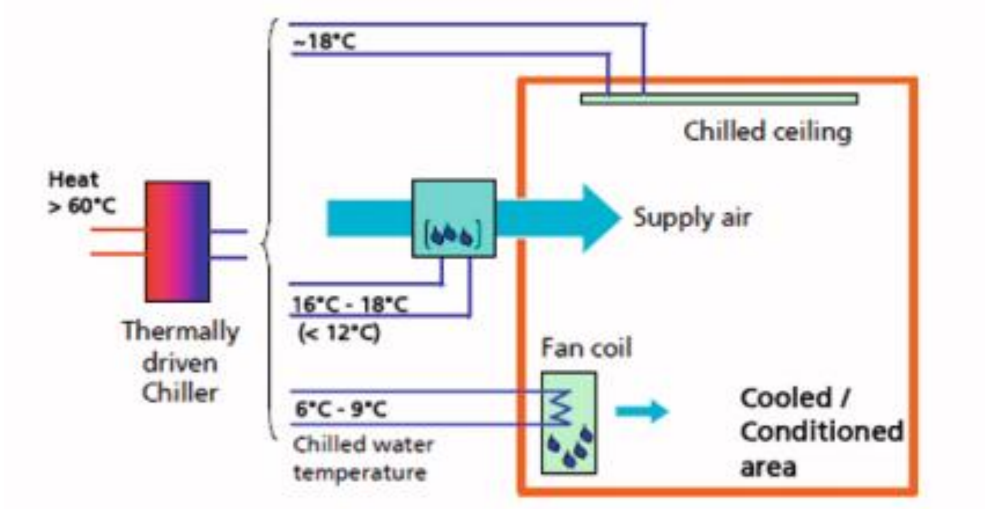


Figure 3.7: Solar cooling; closed cycle
Source: www.solarserver.com

Open cycle

Open cycle systems use water as the refrigerant and a desiccant as the sorbent for direct air treatment in a ventilation system. Thus they also called as desiccant evaporative cooling system (DEC). Open cycle systems may be applicable for ventilation systems of the buildings or for the parts where ventilation is controlled by cooling load cover. Low temperature collector panels are the most suitable ones, such as solar air collectors and flat plate collectors in case open cycle process is used as the cooling system. Configuration of the system is shown on the figure below.

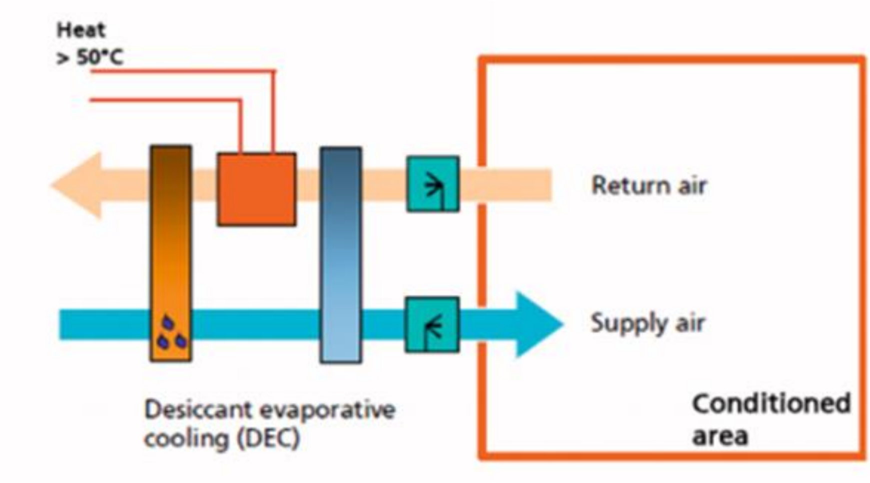


Figure 3.8: Solar cooling; open cycle.
Source: www.solarserver.com

3.1.1.1. Solar Thermal Collector applications on roof

Solar thermal collector integration and location for roof applications can be defined in 2 subcategories as they are listed below;

Building integrated solar thermal (BIST)

Collectors used for heat generation both charge as an architectural element. For roof applications, collectors are replaced instead of roof tile which means that they also acts like the construction elements of building that provides considerable reduction on some system application requirements. This method is most suitable for new constructions. Applicable collector technologies for BIST roof systems are; flat plate collectors, unglazed collectors and evacuated tube collectors. Suitable collector area and weight are defined and made accordingly to the application areas.

Figure 3.9: BIST solar thermal collectors.
Source: www.uksolarenergy.org.uk

Building added solar thermal (BAST)

Building added solar thermal system is a simple and conventional method for existing buildings. The solar collectors are mounted on building façade or roof. In this method, the collector does not replace any other building elements such as tile. Consequently, there is no material or cost saving when they are compared to BIST systems. Parabolic through collectors can also be defined as an applicable solar thermal collector technology additively to applicable BIST technologies.

Figure 3.10: BAST solar thermal collectors
Source: www.mint.com

Depending on the available area in the building, storage of the storage tanks can be placed as integrated or inside storage. In case of integrated storage, tank is attached to the solar thermal panel as shown in the figures below;

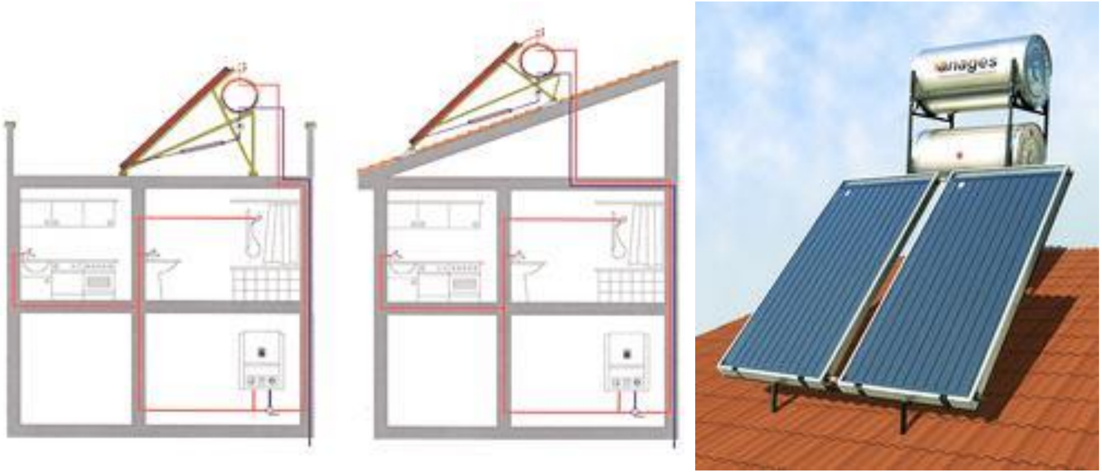


Figure 3.11: Integrated storage of solar thermal storage tanks
Source: Solar thermal in major renovations and protected urban areas, URBAN SOL PLUS

When the storage of the tank is done in the available internal space, storage tank locates as it is shown in the figure below. Inside storage is the best solution in order to provide protection for the tank.

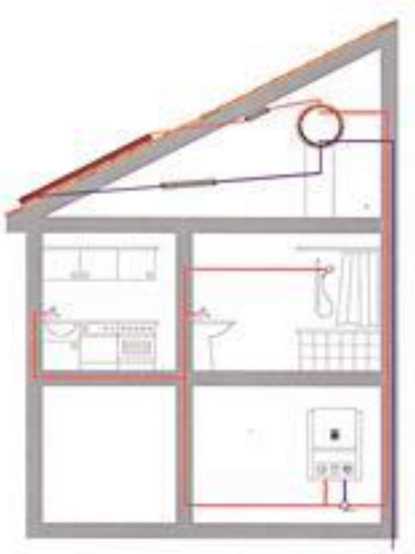


Figure 3.12: Internal storage of solar thermal storage tanks.
Source: Solar thermal in major renovations and protected urban areas, URBAN SOL PLUS

Piping system of the solar thermal solution

Piping system of the solar thermal technology provides the connection between collector panel and the storage tank. According to the location of the system, piping may be visible or hidden. Visible piping systems are the one that locates between panels on the roof area and can be seen easily. Hidden piping systems locate generally in the backside of the panel, in the garret of the building so that becomes invisible. Hiding the technical part of the system is always better in terms of aesthetic and safety.

Figure 3.13: Example of system with visible or hide piping system
Source: www.greenbuildingadvisor.com and solarenergy-usa.com

STC system Integration into the existing building

There are two types of integration system for solar thermal technologies application into the existing buildings as decentralized and centralized system. In case of decentralized system, one storage tank and one solar thermal collector panel supply hot water for a single apartment.

Decentralized system application is more suitable for the buildings which are already exist and for the single-detached dwellings.

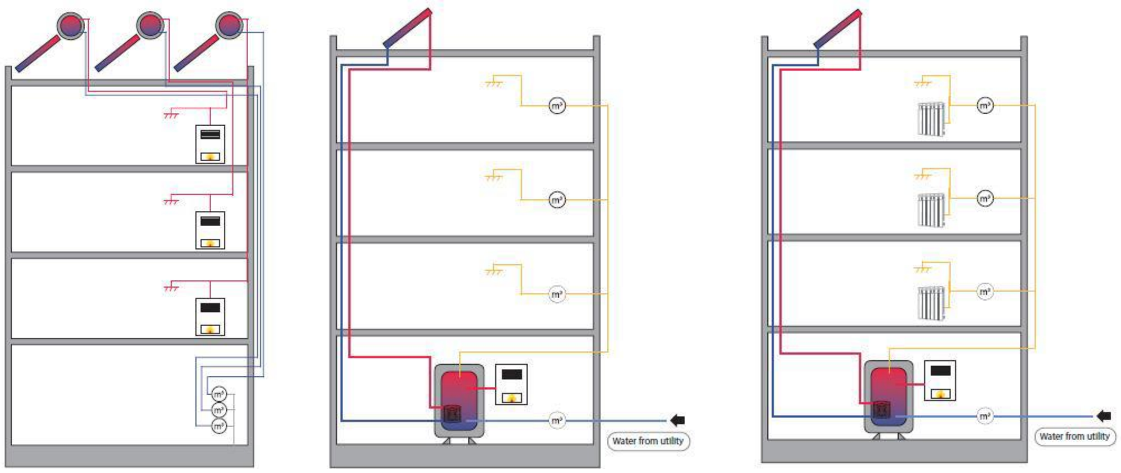


Figure 3.14: Decentralized system for DHW, centralized system for DHW and centralized system for space heating and DHW
Source: Solar thermal in major renovations and protected urban areas, URBAN SOL PLUS

In case of centralized system application, collected solar energy from a single panel is stored in a single storage tank which is relatively greater than the one used for decentralized system. Collected energy is distributed to each apartment unit afterwards. Centralized system is more efficient for large scale dwellings thus it minimizes the number of auxiliary equipment and simplifies the piping system. Moreover with the reduced number of storage tanks, system cost and heat losses from the unit decrease.

Storage for the district level

When solar thermal collector system is installed for the district level, the storage serves for the all buildings inside the district which means that there is a common technical room is required.

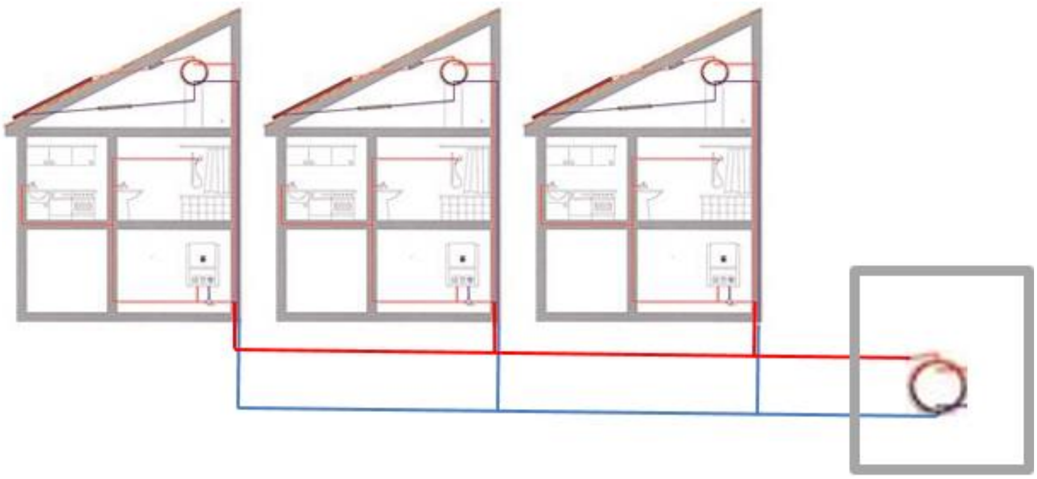


Figure 3.15: Installation storage for the district level.
Source: Solar thermal in major renovations and protected urban areas, URBAN SOL PLUS)

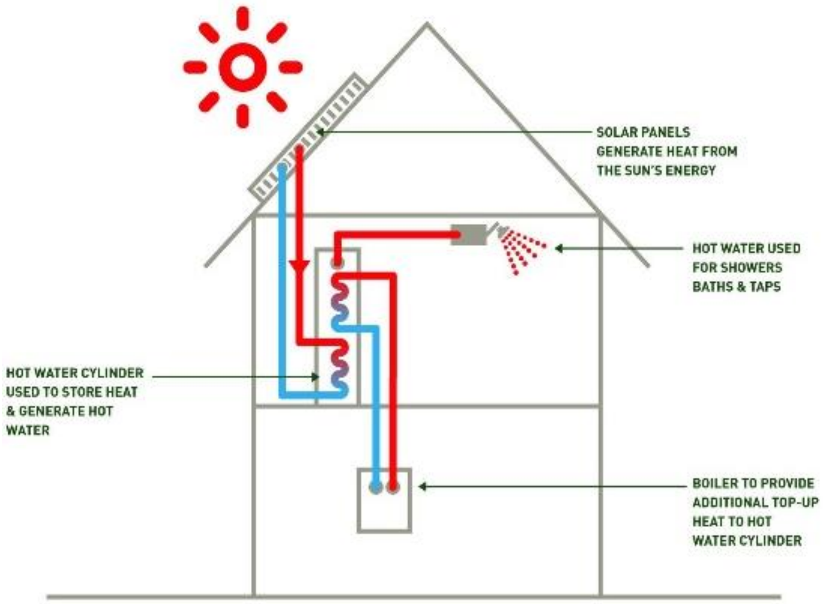
Solution type	Technology based solution
Application Area	Roof
Working scheme	 Figure 3.16: Working scheme of solar thermal panel. Source: www.enertekglobal.com
Brief description	Solar thermal panels are devices that take the advantage of direct sunlight and convert it to heat that can be used in different processes most commonly for domestic hot water supply.
Types of materials	Concentrating and non-concentrating solar thermal collectors as glazed, unglazed, evacuated or parabolic and high concentrating collectors
Advantages	Renewable energy source Non-polluting Creates new layer of envelope Improves thermal capacity Low heating cost Can be used in modular manner Short repayment period
Disadvantages	Depends on climatic conditions Requires a supporting structure Needs qualified technical support team Location and size limitation High initial cost

Table 3.1: Working scheme of a solar thermal panel
Source: www.enertekglobal.com

3.1.1.2. Solar Thermal Collector applications on façade

Integration and application of solar thermal collectors onto the façade area of the building is on the rise through its visible properties and their overall aesthetic look. Façade integration of the collectors provides opportunities of uniform sunlight capture as an advantage of vertical positioning. They are profitable in terms of being adequate to use maximum irradiation even in winter conditions when the space heating demand is at its peak. Moreover, for multi-family used buildings or for the apartments with high number of floors, solar thermal collector integration on roof area may not be possible for every single house due to the scarce of required roof area or unqualified roof orientation. Façade applications solve those arguments about the application by serving sufficient space.

Façade integration of the solar thermal collectors enable several functions as they are energy generation for water heating, thermal insulation for the whole building, weather skin for the façade area through glazing and formation of structural element. Moreover solar thermal integration contributes to decrease in heat loss due to the absorbers that warm up the building even in inefficient days of winter with low sunlight gain.

Direct façade integration

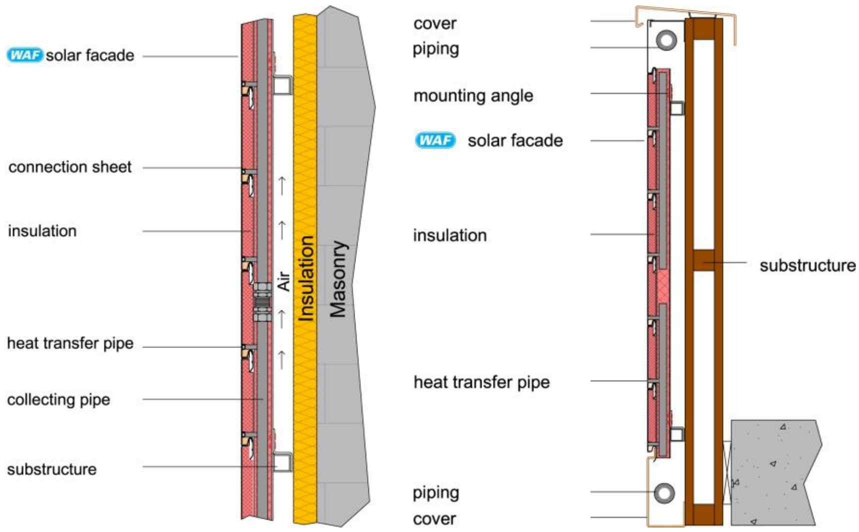
Direct façade integration is an application where the collector element is directly integrated in the façade that also involves heat insulation as a component of itself. In case of direct façade application, there are no thermal separation between solar thermal collector and the heat insulation application.

Figure 3.17: Facade integration of unglazed flat-plate collector, Cern, Switzerland
Source: www.ntnu.no

Solar thermal collectors as balcony railings

Solar thermal collector panels can be used as balcony railings in order to take the advantage of their orientation towards south and west. They are able to satisfy both energy and aesthetic requirements of the buildings by their integration instead the railing or addition on the railing surface. For the integration that can equally be used as the railing, tubular vacuum collectors are more preferable and flat plate collectors are more suitable for their addition on the existing railings.

Figure 3.18: Use of evacuated tube collectors as balcony railings, Sunny Woods multi-family housing in Zurich, Switzerland
Source: www.intermasolar.com & csc.esbensen.dk

Solution type	Technology based solution
Application Area	Façade
Working scheme	 Figure 3.19: Sections of direct façade and balcony railing applications Source: www.waf-solarfassade.at
Brief description	Façade-integrated collectors are energy generators for heating water which improves the building's thermal insulation, acts as a weather skin for the façade through the glazing and plays role as a structural element of the façade

Types of materials	Concentrating and non-concentrating solar thermal collectors as glazed, unglazed, evacuated or parabolic and high concentrating collectors
Advantages	Renewable energy source Non-polluting Creates new layer of façade Improves thermal capacity Low heating cost Can be used in modular manner Short repayment period
Disadvantages	Depends on climatic conditions Location and size limitation Needs an extra structure (in case of BAST application) High initial cost Needs qualified technical support team

Table 3.2: Working scheme of a solar thermal collector
Source: www.waf-solarfassade.at

3.1.2 Photovoltaics

As it is described by its name, photo (light) voltaic (voltage) panels use direct sunlight in order to convert it into electricity. Those panels are formed by many photovoltaic cells. Integration of cells to the rooftops and façade area of the buildings are the most popular PV applications. The main purpose of PV system to generate electricity is to get direct penetration of the sunlight without hitting any physical barrier. Energy supplied from PV panels can possibly be used in order to provide energy demand in buildings as well as districts.

Consolidated PV technologies

Consolidated BIPV technologies can be evaluated in two different subtitles as they are Crystalline Silicon Technology and Thin-Film Technology.

Crystalline Silicon Technology

Crystalline silicon photovoltaic panels are preferred as BIPV products due to their properties as they are listed below:

- Development of the technology and its market recognition provides high variety of product range.
- Quality level is so high when it is compared to other technologies as a result of researches done about it for a long period of time.

- Conversion efficiency of the PV gain importance for limited applications because of limited integration area and crystalline silicon technology is able to provide more efficient results with high efficiency of energy conversation.

Despite crystalline silicon technology is the most efficient one from all BIPV technologies, its thick and rigid physical characteristic grounds to disadvantages on application especially for the glass configurations which rejects visual barrier. Moreover, efficiency of them varies in accordance with the orientation of the building thus their performance is directly related to the light incidence angle. An example of a crystalline silicon cell with seven layers can be seen in the figure below.

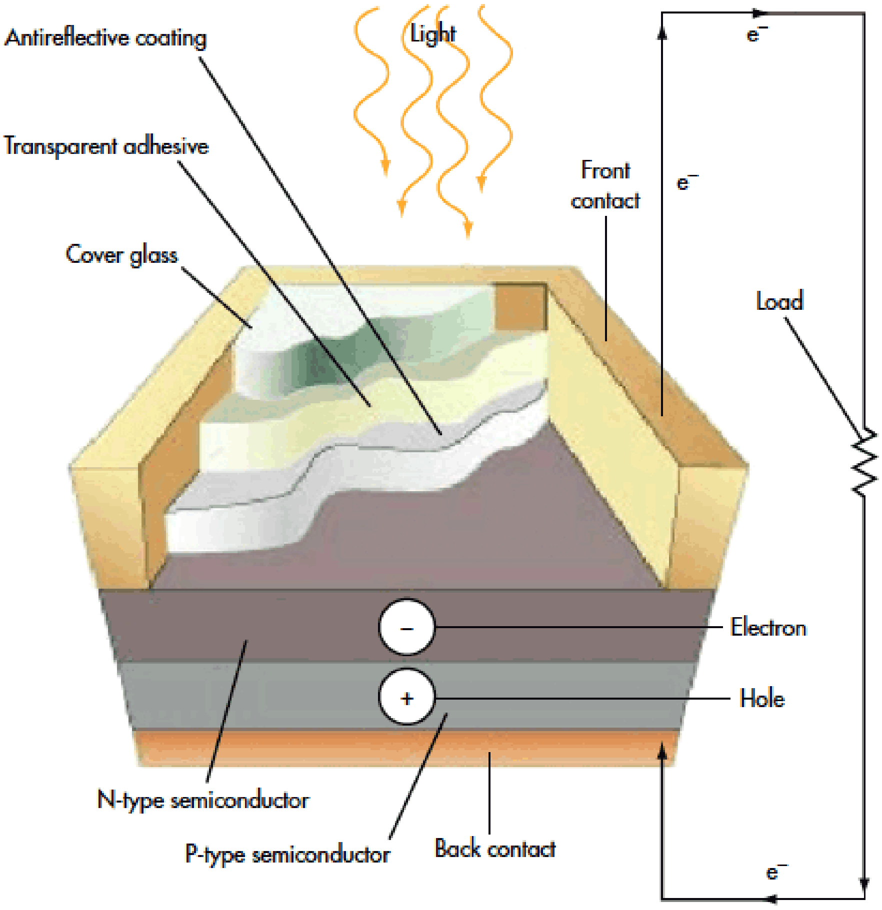


Figure 3.20: Examples of a Crystalline Silicon Technology
Source: electronicdesign.com

Thin-Film Technology

Thin film solar panels can be one of three types in accordance with the used material:

- Amorphous silicon (a-Si) and thin-film silicon (TF-Si)
- Cadmium telluride (CdTe)
- Copper indium gallium deselenide (CIS or CIGS)

Thin film technologies may refer to lower energy production when they are compared to crystalline silicon technology. However, their properties like easy installation, adaptability and high success of radiation collection should be considered too as their main advantages. While making a decision about type of the PV technology, temperature factor should be considered in order to choose the most effective solution. Thin film technology gives opportunity of being useful at a wide variety of temperature conditions. Moreover, it has a high performance rate even in case of indirect radiation which also leads to a constant efficiency that does not affected by light intensity. Thin film technology can be described as the optimal solution when considering installation cost due to its adaptability and convenience on integration and installation.

An example of six layers containing thin film solar cell is shown in the figure below.

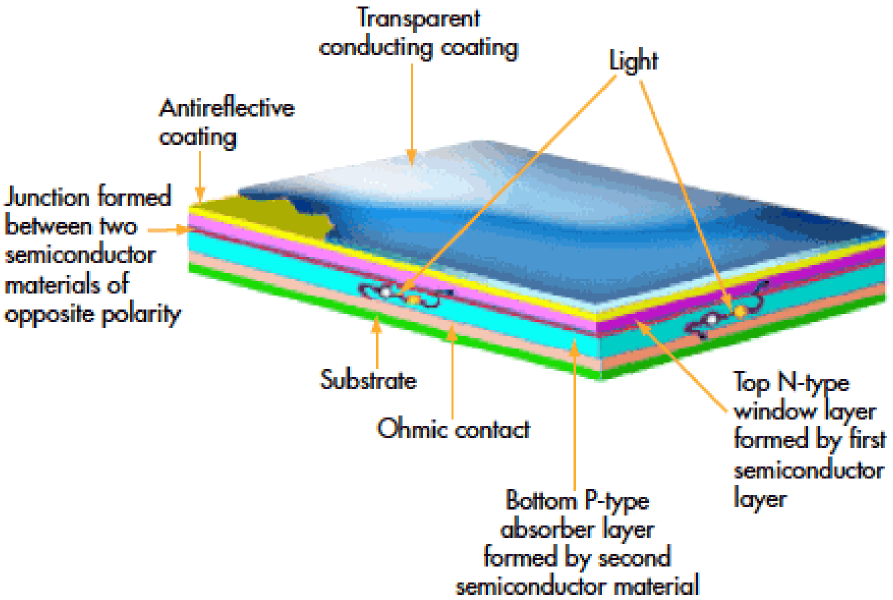


Figure 3.21: Examples of Thin-Film Technology
Source: electronicdesign.com

Crystalline silicon technology plays the main role with an approximate share of three quarter. According to European Photovoltaic Industry Association, more than 70% of the total solar products use this technology. From that kind of distribution, it is possible to state that the crystalline silicon is the most developed PV technology.

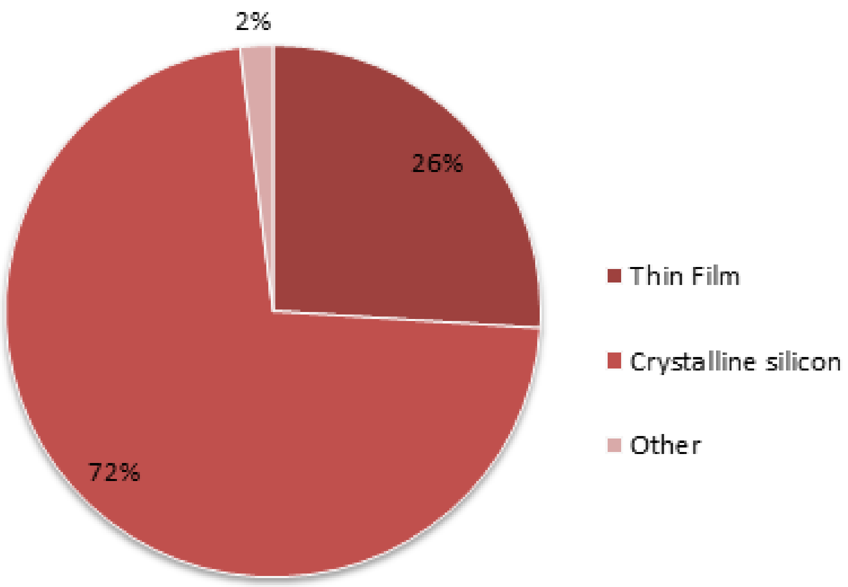


Figure 3.22: PV Technologies distribution
Source: European Photovoltaic Industry Association

Emerging technologies

Emerging photovoltaic panel technologies consists of two types as they are organic PV and dye sensitized solar cells.

<u>Organic Photovoltaics (OPV)</u>

Organic photovoltaic panels can be taken into account as the best beneficial PV type as an emerging technology. Their properties such as multiple colour design, flexibility of the capacity, extreme thinness and excellent lightness makes it the best in aesthetical sense. Moreover, it overcomes low energy production, high cost and lifetime limitations better compared to other technologies.

Figure 3.23: OPV cells incorporated into Parking Canopy
Source: www.energie-loesungen.de

Figure 3.24: Image of OPV cell deposited on flexible substrate
Source: www.bigspaceballoon.co.uk

The most important profit of OPV technology is the physical applicability even on flexible surfaces which allows new architectural applications which are not possible by use of consolidated technologies as silicon technology.

Dye Sensitized Solar Cells (DSSC)

Dye sensitized solar cells as a thin film technology allows conversion of both diffused and direct light into electricity. Moreover, they are applicable for cloudy regions and not sunny climates. From architects and engineers point of view, their semi transparency and colour varieties adds them high aesthetic value. DSSCs are not effected by temperature changes in a negative way, their efficiency is able to stay steady up to 80ºC.

Owing to their limited format size, large time demand for manufacturing and lamination process limitations, their current state prevents their opportunity of carrying out large scale market exploitation.

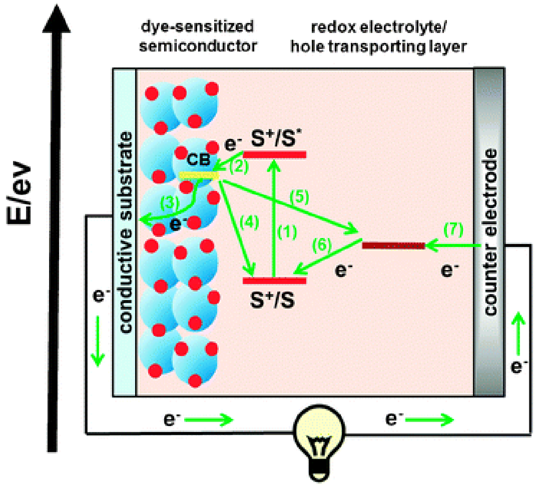


Figure 3.25: Schematic structure and operation principle of a dye-sensitized solar cell
Source: http://pubs.rsc.org

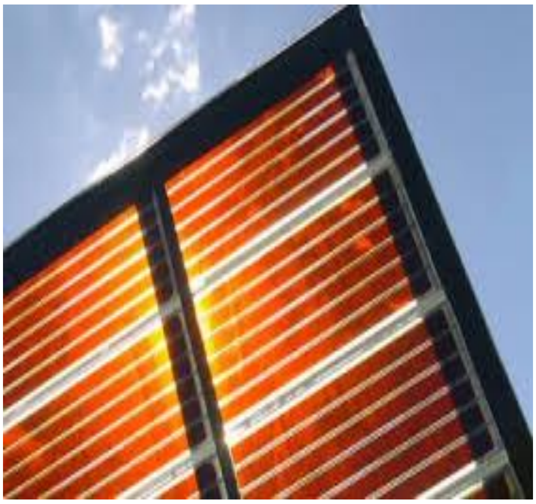


Figure 3.26: Image of DSSC mini module
Source: www.plusplasticelectronics.com

Application of photovoltaic technology is identified under three main categories: roof, façade and window applications.

3.1.2.3. PV applications on roof

PV application on roof is done by addition or integration of photovoltaic systems on top of the building structure. Application can be categorized in two main categories as building added and building integrated.

Building Applied Photovoltaics (BAPV)

Building Applied Photovoltaics are referring to photovoltaic panels which are mounted on roof, top of the building's existing structure – tile most commonly. BAPVs only provide electricity production from the solar energy. There are no any additional benefits provided besides.

BAPV are generally preferred in case of application after the construction period of the existing building is finished.

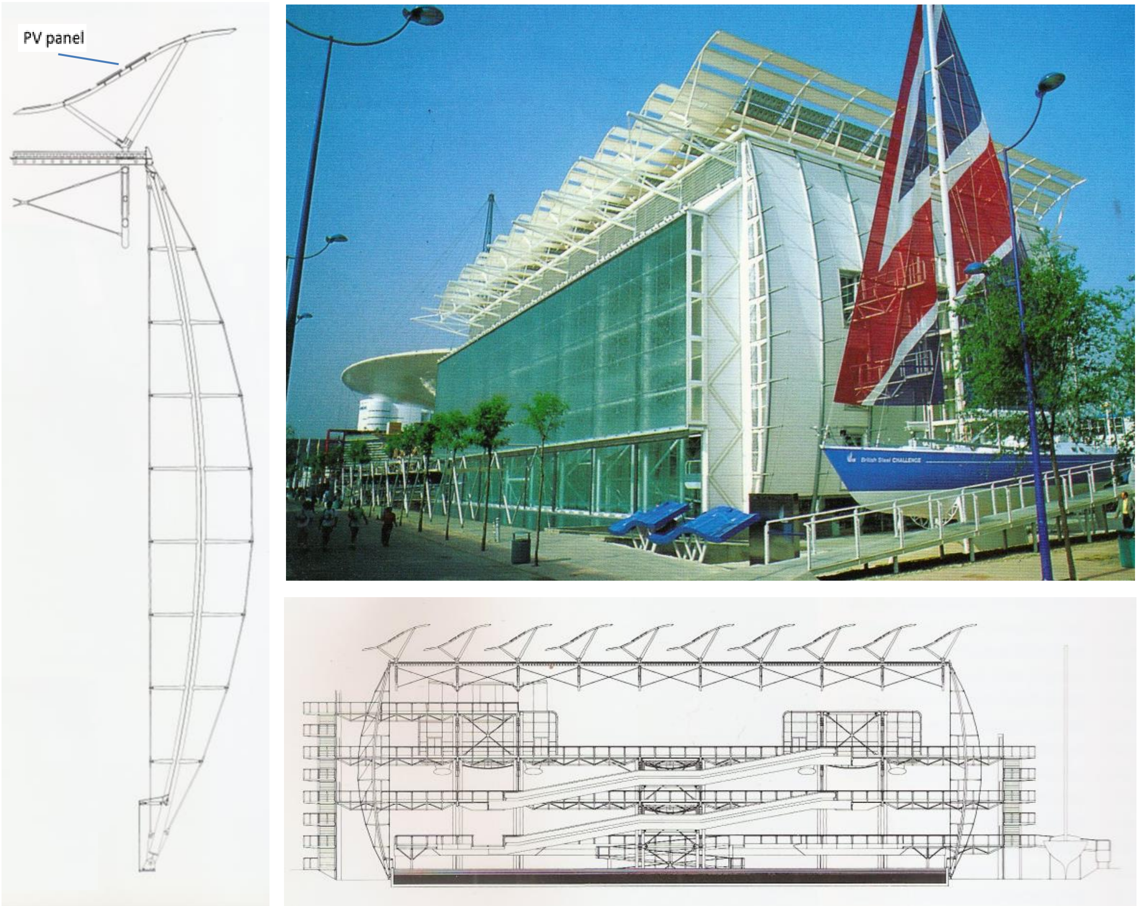


Figure 3.27: BAPV in Expo 92 building, Sevilla.
(Source: Photovoltaics in Architecture, Humm O. and Toggweiler P., Berlin).

Building Integrated Photovoltaics (BIPV)

Building integrated photovoltaics are solar cell panels which can possibly be used as an original component of the building instead of conventional materials such as roof tiles. It gives opportunity of installation even during the construction phase of the building. Within their energy producer mechanism, they also satisfy building demands as the building element. They assure a boundary between interior and the exterior space of the building. By providing layer for both waterproof and air stabilizer function it increases thermal comfort relatively thus BIPVs are also responsible from daylighting, ventilation and energy production issues in accordance with their application surface.

At the decision state of BIPV module integration, every single parameter should be taken into account and appropriate products should be chosen afterwards in order to get the highest benefit. With their wide variety and the advantageous properties, it is sensible to replace existing materials mainly on facade and roof areas of the buildings in order to maximize energy efficiency.

Figure 3.28: BIPV system in a family house, Brunnadern
Source: Photovoltaics in Architecture, Humm O. and Toggweiler P., Berlin

Photovoltaic skylights

A photovoltaic skylight application provides optimum conditions for both energy production and thermal comfort inside the building. In case of pv skylight application, a silicon-based material is preferred to be used thus it also has a mission of being a sunscreen due to their ability of harmful ray prevention. Photovoltaic skylights can provide not only the electricity generation, but also daylighting.

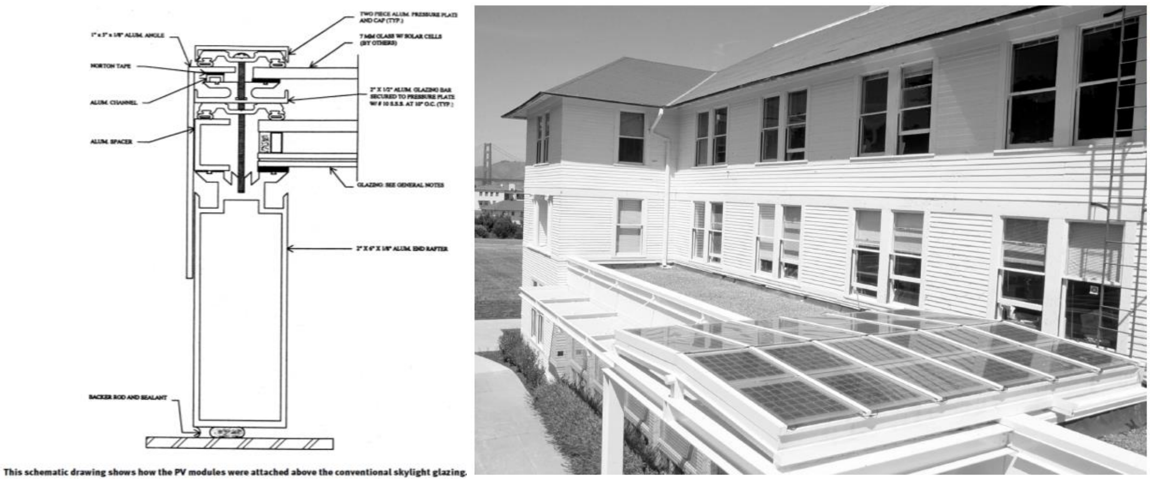


Figure 3.29: Section and photo of photovoltaic skylight
Source: www.nrel.gov

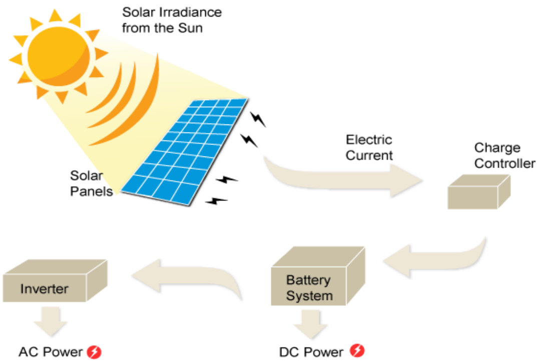
Solution type	Technology based solution
Application Area	Roof
Working scheme	
Picture	 Figure 3.30: Mounting types for rooftop applications
Brief description	PV panels which are formed by photovoltaic cells use direct sunlight in order to convert it into electricity. Integration of cells to the rooftops of the buildings is the most popular PV application in the world. Domestic energy consumption can be categorized in three main categories as; thermal energy, electrical energy and refrigeration. Energy supplied from PV panels can possibly be used in order to provide that energy demand in districts and buildings.
Types of materials	According to different technics, crystalline silicon or thin-film can be used for photovoltaic panels
Advantages	In-Situ energy production Absorption of UV and IR components of light Daylight Entrance inside the building Aesthetical Added Value Thermal Envelope Benefits and Acoustic Comfort Easy Installation
Disadvantages	Surface pollution may decrease the efficiency Extensive installation space is needed May need an extra structure (for building added types) No production when there is no sunlight High installation cost Needs qualified technical support team

Table 3.3: Photovoltaic skylights.

3.1.2.2. PV applications on façade

Photovoltaic panel application on the façade area is also a useful active envelope solution which is considered mostly after roof applications.

Photovoltaic Ventilated Façade – Double skin

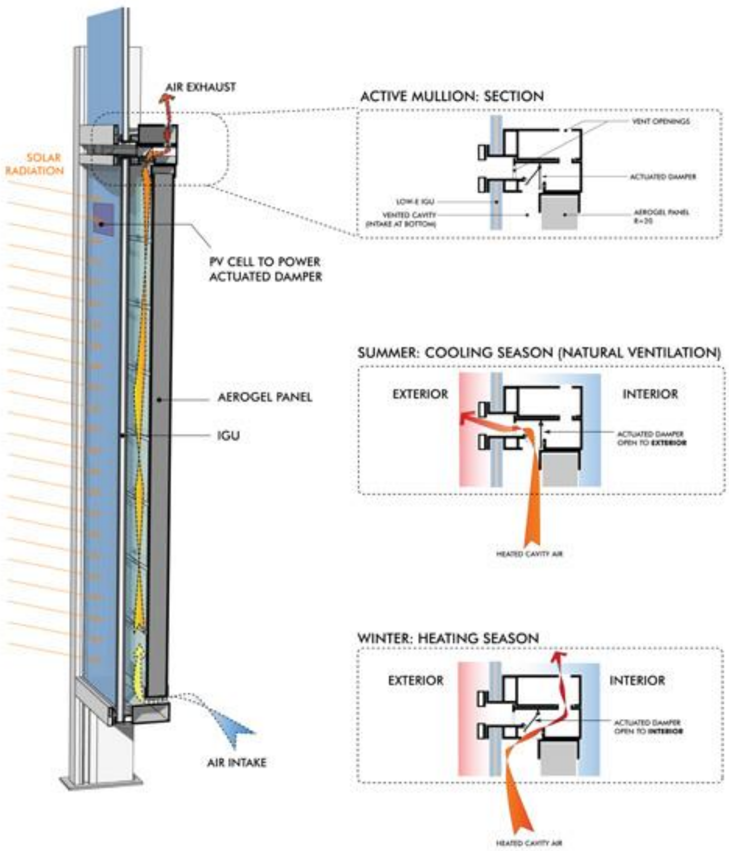
Photovoltaic ventilated facades which are also refers to double skin are the growing sustainable alternative for buildings with their advantages on electrical, thermal and acoustic perspectives. By their working principle, within their energy production properties, double skin facades are efficient on equalizing interior and exterior ambient pressure, solving high temperature problems of the building and minimizing effect of the wind loads towards building surface. When the economic analysis is considered of the double ventilated skin, accordingly to their location and orientation, they can achieve an internal return rate more than 25% with an excellent payback period.

Figure 3.31: Example for Photovoltaic Ventilated Façade
Source: www.onyxsolar.com

Photovoltaic Curtain Wall

As another efficient combination of technology and architecture, photovoltaic curtain walls offer various solutions as they are clean and free energy generation, natural daylighting, infrared and UV radiation prevention. With their wide variety in form and colour and transparency level, PV curtain walls allow designers and the architects to create both aesthetic and efficient constructions. By providing thermal comfort and minimizing ageing effects on buildings, PV curtain walls also address for a renovation in order to create more elegant and smart buildings.

Figure 3.32: Example for Photovoltaic Curtain Wall
Source: www.onyxsolar.com

Solution type	Technology based solution
Application Area	Façade
Working scheme	 Figure 3.33 Ventilated façade and curtain wall working scheme Source: http://spie.org & www.constructionlawtoday.com

Picture	 Figure 3.34: Example for PV applications on façade area Source: www.usgnn.com
Brief description	Integration of photovoltaic panels to the façade area provides higher efficiency in terms of heating and cooling mechanism of the building. Energy required for thermal comfort, electric and refrigeration related consumptions can be supplied from PV panel applications.
Types of materials	According to different technics, crystalline silicon or thin-film can be used for photovoltaic panels
Advantages	In-Situ energy production Absorption of UV and IR components of light Daylight Entrance inside the building Creates new layer of façade Improves thermal capacity Aesthetical Added Value Acoustic Comfort Easy Installation
Disadvantages	Surface pollution may decrease the efficiency Extensive installation space is needed May need an extra structure (for building added types) No production when there is no sunlight High installation cost Needs qualified technical support team

Table 3.4: Photovoltaic Curtain Wall

3.1.2.3. PV applications on window

Windows and glazed facades of the buildings are able to generate electrical power by their usage as luminescent solar PVs. Process occurs by a fitted thin film of material which absorbs the solar energy and transmits it to a narrow solar cell at the perimeter of the window in order to generate power. As an active solution, luminescent solar PVs allow production of cheap solar energy by electricity generation in buildings even where the orientation and tendency is not at its optimum like north façade.

Solar cell modules located in the glass are designed detailed in terms of different thickness, transparency and size values to meet the need of safety for building.

Those power generating windows with solar cells have shorter energy payback period. Frameless and colour elective windows are also comply with the building requirements in terms of high visibility and aesthetic property.

Glazed PV glasses

Rather than fully transparent windows, semi-transparent double glazed photovoltaic insulating glass units can be used in order to provide a better thermal insulation property. In case greater thermal insulation is required, semi-transparent triple glazed insulating photovoltaic glass units might be considered as the possible solution. To receive better insulation performance, inert gas filling can be considered as well.

Figure 3.35: Glazed PV glasses.
(Source: www.onyxsolar.com).

Windows and glazed facades of the buildings are able to generate electrical power by their usage as luminescent solar concentrators. Process occurs by a fitted thin film of material which absorbs the solar energy and transmits it to a narrow solar cell at the perimeter of the window in order to generate power. As an active solution, luminescent solar concentrators allow production of cheap solar energy by electricity generation in buildings even where the orientation and tendency is not at its optimum like north façade.

Solar cell modules located in the glass are designed detailed in terms of different thickness, transparency and size values to meet the need of safety for building as distinct from other PV applications on other envelope aspects such as roofs thus it takes role of both energy producer and being a classic window.

Those power generating windows with solar cells have shorter energy payback period compared to traditional PV modules. Frameless and colour elective windows are also comply with the building requirements in terms of high visibility and aesthetic property.

Transparent luminescent solar PV

Transparent luminescent glasses allow the entrance of the sunlight to the internal space by avoiding UV and infrared radiation. Moreover it makes seeing through the glass possible. In the market place there are glasses with transparency degree of 10%, 20% or 30% which can be chosen accordingly the required luminosity and desired view quality.

Figure 3.36: Transparency and electricity relation on interior area
Source: www.sciencedaily.com

Coloured luminescent solar PV

The maximum amount of power that can be generated is not only related to the amount of received solar energy, but also related to the colour of window glass. Thus, coloured glass containing photovoltaic windows are tending to offer more solar power.

Wide range of colour option for solar concentrator glasses are available in the market to be integrated as an artistic PV skylight, curtain wall, balcony or any other multifunctional constructive solution by satisfying aesthetic concerns.

Figure 3.37: Coloured solar glasses
Source: www.onyxsolar.com

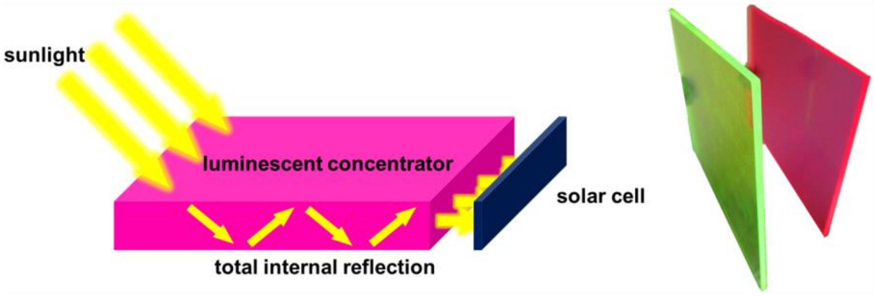
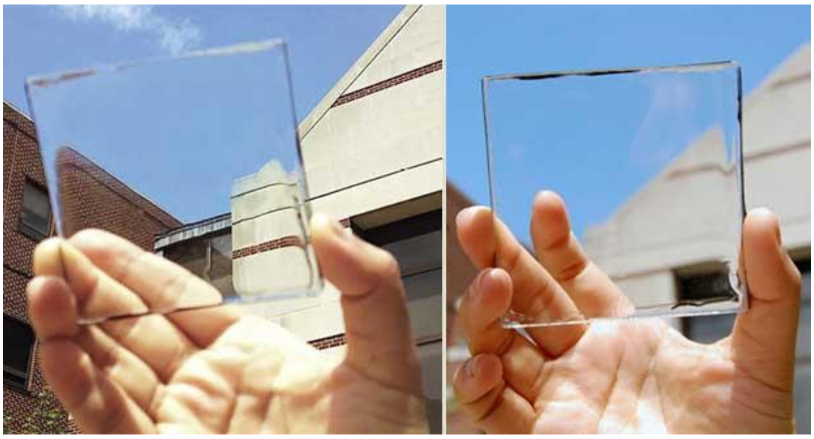
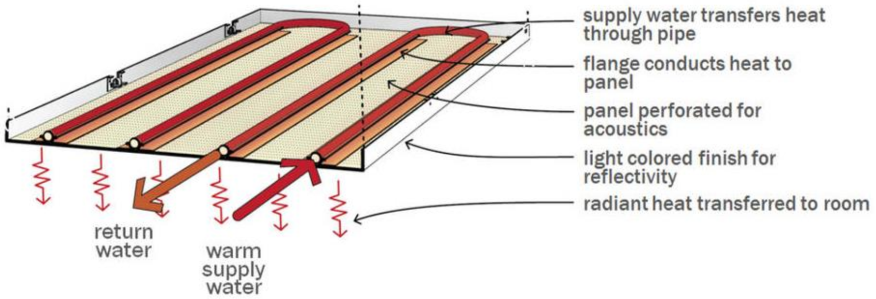
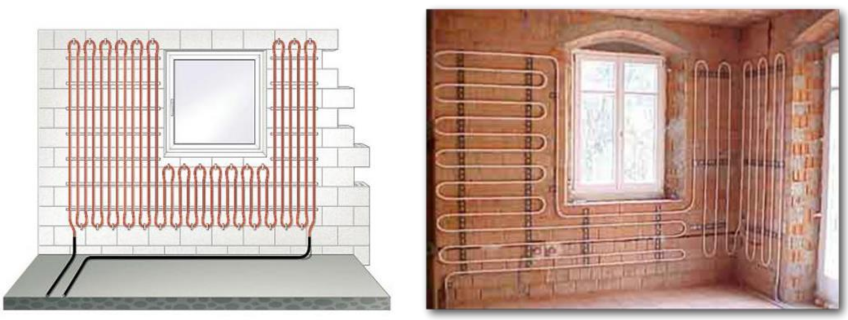
Solution type	Technology based solution
Application Area	Windows
Working scheme	 Figure 3.38: Working principle of luminescent solar PV Source: www.thesolarspark.co.uk
Picture	 Figure 3.39: Transparent luminescent solar PV Source: http://csglobe.com
Brief description	Luminescent solar PVs are devices which concentrates solar radiation in order to produce electricity. They are capable of generating dozens of watts per square meter. The actual power production by windows areas are related to the colour of the glass, light-emitting layer quality and the solar cell's performances.
Types of materials	Photovoltaic cells (glaze or coat on window material is optional)
Advantages	Improves envelope quality Innovative design Natural illumination UV filter Insulation both thermal and acoustic
Disadvantages	Surface pollution may decrease the efficiency No production when there is no sunlight High installation cost

Table 3.5: Coloured luminescent solar PV

3.2 Radiant heating and cooling

Radiant heating panel systems assure characteristic benefits in terms of large amounts of energy saving with low consumption rate while providing better thermal comfort zones subject to the building location and climate. To achieve a successful heating and cooling by radiant panel system is possible by the correct identification of the optimum temperature for the space in order to keep thermal comfort of the residents high. When radiant heating and cooling technology is considered as the active envelope solution, it should be known that heat conduction through the walls, heat convection between the indoor air and the heating or cooling panel, radiation of the heat between the panels and the surrounding areas are the heat transfer mechanisms that involved in and makes system complex. Therefore, such a serious and detailed study should be done before the application.

Solution type	Technology based solution
Application Area	Wall, Floor Ceiling
Working Scheme	 Figure 3.40: Radiant heating & cooling Source: www.aiatopten.org
Picture	 Figure 3.41: Radiant heating and cooling
Brief description	Radiant heating and cooling panel system is one of the most efficient system that is used in order to satisfy thermal comfort criteria of building's internal space. Energy consumption reduction is targeted in this technology.

Types of radiant panel applications	Direct heating/cooling by electric resistance. Heating/Cooling by circulation of the water inside panels (which only needs to be 2-4°C below the desired indoor air temperature). Heating/Cooling by hot/cold air.
Advantages	Ideal thermal comfort Sustainable source usage Low energy consumption Improves thermal capacity Aesthetic and expanded living area Low installation and operating cost
Disadvantages	Risk of condensation Drainage problems of the heat taken in vapour No quick respond to temperature settings Capacity limitation High capital cost Needs qualified technical support team

Table 3.6: Radiant Heating and Cooling

Radiant heating is done by hot water circulation inside manually installed pipes inside of the radiant panels. Heating processes that are using conventional radiators requires water at the temperature level of 60-80°C in order to reach 20°C indoor air temperature. However radiant heating systems achieve the same heating level by requiring water at lower temperature rates so that they referred to low temperature systems. With that technology, uneven temperature distribution inside the building can be possibly prevented. It also provides healthier interior humidity level as a result of improved room climate.

In case of radiant cooling system is considered, working of the system is done in the same way with only difference in heat transfer direction. Chilled fluid circulates inside the pipes instead of heated fluid on the walls or ceiling areas. Radiant panels absorb the thermal energy that radiates from the surrounding systems in order to decrease mean radiant temperature of the interior area. The main difference between radiant cooling solutions and air conditioning systems is the transport mechanism. Air conditioning systems use only convection whereas radiant cooling uses a combination of both radiation and convection.

3.3 Advisable solutions depending on aesthetic, dimensional and functional requirements

Solar thermal panels, photovoltaics and radiant heating panels are the main active solutions that considered within the report on retrofitting of building envelope. When those technologies are considered deeply in detail, wall and roof applications can be seen as the most common applicable areas.

There are many different types of profits can be provided by selected solutions. First of all, their application compatibility on not only for new buildings but also on the existing building leads them to be a reason for preference for any type of building envelope. Secondly, their multifunctional properties can be listed as another reason of selection. When solar technologies are considered, it can be easily seen many advantages that they provide gives opportunity of cost reduction.

For example building integrated technologies on roof or façade area can be replace the existing conventional construction materials such as roof tiles. By their improved aesthetical properties, roof area can be built by proper PV panels which produces energy and reduces roof material cost at the same time. Moreover, they can even reduce insulation material demand by their direct application on the façade area which provides thermal protection on the façade surface. Thin film solar cells have the same effect on window areas as well by satisfying the need of conventional glasses with their transparent properties beside energy production facilities. In case of radiant panel applications are selected, due to their low energy consumption and low installation costs, their operating cost will be low as well. So their profits on energy consumption and easiness about installation lead to a minimization on cost in total.

All these properties ensure the major profitability of the solutions which are selected in order to create more efficient buildings – so that districts. And every single advantage results by the cost reduction. Requirements of the considered technologies are identified in three main columns as they are aesthetic requirements, dimensional requirements and functional requirements.

Technology	Application area	Aesthetic requirements	Dimensional requirements	Functional requirements
Solar Thermal Panels	Roof	Collector material, surface texture and absorber colour Shape and size of modules Type of jointing	Equipment Area Size and position of collector Shape and size of modules Easy Accessibility	Shadow limitation

Technology	Application area	Aesthetic requirements	Dimensional requirements	Functional requirements
	Façade	Collector material, surface texture and absorber colour Shape and size of modules Type of jointing	Equipment Area Size and position of collector Shape and size of modules Easy Accessibility	Shadow limitation
Photovoltaic Panels	Roof	Shape and size of modules Architectural suitability Suitability with roof tiles (for BIPVs)	Minimum area required for the integration Easy Accessibility Equipment Area	Shadow limitation State of electricity grid Electrical storage
	Façade	Shape and size of modules Architectural suitability Suitability with façade area	Minimum area required for the integration Easy Accessibility Equipment Area	Shadow limitation State of electricity grid Electrical storage
Radiant Heating	Façade	There are not aesthetic requirements because radiant panels are covert	There are no additional dimensional requirements	Heating or cooling performance maximization Energy consumption reduction
Solar concentrators	Windows	Architectural suitability in terms of colour, size and transparency	Technology done directly to the existing window location so there are no additional dimensional requirement	Energy production Natural lighting Insulation

Table 3.7: Technologies and their requirements
Source: www.e-education.psu.edu

4 Synergies between bioclimatic, passive and active technologies

Combination of various technologies that produces an achievement greater than the success result by their individual performance can be defined as synergy between them. Synergy is the potential property of technology's interaction and it can possibly be applied to many different aspects of science. When it comes to the retrofitting issue, benefits of synergy cannot be passed over. Thus, it can be easily said that envelope applications are able to be combined with both each other and different technologies belongs to the rest of the building system in order to maximize the building sustainability.

4.1 Envelope application synergies between bioclimatic architecture and passive technologies and active technologies

A synergy table is prepared to show relations between technologies. Grey coloured part represents the mirror view of the part below, and yellow blocks are showing where the creation of synergy is possible.

Applied Technologies		Active Solutions			Bioclimatic Solutions					Passive Solutions		
		Solar thermal p.	PV panel	Radiant Heating p.	Evaporating cooling	Radiant cooling	Earth cooling	Natural ventilation	Solar shading	Thermal insulation	Opaque elements	Translucent elements
Active Solutions	Solar thermal panel											
	PV panel	Secondary										
	Radiant heating panel	Primary	Primary									
Bioclimatic Solutions	Evaporating cooling	Secondary	Secondary	Secondary								
	Radiant cooling	Secondary	Secondary	Secondary	Secondary							
	Earth cooling	Secondary	Secondary	Secondary	Secondary	Secondary						
	Natural ventilation	Secondary	Primary	Secondary	Secondary	Secondary	Secondary					
	Solar shading	Primary	Primary	Secondary	Secondary	Secondary	Secondary	Secondary				
Passive Solutions	Thermal insulation	Secondary	Primary	Primary	Secondary	Secondary	Secondary	Secondary	Secondary			
	Opaque elements	Secondary	Primary	Secondary	Secondary	Secondary	Secondary	Secondary	Primary	Primary		
	Translucent elements	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary	Primary	Primary	Secondary	

Primary use of synergy

Secondary use of synergy

Table 4.1: Identification of synergistic effects of envelope solutions

Focusing on envelope strategies, synergy between technologies in terms of passive, bioclimatic architecture and active envelope solutions can be exemplified as follows.

Passive shading elements + PV collectors

PV collectors can act as the shading provider elements for the districts according to their integration type on building facade. Further information about building integrated and building added photovoltaic panel applications is given in the section 3.1.

Figure 4.1: PV panels used as shading elements
Source: www.tenum.ch

Radiant heating + Solar Thermal

Radiant heating panels which are designed and planned to be work with a hot water flow inside can create a synergistic operation with solar thermal applications. By transferred domestic hot water which has supplied from solar thermal panels possibly used for radiant heating process.

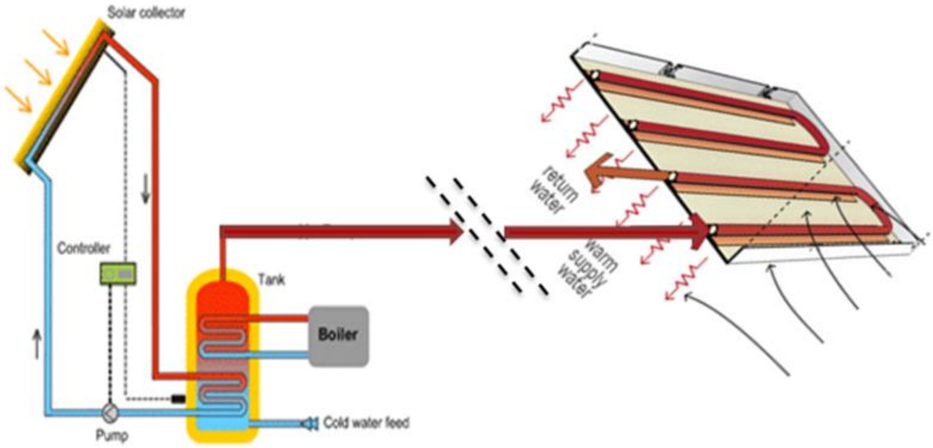


Figure 4.2: Possible synergy between radiant heating systems and solar thermal collectors

Radiant heating + Photovoltaic panels

In case of direct heating by electric resistance preferred for the radiant heating solutions, converted electricity by PV panels can be used as the energy supplier.

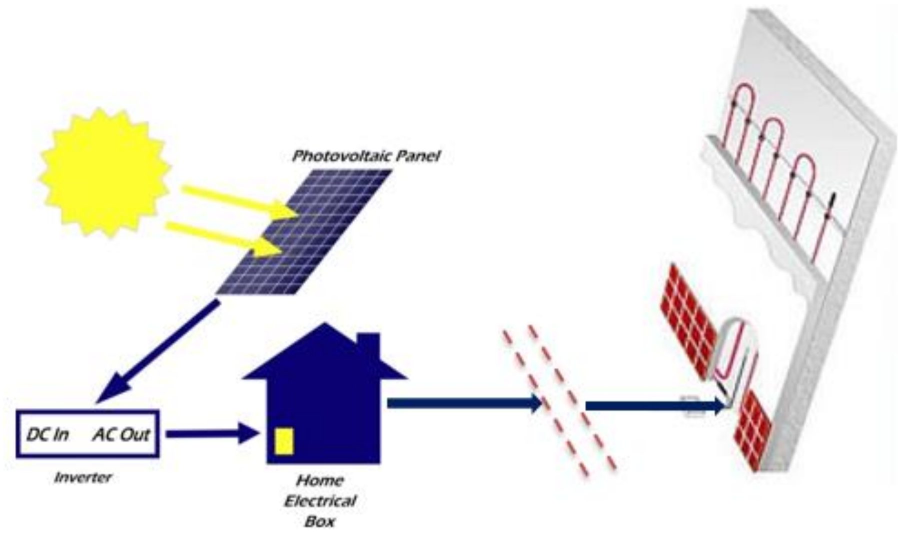


Figure 4.3: Possible synergy between radiant heating and photovoltaic technology

While taking advantage of the synergy between systems, their advantages and disadvantages should be considered and decision should be done as a result of a detailed evaluation.

Summary of advantage and disadvantages are shown in the table below.

Advantages	Disadvantages
Increased potential of maximum achievement	Easier in theory than practise
Gain in efficiency by reduction in energy consumption	Higher investment cost
Higher economic benefits	Aesthetic parameters may play second fiddle
Enhancement of building image in construction and energy sector	Complicated control mechanism
Share of technologic skills	Power distribution problems
Developed strength of combined technologies	Negative interaction in case of failure
Influence public opinion	Possible retarding effect of systems on each other
Risk reduction by diversification	Difficulty in problem identification
Commercial interest spread	Lack of experience on emerging technologies

Table 4.2: Advantages and disadvantages between synergy of envelope applications

5 European research approach to energy-efficient building envelope retrofitting

Transforming typical building retrofitting to make way for deep reductions in energy consumption (known as deep renovation) is a high priority settle by the International Energy Agency [10] and pushed by the European Commission. As well as enabling permanent ongoing reductions in energy costs, deep renovation can reduce the capital cost of heating, ventilation and air-conditioning (HVAC) equipment. Also, building envelope improvements can increase the comfort of the occupants and the quality of life to millions of citizens, while offering significant non-energy benefits such as reduced health care costs and reduced mortality of “at risk” populations.

The goals settled internationally push for the transformation of the actual inefficient building stock into zero-energy buildings in the future.

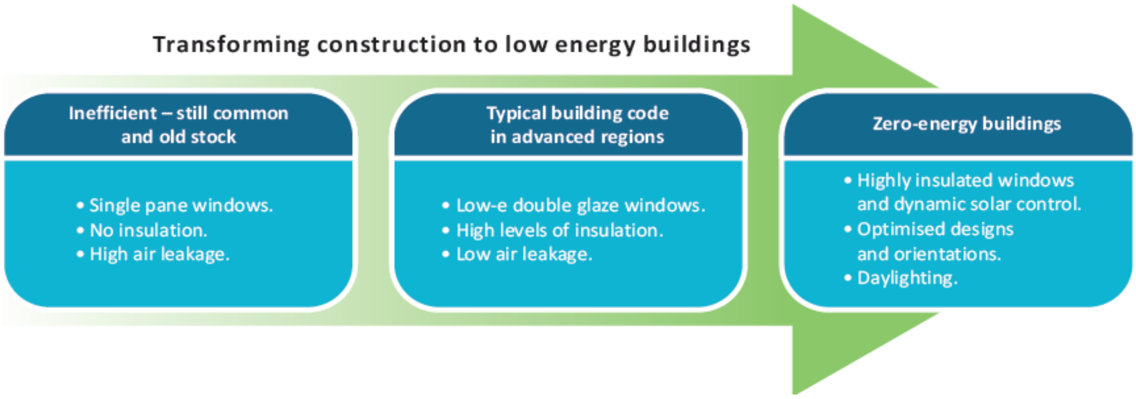


Figure 5.1: Progression of building envelopes from old stock to future technology
Source: International Energy Agency

This need advanced options, not only to support whole-building approaches but also to improve the energy efficiency of the individual components:

- High levels of insulation in walls, roofs and floors, to reduce heat losses in cold climates, optimized through life-cycle cost (LCC) assessment
- High-performance windows, with low thermal transmittance for the entire assembly (including frames and edge seals) and climate-appropriate solar heat gain coefficients (SHGC)
- Highly reflective surfaces in hot climates, including both white and “cool-coloured” roofs and walls, with glare minimized
- Properly sealed structures to ensure low air infiltration rates, with controlled ventilation for fresh air
- Minimization of thermal bridges (components that easily conduct heat), such as high thermal conductive fasteners and structural members, while managing moisture concerns within integrated building components and materials

In the next table main developed and ongoing technology solutions for building envelope are shown, classified according to economy and climate and construction types (new buildings and retrofitting purposes).

Type of economy	Climate	Technology	
		New construction	Retrofit
		Insulation, air sealing and double-glazed low-e windows for all buildings*	
Developed	Hot climate	– Architectural shading – Very low-SHGC windows (or dynamic – Shades/windows) – Reflective walls/roofs – Advanced roofs (integrated design/BIPV) – Optimised natural/mechanical ventilation	– Exterior window shading and dynamic glass/shading – Reflective roofing materials and coatings – Reflective wall coatings – Window film with lower SHGC – New low-SHGC windows
	Cold climate	– Highly insulated windows – Passive heating gain (architectural feature /dynamic glass/shades) – Passivhaus-equivalent performance based on LCC limitations	– Highly insulated windows – Low-e storm or interior panels – Insulated shades and other insulating attachments (low-e films) – Exterior insulating wall systems – Interior high-performance insulation
Developing	Hot climate	– Exterior shading and architectural features – Low-SHGC windows – Reflective roofs and wall coatings – Optimised natural/mechanical ventilation	– Exterior shading – Reflective coatings (roof and wall) – Low-cost window films – Natural ventilation
	Cold climate	– Highly insulated windows (possibly double-glazed with low-e storm panel) – Passive heating gain (architectural feature) – Optimised low-cost insulation and air sealing	– Low-e storm or interior panels – Insulated shades and other insulating attachments (low-e films) – Exterior insulating wall systems – Cavity insulation, lower-cost (e.g. expanded polystyrene) interior insulation

Notes: BIPV = building-integrated photovoltaic. Passivhaus, an advanced residential building programme that calls for very high levels of building envelope performance, has gained significant momentum in Europe and is active globally (see www.passiv.de/en/index.php).

* The IEA recommends a minimum performance for all new windows globally to meet the performance of double glaze low-e with low-conductive frames and climate-optimised SHGC. Air sealing is needed for any building that will have heating and cooling provided. Insulation is needed for all applications, renovation is more challenging but possible, especially for roofs in all climates.

Table 5.1: Building envelope technologies according to economy, climate and construction type
Source: International Energy Agency

5.1 Current status of research activity

5.1.1 Initiatives implemented and funded at European level

The concept of a common European Research Area is put into practice by the Strategic Energy Technology Plan (SET-Plan) [11]. The SET-Plan proposes bringing together decision-makers from the Member States, industry and research and financial communities. Together they should jointly define priorities and propose actions in a structured and mission-oriented way. Thus fragmentation will be overcome and coherence reinforced between national, European and international efforts.

Technology Platforms provide a more stable framework for cooperation in a specific area. They are led by industry and have the objective to develop a common vision and working towards their implementation. European Technology Platforms (ETPs) are industry-led stakeholder to develop short to long-term research and innovation agendas and roadmaps for action at EU and national level to be supported by both private and public funding.

ETPs span a wide range of technology areas and have to date played an important role by developing joint visions, setting Strategic Research and Innovation Agendas and contributing to the definition of the research priorities including those under the Research Framework Programs. European Technology Platforms are independent organizations.

Building on the strategies for Europe 2020 and for an Innovation Union, the Commission's Horizon 2020 proposal for an integrated research and innovation framework programme recognises the role of ETPs as part of the external advice and societal engagement needed to implement Horizon 2020.

Bio-based economy	Energy	Environment	ICT	Production and processes	Transport
EATIP	Biofuels	WssTP	ARTEMIS	ECTP	ACARE
ETPGAH	EU PV TP		euRobotics	ESTEP	ERRAC
Food for Life	TPWind		ETP4HPC	EuMaT	ERTRAC
Forest-based	RHC		ENIAC	FTC	Logistics
Plants	SmartGrids		EPoSS	SusChem	Waterborne
FABRE TP	SNETP		Networld 2020	Nanomedicine	
TP Organics	ZEP		NEM	ETP-SMR	
			NESSI	Manufuture	
			Photonics 21		
Cross ETP Initiatives					
Nanofutures					
Industrial Safety					
PROSUMER.net					

Figure 5.2: Individual ETPs
Source: http://cordis.europa.eu/technology-platforms/individual_en.html

Starting at this point, Joint Technology Initiatives (JTIs) are a means to implement the Strategic Research Agendas (SRAs) of a limited number of European Technology Platforms (ETPs). In these few ETPs, the scale and scope of the objectives is such that loose co-ordination through ETPs and support through the regular instruments of the Framework Programme for Research and Development are not sufficient. Instead, effective implementation requires a dedicated mechanism that enables the necessary leadership and coordination to achieve the research objectives. To meet the needs of this small number of ETPs, the concept of "Joint Technology Initiatives" has been developed.

5.1.2 CORDIS: Community Research and Development Information Service

It is the European Commission's primary public repository and portal to disseminate information on all EU-funded research projects and their results in the broadest sense.

The website and repository include all public information held by the European Commission (project factsheets, publishable reports and deliverables), editorial content to support communication and exploitation (news, events, success stories, magazines, multilingual "results in brief" for the broader public) and comprehensive links to external sources such as open access publications and websites.

The European Construction Technology Platform (ECTP) [12]

The objective of this platform is the analysis of the major challenges that the construction sector faces in terms of society, sustainability and technological development.

Its focus areas are:

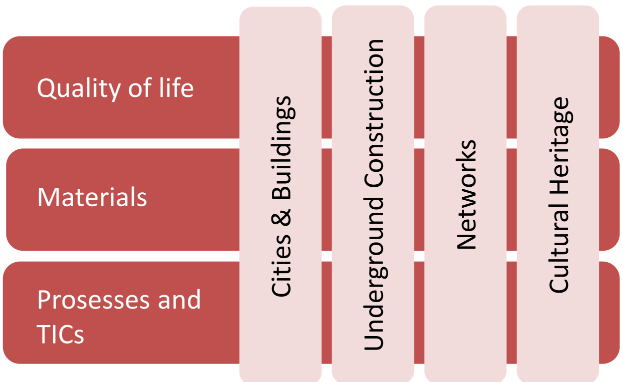


Figure 5.3: ECTP focus areas

Energy Efficiency Buildings (E2B) [13]

The overall vision of the Energy Efficient Buildings European Initiative (E2B EI) is to deliver, implement and optimize building and district concepts that have the technical, economic and societal potential to drastically decrease energy consumption and reduce CO2 emissions in both new and existing buildings across the European Union (EU) incentivizing the level of research into key technologies and develop a competitive industry in the fields of energy efficient construction processes, products and services.

Environmental Technologies Action Plan (ETAP) [14]

Eco-innovation for a Sustainable Future: Eco-friendly technologies are good for business, reduce pressure on the environment, and can create new jobs. The European Commission invites all stakeholders and the public to discover and share promising opportunities to make eco-innovation an everyday reality throughout Europe.

ECCREDI [15]

The aim of ECCREDI (European Council for Construction Research, Development and Innovation) is to contribute to the competitiveness, quality, safety and environmental performance of the construction sector and to the overall sustainability of the built environment, by increasing the extent and effectiveness of construction research, technical and process development as well as innovation.

ENCORD [16]

ENCORD's main objective is to be Europe's forum for the promotion of industry-led research, development and innovation in the construction sector.

Eracobuild [17]

Eracobuild (Strategic Networking of RDI Programmes in Construction and Operation of Buildings) aims at strengthening and enlarging the strategic networking of RDI programmes in the field of "construction and operation of buildings" initiated in the previous ERABUILD coordination action. Eracobuild gathers 34 programme owners or managers coming from 17 EU Members States, 4 Associated Countries and 1 European Region.

In the European Commision's web page devoted to Research & Innovation [18], there is a compilation, in the Energy section, of the main research fields and technological developments, including the list of funded projects. Some of them are applicable to building envelope and building and district retroffiting.

Figure 5.4: European areas of energy & innovation research
Source: European Commission

On the other hand, CONCERTO [19] is a European Commission initiative within the European Research Framework Programmes (FP6 and FP7) that will continue in the Horizon2020 supporting Smart City projects. According to the demostrative experience performed in CONCERTO Innitiative, a list of innovative technologies that are ready to be applied is offered. These measures promote the use of renewable energy sources in cities and the application of energy efficiency measures, as well as the development of sustainable buildings and districts. This source is considered of great interest because of its specific focus on buildings and urban communities. The technology´s information is divided into renewable energy sources and low carbon technologies:

Figure 5.5: List of renewable energy sources included in CONCERTO
Source: http://concerto.eu

Figure 5.6: List of Low-carbon technologies included in CONCERTO
Source: http://concerto.eu

5.2 Prospective: the future of building envelope research activity

The document *Energy Futures: The role of research and technological deveopment* (European Communities, 2006) [20] explores, by means of several technics and resources, the future of the European research in the field of energy efficiency. Its main sources are several European reseach projects such as SAPIENTIA, WETO-H2, EURENDEL [21] and VLEEM. Some additional projects are included in this report too: CASCADE-MINTS, HYWAYS, EUSUSTEL, ENCOURAGED, RELIANCE, SOLID-DER or ERMINE. The conclusions of this work could be summarize in three:

- Energy system change slowly: building sector, power generation and energy intensive manufacturing require innovations that will need many years to be implemented
- There is a high cost of not doing research in the field of energy in terms of innovation and CO_2 emissions
- Real paradigm shift is needed

Next table stablish a learning velocity and characteristics for main energy efficiency technologies.

Capital Costs			
	Mostly Learning by doing	**Balanced Learning**	**Mostly Learning by research**
Fast Learning	Hydrogen internal combustion engine passenger car	New Nuclear (4th gen.)/Building integrated PV	Fuel Cell/Wind turbines offshore/Post-combustion CO_2 capture (Supercritical pulverized coal)/Pre-combustion CO_2 capture (Integrated gasification combined cycle)
Medium Learning	Nuclear (2nd and 3rd gen.)/Cogeneration from gas/Post-combustion CO_2 capture (Gas turbine combined cycle)	Hydrogen from biomass Pyrolysis/Hydrogen from Nuclear High-temperature Thermochemical Cycles/Hydrogen from Water Electrolysis and dedicated Nuclear power plant/Pre-Combustion CO_2 capture(Coal Partial Oxidation)/Large Hydro/Supercritical pulverized coal/Electric passenger car/	Hydrogen from Coal Partial Oxidation/Hydrogen from Solar High-temperature Thermochemical cycles/ Oil fired Open cycle gas turbine/Wind turbines Onshore/Solar Thermal power plant cylinder-parabolic/Biomass thermal/Biomass gasification plus combined cycle/Hybrid passenger car
Slow Learning	Hydrogen from Gas Steam Reforming (large scale)/Lignite conventional thermal/Coal conventional thermal/On board reformer cost (Natural gas fuel cells passenger cars)/Hydrogen storage cost (hydrogen fuel cell passenger cars)	Gas turbine open cycle	Hydrogen from Water Electrolysis (base load electricity from Grid)/Pre-Combustion CO2 capture (Gas Steam Reforming)/Integrated coal gasification/Oil conventional thermal/Gas conventional thermal/Gas turbine combined cycle/Small hydro (<25 MW)/CO_2 sequestration

Table 5.2: Technology learning velocity & characteristics
Source: EURENDEL

The Delphy survey of EURENDEL [21] find a great consensus about that doubling the energy efficiency in industrial production is considered to be likely before 2030 (65% of the responses). Also is a big consensus on the prediction that the 50% of all new buildings in Europe will be low energy buildings before that date (75% of the responses).

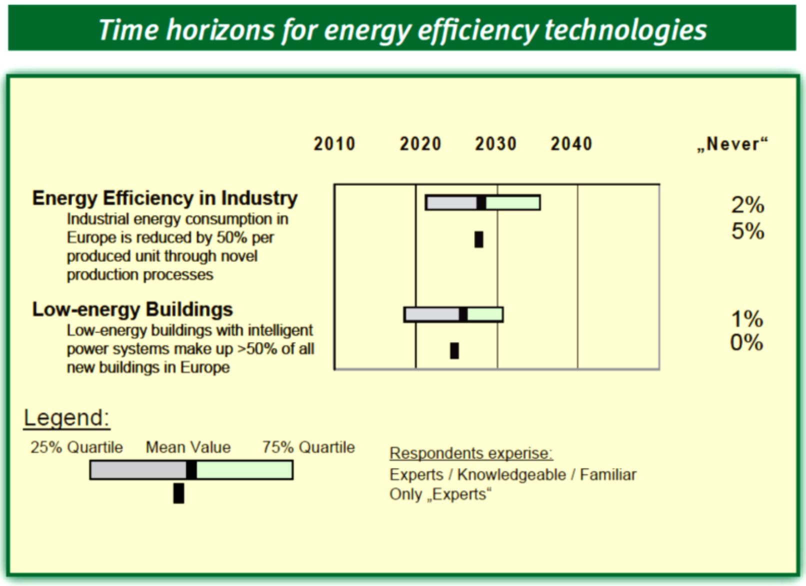


Figure 5.7: Time horizons for energy efficiency technologies
Source: EURENDEL

On other hand, the analysis of the time horizon for renewable energy technologies shows that the majority of experts believe that 25% of Europe´s total energy demand can be met by renewable energy sources before 2030. But that expectation is considered dependent on the existence of appropiate support th new technologies. Photovoltaic technology can play a significant role in Europe´s energy future. A 5% contribution to energy mix is considered possible between 2030 and 2040.

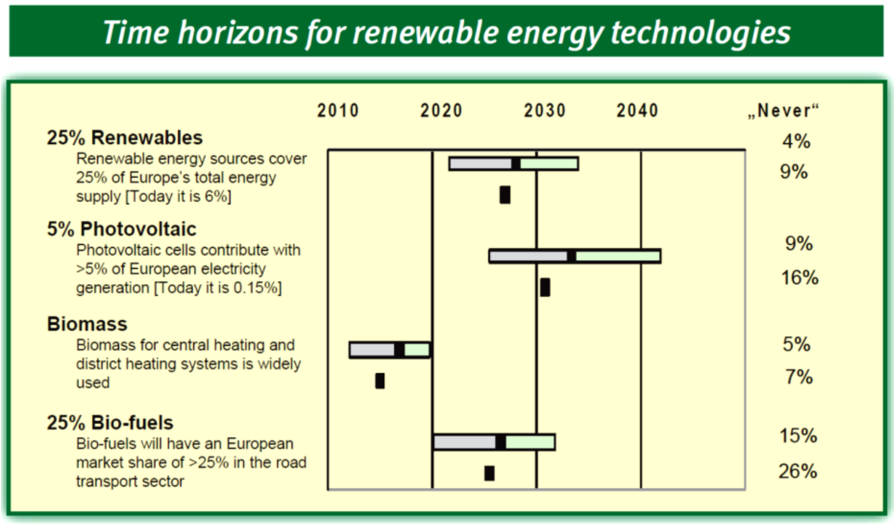


Figure 5.8: Time horizons for renewable energy technologies
Source: EURENDEL

Energy storage technologies are consiered an important gap on energy market and a key component on renewable energy implementation. The EURENDEL [21] survey shows the risk of the under-investment in energy storage percibed in the current support schemes. The hydrogen system is considered a major storage option. But other storage alternatives such as batteries, flywheels or super-capacitators are also considered highly relevant. Is still needed to identify a suitable long term growth path for the large new infraestructure need required in the expansion of the hydrogen economy.

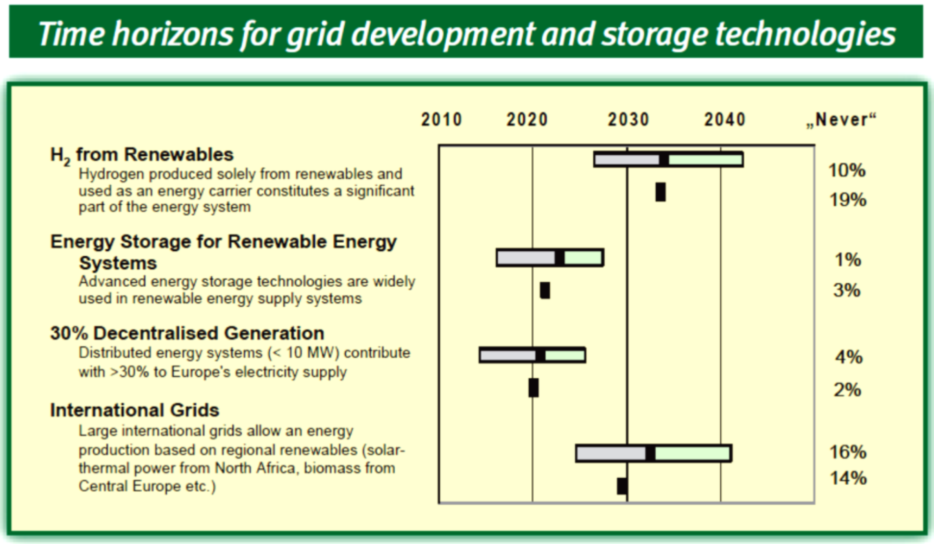


Figure 5.9: Time horizons for grid development and storage technologies
Source: EURENDEL

The *Technology Roadmap for Energy efficient building envelopes* presented by the International Energy Agency [10] sets the R&D priorities on the following technologies as future leaders of most important returns on investment:

- Highly insulated windows
- Advanced, high-performance, “thin” insulation
- Less labor-intensive air sealing, and lower-cost validation testing
- Lower-cost automated dynamic shading and glazing, and
- More durable and lower-cost reflective roof materials and reflective coatings

According to the European Commission document: *Energy-Efficient Buildings: multi annual roadmap for the contractual PPP under Horizon 2020* (E2B and ETPC, 2013) [22], the building envelope is a critical element to reach the 2050 decarbonisation goals. Indeed, according to the *Building Technologies Program, Roadmap overview estimation* [23], the building envelope impacts 57 % of the building thermal loads.

The next tables shows an overview of the main challenges and barriers identified by the European Commission related to the building design and its envelope.

	Challenge	Barriers	
Design	The design of energy/resource efficient buildings (new or to be refurbished) must involve all stake-holders within a collaborative approach, allowing cost-efficient solutions Improving the planning process implies shared data, practices and tools with proper training and education	**Technical/ Technological**	No proper tools for easy holistic planning of energy-efficient buildings exist for a number of building types, especially for refurbishment. Several software products and lack of tool interoperability: exchange of error-free data from one 3D building-CAD to another is not possible at present; Reliable material and equipment data base for holistic planning
		Industrial	Software vendors still hesitate to invest in BIM interoperability due to the lack of demand in having compatible BIM, IFC, IFD, IDM/MVD limitations
		Economic	Little realization at district or city level for large scale improvements of the existing stock or new urban development at reasonable costs. Time constraints impact iterative design in terms of energy efficiency
		Societal	Resistance to change Considerations for cultural heritage buildings
		Organizational	Building Information Modelling makes responsibility sharing fuzzy Lack of Experts on combined BIM and IFC knowledge
		Regulatory	Simplification in approval procedures for building permissions of energy-efficient districts IFC certification suffers low quality Regulating qualitative issues is difficult

Table 5.3: Building design challenges and barriers
Source: European Commission

	Challenge	Barriers	
Envelope	A reliable multi-objective envelope optimization methodology allows integrating all envelope constraints for new and refurbished buildings Performances keep improving in terms of insulation, costs, energy harvesting, building integration and building adaptability Innovative materials and prefabricated components help improving energy & resource efficiency durably Users are accounted for the delivery of the full energy performance potential of envelopes Full exploitation of different climate potential	**Technical/ Technological**	Meeting the design performances of integrated envelopes is still difficult; Assessing the contribution of each envelope component to the system performance over time is still difficult; The detection of users' misbehavior is very limited; Data on material characteristics and energy needs are lacking
		Industrial	Industrialization of building envelope solutions still very costly and prefabrication is under represented; Characterization methods and standards lack high volume /high performance eco construction materials
		Economic	The selection of envelope solutions is still driven by investment costs and building codes; Integrating the envelope components is still costly to meet the final performance targets; Return on investment for refurbishment projects is not attractive; High intrusiveness in refurbishment intervention;
		Societal	Building owners are not open enough to make sustainable choices; High intrusiveness in refurbishment intervention; New multifunctional components require continuous education of craftsmen which is often not the case; Limited awareness of cultural heritage value
		Organizational	Lack of performance commitments on refurbishment contracts; Skills on envelope design and selection to be raised; Dispersed ownership in large housing/buildings prevents from refurbishment; Fragmented value chain often leads to non-optimal overall performance; Building planners often have problems with innovative materials and components
		Regulatory	Differences in national standards slow components standardization and prefabrication; Guarantee and insurance schemes for refurbishment; Regulations for public decision promote lowest prices, not best performances; Regulations for historic buildings preservation may be complex and it may vary considerably from country to country

Table 5.4: Building envelope challenges and barriers
Source: European Commission

Energy efficient buildings would use envelopes that are well-performing in terms of heat transfer and air tightness, durable, adaptable, user-centric and cost effective. Envelopes become more resistant to external (i.e. climate, fire, and natural hazards) and internal aggressions (moisture): they require less maintenance and allow for easier and better-quality maintenance work. Thermal bridges are addresses and the ageing of components is better understood which allows appraising their loss of performance over time. The main targets are:

- Energy efficient envelopes combine easy to integrate materials and components to lower building energy demand
- User centric envelopes maximize the envelope value, including improved aesthetics, acoustic and lighting comfort, quality of indoor environment
- Envelopes are adaptable to a dynamic and complex environment
- Envelopes are able to integrate generation and conversion of incoming solar radiation

Energy efficient envelopes combine easy to integrate materials and components to lower building energy demand

Materials and components are critical to the envelope for its insulating properties but also for anchoring the resulting envelope on existing or new structural elements. Current technologies are not efficient enough in terms of performance and costs, especially for refurbishment and cultural heritage where details and original aesthetics need to be kept (e.g. windows). Further research is needed to improve understanding of material and component behaviour in the whole life cycle and, as a consequence, to be able to produce the corresponding products. Know-how is thus needed to help designers and construction companies to define more exactly the materials and components really needed to fulfil the needs of the works through service life modelling and design. Durability has to be evaluated in real installation conditions, as these may influence the final product performances.

Mass manufacturing including pre-fabrication must be investigated to lower manufacturing costs and ease building integration processes, including aesthetics. Advanced and high-performance materials/products (i.e. concrete and composite products, steel-based products, ceramic products, tiles, bricks, nanotechnology-based insulation materials and coatings…) are needed mainly to reduce the building energy demand in the use-phase. Further actions are necessary to lower the content of embodied energy. New materials combining structural properties and/or thermal resistance/inertia and/or light weight need to be developed. Solutions should address the well-known problem of thermal bridges while taking into account overall resource efficiency issues along life cycle.

The following research and innovation 'Targeted Areas' can be identified:

- Development of innovative super insulating materials and components, and associated manufacturing processes, for refurbishing existing buildings (including those of historical and cultural value) and new buildings:
  - New cost-effective energy efficient insulating materials from renewable sources or waste materials

  - Materials with thermal conductivity of <0.03 W/mK based on nano-foams, silica aerogels or mineral foams, capable to both retain and reflect heat from inside or outside or integrate other functions with solutions for both new buildings and for energetic improvement of existing ones
  - Bio-based materials like natural fibres or foams for insulation with high durability
  - Innovative materials for barriers, pipes etc. for easy integration and reduction of thermal bridges
- New value chains for bio-based construction materials and bio-based treatments considering the complete life cycle
- Improve technical properties (e.g. fire resistance) for organic materials;
- Development of chemical coupling agents and binders; insulation materials;
- Low-CO_2 advanced concrete available for durable building envelopes;
- Basement insulation, moisture protecting systems and new building materials for draining;
- Mass manufactured prefabricated modules for optimum cost, performance, product handling and personal safety during construction, both for new buildings and for refurbishing;
- Demonstration of photo-catalyst or other de-polluting materials to extend the life of construction materials (with e.g. automatic cleaning process) and at the same time substantially decrease the concentration of some air pollutants in urban air (COV, SOx, NOx), especially in confined spaces such as canyon streets, tunnels and parking;
- Modular, ‘plug and play’, mass customised envelope solutions to ease construction processes and replacement of components (i.e. windows).

<u>User centric envelopes maximize the envelope value, including improved aesthetics, acoustic and lighting comfort, quality of indoor environment</u>

Envelopes demonstrate usability and flexibility to contribute to improved health and comfort, while taking into account use values which reinforces users’ acceptance:

- The adaptation to the users’ evolution (people ageing) and users’ behaviour;
- The reduction of the intrusiveness of façade retrofitting activities in order to maintain the general building functionalities and reducing the impact for the user.

The following research and innovation ‘Targeted Areas’ can be identified:

- Technologies and methods to understand and maximise user acceptance of adaptable envelopes in new and existing buildings (including buildings of historical and cultural value), addressing for instance air quality, moisture control, ventilation control or automated blinds, with interrelated issues of summer overheating, airtightness and indoor air quality;

- Techniques to minimise the Volatile and Semi-volatile Organic Compound (VOC, SVOC) content of building materials (in the production phase and the use-phase).

Envelopes are adaptable to a dynamic and complex environment

The envelope functional characteristics enable the building envelope to adapt to a dynamic and complex environment during its lifetime 30 ("Perception, Reasoning, Action"). Envelopes also facilitate the future renovation or conversion of the whole or part of the building fostering creativity and an active role of architects and engineers at design stage:

- The capability of adapting to different shapes, façade conditions, building orientations and general conditions of the building along its lifetime;
- The conversion of rooms, or buildings, to new usage;
- The possibility to integrate new solutions (upcoming technologies) and systems;
- The capability of dynamic adaptation or self-adaptation, which becomes also crucial due to:
  - Current weather and building load situation, taking into account the actual user's preferences.
  - Changing use patterns, including new users, or family instead of single users.

The following research and innovation 'Targeted Areas' can be identified:

- Development and manufacturing of envelope improving and optimizing natural light and ventilation inside building;
- Development and manufacturing of energy storing converting materials (e.g., Phase Change Materials and switchable glazing (e.g. thermochromic, photochromic or electrochromic) combined with PV in glazing panes);
- Development of semi permeable insulation membranes and pigments with adaptable absorption reflection spectrum, Façade component with changing IR absorption and reflection on demand in combination with insulation and switchable U-values;
- New testing procedures to measure material performances (e.g. with reference also to adaptive performances), including a wide range of expected exposure conditions;
- Seamless system integration of ICT components used to optimise the real time performance of envelopes;
- Improved flexible and durable façade systems with movable sun barriers;
- Full scale demonstrations of adaptable envelope integration in building refurbishment projects, including smart insulation materials (e.g. aerogels, vacuum insulation panels or other innovative materials);
- Full scale demonstrations of adaptable envelope integration in district refurbishment project.

Envelopes are able to integrate generation and conversion of incoming solar radiation

Both PV and thermal conversion can be smartly integrated to recover further solar incoming radiation, together with storage solutions. Façades can then be made active or reactive to signals from energy management systems. System integration must then be based on interoperable IT systems and interfaced with building energy management systems, smart grids or smart cities.

The following research and innovation 'Targeted Areas' can be identified:

- Smart building envelopes capable of adapting their energy generation and storage to external condition;
- Integration of existing and innovative PV components (e.g. OPV, DSSC) into building envelopes;
- System integration of 'thermally activated' material to reduce energy consumption;
- Interaction with smart grid/city systems.

Another source is the *Energy-Efficient Buildings PPP: Multi-annual roadmap and longer term strategy* (2010) [24], prepared by the Ad-hoc Industrial Advisory Group of the E2B Platform sets key challenges for a long term energy efficiency strategy in the construction sector, establishing the requirement of new knowledge and technologies to overcome current limitations to look forward energy independence and against climate change risks. Is considered that building industry´s transformation has to be achieved. The gaps are on systemic approaches for refurbishment, building design and quality of installations:

- Definition of energy-efficient solutions for renovation. Necessity of holistic approach for the integration of building components.
- Proposal: systems composed of insulation and thermal storage materials, and renewable energy harvesting).

The outcome of research into understanding barriers and drivers for non-technical (e.g. behaviour) and technical aspects, such as the development of multifunctional solutions (e.g. eco-efficiency, comfort, aesthetic value...), would speed up the transformation of the market.

Cost savings can also help greatly in supporting the development of the energy efficiency market. R&D together with deployment has to reduce drastically the cost of certain technologies (market of hundreds of thousands of units), such as heat pumps, photovoltaics or emerging lighting solutions. There is also a large potential for an increase of performance from the economic and CO_2 point of view.

Low carbon technologies have to move from a several-hundred-thousand to a multi-million-unit-per-year market. Financing issues also need to be tackled, jointly implementing new business models and services with a life cycle perspective.

REFURBISHMENT TO TRANSFORM EXISTING BUILDINGS INTO ENERGY-EFFICIENT BUILDINGS

Systems and Equipment for energy use for existing buildings
Envelope (for existing buildings)
Solutions for Cultural Heritage (including diagnostics)
Systemic Approach for existing buildings

CROSS-CUTTING CHALLENGES

HORIZONTAL ORGANIZATIONAL ASPECTS

Relationship between User and Energy
Geoclustering

Value Chain and SMEs focus

Knowledge transfer

Business models, organizational and financial models (including ESCOs)

HORIZONTAL TECHNOLOGICAL ASPECTS

Systems and Equipment for energy use (horizontal)

Storage of energy

Quality indoor environment

Design – integration of new solutions

Envelope and components

Industrialization and mass customization

Automation and control

Life cycle analysis (LCA)

Energy Management Systems

Labeling and standardization

Materials: embodied energy and multi-functionality

Diagnosis and predictive maintenance (continuous commissioning)

Systems and Equipment for energy production (horizontal)

Diagnosis

NEUTRAL/ENERGY POSITIVE NEW BUILDINGS

Systems and equipment for energy use for new buildings
Systemic approach for new buildings

ENERGY EFFICIENT DISTRICT/COMMUNITIES

Interaction (integration) between buildings, grid, heat network ...
Systems and Equipment for energy production (district)

District and urban design
Systems and Equipment for energy use (district)
Storage of energy (district): thermal, electrical or other
Retrofitting (district)

Figure 5.10: R&D Challenges
Source: E2B Multi-Annual Roadmap, 2010

6 From innovation to market

The transition towards more energy-efficient building envelopes will require rapid deployment of a large range of advanced building envelope technologies. Many of these technologies are significantly more expensive and will require higher upfront investment costs.

To achieve the large energy savings that efficient building envelopes can offer, full market deployment of high-priority, energy-efficient building materials is essential. Data on current market share are difficult or expensive to obtain in developed countries and are often not available in emerging markets, so the International Energy Agency [10] has used several assessment and inputs from experts worldwide to estimate three levels of market saturation: mature market (greater than 50%), established market (approximately 5% to 50%), and initial market presence (available but less than 5%), as it is presented in the following table. The European Union and the United States have made the most progress in deploying energy-efficient building envelopes.

Market maturity/ saturation	ASEAN	Brazil	China	European Union	India	Japan/ Korea	Mexico	Middle East	Australia/ New Zealand	Russia	South Africa	United States/ Canada
Double-glazed low-e glass	●	▲	▲	★	▲	●	●	▲	●	●	●	★
Window films	▲	▲	▲	●	▲	●	▲	▲	●	▲	▲	●
Window attachments (e.g. shutters, shades, storm panel)	●	▲	●	★	▲	●	▲	●	●	▲	●	●
Highly insulating windows (e.g. triple-glazed)		▲	▲	●		▲		▲	▲	▲	▲	▲
Typical insulation	★	●	★	★	●	★	●	★	★	★	●	★
Exterior insulation	●	▲	●	★	●	●	▲	●		▲	▲	★
Advanced insulation (e.g. aerogel, VIPs)				▲		▲				▲	▲	▲
Air sealing	●	▲	▲	★	▲	●		▲	▲	▲		●
Cool roofs	▲	▲	▲	●	▲	▲	▲	▲	▲			★
BIPV/ advanced roofs	▲	▲		▲	▲	▲			▲	▲	▲	▲

★ Mature market ● Established market ▲ Initial market

Notes: ASEAN = Association of Southeast Asian Nations. Blank cells indicate that there is currently not any market presence or it is so low that it is not known to domestic experts. Some technologies may not be recommended for all climates, such as cool roofs in Russia or highly insulated windows in hot climates. Typical insulation refers to widely available products such as fibreglass and various foams with thermal conductivities higher than 0.02 watts per meter Kelvin (W/mK). VIP = vacuum-insulated panel. See Annex A and Glossary for more detailed descriptions.

Table 6.1: Market deployment for high-priority building envelope components
Source: international Energy Agency

From a technology perspective, the deployment of typical insulation has been successful with full maturity in most regions, followed by low-e glass with some established markets but much more work is needed globally to promote market saturation for advanced building materials.

The next map shows the number of industries in different European countries related to construction; construction materials and buildings fixtures, equipment and services.

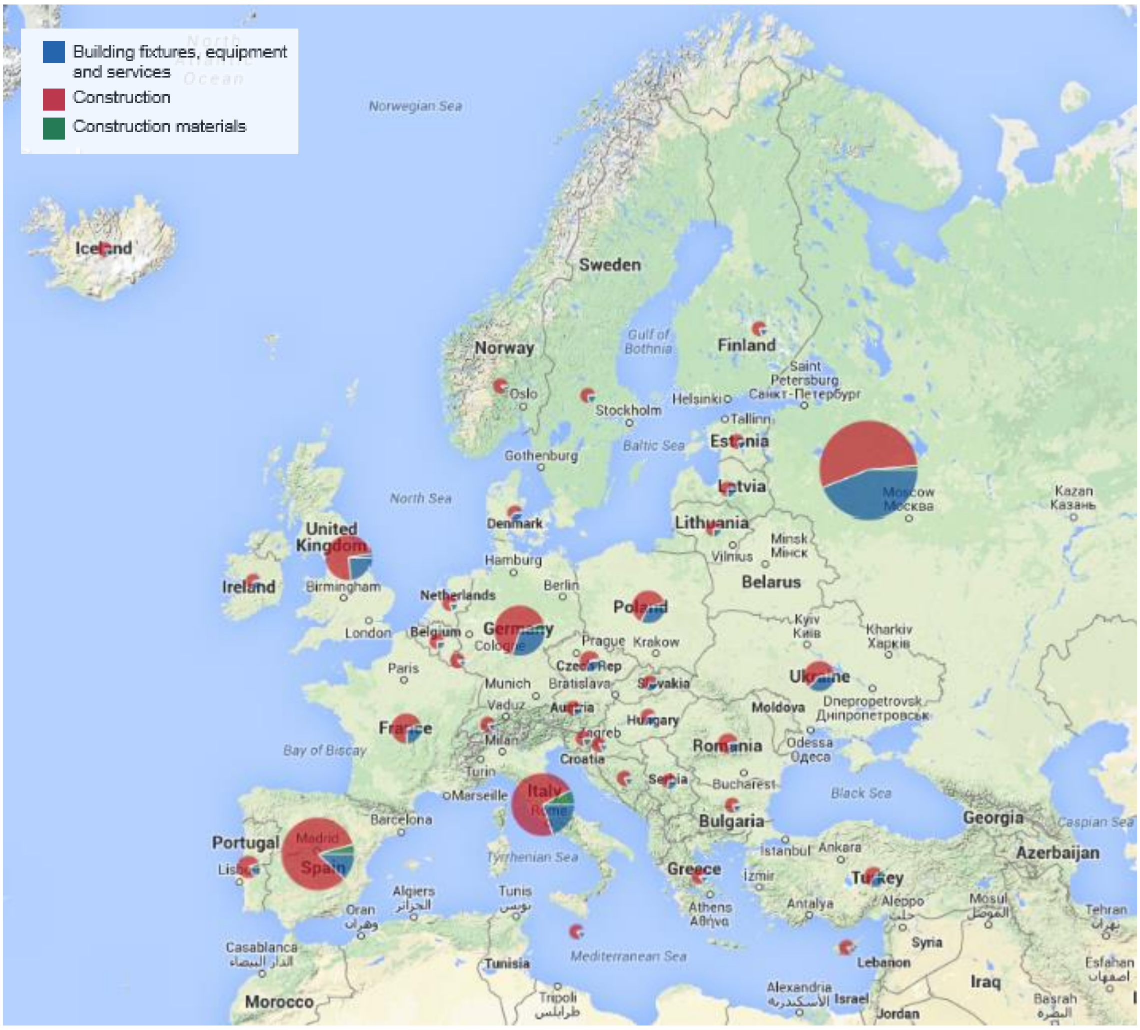


Figure 6.1: Map of the industries related to construction; construction materials and buildings fixtures, equipment and services

Source: Cluster Observatory

6.1 Industrial clusters in Europe: clusters policy & market deployment

Further integration of European markets is essential to enable a more efficient economic geography and stronger clusters. Governments can be important actors in European cluster policy but government must play the right role:

- Government must act as facilitator, not the driver

- Governmental responsibilities for cluster development should be allocated across geographic levels, with a focus on the regional level
- European support for cluster development must be based on competitive principles

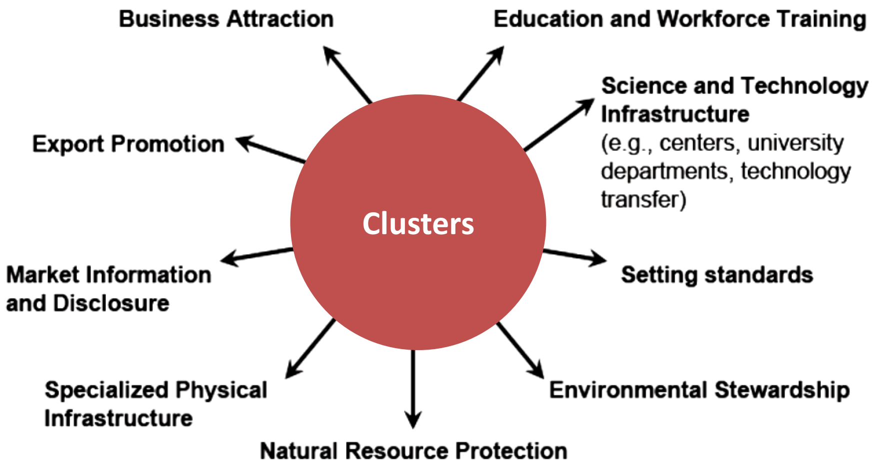


Figure 6.2: Cluster initiatives for the implementation of public economic policies
Source: European Cluster Policy

A business cluster is a geographic concentration of interconnected businesses, suppliers, and associated institutions in a particular field. The term was introduced by Michael Porter [25] in *The competitive advantage of nations* (1990). The underlying concept, referred as "agglomeration economies" dates back to 1890, to Alfred Marshall work.

	Economic activity in general	Technologically related industries
Efficiency (scale) and flexibility	Metropolises	Industrial districts
Innovation and upgrading	Creative regions	Clusters

Figure 6.3: Types of economic agglomerations
Source: Sölvell, Lindqvist, Ketels, 2003 [26]

Attention put on networks and clusters in several studies has an incremental tendency, attached to territorial economy dynamism dimension. This interest has been also represented in some public policies of spatial planning. When we consider a network of enterprises, we are talking about an "organized system of relationships" [26]. It could be assumed that those territories with more or less dense cluster networks will have advantages over other territories without a reticular structure. Three basic types of networks are identified: of complementarity, of synergy and of innovation.

The firms and institutions in a particular cluster share four critical characteristics [27]:

- Proximity; they need to be sufficiently close in space to allow any positive spill-overs and the sharing of common resources to occur
- Linkages; their activities need to share a common goal, for example, final market demand, for them to be able to profit from proximity and interaction
- Interactions; being close and working on related issues is not enough – for positive cluster effects to occur some level of active interaction has to be present
- Critical mass; finally, there needs to be sufficient number of participants present for the interactions to have a meaningful impact on companies' performance.

The importance of location and locational context has increased for many companies. In an increasingly global economy, company's location is one of the few sources of differentiation competitors cannot easily copy. Companies are looking to understand the opportunities that clusters can provide, and many executives see their active participation in efforts to strengthen their home clusters as a new and important part of their role [27].

The research done tried to understand the main objectives of cluster initiatives trend to show six main groups or areas of development:

- Research and networking
- Cluster expansion
- Innovation and technology
- Policy action
- Commercial cooperation
- Education and training

In that context, people and company networks (from research and networking field) facilitate innovativeness and new technology (from innovation and technology field) and company growth (from cluster expansion field) appear as the most frequently shared objectives between clusters.

Secondly, other objectives, like the attraction of firms or regional branding, spin-offs, cluster awareness, technical trends, technology diffusion, technical or management training, export promotion, business assistance, market intelligence or infrastructure lobbying are in the next range or frequent objectives.

6.1.1 Existing energy efficiency cluster initiatives in Europe

Energy is a core challenge faced by all European regions. The partnership intends to activate SMEs with high competencies in energy efficiency or in developing effective energy transformation systems. Procurement officers of a wide range of energy industries will find creative SME suppliers and manufacturers of energy production, distribution, consumption, energy efficiency technologies and effective energy transformation systems. Most part of Energy efficiency clusters are focused on:

- Wind Energy
- Energy cogeneration (Biomass)
- Bio-energy conversion
- Renewable Energy Sources (RES) Offshore Wind Energy
- Eco-energy innovation

The project GE2O (Geo-clustering to Deploy the potential of Energy efficiency buildings in Europe) [28] has defined the Energy Efficiency cluster profile as:

- A joint theme-based (EEB) initiative for a geographic area, that
  - Brings together companies, research centres, educational institutions in order to develop synergies and cooperative efforts
  - May also include local or national authorities but must not be driven by them
  - Aims at stimulating businesses, increasing productivity and driving innovation
- Membership must be on a voluntary basis.

According to this definition, the following were not considered as clusters:

- Public agencies
- Foundations / Institutes
- Professional federations/associations and branch organizations where membership is “mandatory”

This project GEO2 made an exhaustive analysis on the existing cluster initiatives focus on Energy Efficiency construction market. From the analysis of these initiatives extract the next conclusions:

- Although the geographical spread of the investigated clusters covers more or less the half of the Europe, the total number of members is quite high (more than 12,500). It is estimated that 90% of these are companies. Most of these companies are SME’s.
- The number of different regions (or well defined geographic zones) covered by this set of clusters is nearly 40.
- Among the 56 valid clusters, 38 have declared also dealing with research activities. These can be official “competitiveness clusters” as in France or Belgium, or simply involved in research projects as a partner.
- Concerning the technological focus, 12 clusters can be considered as “generic” or “umbrella” clusters, as they address all the aspects of EEB. On the other side, 14 are considered as focused on one specific technology (renewable energy sources being the most frequent). The rest is dealing with a set of diverse technology.

- The global spread of technological focus among all the 56 clusters is given on the following chart. Even if it looks more or less well balanced, it may be interesting to quote that:
    - The "top 3" are composed of renewable energy sources (frequent in regions of the South of Europe), control systems and prefabricated elements (mainly timber work)
    - At the bottom of the list are lighting, glazing and ventilation systems

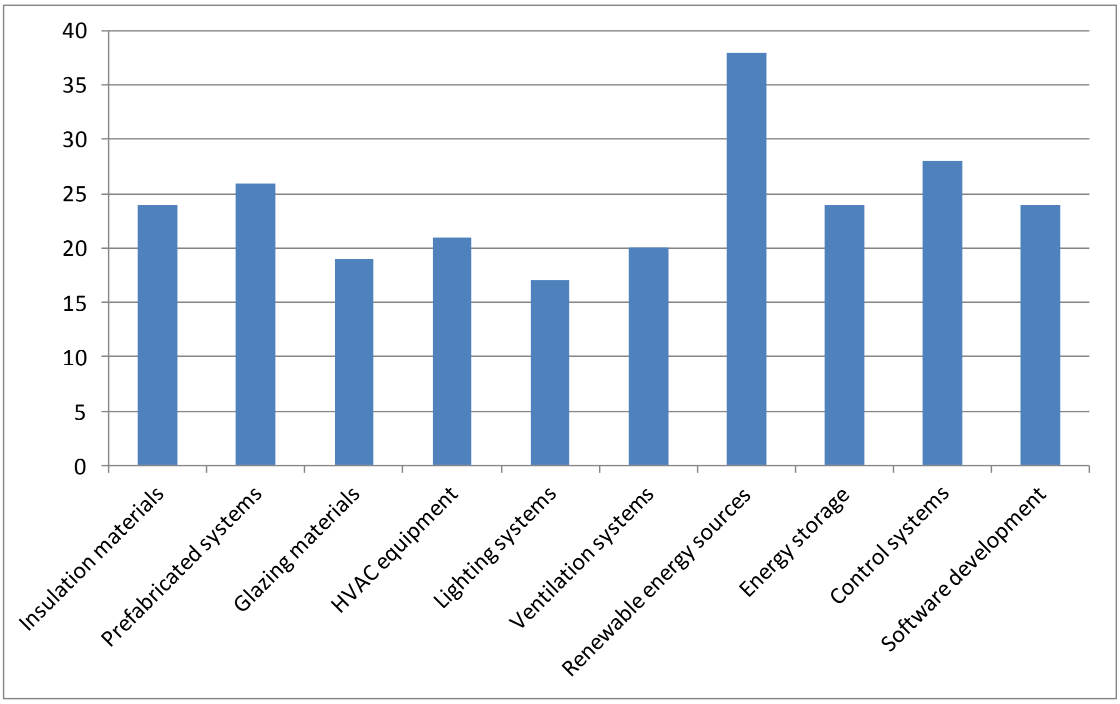


Figure 6.4: Technological focus relevance of analysed cluster initiatives.
Source: GE2O project

Other focus areas were also mentioned by some clusters are:

- Management on sustainable construction
- Development of labels and certification (national GBC committees)
- Sustainable cities, eco-districts, mobility, ...
- Smart grids
- Refurbishment of heritage/historical buildings
- Green roofs & facades
- Social Housing

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
ERRIN	ERRIN	ERRIN, the European Regions Research and Innovation Network, is a dynamic network of more than 90 EU regions and their Brussels-based offices. They have different working groups and are going to create a subgroup on energy efficiency in Buildings.	http://www.errin.eu/en/	Europe	EUROPE
EuroACE	EuroACE	EuroACE is the European Alliance of Companies for Energy Efficiency in Buildings	http://www.euroace.org/	Europe	EUROPE
ERACOBUILD	ERACOBUILD	Eracobuild aims at strengthening and enlarging the strategic networking of RDI programmes in the field of "construction and operation of buildings"	http://www.eracobuild.eu/index.php?id=61	Europe	EUROPE
Active House Alliance	Active House Alliance	Active House is a non-profit organization supported and managed by a group of Alliance Partners in order to unite interested parties based on a balanced and holistic approach to building design and performance, and to facilitate cooperation on e.g. building projects, product development, research initiatives and performance targets that can move us further towards the vision.	http://activehouse.info	Europe	Europe
Klaster Budownictwo Polski Centralnej	Construction Cluster of Central Poland	Construction Cluster, aimed to encourage small and medium-sized enterprises to cooperate in order to implement new technologies in construction and transform the sector in innovative branch	http://www.arreks.com.pl/klaster/	Poland	Central Poland
Klaster Budownictwa Pasywnego i Energooszczędnego	Cluster of Passive and Energy Efficiency Construction	Cluster of Passive and Energy Efficiency Construction, joint activities in area of designing, building and managing energy efficient buildings	http://klasterbudownictwa.pl/pl/o_klastrze	Poland	Upper Silesia

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Nadwiślański Klaster Energii Odnawialnej i Poszanowania Energii	Vistula River Valley Renewable Energy Sources Cluster	Renewable Energy Sources Cluster, main objective of the initiative is to transfer and commercialize innovation, also to exchange experience in energy efficiency and RES	http://klasteroze.pl/?/content/read/About_Us	Poland	Gdańsk Pomerania
Gdański Klaster Budowlany	Gdańsk Construction Cluster	Construction cluster, one of the major tasks of the GKB is a cubature energy efficiency construction, in particular - passive.	http://ppnt.pl/gdanski-klaster-budowlany.html	Poland	Gdańsk Pomerania
Klaster Termomax	Termomax Cluster	Termomax Cluster, implementation of innovation in energy efficient construction, insulation systems for buildings, the use of eco heating systems in private and industrial construction	http://www.not.opole.pl/projekty-ue/projekty-zakoczone/termomax.html	Poland	Opole Region
Klaster Technologii Energooszczędnych Euro-Centrum	Euro-Centrum Cluster of Energy Saving Technologies	Euro-Centrum Cluster of Energy Saving Technologies, members operate in the energy efficient technologies and technologies of energy saving in buildings	http://www.euro-centrum.com.pl/klaster-technologii-energooszczednych	Poland	Upper Silesia in majority, Lesser Poland and Central Poland partly
Świętokrzysko – Podkarpacki Klaster Energetyczny	Świętokrzysko – Podkarpacki Energy Cluster	Energy Cluster, promotion of activities to reduce energy consumption in buildings and manufacturing processes (e.g. through the promotion and assistance in building renovation and modernization of local energy sources through renewable energy and innovative technologies	http://klasteroze.it.kielce.pl/?id=2	Poland	Podkarpacie and Świętokrzyski Region

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Lubelski Klaster Ekoenergetyczny	Lublin Eco-Energetic Cluster	Eco-energetic Cluster, supporting all activities related to sustainable use of renewable energy sources based on the potential of the Lublin province, development and implementation of technological innovations, manufacturing and process, and popularization of renewable energy sources in the Region	http://fundacja.lublin.pl/index.php/pl/lubelskiklasterekoenergetyczny	Poland	Lesser Poland
Cluster de la Construcción Sostenible	Sustainable Construction Cluster	Sustainable Construction	http://www.clusterccs.org	España	Canarias-Tenerife
Cluster de la Construcción de Extremadura	Extremadura´s Construction Cluster	Construction	http://www.clusterconstruccion.org	España	Extremadura
Cluster de la Construcción de Euskadi	Euskadi´s Construction Cluster	Construction	http://www.eraikune.com	España	País Vasco
Civic Association Moravian timber Cluster (MSDK, o.s.)	Civic Association Moravian timber Cluster (MSDK, o.s.)	The main goal is to innovate and develop timber cluster of activities that improve conditions for doing business in the woodworking industry and strengthen links between research, universities and businesses	http://www.msdk.cz/	Czech republic	Moravian Region
EKOGEN	EKOGEN	Building materials with minimal energy consumption in order to increase competitiveness of the region	http://www.ekogen.cz/	Czech republic	Czech Republic
KLASTR PŘESNÉHO STROJÍRENSTVÍ VYSOČINA		Mechanical Engineering MSEK aim is to support the use renewable energy sources and promotion and education for energy savings	http://www.kpsv.cz/index.php?page=info-o-klastrech	Czech republic	Czech Republic

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
BSRIA	BSRIA	A consultancy, test, instruments and research member organisation seeking to improve the quality of the built environment in both the domestic and non-domestic strand of the industry through research and providing supporting testing and best-practice guidance to the industry. Strong focus is on management of facilities and services in buildings.	www.bsria.co.uk	United kingdom	United Kingdom
PassivHaus Trust	PassivHaus Trust	A member organisation seeking to advance PassivHaus in the UK, a German-based standard of construction, which is undergoing some adaptation to be suitable for the UK climate	http://www.passivhaustrust.org.uk/	United kingdom	United Kingdom
AECB the sustainable building association	AECB the sustainable building association	AECB is the leading network for sustainable building professionals in the UK. A member organisation seeking to reduce the environmental impact of the built environment by encouraging design approaches such as passivhaus and others to reduce primary energy requirements, though the design of the building fabric	www.aecb.net	United kingdom	United Kingdom
Good Homes Alliance	Good Homes Alliance	A group of housing developers, building professionals and other industry supporters seeking to advance the quality of home building in the UK, including an expectation that developers undertake post-occupancy evaluation on new developments.	www.goodhomes.org.uk	United kingdom	United Kingdom
Construction industry research and information association (CIRIA)	Construction industry research and information association (CIRIA)	CIRIA is the construction industry research and information association supporting businesses engaged with the delivery and operation of the built environment.	www.ciria.org/	United kingdom	United Kingdom

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
TWI	TWI	Independent research and technology membership organisation focused in invention, innovation and knowledge transfer across all aspects of manufacturing, fabrication and whole-life integrity management technologies with particular focus on joints and interfaces.	www.twi.co.uk	United kingdom	United Kingdom
Energy efficiency partnership for buildings (EEPB)	Energy efficiency partnership for buildings (EEPB)	A network of over 1000 organisations from the public, private and voluntary sectors working together to reduce the energy consumption by UK households and fighting fuel poverty.	www.eepb.org.uk	United kingdom	United Kingdom
Timber Research and Development Association (TRADA)	Timber Research and Development Association (TRADA)	An internationally recognised membership-based organisation and centre of excellence on the specification and use of timber and wood products.	http://www.trada.co.uk	United kingdom	United Kingdom
UK Green Building Council (UKGBC)	UK Green Building Council (UKGBC)	Charity and membership organisation, campaigning for a sustainable built environment and facilitating dialogue between industry and Government to promote greener approaches in the construction sector.	http://www.ukgbc.org/	United kingdom	United Kingdom
REGEN SW	REGEN SW	Leading centre of sustainable energy working to enable business, local authorities, community groups, and other organisations to deliver renewable energy and energy efficiency projects with thriving local supply chains.	http://www.regensw.co.uk	United kingdom	South West England
Thames Valley Energy	Thames Valley Energy	Regional energy agency working with a number of partner organisations from both the public and private sector within the Thames Valley to promote and advise on renewable energy technology integrated into buildings.	http://www.tvenergy.org	United kingdom	Thames Valley

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
MBE KTN - Energy and Carbon Efficiency Group	MBE KTN - Energy and Carbon Efficiency Group	This group is focused on the Energy and carbon efficiency, with special focus on using the right products in the most appropriate way with flexibility of energy supply depending on local sources. Priority areas include: Lower Carbon Products with key areas lighting, positive air flow and heating systems), Lower Carbon Energy Supply and Building Controls.	https://connect.innovateuk.org/web/69132	United kingdom	United Kingdom
Slovenski gradbeni grozd	Construction Cluster of Slovenia	Construction Cluster	http://www.sgg.si	Slovenia	Slovenia
PV-platforma	PV-platform	pfotovoltaic platform	http://www.pv-platforma.si	Slovenia	Slovenia
GROZD URE in OVE, Zavod za trajnostni razvoj energetike in ekologije	Institute for sustainable energy development and ecology	Cluster for efficient use of energy and RES	http://www.vransko.eu/grozd-ure-in-ove--zavod-za-trajnostni-razvoj-energetike-in-ekologije-podjetje-20	Slovenia	Slovenia
Federcasa	Italy's House Federation	Federation of social housing	http://www.federcasa.it	Italy	Italy
ANIT Associazione nazionale per l'isolamento termico e acustico	National Association for Thermal and Acoustic Insulation	Thermal and acoustic insulation association	http://www.anit.it/	Italy	Italy
ANCE - Associazione nazionale costruttori edili	ANCE - Associazione nazionale costruttori edili	Association of building companies	http://www.ance.it	Italy	Italy
Confindustria	Confindustria	National industry association, it has an EE Task Force	http://www.confindustria.it	Italy	Italy

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Green Building Council Italia	Green Building Council Italia	Italian member of World GBC	http://www.gbcitalia.org	Italy	Italy
Unione nazionale costruttori serramenti in alluminio, acciaio e leghe	Unione nazionale costruttori serramenti in alluminio, acciaio e leghe	Association of doors and windows fabricants (aluminium, steel, alloys)	http://www.uncsaal.it/	Italy	Italy
Lignius - Associazione nazionale italiana case prefabbricate in legno	Associazione nazionale italiana case prefabbricate in legno	Association of prefabricated wood houses manufacturers	http://www.lignius.it	Italy	Italy
CONAFI	CONAFI	National association of flat owners	http://www.conafi.net/	Italy	Italy
ANACI	ANACI	National association of property managers	http://www.anaci.it/	Italy	Italy
Cluster di Efficienza Energetica dell'Emilia Romagna	Cluster di Efficienza Energetica dell'Emilia Romagna	EE regional cluster	http://www.ecuba.it/pdf/Piano_dazione_in_Emilia_Romagna.pdf	Italy	Emilia Romagna
Habitech	Habitech	EE in buildings regional cluster	http://www.trentinosviluppo.it/Contenuti-istituzionali/Progetti/Habitech-il-Distretto-Energia-Ambiente	Italy	Trentino Alto Adige
ENERGY CH-IT	ENERGY CH-IT	EE Italian-Swiss project	http://www.energychit.com	Italy/ Switzerland	Lombardia/ Canton Ticino

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Programma Operativo Interregionale Energie Rinnovabili e Risparmio Energetico		EE and renewables in Southern Italy	http://www.poienergia.it/	Italy	Campania, Calabria, Puglia, Sicilia
Stichting Passiefhuis Holland (PHH)	Dutch council of passive houses	Cooperation between several businesses of the building industry: – to stimulate energy efficient buildings conform the passive house principle – to spread knowledge and experience of the passive house technology – - to develop specific products and services for the passive house concept	www.passiefhuis.nl	Netherlands	Netherlands
Stichting Experimentele Volkshuisvesting (SEV)	SEV (Housing Experiments Steering Group)	SEV (Housing Experiments Steering Group) aims to develop innovative responses to social housing issues. In order to achieve this, we are looking for innovative, solution-oriented ideas that open up new horizons. These ideas are subsequently implemented in the form of practical experiments. This way we find out whether the innovative solution is effective in the environment and situation for which it is intended. If the solution is effective in practice and indeed solves a social issue, arrangements are made to introduce the innovation and promote the distribution thereof on a wider platform.	www.sev.nl	Netherlands	Netherlands

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Dutch Green Building Council	Dutch Green Building Council	The Dutch Green Building Council (DGBC) was founded in 2008 in The Netherlands as a market initiative. The aim was to make Sustainability in the building industry measurable by developing a sustainability label allowing for the uniform rating of buildings throughout the Netherlands.	www.dgbc.nl	Netherlands	Netherlands
Uneto-VNI	Uneto-VNI	Association of HVAC installers	www.uneto-vni.nl	Netherlands	Netherlands
Bouwend Nederland	Dutch construction and infrastructure federation	Bouwend Nederland represents about 5,000 affiliated construction and infrastructure companies and is therefore by far the biggest employers' organization in the construction and infrastructure industries.	www.bouwendnederland.nl	Netherlands	Netherlands
Agentschap NL	NL Agency	Focussing on sustainability, innovation, international business and cooperation, NL Agency is the number one contact point for businesses, knowledge institutions and government bodies.	www.agentschapnl.nl	Netherlands	Netherlands
Nederlandse Isolatie Industrie (NII)	Dutch Insulation Industry	Association of several Dutch branch organizations for opaque insulation materials	www.nii.nl	Netherlands	Netherlands
Dutch Heat Pump Association	Dutch Heat Pump Association	Association to promote the use of heat pumps.	www.dhpa-online.nl	Netherlands	Netherlands
Utrecht Sustainability Institute	Utrecht Sustainability Institute	Cooperation of knowledge institutes and businesses to stimulate innovations in the region of Utrecht. One cluster focuses on energy neutral living and working.	www.usi-urban.nl/living-labs/cluster-1	Netherlands	Utrecht
Holland Solar	Holland Solar	Branch association of Dutch experts in solar energy (approx. 100 members), including suppliers, industry, installers, consultants and architects.	www.hollandsolar.nl	Netherlands	Netherlands
Smart Energy Regions	Smart Energy Regions	Cluster of companies, knowledge institutes and local authorities to develop and implement energy concepts.	www.smartenergyregions.com/	Netherlands	Noord-Brabant

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Vereniging Leveranciers Luchttechnische Apparaten	Association Suppliers Ventilation Systems	Branch association of Dutch suppliers of ventilation systems.	www.vla.nu	Netherlands	Netherlands
New Energy Business Community (NEBC)	New Energy Business Community (NEBC)	Network for SME's to support activities related to Smart Grids and Smart Energy.	http://nebc.nl	Netherlands	North part of the Netherlands
Kenniscentrum Glas	Glass Knowledge Centre	Collecting and spreading knowledge about glass.	www.kenniscentrumglas.nl	Netherlands	Netherlands
Dutch National Liaison Point E2B	Dutch National Liaison Point E2B	Dutch National Liaison Point for Energy Efficient Buildings	www.nlp-e2b.nl	Netherlands	Netherlands
Nederlandse Bond van Timmerfabrikanten	Dutch Association of Timberwork Producers	Branch association for timberwork producers (window frames, doors, stairs, etc)	www.nbvt.nl	Netherlands	Netherlands
CAP2020	CAP2020	Cluster gathering building contractors, materials producers and architects for business development of sustainable buildings	www.cap2020.be	Belgium	Walloon Region
GREENWIN	GREENWIN	Competitiveness cluster for green technologies with a focus on green buildings to speed up innovation in the field of new materials and equipments	www.greenwin.be	Belgium	Walloon Region
ECOBUILD	ECOBUILD	Promotion of sustainability in construction (with a focus on retrofitting)	www.ecobuild.be	Belgium	Brussel Capital Region
TWEED	TWEED	Promotion of renewable energy sources with focus on their integration in buildings	www.clusters.wallonie.be/tweed/	Belgium	Walloon Region

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Kamp C	Kamp C	Local agency for sustainable buiding and living	www.kampc.be	Belgium	Flemish Region
TENERRDIS (Technologies Energies Nouvelles Energies Renouvelables Rhône-Alpes, Drôme, Isère, Savoie	New Energy and Renewable Energy Technology	Competitiveness cluster covering all the "New Energy Technologies "sectors. The cluster covers 3 core sectors: – Construction: optimise energy production, management and consumption in new buildings and renovations – Transport: develop clean transport systems (biofuels and fuel cells) – Energy production: develop production of renewable energies and convert them into four energy carriers (electricity, heat biofuels and hydrogen)	http://www.tenerrdis.fr/	France	Rhône-Alpes
DERBI (Developpement des Energies Renouvelables pour le Bâtiment et l'Industrie)	Renewable Energy Development for building and Industry	Competitiveness cluster covering 3 main fields: – Neywork managements and energy storage – Energy-producing buildings in a mediterranean climate – Energy production outside buildings	http://www.pole-derbi.com/	France	Languedoc-Roussillon
ENERGIVIE	Zero energy building	Regional competitiveness cluster working on energy efficient project and renewable energy in Alsace. The four main steps of a project are detailled: Design, building, energy production equipment and process control systems, marketing	http://pole.energivie.eu	France	Alsace

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Effinergie	Energy efficiency	National association to create a supprotive dynamic within the construction market that facilitates the builing of comfortable, energy efficient buildings. The main objectives of the association are to : – Develop building references and tools – Unite people from all sectors – Ensure coordination between governmental authorities and regional initiatives – Illustrate technical and economic feasibility	http://www.effinergie.org	France	France
ADVANCITY (Ville et Mobilité durable)	Green technologies and sustainable cities cluster	Regional competitiveness cluster defined as the meeting between opportunities for green growth and a melting pot of skills. Four major economic sectors are involved by AVANCITY: – Urban and spatial planning and development – Housing and construction – Mobility and transport – Resources and environment	http://www.advancity.eu	France	France
S2E2 (Science et système de l'Energie electrique)	Smart electricity cluster	Regional competitiveness cluster pooling companies and research laboratories. The cluster work on four main fields: – Energy conversion – New energy sources – Energy management in building – Sensors in link with energy	http://www.s2e2.fr/	France	Centre - Limousin - Pays de la Loire

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
XYLOFUTUR	Products and Materials from cultivated forest	Regional cluster working on the development of materials and products issued from managed forestery. The complementary activities are separated as wood products, forestery management and wood chemistery / green chemistery. Throught the project ABER, they use domestic wood and innovative wood solutions for building rehabilitation.	http://xylofutur.fr	France	Aquitaine
Cluster Eskal Eureka	Cluster Eskal Eureka	Regional cluster of traditional building compagnies in order to develop new knowledge , new materials, new techniques for energy efficiency and environment.	http://www.eskal-eureka.fr	France	Aquitaine
Cluster bâtiment économe	Efficient building cluster	Regional cluster workin essentially on four main fields: – New materials and Buildings – Solar thermal energy storage – Smart energy systems – Anticipation of creation of new cycle training	http://www.batimenteconome.com	France	Midi-Pyrénées
Materalia	Materalia	MATERALIA has selected 4 lines of technological progress to support its industrial development, based on regional skills: – Producing and implementing materials that are more functional and have wider ranges of use – Developing modelling of the materials and their implementation – Industrializing new transformation processes – Promoting intelligent maintenance based on intelligent materials	http://www.materalia.fr/	France	France
Pole Fibres	Pole Fibres	To reinforce the commercial development of fibre materials and ECO materials coming from sustainable production	http://www.polefibres.fr	France	France

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Green Valley	Green Valley	Eco construction. Cluster of construction companies on energy efficiency	Olivier Legrand (nr Gaia) lt.capital@yahoo.fr	France	Epinal
Eden Green Valley	Eden Green Valley	Energy, Garbage gestion, environmental construction, eco-architecture and eco-construction, energy efficient construction	http://eureka.lorraine.eu/jahia/Jahia/lang/fr/pid/1705?view_id=17893	France	CCI 54 - Antenne du Pays-Haut
CapEnergies	CapEnergies	The cluster brings together more than 400 members working on projects to innovate and create opportunities to boost the energy industry's economic growth. Capenergies' mission is to facilitate contacts, assist and support its members in attaining a leading position in the energy sector and in fulfilling our regions' future needs. The measures undertaken by the cluster since 2005 have led to the growth of many companies, an increase in sector jobs and the creation of innovative energy systems.	http://www.capenergies.fr/	France	Provence-Alpes-Côte d'Azur, Corse, Guadeloupe, Réunion, Principauté de Monaco
Luxembourg EcoInnovation Cluster	Luxembourg EcoInnovation Cluster	The Luxembourg EcoInnovation Cluster is an active network that supports the various actors of the eco-technologies sector in Luxembourg with the goal of creating and developing new and sustainable business opportunities through collaborative R&D and innovation projects. The members of the Luxembourg EcoInnovation Cluster are active in many different areas such as: eco-Construction/ eco-materials, renewable and alternative energies (biomass, biogas, photovoltaics…), eco-design/eco-conception, rational use of energy.	www.ecoinnovationcluster.lu	Luxembourg	Luxembourg

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Cluster Habitat Sustentável	Sustainable Habitat Cluster	This cluster has adopted the subject of Sustainability as a dynamic factor to its strategic development, aiming to contribute for a more "Sustainable Habitat". Sustainability is the driving force for innovation and the desired transformation for the cluster, with impact on economic, social and environmental aspects. While, in the national market, the strategic perspectives interventions mainly related to rehabilitation, conservation and qualification of the built heritage, in the international market, especially in developing countries, the prospect is also related to new construction. In both markets, the statement of a specialization in sustainable construction by companies and other cluster agents can be an element of differentiation, generating factors of international competitiveness.	http://www.centrohabitat.net	Portugal	Beira Litoral
Mi-Cluster	Nano/microelectronics based systems and applications Cluster (Mi-Cluster)	The mi-Cluster is the first innovation cluster in Greece and since its establishment in 2006, it demonstrates a continuous increase of members, exceeding today 100 organisations, including Greek innovative companies, academic labs and research institutes, from all over Greece.	http://www.corallia.org/en/innovation-clusters/mi-cluster-knowledge-base.html	Greece	Greece

ORIGINAL NAME	NAME IN ENGLISH	SUBJECT	WEB	COUNTRY	REGION
Praxi Help Forward Network	Praxi Help Forward Network	PRAXI / HELP-FORWARD Network is a technology transfer organization addressed to small and medium sized enterprises and research institutions all over Greece. Its services range from information to mediation and advisory support, covering the whole spectrum of activities related to research collaboration, technology transfer and commercial exploitation of research results. PRAXI / HELP-FORWARD Network is an autonomous entity, falling under the Central Administration of the Foundation for Research and Technology - Hellas. PRAXI / HELP-FORWARD Network started its operation in 1991 as a joint initiative of the Foundation for Research and Technology - Hellas (FORTH), the Hellenic Federation of Enterprises (SEV) and the Federation of Industries of Northern Greece (FING). The mission of PRAXI / HELP-FORWARD Network is to stimulate competitiveness of Greek enterprises and research institutions via linking research and industry, promote innovation and entrepreneurship as well as transnational cooperation.	http://www.help-forward.gr/en/index/index.php	Greece	Greece

Table 6.2: Cluster initiatives in Europe
Source: GE2O Project

6.1.2 Other relevant information sources

Innova Cluster Mapping Project [29]

The project aims to map clusters and cluster policies and institutions in 15 "old" EU member countries plus Norway, Iceland, Switzerland, Israel, Romania, Bulgaria, and Turkey. Clusters are increasingly seen as a critical element in understanding the competitiveness and innovative capabilities of regional and national economies.

There are three main objectives for this cluster mapping project: first, to establish a Europe-wide database on regional clusters; second, to analyse a number of business clusters identified and document national government agencies and policies related to clusters; and third, to develop policy recommendations for cluster-driven policies to improve innovation and competitiveness in Europe. This project has the potential to develop a truly strategic tool for Europe to devise effective policies to increase competitiveness and innovation and achieve the ambitions outlined in the Lisbon Agenda.

The project is carried out by a group of partners including the Centre for Strategy and Competitiveness at the Stockholm School of Economics (Sweden), which is the coordinating partner in the project, Cluster Competitiveness Group S.A. (Spain and U.K.), the Fondation Sophia Antipolis (France), and Oxford Research AS (Norway).

Cluster Observatory [30]

The European Cluster Observatory is an online platform that provides a single access point to information and analysis of clusters and cluster policy in Europe. Originally launched in 2007, the Observatory is now offering a range of new services. It provides data and analysis on clusters and competitiveness, a cluster library, and a classroom for cluster education.

The European Cluster Observatory also produces analysis and reports on regional competitiveness conditions, transnational cluster networks, clusters in emerging industries, and studies on better practices in cluster organisations.

The Observatory is aimed at three main target groups:

- Policy makers and government officials at the European, national, regional and local levels
- Cluster management staff
- Academics and researchers.

European Cluster Collaboration Platform [31]

This platform provides online quality information and networking support for clusters (organisations and members) aiming to improve their performance and increase their competitiveness through the stimulation of trans-national and international cooperation.

This brand new online portal rich in features and information has been developed aiming to build communication bridges between cluster players from the same or a different sector. The ultimate goal is to facilitate cluster cooperation, both between cluster organisations, as well as between cluster members (i.e. companies, R&D institutions, other players).

The European Cluster Collaboration Platform is embedded within the European Cluster Excellence Initiative and financed by the Competitiveness and Innovation Programme, since it is an instrument provided by DG Enterprise & Industry to enable cluster organisations to actively play a role on the international cluster arena. This can be achieved either through a professional presentation of their activities/members, through a dynamic interaction in virtual or personal dialogue with peers in communities or through accessing structured cluster information and using it to become better. “Striving for excellence” represents the mind-set of those cluster people who intend to bring their clusters to an excellent level of performance. Some of them are at the beginning of this process, some of them already advanced, but it is this shared spirit that makes their getting together on/through the platform that creates a win-win situation.

What the platform does not target: to become just a telephone book or a data graveyard. It targets a quality approach through the quality information provided by its users in their profiles, through their contributions, postings, intensity of use, but also in their feedback on how the platform could better serve their expressed needs.

7 Selected strategies and technologies in the demo sites

Different strategies and envelope solutions are defined by evaluating the existing condition of all demo sites. In light of the information received by various surveys, certain strategies have been developed. As a result, both passive and active envelope solutions have been considered, synergies between them are examined and the optimum results are targeted to be accomplished.

7.1 Selected strategies for the Spanish demo site

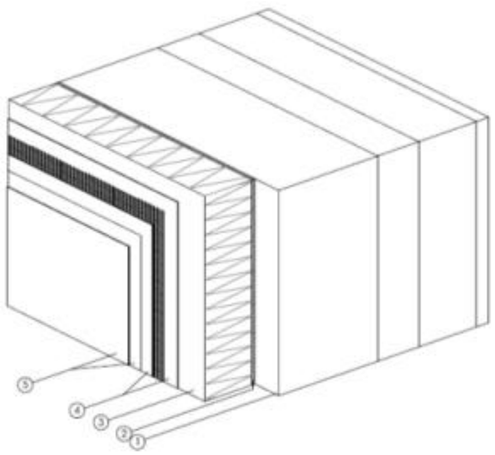
Most of the façade surface is made of brick cavity walls without insulation layer (12 cm ceramic brick + 5 cm air chamber + 7 cm ceramic brick + 1,5 cm gypsum plaster). The original wall has a width of 25.5 cm and a U-value = 1.36 W/m^{2}K. Façades presents numerous pathologies, such as thermal bridges, fissures due to thermal expansion, fissures along the expansion joints and air infiltration through the facade.

There will be no intervention on the structure, installations, indoor spaces, use of the buildings and size, or composition of holes on façades.

Passive strategies: ETICS

The façade solution consists of an ETICS (Exterior Thermal Insulation System) that will be attached to the exterior wall of the buildings. This system will be composed by:

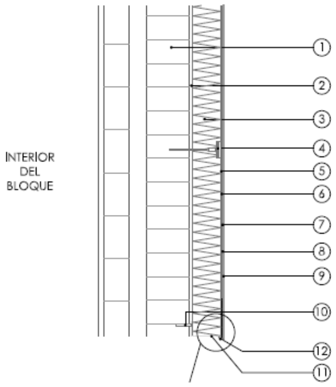
- 8 cm expanded polystyrene (EPS) layer for insulation (density 15-20 kg/m^3) fixed by adhesive mortar and mechanical anchors.
- 1.5 cm mortar layer (cement mortar + fiberglass mesh + cement mortar + white finishing mortar).



Legend:

1. Existing wall
2. Adhesive mortar
3. EPS insulation sheet insulation
4. Cement mortar + fiberglass mesh + cement mortar
5. Finishing mortar

Figure 7.1: Detail. ETICS System



Legend:

1. Existing wall
2. Adhesive mortar
3. EPS insulation sheet
4. Anchors
5. Cement mortar
6. Fiberglass mesh
7. Cement mortar
8. Prime
9. Finishing mortar
10. Fixing metal profile
11. L Profile
12. Edge profile.

Figure 7.2: Detail. ETICS System

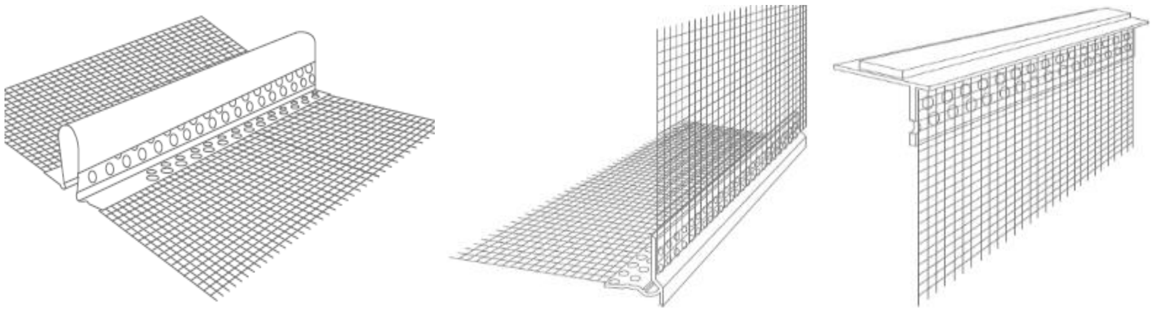


Figure 7.3: Fiberglass meshes details

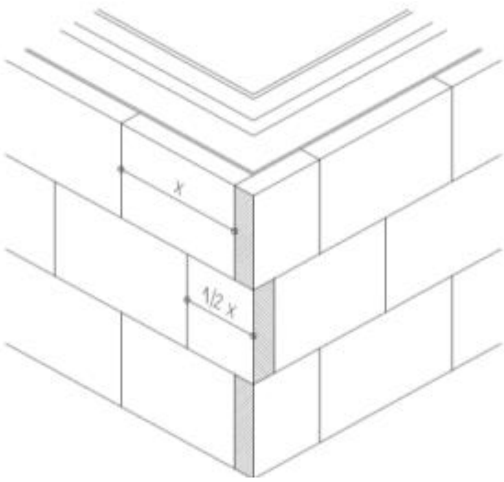


Figure 7.4: Detail. Placement of the EPS sheets in the corners

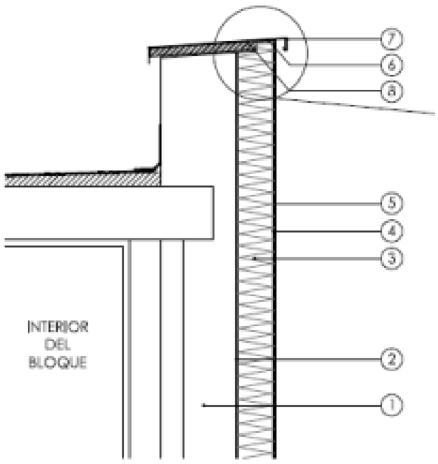


Figure 7.5: Detail. Roof zones ending

Some of the issues considered for the selection of this solution were its resistance, stability, security, durability, cost-effectiveness, ease of assembly and modulation possibilities.

After de retrofitting, the resulting wall (1.5 cm mortar finish + 8 cm EPS + 12 cm ceramic brick + 5 cm air chamber + 7 cm ceramic brick + 1.5 cm gypsum plaster) will have a thickness of 35 cm with a U-value of 0.339 W/m^{2}K. The Spanish Technical Building Code [32] requires a U-value ≤ 0.66 W/m^{2}K for the climatic zone (D2) where Laguna de Duero is located.

The ETICS solution defined takes into account thermal and comfort issues (temperature and humidity) as well as aesthetic design. Block final appearance will be mainly white, with some colored areas on each block.

Figure 7.6: Infographics of the appearance of buildings after the intervention

7.2 Selected strategies for the Turkish demo site

In the Turkish demo site, strategy selections and technology applications are evaluated in three main categories as they are roof, wall and window. Detailed information about the envelope retrofitting in Soma is given below.

Active Strategies

<u>Roof: Solar thermal panels</u>

Solar thermal panel integration is applied for all buildings as they are one, two, three story residential buildings, guesthouse, single lodging and convention centre in the Soma demo site in order to supply domestic hot water need of the buildings. Hot water production for 24 hour at minimum temperature of 40 °C will be provided by 518 solar thermal panels.

Figure 7.7: Solar thermal panels in Soma district

Roof: Photovoltaic panels

Photovoltaic panel integration is planned to be applied only in both two guesthouses and convention centre. The PV panel size that are going to be used will be 1345 X 990 X 50 mm, with an energy production of 230 W. Approximately, 900 PV panels will be installed on the southern areas of the roofs belonging to the buildings of the demo site.

Figure 7.8: Planned PV integration to the demo site

Exterior wall: Radiant heating and cooling panels

Radiant heating and cooling panels that are going to be applied on the ceiling area consist of two layers, as they have PEX pipe inside of a gypsum plank and insulation layer. Two blocks from the three story residential building type were chosen for the demonstration of the new heating & cooling systems into the ceiling area of the floors, called radiant heating and cooling.

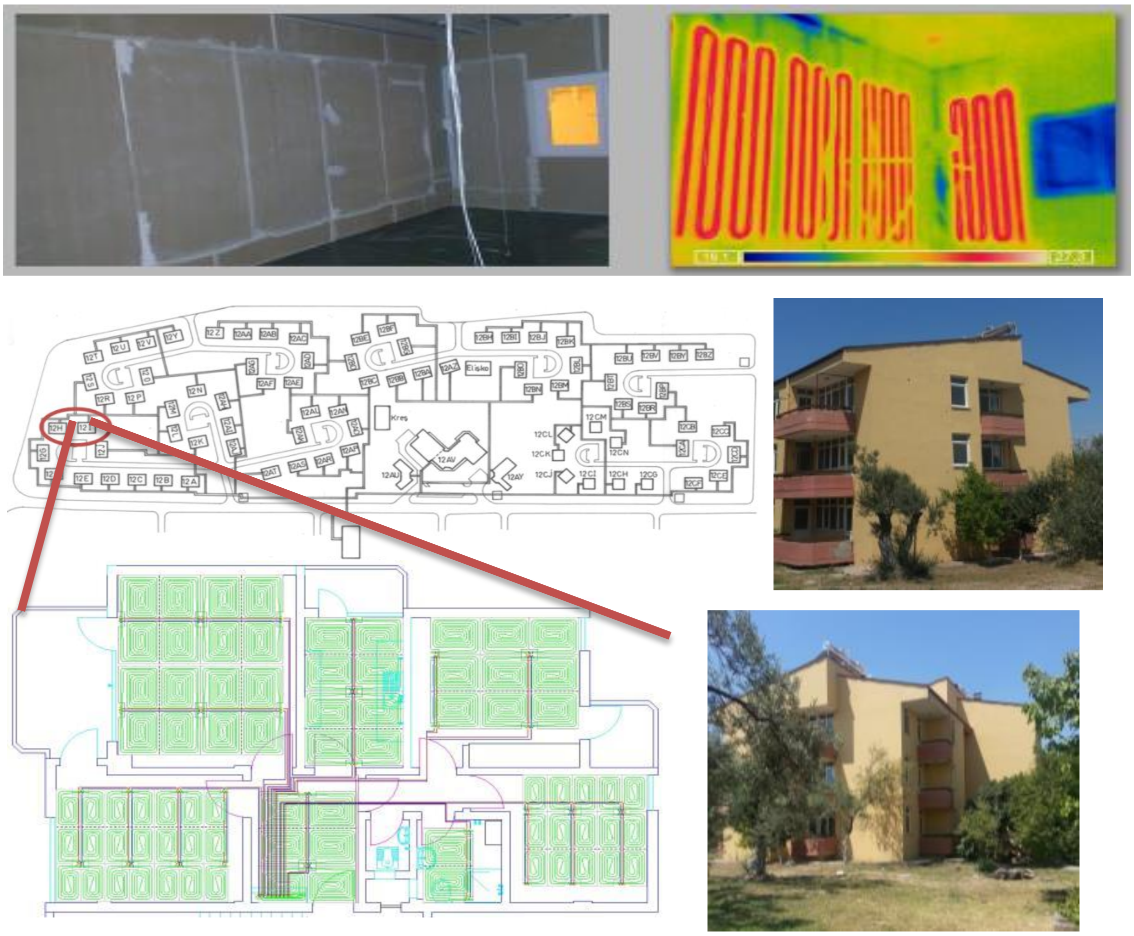


Figure 7.9: Radiant heating and cooling application in three story building

Passive Strategies

Exterior walls: Envelope insulation

Thermal insulation application is done for all building types unless the convention centre. Adequate insulation thickness calculated as 5 cm of EPS (expanded polystyrene).

- Brick wall
- Adhesives
- Thermal Insulations (EPS foam)
- Mechanical Fixing
- Reinforced Layer: with glass fibre mesh
- Primer Coat
- Finishing Coat

Figure 7.10: Insulation application in different building types in Soma

Windows: Window glazing

Window unit replacements are done for the convention centre of the demo site. Double glazed windows are replaced with previous – non efficient windows in order to minimize heat losses and increase thermal efficiency.

<table>
<tr><td rowspan="3"></td><th colspan="2">High performance windows</th></tr>
<tr><td>Type</td><td>Double glazed and PVC frame</td></tr>
<tr><td>U-value (glass + frame)</td><td>1.2 W/m^{2}K</td></tr>
</table>

Table 7.1: Properties of high performance window


Figure 7.11: Window replacement application in convention centre

7.3 Selected strategies for the Swedish demo site

What characterizes the buildings in the Swedish demo site is their concrete façades with metal components and large bands of windows along the sides facing north and south.

Façade renovations have not been deemed necessary as the structure and air sealing are in good state. The results of the airtightness test indicate that the building envelope is largely of such a high standard as to be comparable with the standards for new buildings. Consequently, the renovations will be targeted at the elements in the building envelope that can be given an improved U-value.

Windows

The building's windows currently vary in both quality and type. On the southern façade, the windows on the ground and first floors are the original 1+1 type windows. During the renovations, the south-facing windows will be replaced with a more energy-efficient model. The new windows will be triple-glazed, with low-emission coating, warm edge spacers, argon gas and a U-value of 1.0 W/m^{2}K.

Balcony doors

The existing balcony doors on levels 1 (ground floor) and 2 will be replaced by wider balcony doors to take into account people with disabilities. The new balcony doors have a better U-value that those currently installed in the building.

Additional wall insulation

During the retrofitting, the old curtain wall sections will be demolished, including window surrounds and French windows. A new external wall with a lower U-value of 0.20 W/m^{2}K will be built along the southern long side of levels 1 and 2. The new curtain wall will consist of the following, from the inside out: plasterboard + plastic membrane + 95 mm mineral wool with slit steel wool, upright wooden joists and wooden capping beam + Minerit + 100 mm mineral wool (façade layer) + air gap + façade made of slab material.

Additional roof insulation

The roof will be insulated with an additional 280 mm of loose wool during the renovation. More than 280 mm of insulation is not recommended, meaning that the roof's tongue and groove boards will be colder, which could result in mould spots. The U-value with the additional insulation is estimated to be 0.10 W/m²K.

Glazing of balconies

The renovation will involve glazing of balconies. Glazing the balconies will increase the tenants' rent. As this intervention has an impact on the rent, tenants can choose whether they want to have their balcony glazed or not.

8 Conclusions

This deliverable provides a catalogue of envelope retrofitting solutions, including both passive and active solutions and other techniques related to bioclimatic design. The main conclusions of the performed research are:

- The building envelope is the main responsible for building heat losses and gains. Walls, roofs, windows and floors can be optimized by studying different characteristics:
    - Thermal resistance
    - Thermal bridging reduction
    - Air tightness
    - Thermal inertia, energy storage capacity
    - Optimization of solar energy gains
    - Solar control
    - Passive cooling
    - Passive thermal gains - e.g. transpired solar collectors
    - Natural ventilation
    - Natural daylight transmission through glazing
    - Also the envelope surface could be the support for the introduction of renewable energy generation solutions
- The building envelope cannot be designed in isolation. It is a function of design management to ensure that the performance attributes and the physical connections between the envelope and the rest of the building are integrated in concept and execution from the beginning of the design process.
- Bioclimatic design is also applicable in retrofitting activities. Constructive solutions should adapt to the climate of the place where a building is located, in order to achieve a good energy performance and accurate comfort conditions. In this deliverable, it is possible to find conventional and innovative bioclimatic solutions available for retrofitting activities, most of them related to glazing and thermal mass interventions and also strategies to achieve this goal.
- Active solution technologies are applicable by the use of advanced technology that works co-ordinately with climatic conditions so that natural sources that can be evaluable on site area.
- Combination of various technologies and strategies will produce an achievement greater than the success result by their individual performance can be defined as synergy between them. In the consideration of the envelope retrofitting objectives, benefits of synergy cannot be passed over. Thus, it can be easily said that envelope applications can be combined with each other and with different technologies belonging to the rest of the building system, in order to maximize the building sustainability.

- Transforming typical building retrofitting to make way for deep reductions in energy consumption (known as deep renovation) is a high priority settle by the International Energy Agency [10] and pushed by the European Commission. As well as enabling permanent ongoing reductions in energy costs, deep renovation can reduce the capital cost of heating, ventilation and air-conditioning equipment. Also, the building envelope improvements can improve occupant comfort and the quality of life to millions of citizens, while offering significant non-energy benefits such as reduced health care costs and reduced mortality of "at risk" populations.
- Within the solutions proposed, there are certain barriers about economical, technical and experimental issues such as higher initial expenses despite their low operation costs, demand for qualified and experienced technical team and wide range of product requirement. To overcome these barriers, it is important to raise public awareness, strength infrastructure of the active market and governmental support with related regulations and laws. The outcome of research into understanding barriers and drivers for non-technical (e.g. behaviour) and technical aspects, such as the development of multifunctional solutions (e.g. eco-efficiency, comfort, aesthetic value, etc.), would speed up the transformation of the market. Cost savings can also help greatly in supporting the development of the energy efficiency market. R&D together with deployment has to reduce drastically the cost of certain technologies (market of hundreds of thousands of units), such as heat pumps, photovoltaics or emerging lighting solutions. There is also a large potential for an increase of performance from the economic and CO_2 point of view. Low carbon technologies have to move from a several-hundred-thousand to a multi-million-unit-per-year market. Financing issues also need to be tackled, jointly implementing new business models and services with a life cycle perspective.
- The Technology Roadmap for Energy efficient building envelopes presented by the International Energy Agency [10] sets the R&D priorities on the following technologies as future leaders of most important returns on investment:
    - Highly insulated windows
    - Advanced, high-performance, "thin" insulation
    - Less labour-intensive air sealing, and lower-cost validation testing
    - Lower-cost automated dynamic shading and glazing
    - More durable and lower-cost reflective roof materials and reflective coatings
- The transition towards more energy-efficient building envelopes will require rapid deployment of a large range of advanced building envelope technologies. Many of these technologies are significantly more expensive and will require higher upfront investment costs. To achieve the large energy savings that efficient building envelopes can offer, full market deployment of high-priority, energy-efficient building materials is essential.
- In the CITyFiED project demo sites, several strategies have been selected and envelope solutions have been defined by evaluating the existing condition of all demo sites. As a result, both passive and active envelope solutions are considered, synergies between them examined and the optimum results are targeted to be received.

9 References

[1] AP2BEER (D2.2 Technologies and strategies for Public Building and District Retrofitting)

[2] PIME´S (D2.4.4 Guide for bioclimatic design)

[3] STEEP (D3.1 Knowledge exchange on technologies)

[4] 3ENCULT (D3.1 Report on Energy Efficiency Solutions for Historic Buildings)

[5] GE2O (D2.1. Summary of the best practices, lessons learnt and potential barriers)

[6] Joint Research Centre for Set-Plan Information System. (2011). Technology Map of the European Strategic Energy Technology Plan

[7] Arnold, C. (2009). Building Envelope Design Guide. FAIA, RIBA (Building Systems Development Inc.)

[8] Olgyay, V. (2014). Arquitectura y clima: Manual de diseño bioclimático para arquitectos y urbanistas. ISBN: 9788425214882

[9] Loncour, X., Deneyer, A., Blasco, M., Flamant, G., Wouters, P. (2004). Ventilated Double Facades: Classification & illustration of facade concepts. Belgian Building Research Institute.

[10] International Energy Agency. (2013). Technology Roadmap for Energy efficient building envelopes

[11] http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=policy-set-plan

[12] http://www.ectp.org

[13] http://www.e2b-ei.eu/default.php

[14] http://www.environ.ie/en/Environment/EnvironmentTechnologyActionPlanETAP/

[15] http://www.eccredi.org/

[16] http://www.encord.org/

[17] http://www.eracobuild.eu/

[18] http://ec.europa.eu/research/energy

[19] http://concerto.eu

[20] European Communities. (2006). Energy Futures, The role of research and technological development. European Commission

[21] EURENDEL. (2006). From energy futures. The role of research and technological development. European Communities

[22] E2B & ETPC European Projects. (2013). Energy-Efficient Buildings: multi annual roadmap for the contractual PPP under Horizon 2020. European Commission

[23] LaFrance, M. (2010). Buildings XI Conference DOE Roadmap Meeting. USA Department of Energy

[24] Industrial Advisory Group of the E2B Platform. (2010). Energy-Efficient Buildings PPP: Multi-annual roadmap and longer term strategy. European Commission

[25] Porter, M.E. (2000). Location, Competition and Economic Development: Local Clusters in a Global Economy. Economic Development Quarterly 14, no. 1: 15-34

[26] Sölvell, Ö., Lindqvist, G., Ketels, C. (2003). The Cluster Initiative Greenbook. 6th Global TCI Conference- VINNOVA

[27] Ketels, C. (2004). European Clusters. Structural Change in Europe 3, Innovative City and Business Regions. Hagbarth Publications

[28] http://www.geoclusters.eu/

[29] http://archive.europe-innova.eu/

[30] http://www.clusterobservatory.eu/

[31] http://www.clustercollaboration.eu/map

[32] Ministerio de Vivienda, Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación, CTE (BOE núm. 74, de 28/036/2006)