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Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions

D2.2 A set of basic modular facade and roof elements including renewable energy production and integration of HP insulation

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Table of contents

EXECUTIVE SUMMARY

This report summarizes the work done in the Task 2.2 of H2020 project MORE-CONNECT. The main objective of the task was to provide a basic set of modules for modular refurbishment of residential buildings and test it. The participants in the task could use their own solution best fitting to the local conditions or adjust the general solution provided in the project. The following pages illustrate the process and the reached results.

In the first step, a monitoring of reference buildings was done to collect sufficient data about the pilot cases for which the MORE-CONNECT refurbishment system should fit. The data consisted of building typology description, the boundary climatic conditions, architectural requirements and overall design targets.

In the second stage, according to the geometrical limitations, the possible solutions were described. Each geocluster representative stated their overview of the localised pilot building.

Based on the knowledge of the partners, the options of the design were collected and stated in the Chapter 4. The project partners shared their experience and knowledge for a localized design.

The general solution of the basic set of modules (wall and roof module) was developed and is described in the Chapter 5. The solution presents starting platform to be adjusted for each particular case of the pilot buildings.

The country-specific solutions are presented in the Chapter 6.

Finally, the prototyping of the modules is illustrated in the Chapter 7. The feasibility tests were done together with the other quality assessments. The results are stated and present the final state of the Task 2.2.

1 INTRODUCTION

The presented report describes the main outcomes of the *Task 2.2 Multifunctional Modular Solutions for facades and roofs* (hereafter referred to as T2.2). It summarizes an approach to design of retrofitting modules that shall be used for modular retrofitting of residential buildings in the geoclusters represented in the MORE-CONNECT project.

1.1 Objectives

The objective of the T2.2 was to develop basic modular elements for façades and roofs that will enable modular retrofitting of residential buildings with minimum saving of 80 % primary energy.

1.2 Relation to project Tasks

The work in this Task combines and builds upon outcomes of related M-C Tasks, especially:

- *T2.1 Initial performance criteria and requirements*, which defines boundary conditions in the MORE-CONNECT geoclusters (climatic conditions, requirements on indoor comfort)
- *T2.3 HVAC solutions* which provides information on the technologies that make the engine of the building and have to be fitted together with the building modules
- *T2.4 Integration of renewable energy systems* provides guidance on options of integration of the renewable energy sources directly into the new building's envelope
- *T2.5 High performance insulation* provides overview of possible materials that can be used to prevent thermal bridges in the construction of the modules
- *T2.6 Smart connectors* provides solutions for connection of the modules
- *T2.7 Advanced controls* defines requirements on the elements of the monitoring and control systems of the building that need to be integrated into the modules.

During the works on T2.2 took place also exchange of information and shared data collection with *T3.1 Typology of building stock for relevant markets in geoclusters.*

1.3 Design process

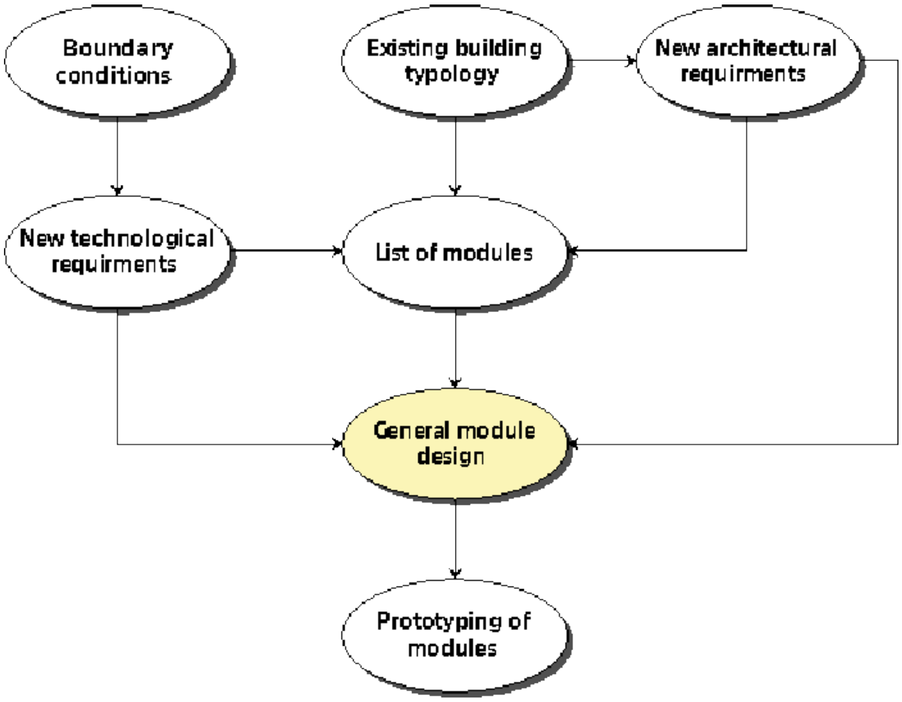


Figure 1.1: Module design process.

The method of design of the basic modules of the multifunctional solutions for façades and roofs comprised the steps:

- Summary of requirements and boundary conditions
- Architectural options in relation to possible building extension and variability in comfort features
- Solutions of basic wall panels in relation to setting of external walls of existing buildings
- Study of the pilot buildings and compilation of list of basic modules
- Design of basic modules
- Prototyping of basic modules

These steps are further described in the following chapters.
Selected features of the developed designs were then tested in laboratory conditions.

2 BOUNDARY CONDITIONS

2.1 Energy and building services

The resulting solutions have to be applicable in the climatic conditions in the MORE-CONNECT geoclusters (Figure 2.1):

- Geocluster 1: Northern. This cluster is focusing on solutions for the Scandinavian market (Denmark is represented in project)
- Geocluster 2: Continental Northern East. This cluster is focusing on a collaboration between Baltic States but also in other former East-European countries (Estonia and Latvia are represented in project)
- Geocluster 3: Continental Centre. This cluster focuses on solutions for continental climates (Czech Republic is represented in project)
- Geocluster 5: Mediterranean. This cluster is focusing on solutions for mild and warmer climates (Portugal is represented in project)
- Geocluster 6: Western Central. This cluster focuses on the Dutch/Belgium markets (Netherland is represented in project)

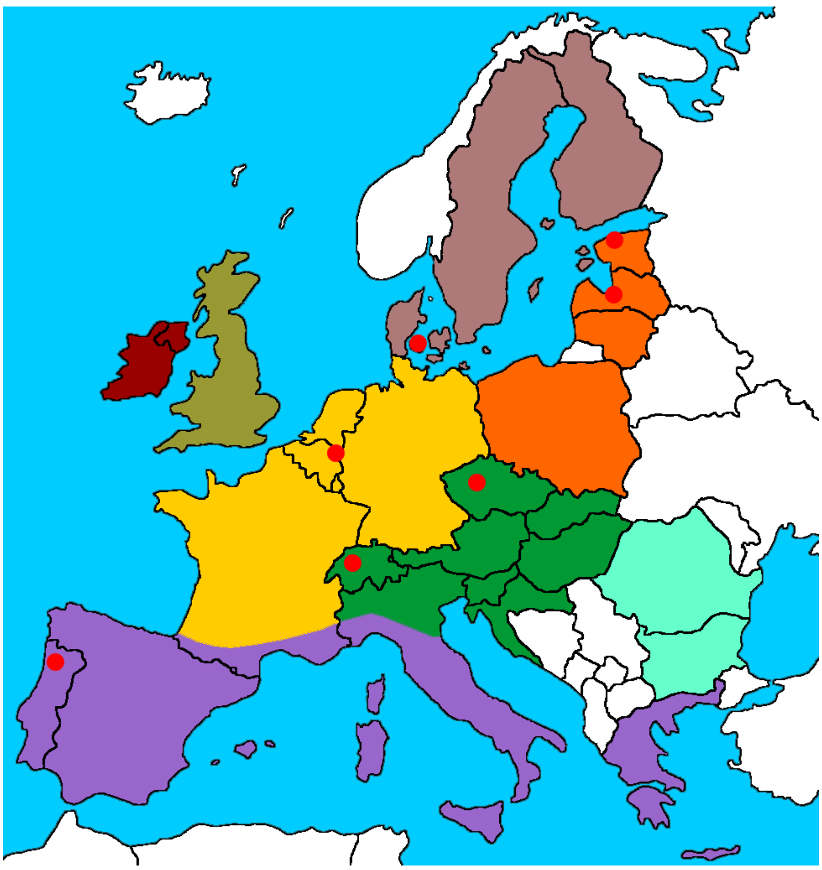


Figure 2.1: Map of MORE-CONNECT geoclusters

Boundary conditions and requirements on the indoor comfort of buildings were set in D2.1.[1]. The requirements on indoor climate were summarized in its sections 3.1, 3.2 and 3.4, requirements on moisture safety are in section 3.3. The overview of nZEB legislation in the respective countries has been made in section 4.2 and the influence of energy performance of buildings to energy related requirements of modular building envelope retrofitting elements was summarized in section 4.3.

The solutions should be variable in their thermal properties, providing various levels of refurbished buildings' energy performance (initial design targeting at zero energy standard, then will be subject of economic and environmental optimization). The target typologies require that the design provides solutions in the following categories:

Energy sources

- Various combinations of electricity, district heating, natural gas, biomass boiler, PV
- To get to zero in primary energy, PV on roofs likely in all cases, plus additional façade installation in some cases

Heating system

- Selection from air, electric radiators, double-pipe system with radiators
- When only air heating, radiators in bathrooms still to be installed for comfort (possible source of heat – electricity or circulating DHW)

Ventilation

- Mechanical ventilation with heat recovery in most cases
- Requirements on air ducts in modules
- Need for HVAC modules (possible locations: cellar / loft / outside)
- Need for indoor air ducts for exhaust air – indoor modules needed

Connectors

- Air ducts in most cases
- In some cases, heating pipes needed to be included
- Low voltage for controls needed in most cases
- PV wiring needed in some cases

Monitoring and control

- Temperature
- Humidity
- CO_2
- Heat flows
- Individual room control

2.2 Architectural options in relation to possible building extension and variability in comfort features

As the pilot buildings have differences, so are the demands of the user, of the stakeholders or the legislation regulations. At the beginning several meetings with architects and designers were undertaken to get as complete as possible list of demands and ideas to know what can be encountered in real practice. The main goals for the design were:

- Minimal intervention to users' life during renovation: The renovation must be fast and as much technology as possible must be mounted or installed in the modules or in the common areas of the existing house (corridors).
- Rapid improvement of users' living comfort through technology and building materials used: All possible technologies used are described in the following chapters of the report, however, the energy consumption decrease made by thick layer of thermal insulation or new low-U-value windows, use of renewable energy sources, control systems, blinds and sunshades are just the typical measures.
- Possible improvement of users' living comfort through extension of flat area: When there is a sufficient space around the building, there is no problem to think "outside the box" and find a way to somehow enlarge the usable area of the housing unit. It can be made either by small additional structures such as balconies or by larger glazed winter gardens.
  Another way is the extension to the loft or upon the roof of the existing building.
- Possible improvement of users' living comfort through changes of layouts of flats: It is not the real modular renovation, however the proposed MORE-CONNECT deep renovation represents a unique opportunity to customize the flat the user's way.

The architectural design of the renovation must be flexible enough to cope with all set of challenges, and yet it still must be distinctive reflecting the idea of an architect. Therefore, the MORE-CONNECT modular system must be variable in:

- Joints: Thinking of apartment houses, panels cannot be manufactured in size of the whole façade, therefore they have to be connected to seal the façade and to ensure the mechanical cooperation of the whole structure. The design also has to enable joint in an inner or outer corner of the building.
- Variety of external surfaces: The designed panel has to allow to execute any common type of façade finishing (thin plaster, wooden cladding, cement boards, etc.).
- Combination of external surfaces: The designed panel has to allow to be combined with other types of façade renovation systems, such External Thermal Insulation Composite System (ETICS) for instance in the basement or at one facade.
- Mounting of extensions: As mentioned above, one of the main goals are the exterior extensions, such as balconies or winter gardens, and if there is no possibility of executing new foundations, the panel (or set of panels) must be capable to bear all the load of such structure (in combination with the existing structure).

The following table summarizes the common design targets related to architectural improvements.

Table 2.1: Design targets based on requirements or needed interventions

Building element	Design targets
Possible changes in layouts	– New balconies, lofts, staircases, elevators, extended layouts
Possible extensions	– Lofts
Façades	– Needed for types of shaping: fragmented, segmented, plain, curved – Target U-values 0.08 – 0.21 W/m2K
Windows	– Planned replacement in all cases

Building element	Design targets
	– New windows to have Ug 0.5–1.0 (probably triple glazed in most cases) – Shading devices for summer period needed in most cases at least for south facing façades
Roofs	– Most of the roofs pitched, needed extension of rafters or complete replacement – target U-values around 0.11 – in Estonia flat roof, target U-value 0.06
Underground floor	– In most cases, underground floor – needed solutions to prevent moisture rise, perhaps additional thermal insulation of the building perimeter

Examples of possible architectural improvements are illustrated in the case study from Czechia described in the following chapter.

2.3 Case study from Czechia showing possible architectural improvements

The studied building (see Figure 2.2) was built in 1958 as a part of social housing settlement in Milevsko, South-Bohemian Region, intended for workers of the simultaneously constructed factory. This particular building has 24 studios (room, kitchen, bathroom, hall), 31 m^2 each, in three upper stories (see Figure 2.3). Technical or housing facilities and cellars were put in the basement. Entrance to the building is on the northern façade, leading to the wide central hall with north-south orientation. At the southern façade, central hall is ended with a loggia. Each flat has two windows oriented either to the east or to the west. The building has a gable roof (33°), attic space is currently unused. Building has longitudinal wall structural system made of bricks (450 mm), ceilings are made of reinforced cast concrete. Façades are plastered, windows and exterior doors are partly original, partly (3 of 24 studios) replaced with insulating double-glazing, both with wooden frame.

Figure 2.2: Typical representative of the target typology in Czechia

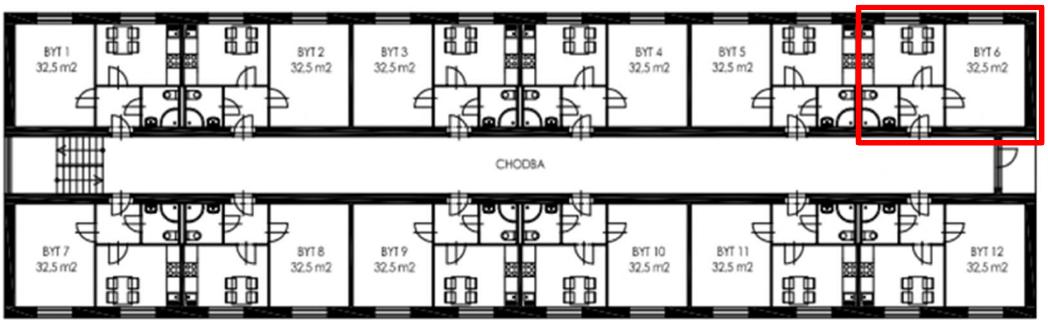


Figure 2.3: Typical layout of flats (one flat unit highlighted in red colour)

In the time the reference building was build, usual U-values varied (there were no standards then): 0.76–1.72 W/(m^{2}K) for the roof, 1.07–1.70 W/(m^{2}K) for the wall, 0.76–1.22 W/(m^{2}K) for floor and 2.18–3.44 W/(m^{2}K) for openings. The total heat loss of the building is 2,037 W/K from which ventilation is responsible for 12 % and remaining 88 % is accounted to heat flow by transmission. The annual energy consumed by one reference building is around 1050 GJ.

A refurbishment of any older building must deal with the typical aging issues that an old building has. The typical problems of the reference building are, first of all, unsatisfying winter thermal comfort and overall energy performance. Second, an old-fashion appearance (i.e. the ruptures in plaster or a devastated common shared areas) can be observed. The insufficient ventilation supports a mould growth mostly in the basement floor or even in the bathrooms or kitchens. The condensation and mould growth is more frequent in the flats with replaced the original badly insulating wooden windows with a loose closing mechanism for the new so-called “Euro” standard ones. Furthermore, the water-proofing failures can be observed both in the basement and in the attics. A water leakage occurs in the area of chimney-roof run through. Moreover, possible overheating caused by the obsolete control of heat distribution system during winter season contributes to the insufficient thermal comfort. These problems come from the lack of maintenance of the building and must be solved during the refurbishment process in full complexity to fulfil a demand for recent comfort standards.

In order to get more complex overview of possible modules needed for extension of existing buildings, there was made an architecture case study for the Czech target typology. The intention of the study was to try and check the most complicated combination of options to be sure, that every simpler design is possible achieve. The choices were:

- Plaster on façade: Using thin plaster solution similar to ETICS was chosen not only because the building is in the settlement composing number of same buildings and design wanted to follow some urban rules, but also because it is the worst choice for prefabrication. Application of thin plaster is a wet process and at least the detail of panel joint must be made on-site.
- Big and small windows: In the case study, both original an extended size of window had to be proven. Taller (French) window increases the sunlight income and thus might be assumed as a contributor to comfort improvement. On the other hand, some demolition works are needed. The new, original size, window is very easy to mount and no intervention is needed, however pipes leading in the panel must somehow come into the interior in the position of the window.

- Integration of various technologies into the modules: Even it can be assumed in many cases it will not be needed to install all technologies (air ducts, heating water distribution piping, new wiring, sensors, etc.), the module has to be capable to bear everything.
- No new foundations allowed: When extension is designed, it is assumed that it is not possible to create new foundation and all load goes through the panels to the existing walls.

The Czech case study followed all the mentioned goals and according to the intervention range the three variants were developed:

- LOW-COST (Figure 2.4): A minimalistic variant where it is assumed no intervention in the flats is possible, and because of lowering costs, only those adjustments are executed which move the building to the nZEB level.
  The architecture is very simple. As mentioned, thin plaster is used around the whole building, the difference between small and bigger windows is eliminated and the former façade order is kept because of the change of plaster colour. New roof is put on the existing wooden structure and the attic space is not used. Because a lot of new technology (including HVAC, for example) is installed in the basement, new chimney comprising air ducts is created on the southern gable facade. This chimney is covered with metallic sheets in the colour of other tinsmith accessories. Basement is not insulated; however, a cement-board plinth is mounted to the existing wall.

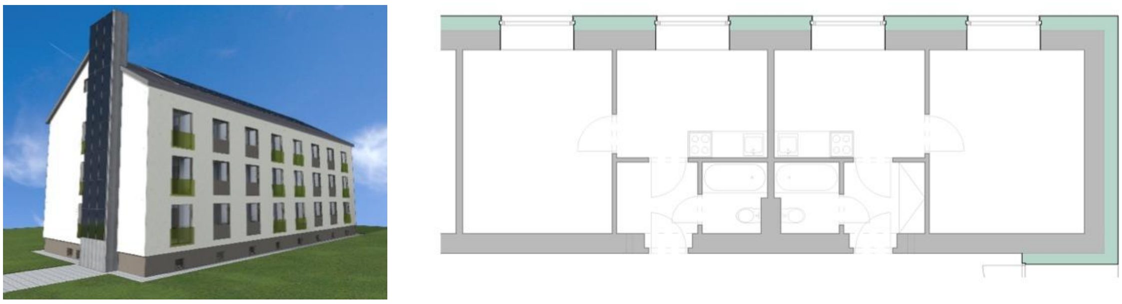


Figure 2.4: Floor plan detail of the LOW-COST variant

- ECO-ECO (Figure 2.5 and Figure 2.6): Design comes from the low-cost variant and it keeps the ideas, however some extensions are made and also minor changes in the disposition of the flat. In this variant, the so far unused attic space is divided and parts are connected to the flats in the upmost floor – the duplex is created. Disposition of flats tries to respect the current state of social housing.

Figure 2.5: Floor plan detail of the ECO-ECO or HI-TECH variant with possible disposition changes

Figure 2.6: Floor plan details with possible disposition changes (attic)

– HI-TECH (Figure 2.7): Design follows the concept of the ECO-ECO variant but the main difference is that in the attic, there are completely new and separate flats created so they can be sold to reduce the costs of the deep refurbishment on the former inhabitants. In addition to that he most advanced technologies are used to significantly improve the indoor comfort. In the standard floors, radical changes in the disposition are designed to improve the social variety of users offering not only social low-area housing but also larger flats (for young families, for example). Therefore, the advantage of longitudinal wall structural system is used and some two small flats are joined together.

Figure 2.7: Floor plan detail of the HI-TECH variant with enlarged flat and loft disposition

2.4 Requirements on construction process

The project objectives impose the following requirements on the construction process. It should:

- Enable fast installation without need of scaffolding
- Be based on modules that are transportable with standard means of transport
- Be compatible with alternative thermal insulation systems
- Fit for all situations where the renovation project requires complete, partial or no removal of existing structures.
- Speed up the renovation process, the accessories such as air ducts for HVAC systems, piping for heat distribution, wiring (electricity, internet, sensors, TV etc.) and renewable energy systems should be integrated in the modules
- Enable anchoring into concrete elements or masonry walls
- Ensure airtight connection to window openings or airtight all panel joints (for NL and LV)
- Provide system solutions for joints with balconies, chimneys
- Work with high-performance insulation (module thickness – shading of daylight) – to be optimized

2.5 Common design targets

The development of the multifunctional modules was based on the premises that the proposed solution has to:

- Be adjustable to fulfil the needs in the climatic conditions of all target typologies in all MORE-CONNECT geoclusters (boundary conditions were set in the D2.1)
- Be variable in its thermal properties, providing various levels of refurbished buildings' energy performance (initial design targeting at zero energy standard, the will be subject of economic and environmental optimization)
- Enable variability in design of external surfaces
- Enable mounting/anchoring of outdoor extensions such as balconies and shading devices according to the architectural requirements
- Integrate air ducts for HVAC systems, piping for heat distribution, wiring (electricity, internet, sensors, TV etc.)
- Integrate renewable energy systems
- Be compatible with alternative thermal insulation systems and
- Fit for all situations where the renovation project requires complete, partial or no removal of existing structures.
- Enable fast installation without need of scaffolding
- Be based on modules that are transportable with standard means of transport

In addition to the basic design targets, a survey among project partners has been made to collect additional requirements in the geoclusters. The following table summarises common design targets coming out form the analysis of the collected forms.

Table 2.2: Design targets based on requirements or needed interventions

Building element	Design targets (based on requirements or needed interventions)
Possible changes in layouts	– New balconies, lofts, staircases, elevators, extended layouts
Possible extensions	– Lofts
Façades	– Needed for types of shaping: fragmented, segmented, plain, curved – Target U-values 0.08 – 0.21 W/m2K
Windows	– Planned replacement in all cases – New windows to have U_g 0.6-1.0 – probably triple glazed in most cases – Shading devices for summer period needed in most cases at least for south facing façades
Roofs	– Most of the roofs pitched, needed extension of rafters or complete replacement – target U-values around 0.11 – in Estonia flat roof, target U-value 0.06
Underground floor	– In most cases, underground floor – needed solutions to prevent moisture rise, perhaps additional thermal insulation of the building perimeter
New modules	– Anchoring into concrete elements or masonry walls – Airtight connection to window openings; airtight all panel joints for NL and LV – Needed system solutions for joints with balconies, chimneys – In most cases needed high-performance insulation (module thickness – shading of daylight) – to be optimized
Energy sources	– Various combinations of Electricity, district heating, natural gas, biomass boiler, PV – To get to zero in primary energy, PV on roofs probably in all cases, plus additional façade installation in some cases
Heating	– Selection from air, electric radiators, double-pipe system with radiators – When only air heating, possible source of heat for radiators in bathrooms (electricity or circulating DHW)
Ventilation	– Mechanical ventilation with heat recovery in most cases – Requirements on air ducts in modules – Need for HVAC modules (possible locations: cellar / loft / outside) – Need for indoor air ducts for exhaust air – indoor modules needed
Connectors	– Air ducts in most cases – Not clear if heating pipes needed to be included – Low voltage for controls needed in most cases – PV wiring needed in some cases
Monitoring and control	– Temperature, humidity – CO_2 – Heat flows – Individual room control

3 CONSTRUCTION MODULES

3.1 Arrangement of basic wall panels in relation to setting of external walls of existing buildings

According to the project proposal, there were three ways to explore:

- Complete removal of the facade and/or roof and full replacement by new elements
- Partial removal of the facade and/or roof and partial replacement and addition of elements
- No removal of facade and/or roof and addition of prefab elements.

Given the variability in external structures of the building types taken into account and the requirement of integration of air ducts, wiring and piping into the external modules, there was a need to look deeper in the possible ways of mounting of the wall insulation modules.

From analysis made in the *T2.6 Smart Connectors* the accessibility of modules' joints from the interior is essential for enabling mounting of the modules without need for scaffolding. The geometry of the wall modules and its relative position depends on the following factors:

- Can the original external wall be removed?
- Is there present any French window (that enables easier connection of the piping, wiring and air ducts close to the floor structure)?
- Can the window openings be extended (depending on the material and structure of the walls)?

The design consequences of the boundary conditions are apparent from the following scheme and figures.

Because of the desired both refurbishment speed and the montage simplicity, the connection of integrated systems shall be done in the openings. The systems' connections can be carefully connected from the interior by the workers during montage and enable further quality check.

The integrated systems and their connections are the reason for the following analysis of the geometrical variants. These are described for the very basic wall module containing all the systems with two openings. For different buildings with different number of openings that can be refurbished by one module installation, more space can be available for the connections and not all the openings must be used for the connections.

The following examples show the basic horizontally oriented module division; vertical division favourable especially for the low floor buildings can be applied as well. The principles of the connection positioning are similar.

In the schemes air ducts are in green colour, heating water loop in red and blue colours, and electric wiring in yellow colour.

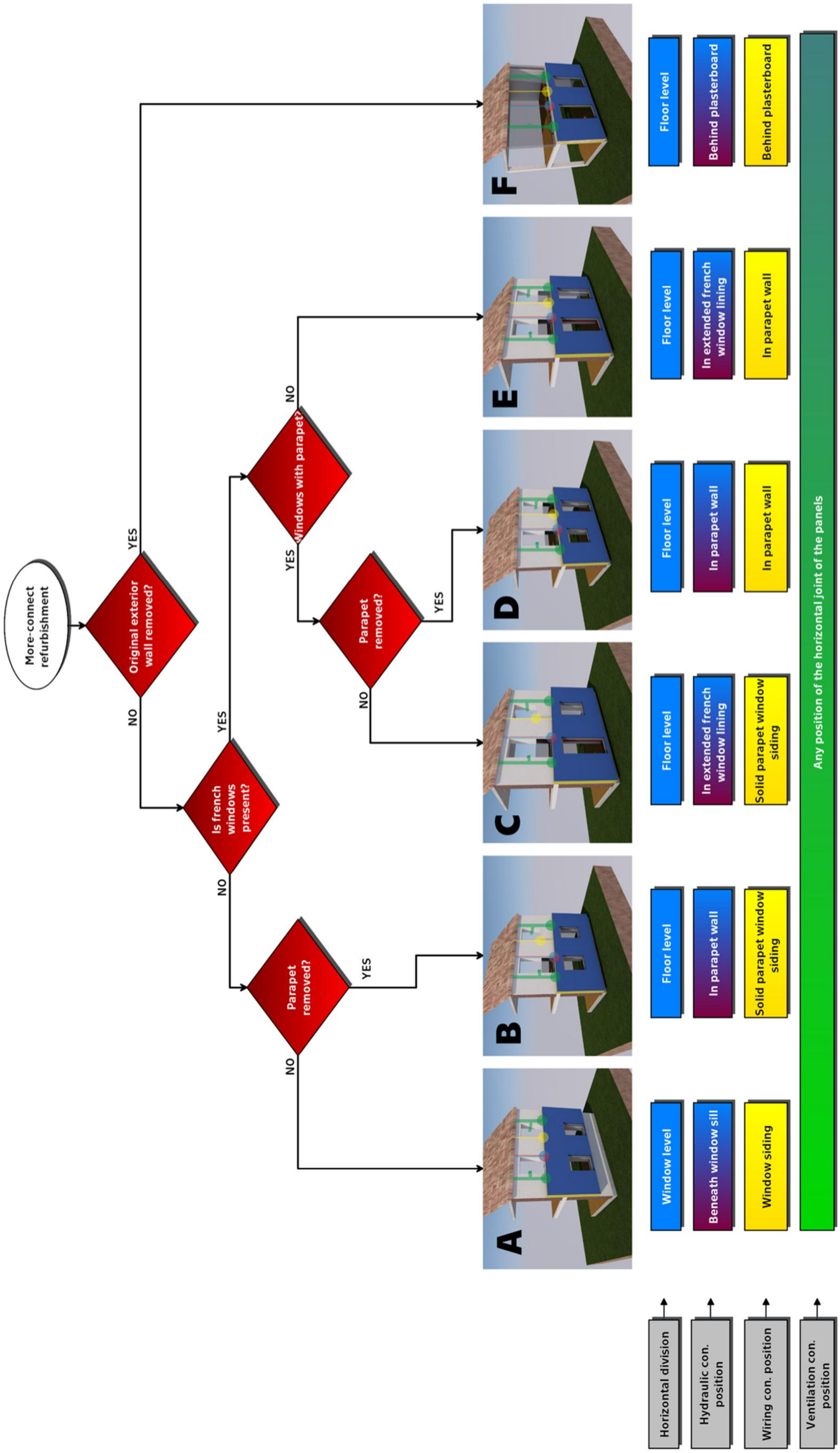


Figure 3.1: Decision diagram of the geometrical design variants of walls and windows.

3.1.1 Geometrical variant A: No removal of existing wall, parapet windows

The first design variant is intended for the cases, where a removal of original façade wall is difficult either from the constructional point of view or the economical point of view. The location of modules' joint is in the level of window parapet to ensure the possibility of connection of all integrated ducts and wires. The labourers can control all the crucial connections from the window.

Ventilation is connected using connection elements at the level of module division.

The airtightness of the house is ensured by original wall and the tape connection of the new window to the airtight layer.

Figure 3.2: Optimal position of modules in situation when in the external wall are windows with parapets that cannot be removed and the opening cannot be enlarged. Pipes of the heating system are connected beneath the window sill. Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.1.2 Geometrical variant B: Possible parapet removal

For the variants B-F, the location of the modules' joint is at the floor level. The hydraulic loop connection is situated in the position of replaced parapet. The electrical wires can be connected in the window siding. The electrical wiring comes prepared from the factory at the upper module long enough to reach the lower module's junction box during module assembly.

The new plasterboard/plywood parapet needs to be created to cover the connection, the ventilation is connected using connection elements at the level of module division.

The airtightness of the house is ensured by original wall and the tape connection of the new window to the airtight layer also in this variant. The ventilation is connected using connection elements at the level of module division as well.

Figure 3.3: Optimal position of modules in situation when there is an option to remove the at least one of two parapets and use the new gap for connections of heat distribution system at the floor level. New parapet cover must be done (left box, in green). Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.1.3 Geometrical variant C: possible parapet removal, new French window

In the case where a new French window is provided by the refurbishment project, the hydraulic heating loop must be connected at the floor level. As there is lack of space, the window opening is narrowed by extended lintel shaft which provides sufficient space for all the necessary connecting elements and further revision.

The electrical connection can be made in the standard window without removing the parapet there, similarly to variant B.

Again, the ventilation is connected using connection elements at the level of module division and the airtightness of the house is ensured by original wall and the tape connection of the new window to the airtight layer.

Figure 3.4: Optimal position of modules in situation when a French window is required by the design. Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.1.4 Geometrical variant D: all parapets removed, different window heights

In case that all parapets can be removed, the large space for the system connection gets available. Placing the heating loop connections to the area of standard window parapet is favourable, the electrical wiring connection can be done in the area of French window siding without need of narrowing the window. Similarly to the variant B, the wires are prepared from the factory long enough to reach the bottom electrical junction box which is then be placed in the window siding. Ventilation is connected using connection elements at the level of module division. The new parapet cover will be provided during the refurbishment.

The airtightness of the house is ensured by original wall and the tape connection of the new window to the airtight layer. The ventilation is connected using connection elements at the level of module division.

Figure 3.5: Optimal position of modules in situation when a French window is required by the design. New parapet and floor cover (left bottom box, in green). Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.1.5 Geometrical variant E: all parapets removed, only French windows present

Sufficient space can be available for the connections in the case all the parapets are removed, but in the case, where only French windows are available in the module, the space is limited. The electrical connections can be done in same the way as in the previous variant (see Variant D). The other window must be narrowed to embed the hydraulic heating loop connection in the extended window siding. Ventilation connections are realised at the module's joint level.

Figure 3.6: Optimal position of modules in situation when two French windows are required by the design. Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.1.6 Geometrical variant F: original façade removal

When whole external walls can be removed, the easiest setting is installation of the modules aligned with the floors with connections at the floor levels. All the connections can be reached easily, fast connected and checked. The new interior plasterboard wall (or other interior finishing) must be provided during the refurbishment. In this variant, new airtight layer must be created in the outstanding quality to ensure excellent parameters of the refurbished house.

Ventilation connections are again realised at the module division level.

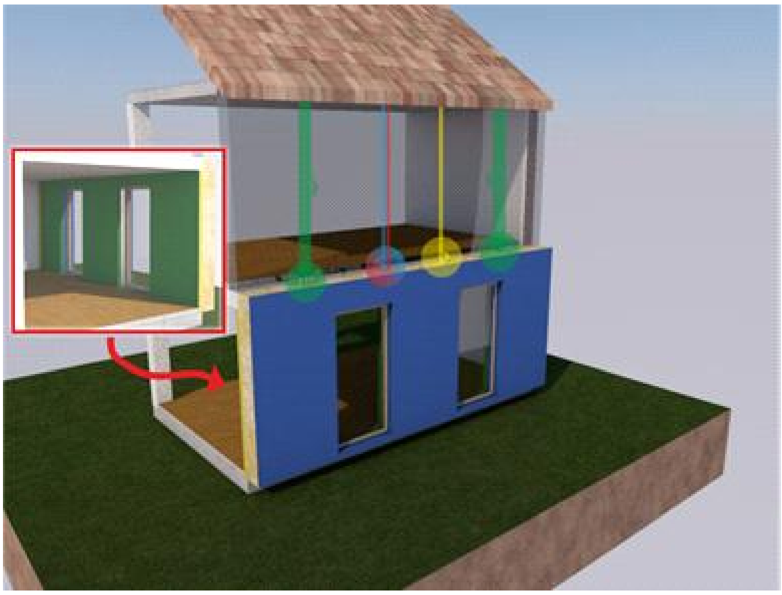


Figure 3.7: Variant F for total replacement of the original façade wall. The newly built interior plasterboard wall (included in the refurbishment modules) will be provided (left box, in green). Legend: air ducts – green, heating water loop – red and blue, electric wiring – yellow.

3.2 Analysis of the pilot buildings and geometrical sectioning of facades into modules

The façades and roofs of the pilot buildings (which are taken as typical representatives of given typologies) were taken and divided into modules.

Based on the analysis of the sectioning of the façades and roofs to the modules, there was identified a set of building modules that needs to be developed to enable completion of renovation of a typical residential building. The set comprises:

- Wall module
- Roof module
- Plinth module
- Connecting module
- Chimney module
- Gable module (with PV)
- Interior exhaust shaft module
- Horizontal shading
- Balcony

The first analysis was made with the scope of different needs in geoclusters. As there are differences between typical building typologies, the following paragraphs describe the division specific for the stakeholders' cases.

3.3 Czechia

The basic sets for two scenarios of renovations for Czechia are illustrated in Figure 3.8 (basic variant) and Figure 3.10 (variant with loft extension).

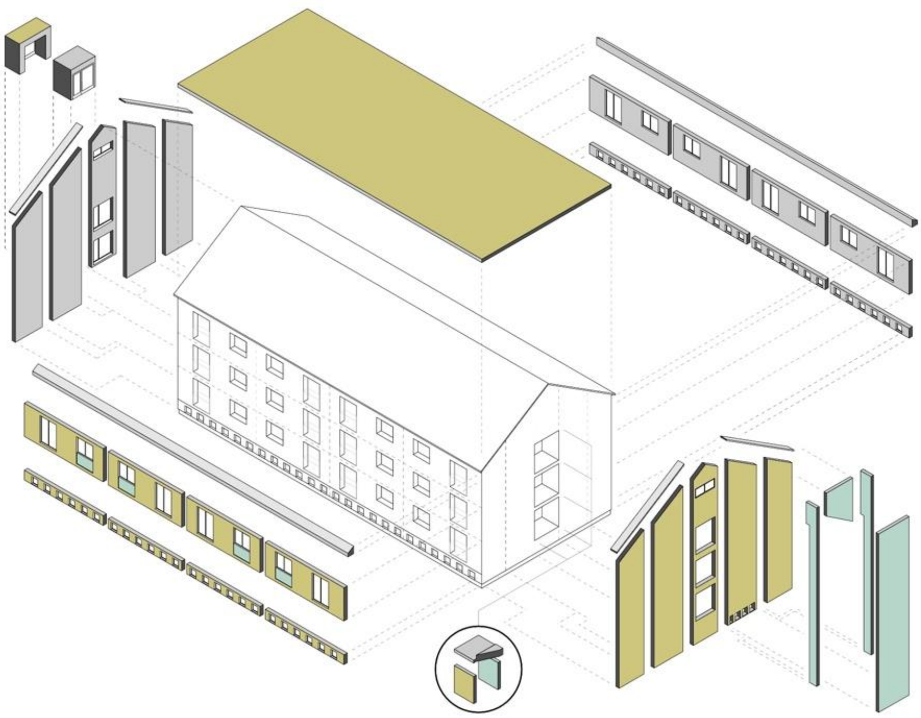


Figure 3.8: Set of modules for the Czech case in basic variant.

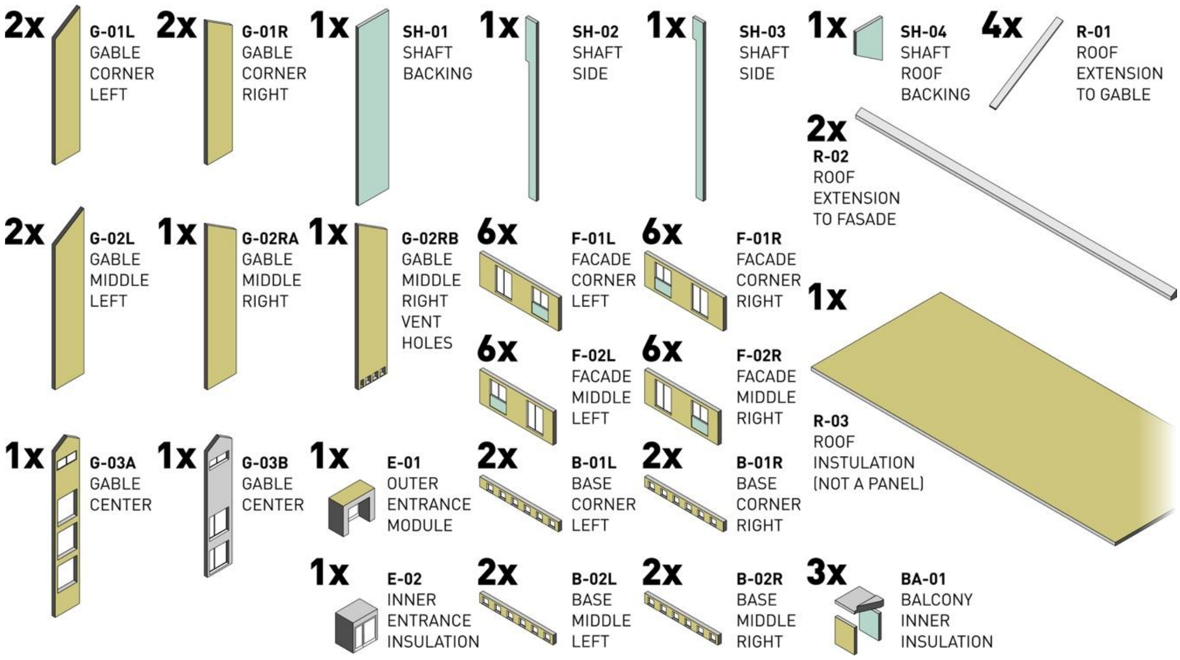


Figure 3.9: List of modules for the Czech case in basic variant

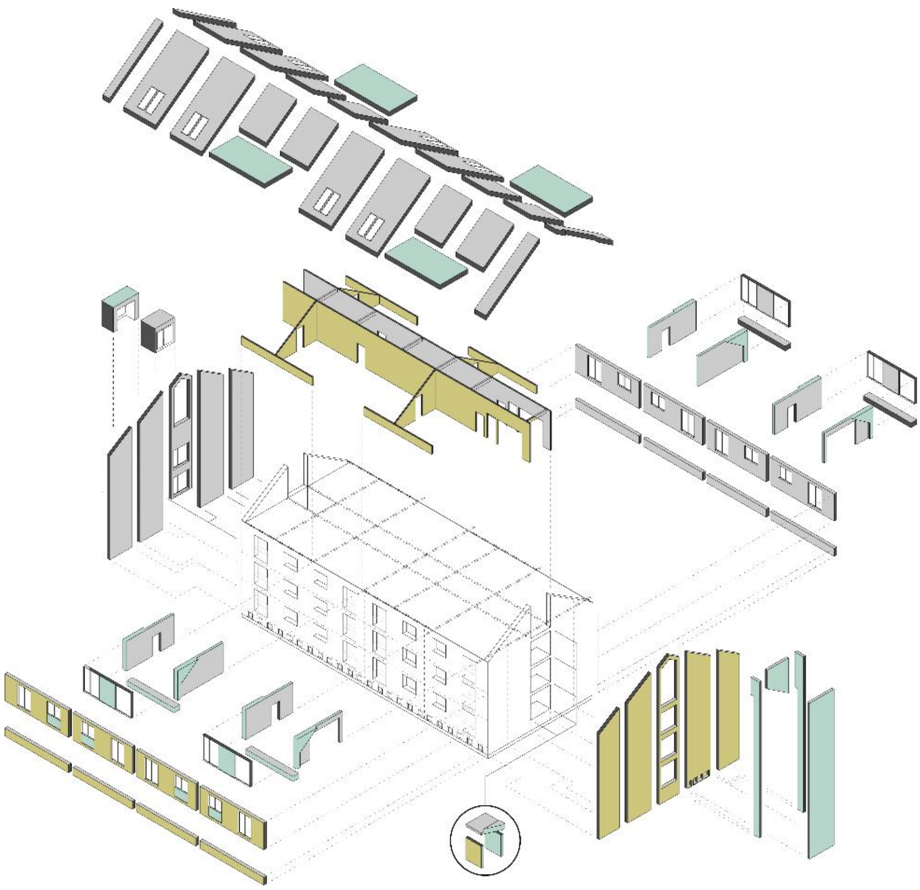


Figure 3.10: Set of modules for the Czech case in advanced variant with loft extension. Basic wall modules are designed in the geometrical variant C or D.

Besides the building modules, there are needed also technological modules (being developed in other Tasks):

- Engine (heat source, ventilation system with heat recovery)
- Monitoring and control modules
- Indoor air ducts (for exhaust air, suspended from the ceilings of corridors of block of flats and modules for exhaust air inlets in the bathroom of each flat – as illustrated in Figure 3.11)
- PV systems (inverters, cabling and accessories)

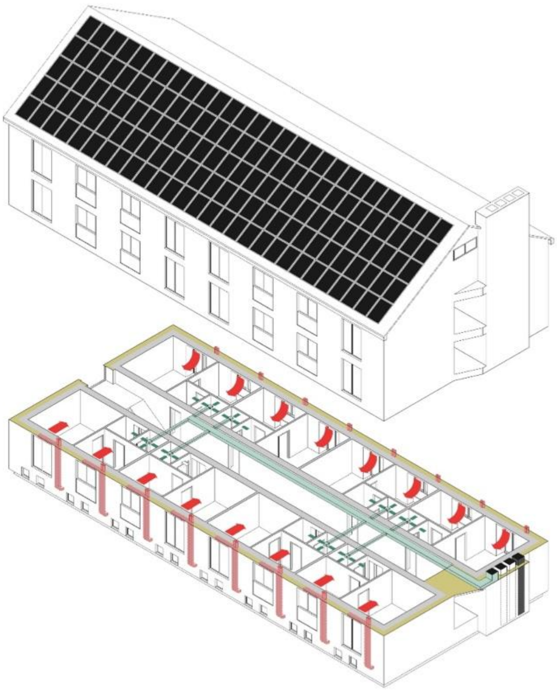


Figure 3.11: Ventilation system for the Czech case – warm fresh air distributed from the HVAC unit located in the cellar through air ducts integrated in the façade modules, suction of exhaust air from the kitchens and bathrooms through air ducts in the under ceilings in corridors to the new "chimney" at northern façade through the heat recovery system in the cellar and through the "chimney" out of the building.

Table 3.1: Definition of modules for the Czech pilot

ID	Count	Name	Description
G-01L	2	Gable corner left module	Sloped ending gable panel
G-01R	2	Gable corner right module	Sloped ending gable panel
SH-01	1	Integrals' shaft backing	Modules to create additional house ventilation and other installation shafts
SH-02	1	Shaft side cover	
SH-03	1	Shaft side cover	
SH-04	1	Shaft roof backing	

ID	Count	Name	Description
R-02	2	Roof extension to facade	Raising overlap of roof
R-01	4	Roof extension to gable	
G-02L	2	Gable middle left module	Standard gable modules
G-02RA	1	Gable middle right module	
G-02RB	1	Gable middle right module with ventilation opening	Standard gable module with a connection for the shaft
F-01L	6	Facade left corner module	Standard facade modules
F-02L	6	Facade middle left module	
F-01R	6	Facade right corner module	
F-02R	6	Facade middle right module	
B-01L	2	Basement corner left module	Connection modules
B-02L	2	Basement middle left module	
B-01R	2	Basement corner right module	
B-02R	2	Basement middle right module	
BA-01	3	Balcony inner insulation set	
G-03A	1	Gable centre module	
G-03B	1	Gable centre module short	
E-01	1	Outer entrance set	
E-02	1	Inner entrance set	

3.4 Denmark

As an example of advanced technologies, at the Danish pilot building will be tested a special new method of 3D printing of thermal insulation layer using automated spraying device with finishing made by special custom made robots.

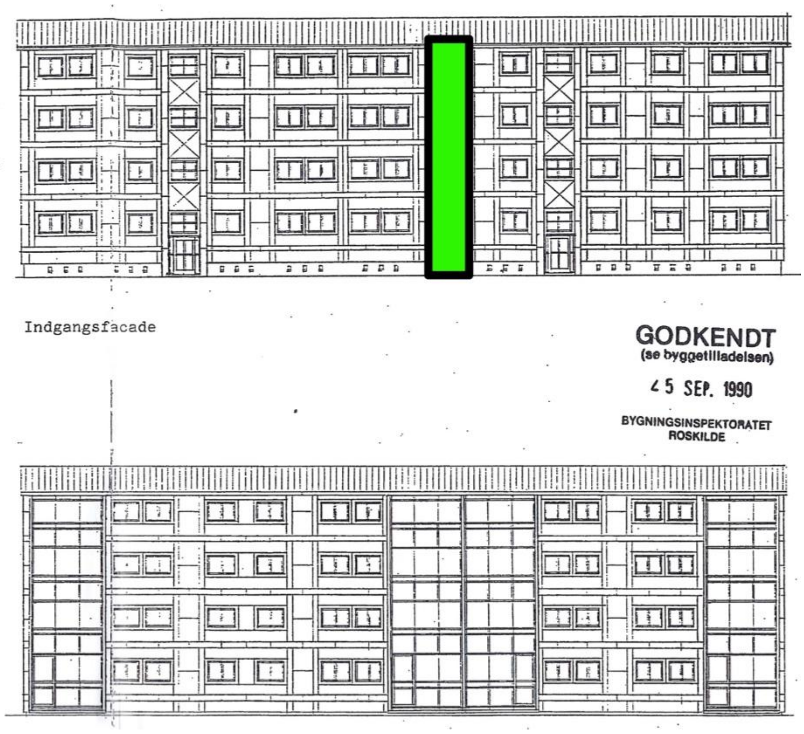


Figure 3.12: Side view - Shows one working area. one layer takes approx. 30 minutes.

Table 3.2: Definition of modules for the Danish pilot

ID	Count	Name	Description	Note
5/52	52	Standard wall module	Dimensions 1.5m wide x 12 m high - Scanning onsite tells where the printing should stop or start or make room for a window or roof etc. - Same material all over. - Design variation comes from Revit architect drawings predefined.	Our solution is fully integrated when first onsite scanning is done. The variation onsite is controlled by programming and drawings plus scanning.

3.5 Estonia

The following documentation illustrate the work on Estonian pilot building and localized modular solution adjusted for the typology.

Figure 3.13: Current view from NW.

Figure 3.14: Design solution from NW.

Figure 3.15: Current view from SE.

Figure 3.16: Design solution from SE.

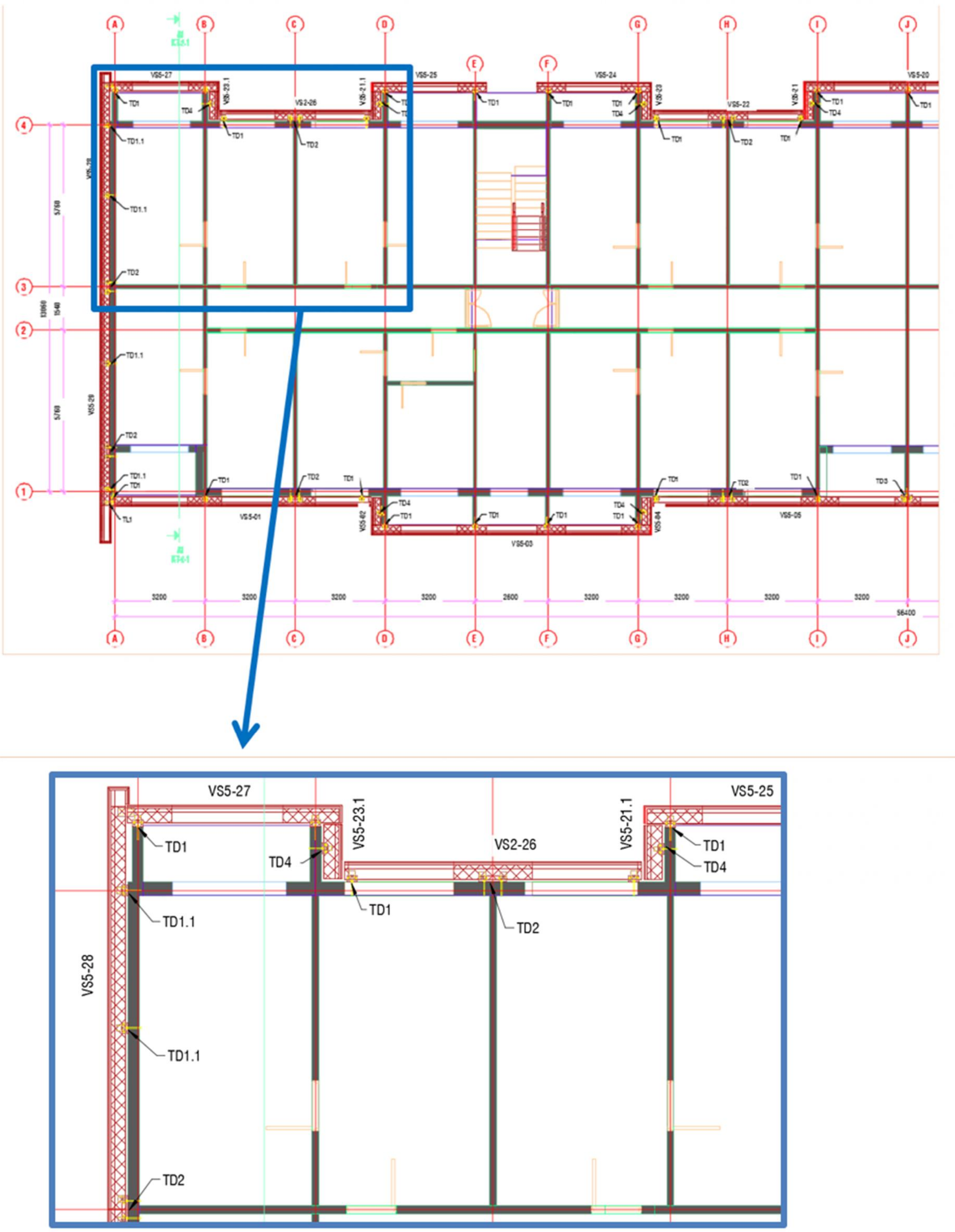


Figure 3.17: Flor plan of the 5th floor with detail.

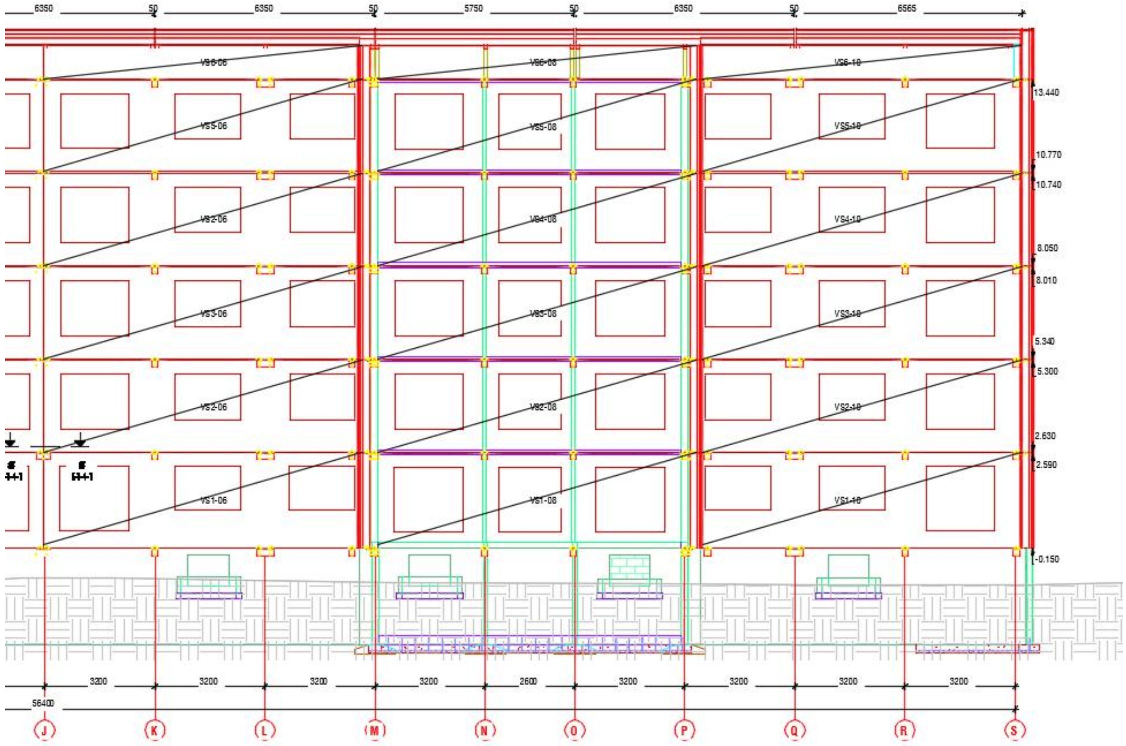


Figure 3.18: View from south.

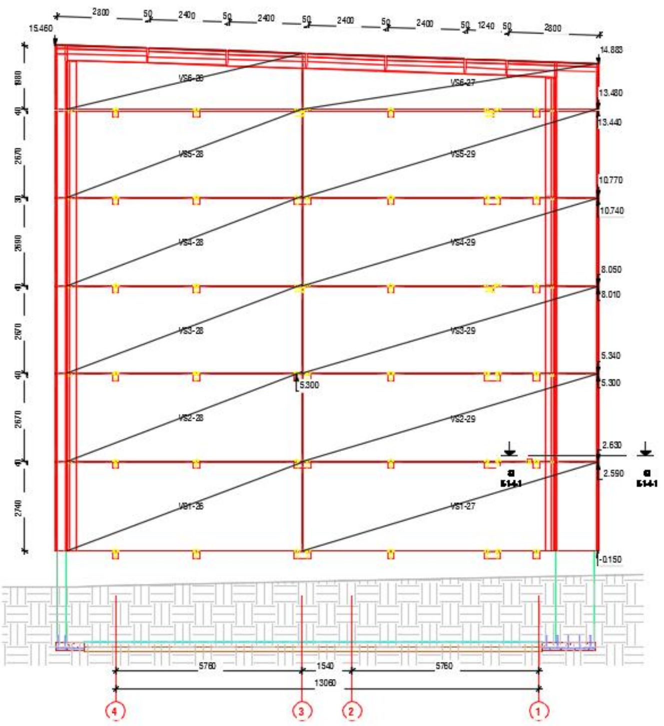


Figure 3.19: View from west.

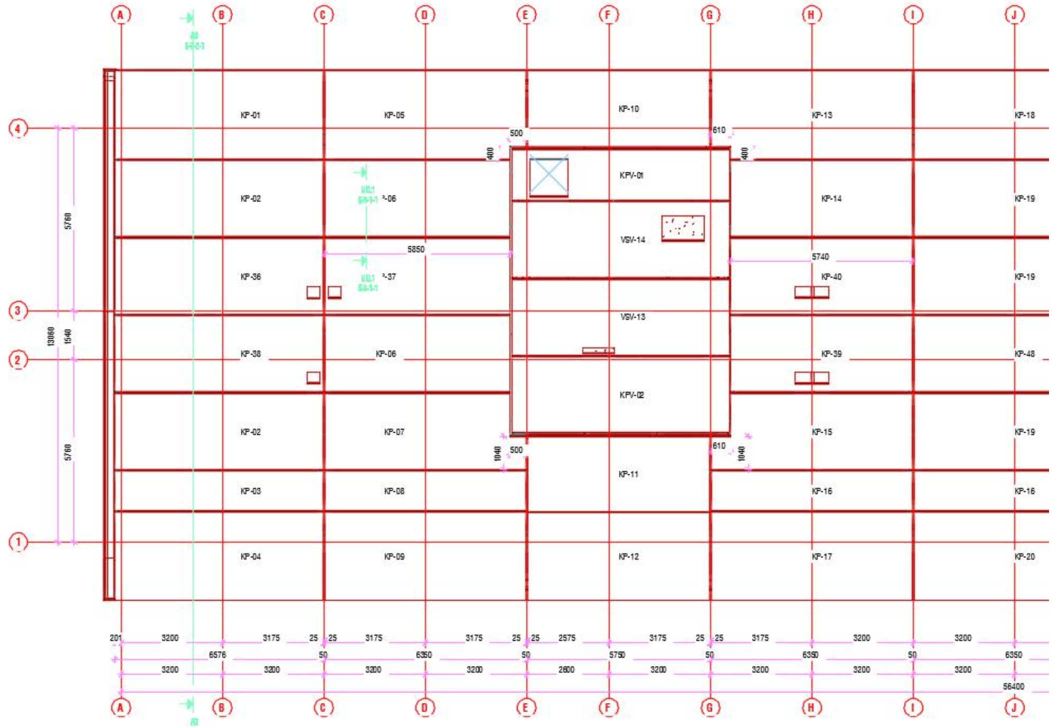


Figure 3.20: Roof's plan (1/2).

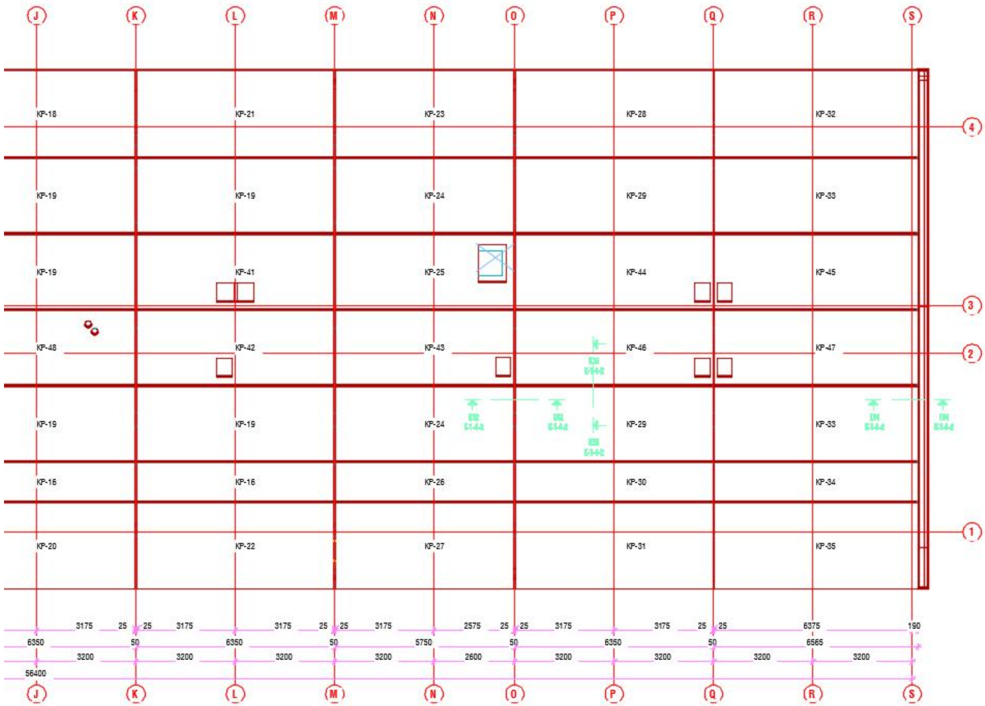


Figure 3.21: Roof's plan (2)

Table 3.3: Definition of modules for the Estonian pilot

ID	Count	Name	Description	Note
Wall panels				
VS1...5-01	5+5	Standard wall module	Dimensions 9.265 x 2.67 m, module with 3 windows	Half panels are in mirror image
VS1...5-03	5+5	Standard wall module	Dimensions 9.969 x 2.67 m, module with 3 windows	Half panels are in mirror image
VS1...5-05	5+5	Standard wall module	Dimensions 9.028 x 2.67 m, module with 3 windows	Half panels are in mirror image
VS1...5-19	5	Standard wall module	Dimensions 7.375 x 2.67 m, module with 2 windows	
VS1...5-21	5+5	Standard wall module	Dimensions 7.375 x 2.67 m, module with 2 windows	Half panels are in mirror image
VS1...5-23	5+5	Standard wall module	Dimensions 9.960 x 2.67 m, module with 3 windows	Half panels are in mirror image
VS1...5-24	5+5	Standard wall module	Dimensions 5.361 x 2.67 m, module with 2 windows	Half panels are in mirror image
VS1...5-25	5+5	Standard wall module	Dimensions 3.875 x 2.67 m, module with 1 windows	Half panels are in mirror image
VS1...5-26	5+5	Standard wall module	Dimensions 7.617 x 2.67 m, module without windows	Half panels are in mirror image
VS1...5-27	5+5	Standard wall module	Dimensions 9.127 x 2.67 m, module without windows	Half panels are in mirror image
VS1...5-2, 4, 20, 22	6+6	Combined shaft module	Dimensions 0.98 x 2.67 m. Module with vertical air ducts.	Half panels are in mirror image
VS6-01	5+5	Standard wall module	Dimensions 9.265 x 1.72 m, module without windows	Half panels are in mirror image
VS6-03	5+5	Standard wall module	Dimensions 9.969 x 1.72 m, module without windows	Half panels are in mirror image
VS6-05	5+5	Standard wall module	Dimensions 9.028 x 1.72 m, module without windows	Half panels are in mirror image
VS6-19	5	Standard wall module	Dimensions 7.375 x 1.98 m, module without windows	
VS6-21	5+5	Standard wall module	Dimensions 7.375 x 1.98 m, module without windows	Half panels are in mirror image
VS6-23	5+5	Standard wall module	Dimensions 9.960 x 1.98 m, module without windows	Half panels are in mirror image
VS6-24	5+5	Standard wall module	Dimensions 5.361 x 1.98 m, module without windows	Half panels are in mirror image
VS6-25	5+5	Standard wall module	Dimensions 3.875 x 1.98 m, module without windows	Half panels are in mirror image
VS6-26	5+5	Standard wall module	Dimensions 7.617 x 1.72...1.98 m, module without windows	Half panels are in mirror image
VS6-27	5+5	Standard wall module	Dimensions 9.127 x 1.72...1.98 m, module without windows	Half panels are in mirror image

ID	Count	Name	Description	Note
VS6-2, 4, 20, 22	6+6	Combined shaft module	Dimensions 0.98 x 1.72&1.98 m. Module with vertical air ducts.	Half panels are in mirror image
VSV-1...12	12	Wall modules for engine on roof	Dimensions ~2.8 x 2.75...3.05 m, module without windows, but some doors and holes.	
Roof panels				
KP-01...47	47	Standard roof module	Dimensions ~1.24...2.84 x 6.35...6.92 m	
KPV	4	Roof modules for engine on roof	Dimensions 2.4 x 6.9 m	

3.6 Latvia

The following documentation illustrate the work on Latvian pilot building and localized modular solution adjusted for the typology.

Figure 3.22 Building general view before renovation

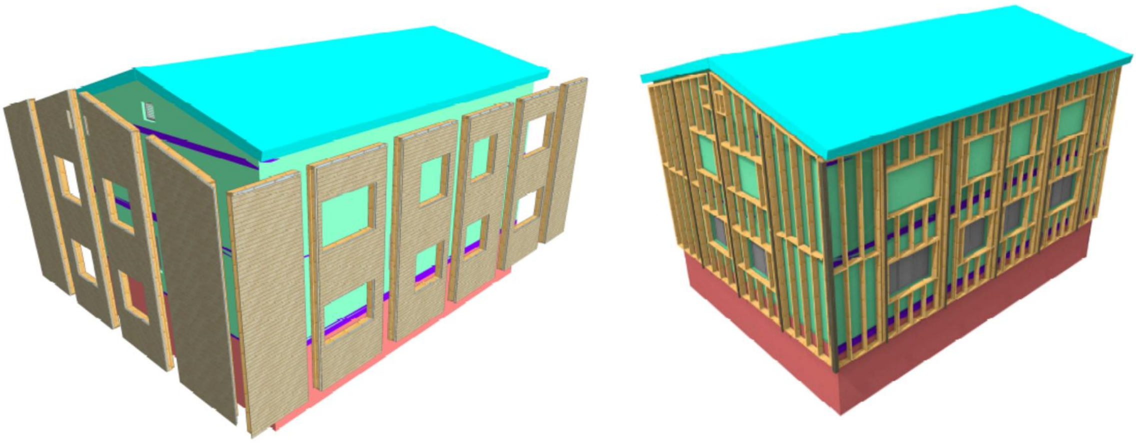


Figure 3.23 Panel visualization

Table 3.4: Definition of modules for the Latvian pilot

ID	Count	Name	Description	Note
S01	2	Standard wall module	Vertical element on main facades (south, north)	Without widows
S04	2	Standard wall module	Vertical element on main facades (south, north)	Without widows
S02	5	Standard wall module	Vertical element on main facades (south, north)	With widows
S011	1	Entrance module	Vertical element on main facade (north)	With widows
S07	2	Standard wall module	Vertical element on side facades (east west)	Without widows. Right corner.

S09	4	Standard wall module	Vertical element on side facades (east, west)	With widows.
S10	2	Standard wall module	Vertical element on side facades (east, west)	Without widows. Left corner

Main façades and side facades modules layouts are shown in Figure 3.24 and Figure 3.25.

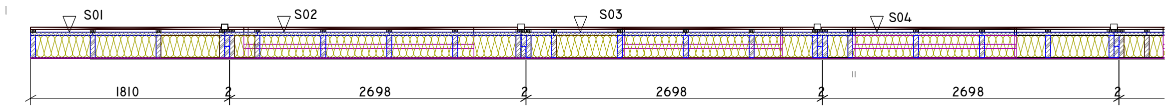


Figure 3.24 Main facade modules layout.

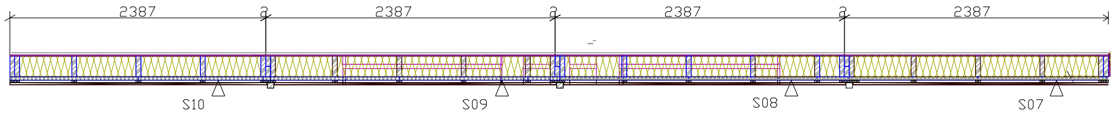


Figure 3.25 Side facade modules layout.

3.7 The Netherlands

The following documentation illustrate the work on the Netherlands' pilot building and localized modular solution adjusted for the typology.

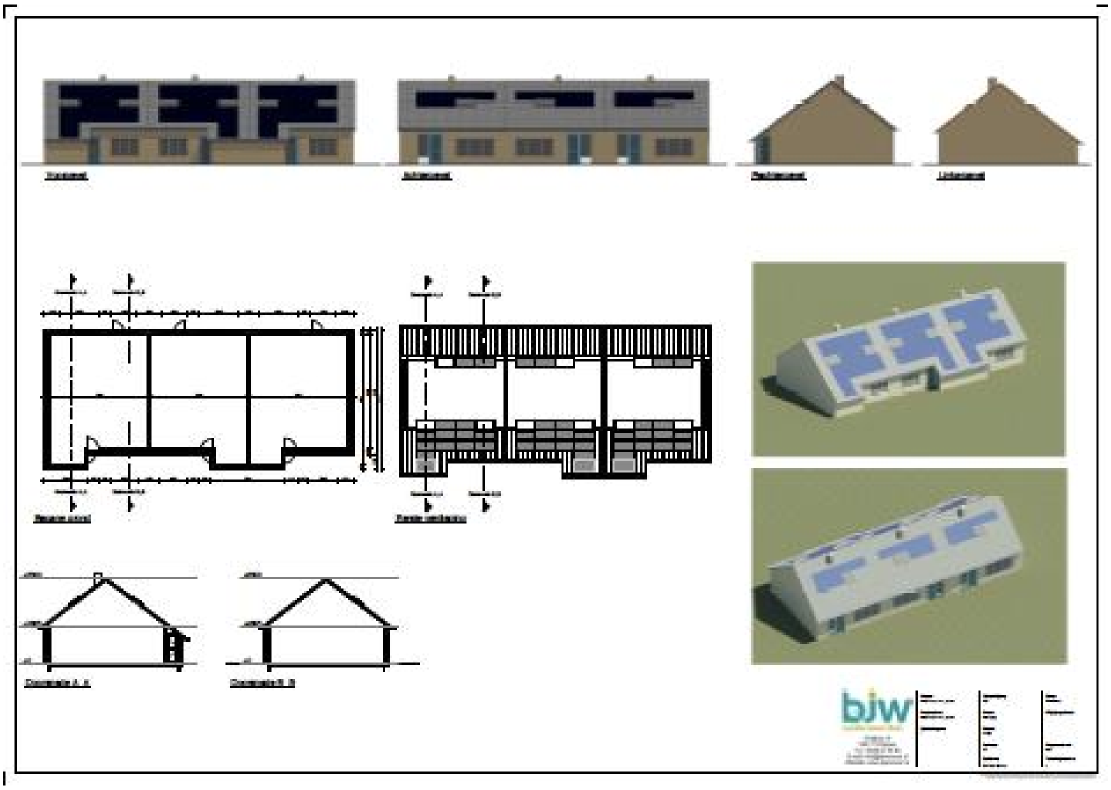


Figure 3.26: Visualisation of the Dutch pilot.

Table 3.5: Definition of modules for the Dutch pilot

ID	Name	Description
STD	Standard wall module front and back wall Inner and outer wall exchanged	Dimensions 2.8 x 6 m, module with windows and air ducts for one row house.
STD/Exch	Standard wall module front and back wall Outer wall exchanged	Dimensions 2.8 x 6 m, module with windows and air ducts for one row house.
KOP	Standard wall module side wall	Dimensions 2.8 x 9 m, module Connections to front wall and roof
ROOF/TIP	Standard roof module	Dimensions 2.8 x 6 m,
ROOF/PV/TIP	Standard roof module including PV	Dimensions 2.8 x 6 m,
ROOF/FLAT	Standard roof flat	No standard size

4 MODULE DESIGN OPTIONS

According to the differences both in the boundary conditions and the building typology in geoclusters, the general design must have been defined for marking use of similarities and overlaps. The general module composition has to be adjustable to the local needs for:

- preferred materials, locally available
- technology, locally reasonable and feasible and
- integrated systems, locally required.

The general module consists of several different layers or elements:

- module bearing structure
- thermal insulating layer
- windows and doors
- airtight layer
- integrated systems
- renewable energy sources
- hanging structures, shading elements
- anchorage elements
- exterior surface layer
- interior surface layer.

The layers can be separate or with more or even all functions joined together in one. Also, depending on the building geometry, refurbishment depth, economical or energy performance, not all layers must occur in the actual design. Similarly, the design is open because of different module purposes (wall, roof, etc.). The ideal solution is to be marked during the optimization process in project's *Work Package 6*.

The examined alternatives are described in the following sections.

4.1 Module bearing structure

4.1.1 Wood-based frame

The wood-based frame present basic solution of module bearing structure which can be favourable thank to:

- sufficient stiffness of the wood
- good workability
- good availability all over the Europe
- satisfying thermal properties
- outstanding environmental parameters.

The wood-based frame utilization comes from the traditional wood construction industry and presents no difficulties for the prefabrication in the current wooden building factories. Also, the computer-aided machinery is broadly available and the preciseness of the production can be very high.

Currently, there are more materials suitable for the application based on wood:

- Natural squared wood

- KVH structural timber
- Laminated timber
- I-beams
- Iso3 beams without the thermal bridges.

For the energy efficient design, the wooden bearing structure must be protected by the compact layer of insulation.

4.1.2 Steel frame

In some applications, the steel frame can be favourable. Steel has less environmentally favourable parameters, but it is 100% recyclable. For the countries, where the cost of the wood is too high or higher stiffness is needed, the steel frame might be a good choice.

4.1.3 Composite frame

The custom-made composite frame can be selected as an advanced material for the similar application as a wooden framework. The material has homogenous structure, guaranteed qualities and may be easily adjusted to any shape, which is desired by the design.

4.1.4 No specific bearing structure

In the case of 3D printed façade, no special bearing structure is needed. The bearing framework is not present in façade at all.

4.2 Thermal insulating materials

The addition of a significant layer of thermal insulation is necessary to provide the house sufficient energy performance after the refurbishment. On the other hand, very thick layer of insulation dims the passive solar gains through by shading the openings. High performance insulation is favourable from the energy or geometrical point of view but very costly at the same time. As the thicknesses of the original walls is significant (see Table 4.1: Original building façade wall thickness) and cannot be removed in every case, the optimal variant for each building needs to be found.

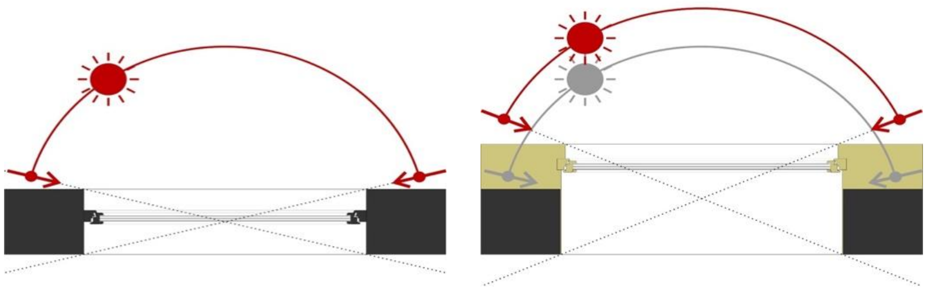


Figure 4.1: The difference of the sunlight coming through the opening before (left) and after the refurbishment (right).

Table 4.1: Original building façade wall thickness

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Exterior wall thickness [mm]	270	280 (180 RC + 100 TI)	380	260 (150 + 110)	450	– (wall is removed)

4.2.1 Mineral wool

The typical problems of the common buildings from the survey pointed out the technical favourability of the mineral wool-based insulating materials. Stone wool or glass wool have low lambda values (below 0.04 $W.m^{-1}.K^{-1}$), they are fire-resistant and available at reasonable cost. These materials allow the water vapour to diffuse naturally in or out from the structure without condensing and raising the moisture content in the original building after refurbishment. This quality is crucial for perfect retrofit and original buildings' problems solving.

4.2.2 Polystyrene, polyurethane foam

Polystyrene boards (lambda values below 0.04 $W.m^{-1}.K^{-1}$), polyurethane (PUR, lambda values 0.033-0.045 $W.m^{-1}.K^{-1}$), polyisocyanurate foams (PIR, lambda values 0.023-0.021 $W.m^{-1}.K^{-1}$), or phenolic foams (lambda values 0.024-0.021 $W.m^{-1}.K^{-1}$) are reasonable materials for dry climates or buildings with airtight original wall in good condition. The cost can be one of the lowest (expanded polystyrene, EPS), however the moisture content of the original structure and the flammability must be considered.

4.2.3 Natural insulating materials

Natural insulating materials, such as wood wool, flax fibre or hemp fibre insulation can be used. These materials have about 20% higher lambda values (0.045–0.05 $W.m^{-1}.K^{-1}$) than average EPS od mineral wool (0.038–0.04 $W.m^{-1}.K^{-1}$). Higher conductivity therefore needs to be compensated by higher thickness, which can be problematic. Also, the cost is considerable higher (about 30 %) than the more frequent ETICS materials. Anyway, very favourable environmental parameters of these materials are the reason why to take these materials in account.

4.2.4 Vacuum insulating panels, aerogel

Vacuum insulating panels (VIPs) or aerogel insulating materials are one of the high-end materials available at the market. The very high price balances with the reduced thickness of the layer (with λ = 0.007 $W.m^{-1}.K^{-1}$ for VIP, λ = 0.02 $W.m^{-1}.K^{-1}$ for aerogel). These materials should be used for detailing, where the lack of space has to be substituted by excellent thermal properties of material. VIPs must be ordered in exact dimensions and shape and cannot be shaped onsite.

4.2.5 3D printed insulating plaster

The material possible for use as a thermal insulation for 3D printed facades might be Ytong Multipor mineral insulation boards. According to [2], it consist of 100 % homogeneous material with a heat conductivity of 0.045 $W.m^{-1}.K^{-1}$. Primarily the mass of structures in contact with the indoor space as well as the percentage of window area in the exterior structures are decisive for the thermal insulation in summer. If the insulating material in the external thermal insulation composite system is calculated by itself, the heat storage capacity of Ytong Multipor is relatively high due to its density (115 kg/m³) at the same insulation thickness.

4.3 Windows and doors

4.3.1 Double and triple glazed windows and doors

The glazing provided with the modules should be adjustable to the customers' and the buildings' need. Therefore, the universal connection must be provided in the standard, usual form to accommodate the available glazing units and reach the competitive prices. The thermal parameters vary according to the geoclusters, the specific parameters will be selected according to the MORE-CONNECT's Deliverable D2.1 "Initial performance criteria and requirements for innovative and multifunctional building envelope elements" [1].

4.3.2 PV-cell glazing

The area of photovoltaic installation can be extended by using the PV-cell glazing. It might be favourable for the building with high glazing ratio. The gains about 115 $Wp.m^{-2}$ can be reached.

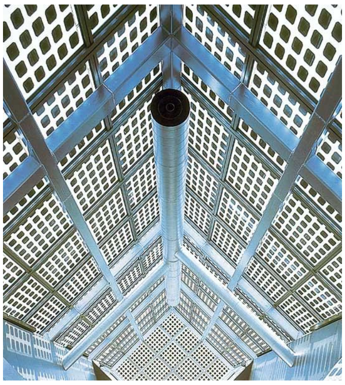


Figure 4.2: Example of PV-cell glazing application [3].

4.4 Airtight layer

The airtight layer's position varies according to the geometrical setting of the modules and the building typology. In cases where the original structure is airtight enough and without faults, the complete new airtight layer is not necessary to be created. When the original structure is demounted (geometrical variant F, see chapter 3), the new airtight layer must be provided by the system. The planar airtightness has to be ensured by application of airtight layer in combination reliable airtight inter-modular joints. See the MORE-CONNECT's Deliverable D2.6: "Smart connectors", chapter 4 [4].

4.5 Exterior surface layer

4.5.1 Fully or partially prefabricated plaster

For buildings surrounded by very similar buildings with plaster facades in a very compact and unified urban settlement (like the one in Milevsko, Czechia), it should be possible to use plaster as a final exterior layer. On the other hand, plastering is a wet process that slows down the deep refurbishment process and applying the whole plaster façade goes just against the MORE-CONNECT goals. Therefore, a mixed solution is designed – a final layer of plaster is made in the factory (a precast plaster) except for 10–15 cm strip along the panel boundary. Rendering mesh is conversely left bigger overlapping the panel. Joint of the panels is later finished on site and overlapping rendering meshes ensure the integrity of the plaster. Finishing process is distinctly less time-consuming and it can be done for example from the scissor lift or small mobile crane. Another solution is the use of robotic 3D printed plaster – see below.

4.5.2 3D printed final façade

Another possibility to make plaster façade is to use robotic 3D print. The preprogramed robot hanging on the wire can “climb” the wall without need of scaffolding, ladder or crane so the application of the plaster is faster and there is no space requirement on the plot around the insulated building. The scanned 3D surface of the façade is installed to the robots’ memory and adjusted by sensors, so the robot knows locations of openings, corners or other obstacles.

4.5.3 Clinker bricks

Brick look can be achieved with bricks or clinker bricks in front of ventilation gap respectively. The advantages are that the panel can be finished in the factory, the surface is divided with mortar, so the panel cleft does not disturb the integrity. Disadvantage of clinker bricks are heavy, which could result in need for more anchors.

4.5.4 Brick tiles

The solution on similarly retrofitted houses in Netherlands uses classic or plastic brick tiles which are glued to the panel surface. They are very easy to install, and can be prefabricated in the factory. Using fine pattern, the cleft between panels can be visible. The physical properties of the tiles, such as diffusion resistance factor or flame spread index, have to be considered. The latter may be a reason disqualifying such solution in some countries (for instance in Czechia, the thermal insulation adjacent to the ventilation gap has to be incombustible, as combustible material in conjunction with ventilation gap chimney effect might allow severe fire spread).

4.5.5 Façade boards

Cavity wall (a wall with ventilation gap) can be also provided with some façade boards of various material base. The most frequent is cement board, such as Cembrit, Cembonit or Equitone, metallic sheets or some kind of composite boards. Production programme of boards is mostly smaller than the dimension of the whole MORE-CONNECT panel and façade pattern must be designed. Therefore, the clefts between panels are on the façade almost unnoticeable or unresolvable respectively.

4.5.6 BIPV

Special type of façade board is Building Integrated Photovoltaics (BIPV). Except the façade face made with the PV panels, position of another accessory such as switchboxes and cables must be taken into account. Switchboxes must be big enough not just to accommodate the switches but also to prevent switches from overheating.

Use of incombustible insulation beneath the façade face is also required.

4.5.7 Wooden cladding

The last type of the cavity wall is the one with wooden cladding. The principle is the same as mentioned in previous chapters, however there are some specifics to be noted. Wooden façade, if untreated, may change its colour and shade and it may change the face of the whole building. The design must count with this feature or frequent renewing wet processes must be planned in the future. Various treatments of wood are available to limit the wear of surface (paints, chemical treatment, heat treatment). Wooden or any other combustible cladding may also limit the use of such façade due to lower fire resistance than other alternatives.

4.6 Interior surface layer

In the interior, a plaster on the wall and on the window lining is assumed. Removing the window and installing the MORE-CONNECT panel, some unevenness or defects of the existing plaster may occur. There are two main options of interior surface treatment: firstly, a new plaster layer can even out the flaws, secondly, additional cladding from boards can be mounted over the existing walls.

4.6.1 Plaster wall

Application of a new plaster on the wall is the simplest choice, when there is a time and space for such activity in the inhabitants' flat. For the best light permeation and for the possibility of combination, white colour on the lining is designed but also other colours can be used.

However, it is a wet process that slows down the whole workflow. More, cables or piping going in the façade panel must enter the interior and it must be somehow covered. Therefore, grooves or sockets must be done in the plaster and covered again.

4.6.2 Cladding

Cladding is chosen, when no time shall be wasted. Using thin high density fibreboards (HDF), a new lining is done very quickly and infrastructure can be led beneath the surface. Again, a white board is universal but other textures and shades are produced. On the other side, the opening dimensions are due to the board and shaft inside narrowed and a detail of the connection of the board on the corner of the lining must be made very accurately.

4.7 Integrated systems

4.7.1 Electrical wiring

All the ducts and wires will be led in the first layer of the module from the side of the interior. The refurbishment modules can provide to the users:

- Internet / Ethernet connection
- TV / Satellite signal
- wireless network (Wi-Fi router)
- Home's control system interface
- Window blinds' control interface.

All those wiring systems and appliances can be offered to the user. The connection may be made in the window siding.

4.7.2 Hydraulic heating loop

The hydraulic heating pipes present one of the challenges for the prefabrication process of whole modular system. For most of the cases, the air heating will be sufficient. For extreme climatic conditions or buildings with higher heating demand, the new hydraulic heating system can be provided. The connections of the pipes will be done during the module's installation. The pipes should be reachable from behind the window siding cover.

4.7.3 Ventilation

The system will be provided with the ventilation system in every refurbishment alternative. Every apartment's window will be provided with the ventilation inlet. In the case the typology allows favourable placement of both, intake and exhaust air ducts, both can be done in the façade modules. In the case of apartment not having favourable disposition, the exhaust ducts have to be done in the interior of the building. The challenge is to prefab the system so that building up the interior ventilation would not affect the duration of the refurbishment significantly.

4.7.4 Window blinds

The refurbishment system should provide sufficient shading devices, where applicable. A sufficient shading might be done by creating the façade elements such as canopies, sun blinds etc. The movable, electric-driven window blinds may be a general option.

4.7.5 Renewable energy sources

The possibilities were reviewed under separate task "Integration of Renewables Technology Overview" (MORE-CONNECT's Deliverable D2.4). For the general design, basically the integration of the PV-panels is assumed in the façade and in the roof modules.

4.8 Hanging structures and shading elements

4.8.1 Balconies

In some cases, an extension of the original building is favourable. The smaller apartments are, the more importance of the newly built additional balcony or reading room can be. It can be observed on the recent, non-refurbished buildings user's behaviour. The modular system should provide the possibility of extending façade by safe systematic solution.

Figure 4.3: Extended Czech pilot-like apartment building extended by an individual solution [5].

Figure 4.4: Possible of Extension of apartment spaces by additional external structures.

4.8.2 Shading devices

The proper shading devices should be part of responsible low energy design. According to the number of sources starting from Socrates in the ancient Greece, the proper shading can save the energy both, during summer and winter seasons. The particular solution has to be adjusted according to the geocluster.

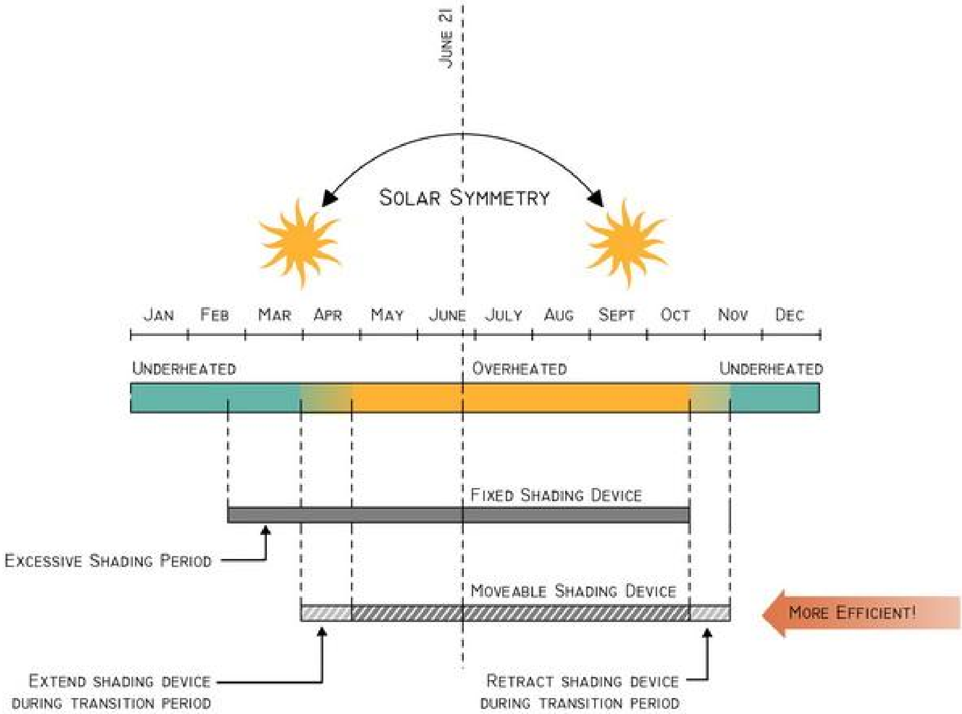


Figure 4.5: Effective shading according to [6].

4.9 Anchorage elements

The connecting elements has to be used for the montage. See the MORE-CONNECT's Deliverable D2.6: "Smart connectors" for the possibilities overview.

5 GENERIC BUILDING MODULES

5.1 Composition of generic wall module

5.1.1 Variants

The general wall module composition was designed originally for the Czech model building, but is easy to be adjusted for any cases using design alternatives described above.

The module was designed in three variants to obtain optimal U-value of the refurbished wall – see Table 5.1. The composition is stated together with the original simple masonry wall.

The basic Variant W1 uses the standard mineral wool insulation in the thicknesses to reach the lowest U-value needed to comply with the design requirements. The Variants W2 and W3 use high performance insulation (HPI, aerogel or vacuum insulation panels) instead of 20 mm basic mineral wool to obtain U-values of the final composition suitable for colder geoclusters. Where possible, the HPI can be replaced by raising the thickness of the basic insulation layer by 55 mm in Variant W2 or 140 mm in Variant W3.

Table 5.1: Basic alternative of the wall module composition (original composition in grey cells)

Refurbished wall (Variant W1)			Thickness d	Heat conductivity λ	Thermal resistance R	Thermal transmittance U
			mm	$W.m^{-1}.K^{-1}$	$m^2.K.W^{-1}$	$W.m^{-2}.K^{-1}$
Boundary condition		*interior Rsi*			0,13	
Material		Note				
1	Interior plaster	original facade	25	0.99	0.03	
2	Masonry	original facade	450	0.86	0.52	
3	Exterior plaster	original facade	25	0.99	0.03	
4	Low density mineral wool	compressible material with steel anchorage	120	0.039	3.08	
5	Cement fibre board		12.5	0.32	0.04	
6	Low density mineral wool	in between wooden frame	120	0.052	2.31	
7	High density wood fibre board		13	0.1	0.13	
8	High density facade mineral wool board		40	0.05	0.80	
9	Thin layer plaster		5	0.47	0.01	
Boundary condition		*exterior Rse*			0.04	
Total module			311.5		6.53	0.15
Total structure			810.5		7.11	0.14

Table 5.2: Alternative of the wall module composition (original composition in grey cells)

Refurbished wall (Variant W2)			Thickness d	Heat conductivity λ	Thermal resistance R	Thermal transmittance U
			mm	$W.m^{-1}.K^{-1}$	$m^2.K.W^{-1}$	$W.m^{-2}.K^{-1}$
Boundary condition		*interior Rsi*			0.13	
Material		Note				
1	Interior plaster	original facade	25	0.99	0.03	
2	Masonry		450	0.86	0.52	
3	Exterior plaster		25	0.99	0.03	
4	Low density mineral wool	compressible material with steel anchorage	100	0.039	2.56	
5	Aerogel		20	0.014	1.43	
6	Cement fibre board		12.5	0.32	0.04	
7	Low density mineral wool	in between wooden frame	120	0.052	2.31	
8	High density wood fibre board		13	0.1	0.13	
9	High density facade mineral wool board		40	0.05	0.80	
10	Thin layer plaster		5	0.14	0.04	
Boundary condition		*exterior Rse*			0.04	
Total module			310.5		7.60	0.13
Total structure			785.5		8.18	0.12

Table 5.3: High-performance alternative of the wall module composition

Refurbished wall (Variant W3)			Thickness d	Heat conductivity λ	Thermal resistance R	Thermal transmittance U
			mm	$W.m^{-1}.K^{-1}$	$m^2.K.W^{-1}$	$W.m^{-2}.K^{-1}$
Boundary condition		*interior Rsi*			0.13	
Material		Note				
1	Interior plaster	original facade	25	0.99	0.03	
2	Masonry		450	0.86	0.52	
3	Exterior plaster		25	0.99	0.03	
4	Low density mineral wool	compressible material with steel anchorage	100	0.039	2.56	
5	Vacuum insulation panel		20	0.0065	3.08	
6	Cement fibre board		12.5	0.32	0.04	
7	Low density mineral wool	in between wooden frame	120	0.052	2.31	
8	High density wood fibre board		13	0.1	0.13	
9	High density facade mineral wool board		40	0.05	0.80	
10	Thin layer plaster		5	0.14	0.04	
Boundary condition		*exterior Rse*			0.04	
Total module			310,5		9.25	0.11
Total structure			810,5		9.83	0.10

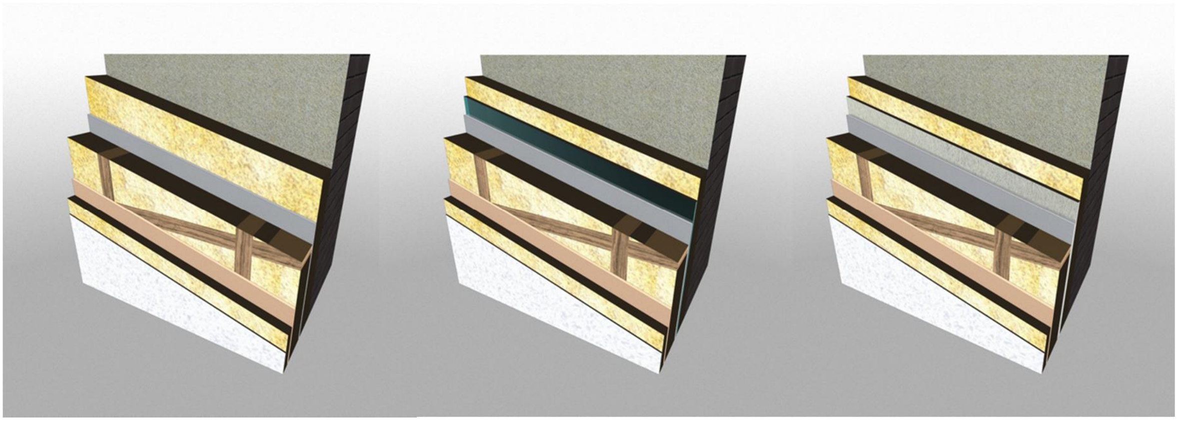
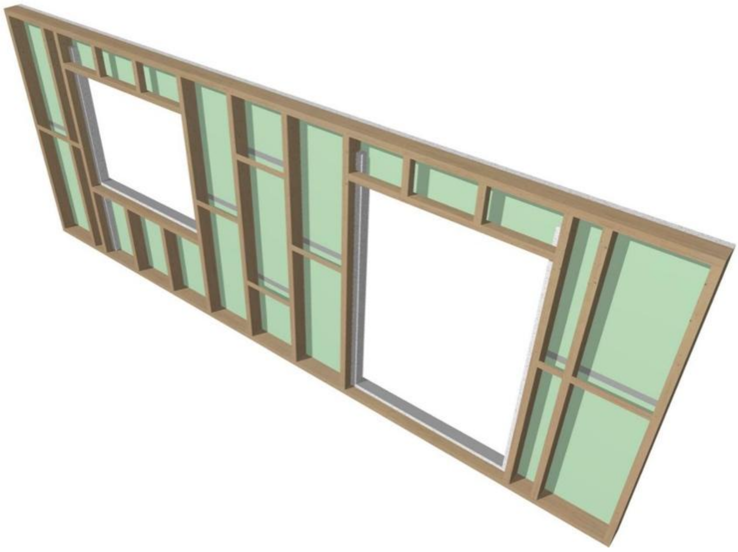
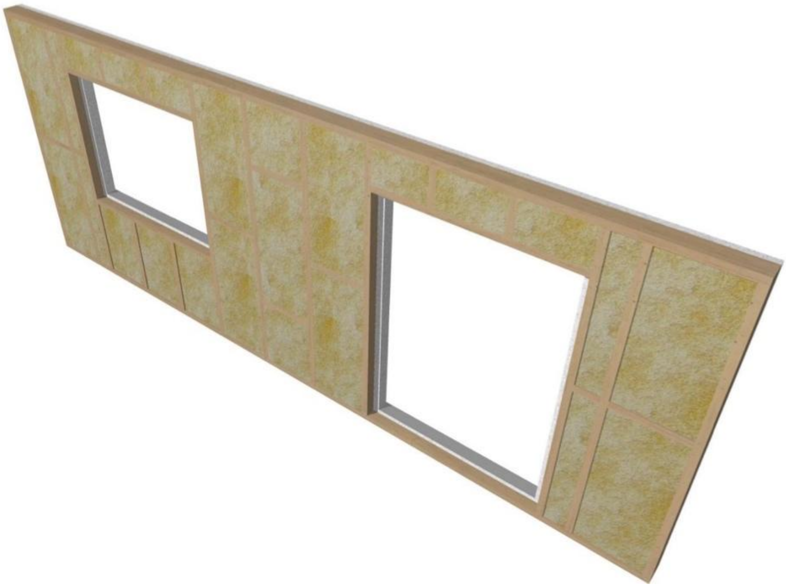


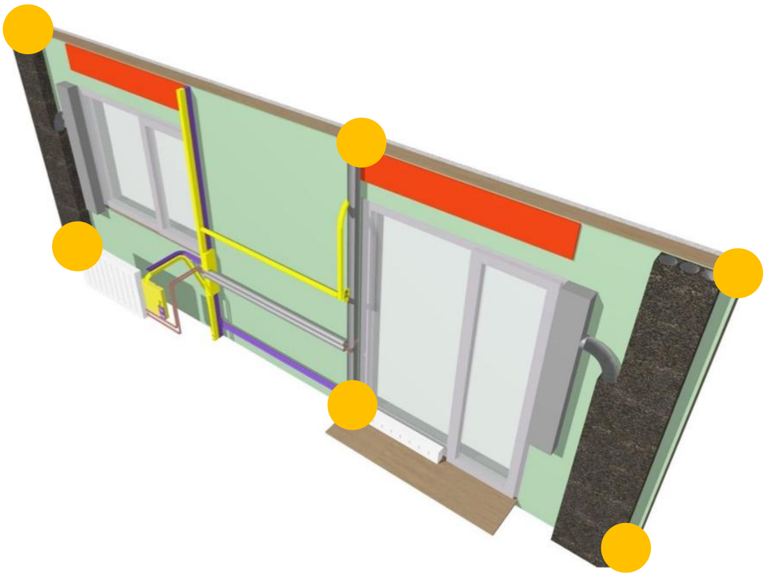
Figure 5.1: Wall module general composition. The modules uses the high performance to obtain mean R value of 6.5 (Variant 1); 7.6 (Variant 2); and 9.25 $m^2.K.W^{-1}$ (Variant 3).

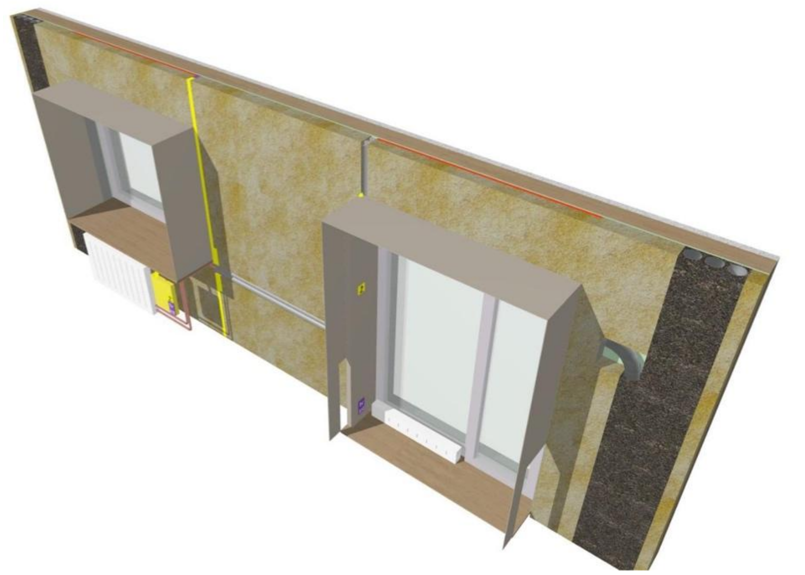
5.1.2 Visualisation

The following visualisation presents the general solution for the general, 2.8 x 7 m module, that can be adjusted for the localised design.

Table 5.4: Commented visualization of the standard wall module (from exterior to interior)

Construction stage / layer	Description
	The main bearing structure presents wooden or wood-based frame with high density mineral wool boards. The boards can be provided with a precast basic plaster, the final surface will be created in situ. The frame thickness is 120 mm.
	The frame is filled with thermal insulating material, generally mineral wool.

Construction stage / layer	Description
	The module's core is closed up by stiff, bracing boards, e.g. cement fibre boards. The installations (electrical wires in yellow and heating loop pipes in purple, insulated ventilation pipes and distribution elements in brown and grey) are fixed to the bracing board. The high-performance insulation (in red) is placed in the thermally weakest detail of the module – behind the electric shading device. *The module can be connected by 6 anchoring elements, shared with neighbouring elements (orange circles, not visualised, developed in Task 2.6).*
	*The integrated systems are covered with soft, compressible insulating layer.*

Construction stage / layer	Description
	The window siding boards will be applied after the installation of the panel to the existing structure. The control elements and electrical junction boxes can be covered by those.
	*Final setting – the wall module mounted on existing wall.*

The wall modules are designed to fulfil the above-listed requirements; the possible adjustment principles are described in the table below.

Table 5.5: Fulfilling the requirements

Original facade	Module setting
Plain facade	Standard solution
Fragmented facade	The fragmentation can be done in in the module's connection or the bearing frame can be fragmented to the 3D structure
Segmented facade	Segmentation can be done in the final surface without any limitations.
Curved facade	Curved look can be done in the final surface. For the original curved façade and building's superstructure, the bearing frame can be adjusted. Depending on the diameter, the bracing boards must be fragmented.

Original facade	Module setting
Concrete surface	The connection elements can be adjusted for the connection to the concrete. Possible roughness of the surface can be compensated with outer compressible insulating material layer of the module.
Plaster surface	Possible roughness of the surface can be compensated with outer compressible insulating material layer of the module.
Masonry/brick surface	The connection elements can be adjusted for the connection to the masonry. Possible roughness of the surface can be compensated with outer compressible insulating material layer of the module.

5.2 Composition of generic roof module

5.2.1 Variants

The roof modules were designed in two basic alternatives – for the roofs with the solar panels and without them (see the tables below). The specific design will differ more according to the geocluster requirements, the shape of the roof, slope etc. See chapter 6 for particular solution.

Table 5.6: The composition of a roof module with photovoltaic panels (PV's)

Roof module (new) with PV, Varaint R1			Thickness d	Heat conductivity λ	Thermal resistance R	Thermal transmittance U
			mm	$W.m^{-1}.K^{-1}$	$m^2.K.W^{-1}$	$W.m^{-2}.K^{-1}$
Boundary condition		*interior Rsi*			0.1	
Material		Note				
1	Fibreboard	installed in-situ	15	0.32	0.05	
2	Rockwool Fasrock		40	0.059	0.68	
3	Vapour-tight foil	connected in situ	0.25	0.35	0.00	
4	Oriented strand board		15	0.18	0.08	
5	Mineral insulation	between rafters	260	0.043	6.05	
6	Medium density wood fibre board		15	0.044	0.34	
7	Above-rafter mineral insulation with the metal anchors		120	0.043	2.79	
8	Air gap and lathing		30	0.1		
9	Waterproofing	connected in-situ	0.05	0.05		
10	Lathing		30	0.14		
11	PV panel	installed in-situ	38			
Boundary condition		*exterior Rse*			0.1	
Total structure			563.3		10.19	0.098

Table 5.7: The composition of a roof module without photovoltaic panels

Roof module (new), Variant R2			Thickness d	Heat conductivity λ	Thermal resistance R	Thermal transmittance U
			mm	$W.m^{-1}.K^{-1}$	$m^2.K.W^{-1}$	$W.m^{-2}.K^{-1}$
Boundary condition		*interior Rsi*			0.1	
Material		Note				
1	Cement fiber board	installed in-situ	15	0.32	0.05	
2	Low density mineral wool	in the wooden frame	40	0.059	0.68	
3	Vapour-tight foil	connected in situ	0.25	0.35	0.00	
4	Oriented strand board		15	0.18	0.08	
5	Medium density mineral wool	between rafters	260	0.043	6.05	
6	Above-rafter mineral insulation with the metal anchors		120	0.043	2.79	
7	Air gap and lathing		30			
8	Medium density wood fibre board		15			
9	Waterproofing	connected in-situ	0.05			
10	Metal sheet plate	connected in-situ	0.6			
Boundary condition		*exterior Rse*			0.1	
Total structure			495,9		9,85	0.102

5.2.2 Visualisation

The following visualisation presents the general solution for the general roof module which can be adjusted for the roof. The connection of the modules is done in the ridge. The waterproofing is sealed after installation.

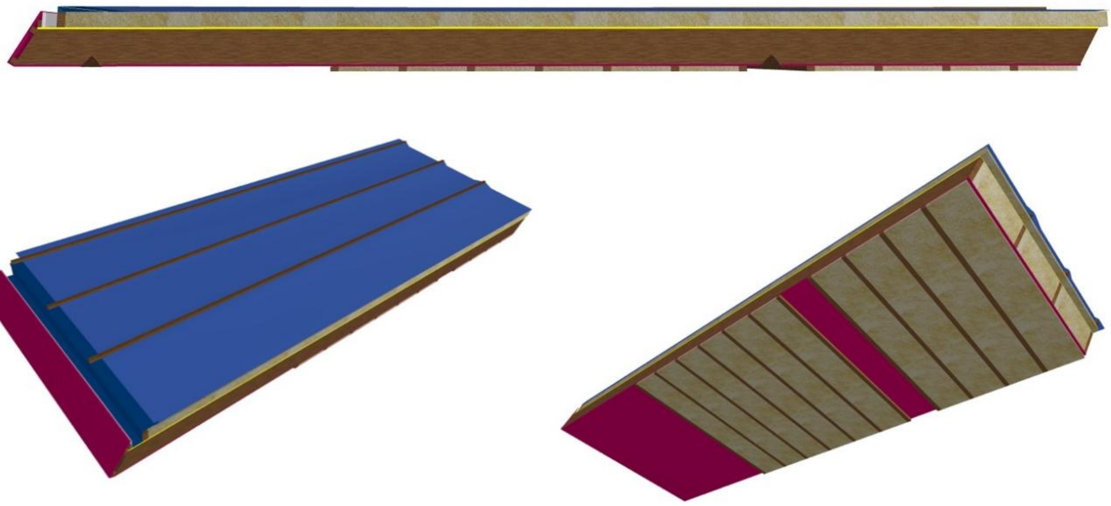
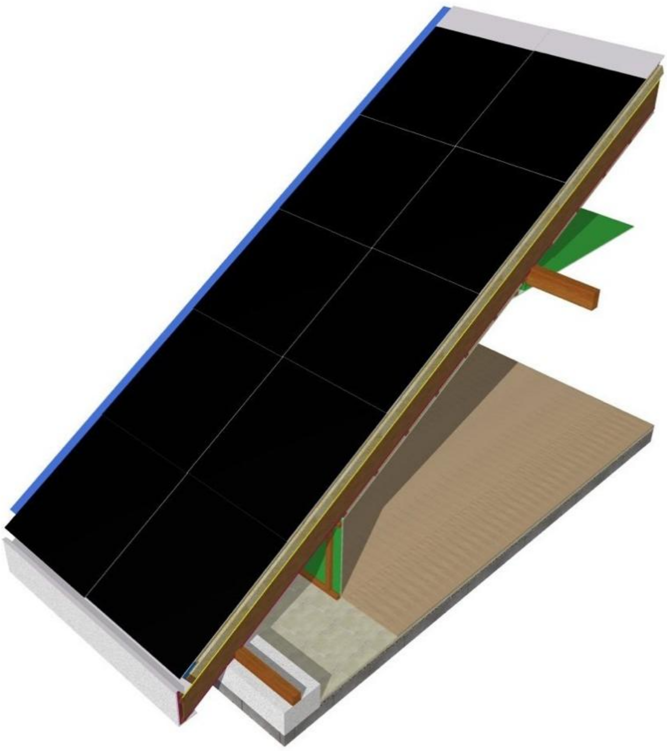
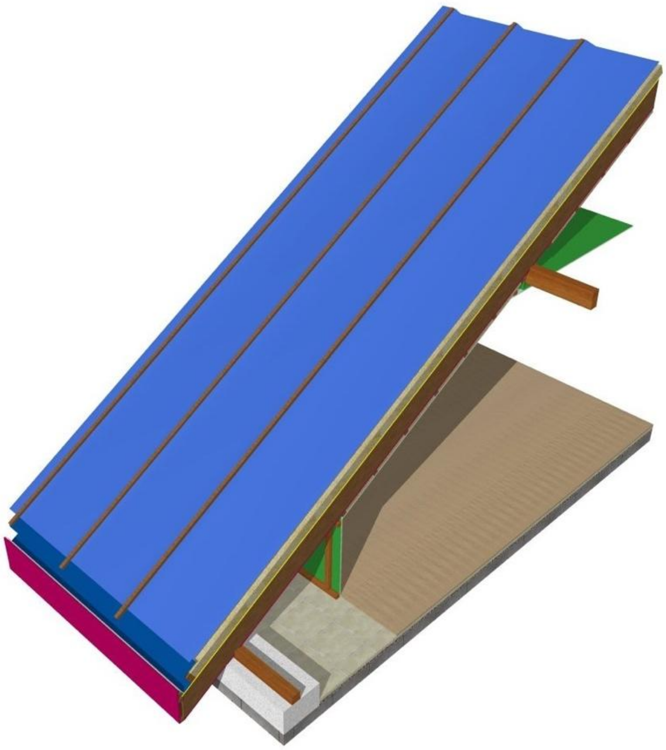
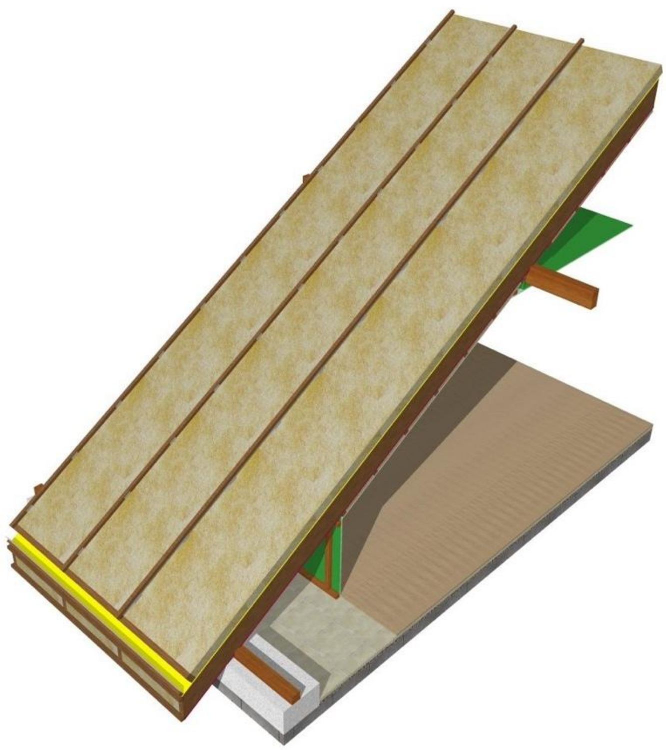
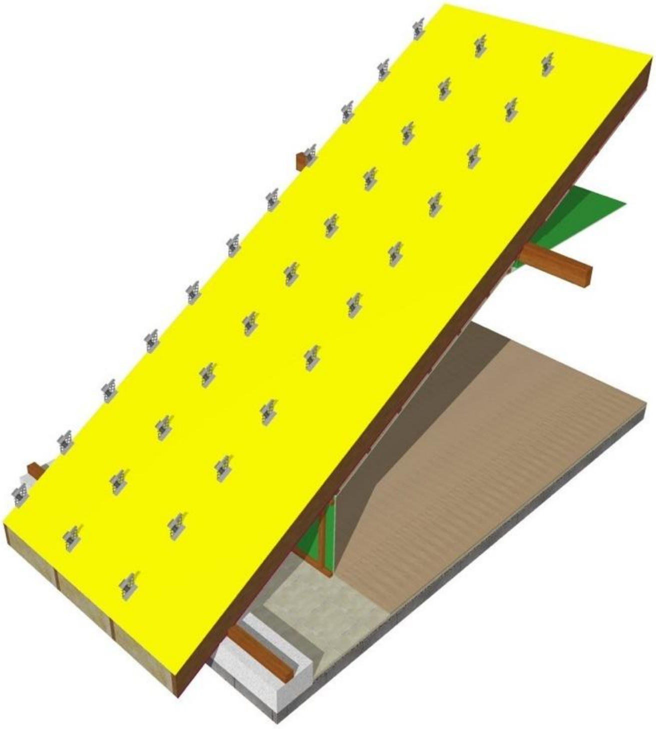
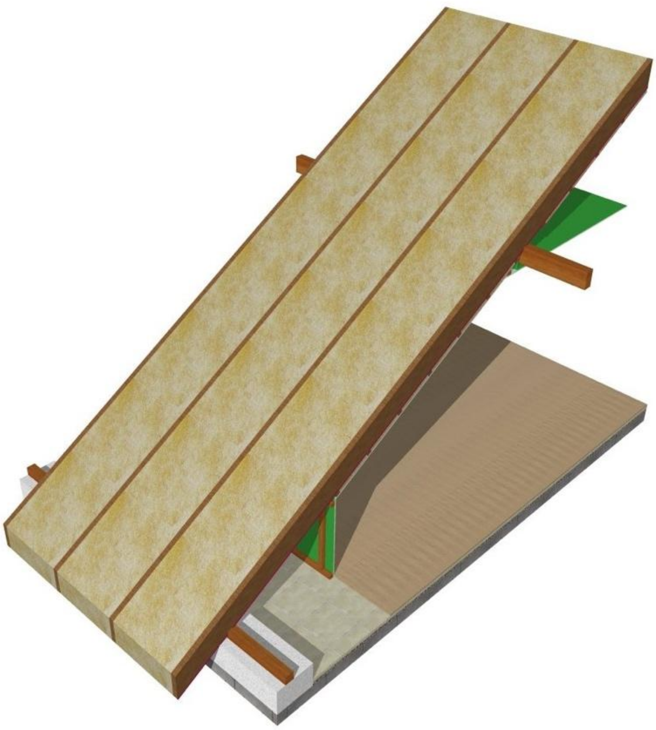


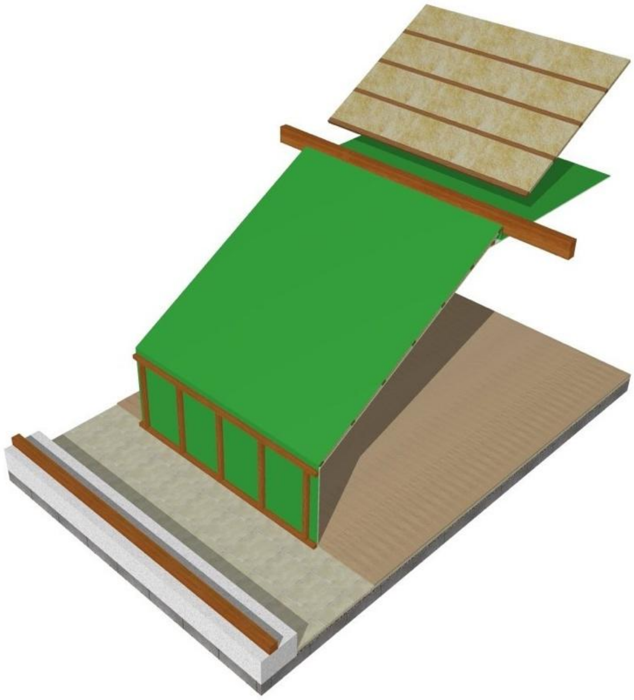
Figure 5.2: Visualisation of the roof composition. Top: cross section; bottom left: view from above; bottom right: view from bellow.

Table 5.8: Commented visualization of standard roof module (from exterior to interior)

Construction stage / layer	Description
	A finished and fully installed module. The photovoltaic modules will be installed in-situ to allow a safe connection of the waterproofing and drainage.

Construction stage / layer	Description
	The factory-ready module placed in its position. The waterproofing is prepared and sealed in the plane of the module. The connections are sealed after placing the modules next to each other. The framework is prepared to support the photovoltaic panels. The drainage space is sealed using the watertight foils.
	The variable insulating layer is created above the rafters. The insulating layer may differ according to the geocluster.

Construction stage / layer	Description
	The counters are supported by the metal holders that are offered to correspond to various thicknesses of the insulating layer.
	The load bearing core of the module is created by wooden rafters (the height varies according to a roof span). The area in between is filled by the mineral wool. In special cases, the high-performance insulation can be used in this layer. Also, the different shape of the beams can be used (I-beams etc.).

Construction stage / layer	Description
	From the interior, the plasterboard on a wooden or metal frame will be created (in the case of utilized attic) of the building. The vapour-tight will be connect after. The not utilized area will be insulated additionally.
	The roof is designed to be supported by two linear supports, the exterior wall (rising it might be needed) and interior beam or bearing wall). The modules will be connected using standard carpenter's tools and connecting elements.

6 LOCALIZED DESIGN OF MODULES

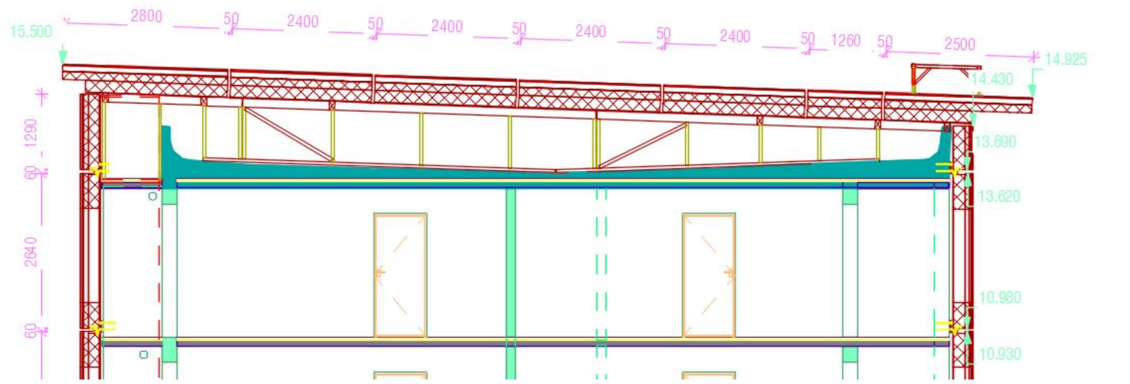
6.1 Czechia

The general solution introduced above fits the conditions of the Central-European geocluster. The changes might be only done later for the system application on the real building (the real-life learning lab installation and test will be done with the original general design).

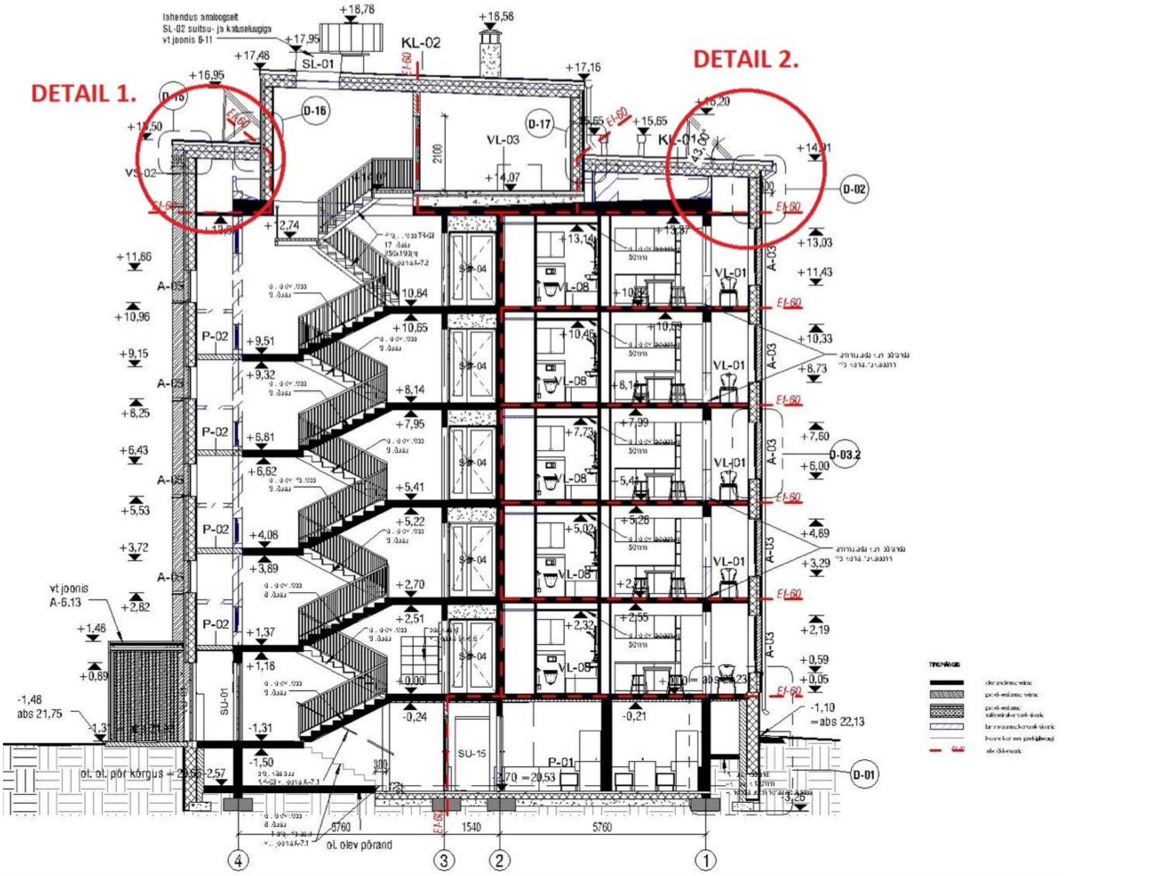
6.2 Estonia

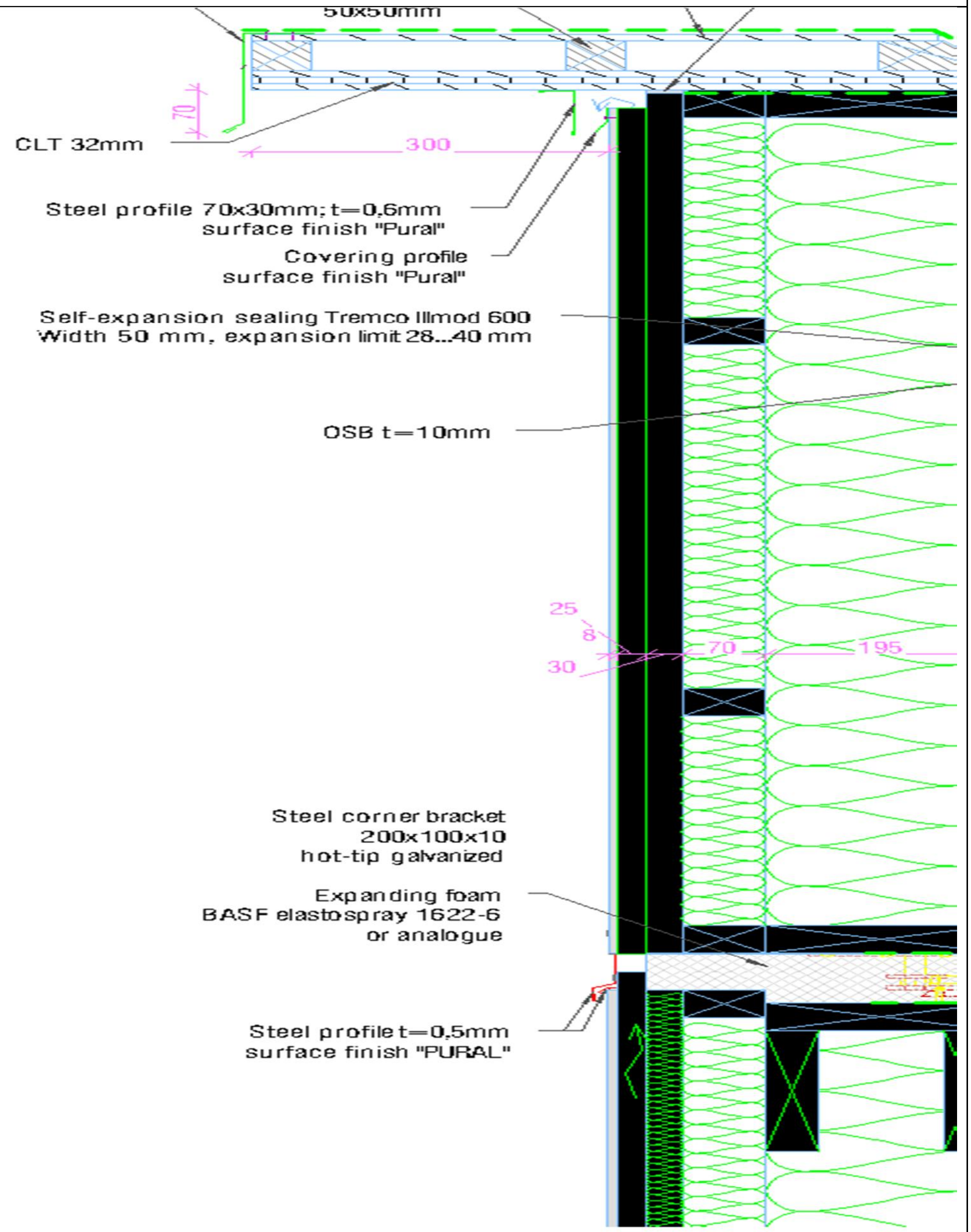
6.3.1. Examples of designed roof modules on Estonian pilot.

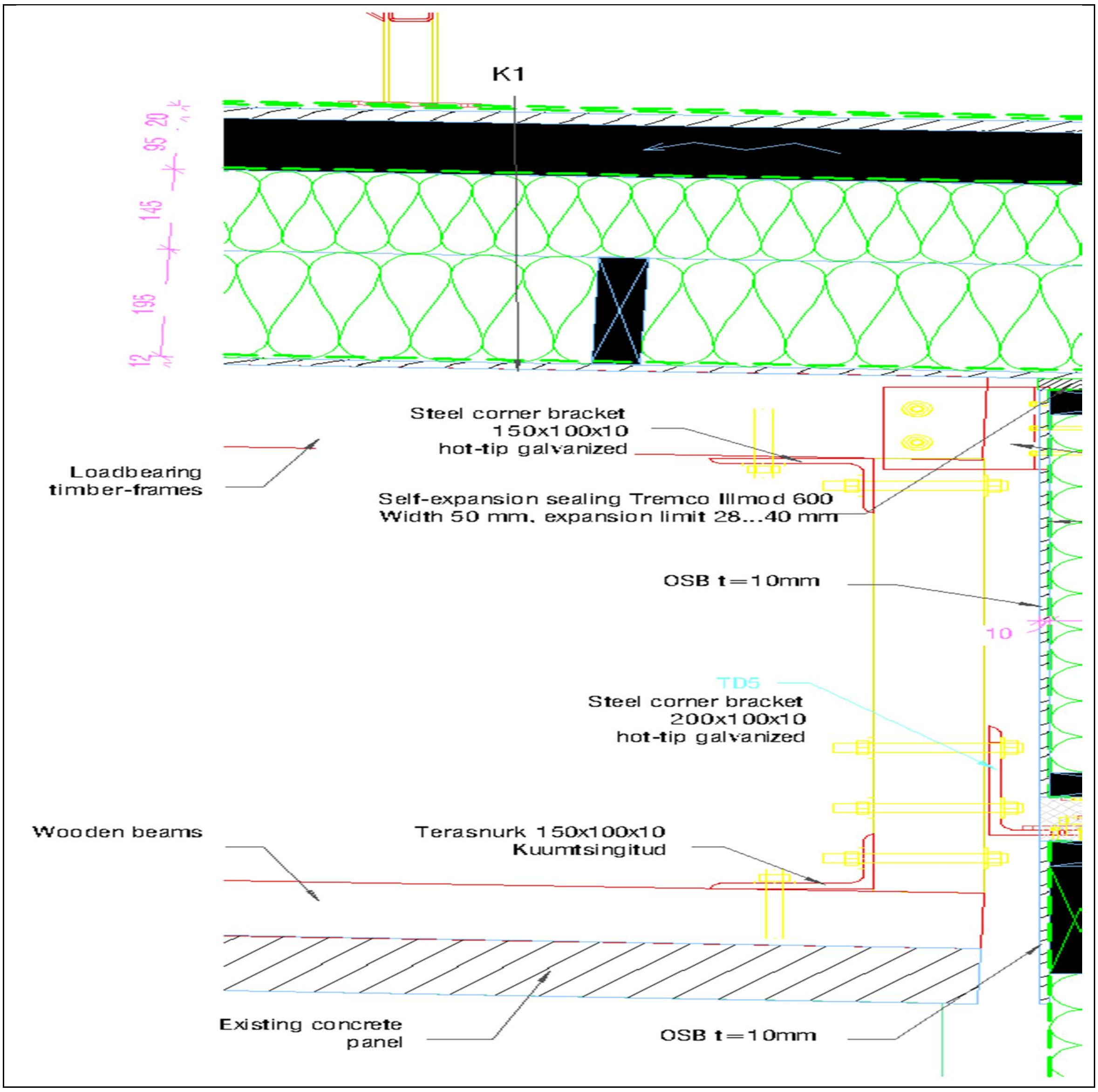
Section view of roof modules



Location of the structural detail 1 and detail 2

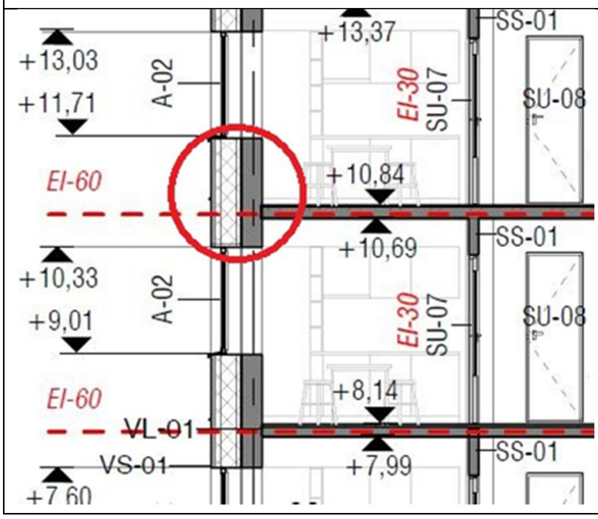


Detail 1.

Detail 2.

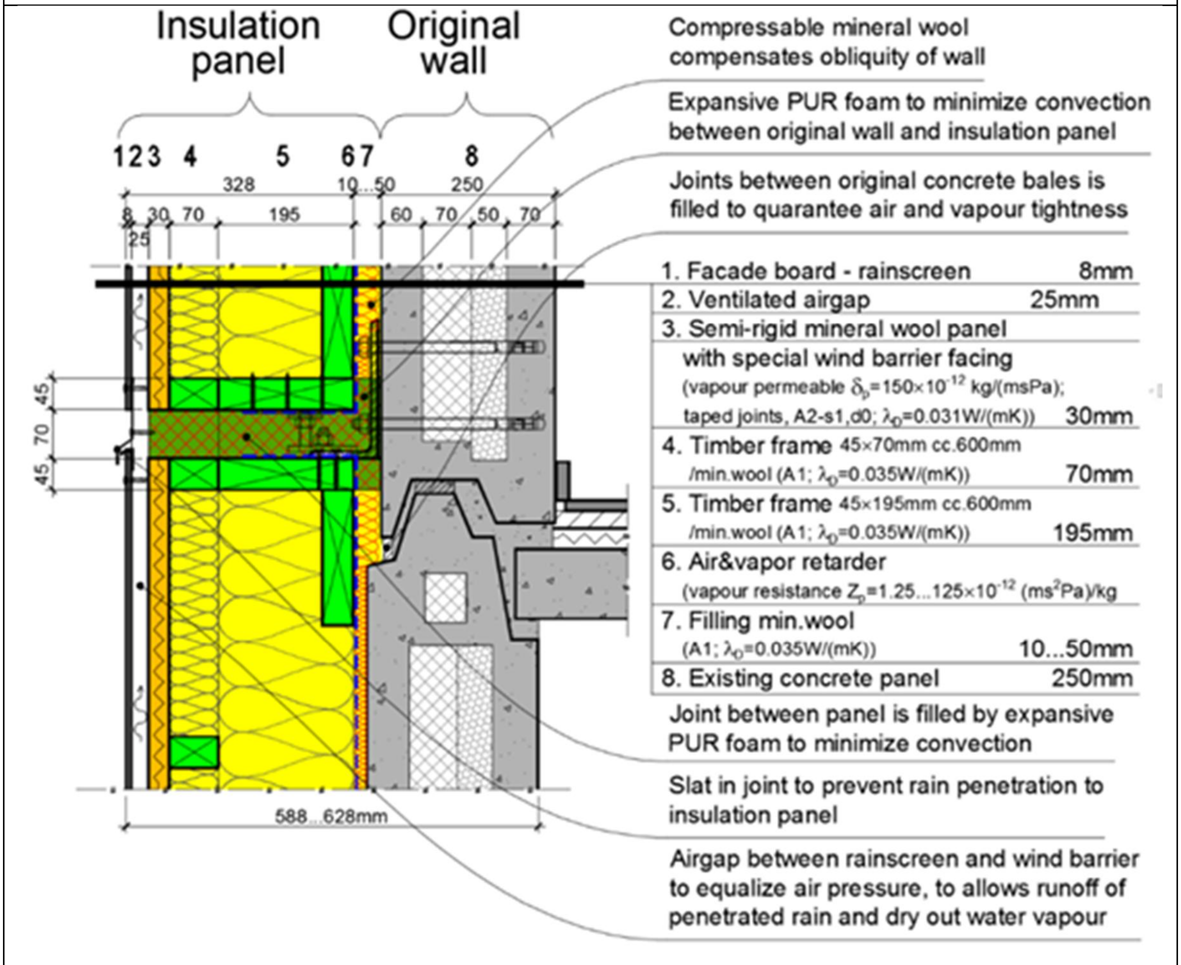


6.3.2. Example of designed wall module on Estonian pilot.

Location of the structural detail 3



Detail 3.


Insulation panel
Original wall
1 2 3 4 5 6 7 8
328
10...50
250
8 30 70 195
60 70 50 70
25
45 70 45
588...628mm
Compressable mineral wool compensates obliquity of wall
Expansive PUR foam to minimize convection between original wall and insulation panel
Joints between original concrete bales is filled to quarantee air and vapour tightness
1. Facade board - rainscreen 8mm
2. Ventilated airgap 25mm
3. Semi-rigid mineral wool panel with special wind barrier facing (vapour permeable δ_p=150×10^{-12} kg/(msPa); taped joints, A2-s1,d0; λ_D=0.031W/(mK)) 30mm
4. Timber frame 45×70mm cc.600mm /min.wool (A1; λ_D=0.035W/(mK)) 70mm
5. Timber frame 45×195mm cc.600mm /min.wool (A1; λ_D=0.035W/(mK)) 195mm
6. Air&vapor retarder (vapour resistance Z_p=1.25...125×10^{12} (ms^{2}Pa)/kg
7. Filling min.wool (A1; λ_D=0.035W/(mK)) 10...50mm
8. Existing concrete panel 250mm
Joint between panel is filled by expansive PUR foam to minimize convection
Slat in joint to prevent rain penetration to insulation panel
Airgap between rainscreen and wind barrier to equalize air pressure, to allows runoff of penetrated rain and dry out water vapour

7 PROTOTYPING

This chapter documents in prototyping of basic modules that took place in several countries.

7.1 Czechia

One standard wall module was created to test the feasibility of the suggested solution. The integration of all desired technologies was checked. Following pictures illustrate the process.

Figure 7.1: Production of the frame for the wall module in Czech variant at a production line at RD Rýmařov, Czechia.

Figure 7.2 Compensator on the hydraulic heating system's pipes were created to provide sufficient manipulation possibilities during montage.

Figure 7.3: Integrated electrical devices in the module's switch box. The box will be further developed.

Figure 7.4: Custom-made ventilation inlet.

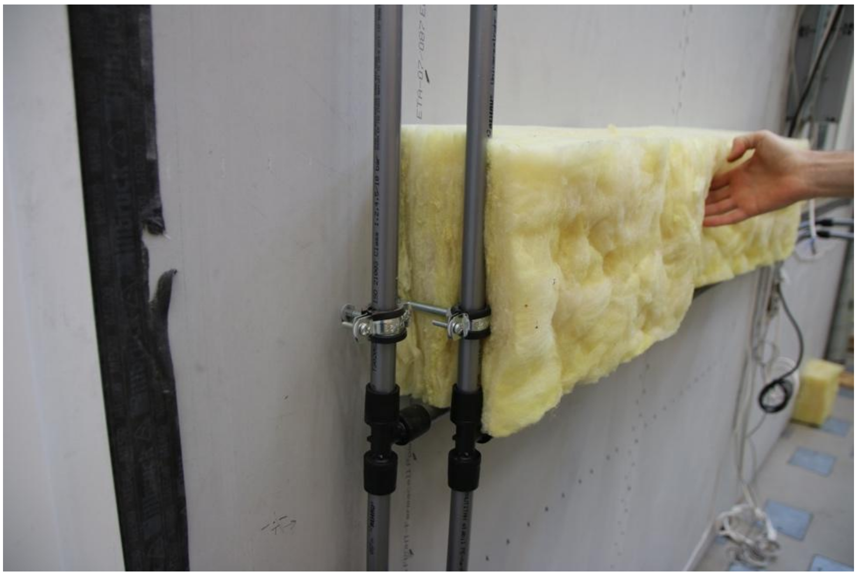


Figure 7.5: Soft, low density mineral wool covers all the installation layers from the interior side of the module. The final material density will be optimized at the Czech pilot.

Figure 7.6: The space prepared for the vacuum insulation and electrical blind installation.

Figure 7.7: Custom-made insulation covering the ventilation pipes

7.2 Estonia

The team at TUT developed and tested samples of the wall elements, their connections and assembly and fixing of the panels to walls. The activities are documented at the figures bellow.

Figure 7.8: Design and construction of panels.

Figure 7.9: Installation of ventilation ducts into the panels.

Figure 7.10: Horizontal joints of the panels.

Figure 7.11: Fixing of panels to the wall.

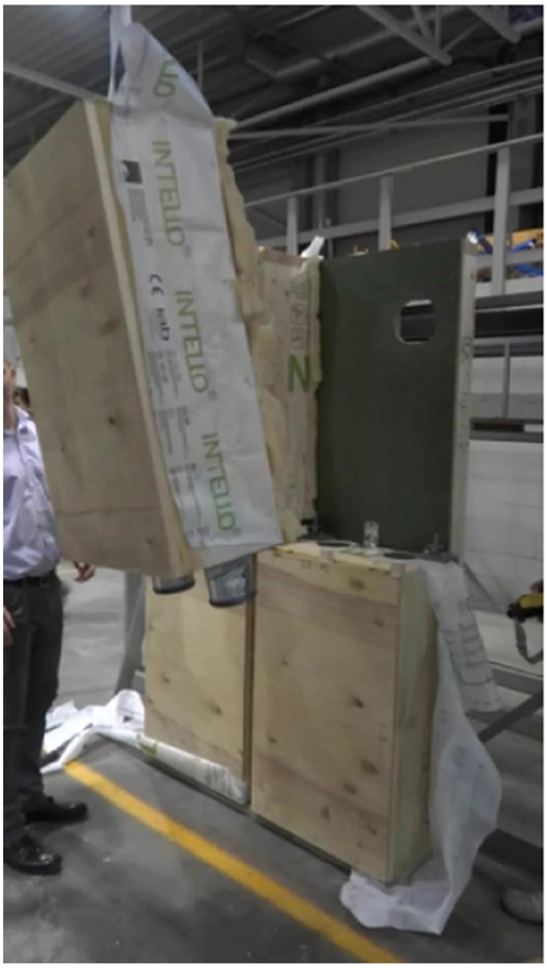


Figure 7.12: Ancohring of panels to the wall.

8 REFERENCES

[1] Targo Kalamees and et. al., "Initial performance criteria and requirements forinnovative and multifunctionalbuilding envelope elements(D2.1)." 2016.
[2] Xella Customer Information, "Ytong Multipor Mineral Insulation Boards: External thermal insulation composite system." Xella Customer Information, Jul-2009.
[3] "PHOTOVOLTAIC CELLS EMBEDDED IN LAMINATED GLASS - Products [T]tectonica-online." [Online]. Available: http://www.tectonica-online.com/products/2058/laminated_glass_embedded_cells_photovoltaic_optisol/. [Accessed: 07-Feb-2017].
[4] M. Kabrhel *et al.*, "Smart connectors WP2 (T 2.6)." 30-Nov-2016.
[5] "Mapy.cz," *Mapy.cz*. [Online]. Available: https://mapy.cz/. [Accessed: 14-Feb-2017].
[6] "The Carbon Neutral Design Project | Society of Building Science Educators | American Institute of Architects - Carbon Neutral Design Strategies." [Online]. Available: http://tboake.com/carbon-aia/strategies1b.html. [Accessed: 11-Feb-2017].

ANNEX I – FORMS SUMMARISING BOUNDARY CONDITIONS OF THE PILOTS

These forms were distributed among the project partners in autumn 2015 with the objective to get overall information about target typologies to which the design of modules should fit.

The "X" sign stands for relevant statements. Where the empty cell is, the statement is not relevant for the particular pilot building, no information was delivered or the information was delivered after creating the overview. Other options are mentioned above the figures.

Building typology

Residential house, masonry wall system	Czech Rep., Latvia, Denmark
Residential house, precast concrete frame	Portugal
Residential house, precast concrete wall system	Estonia
Row family house	The Netherlands

Typical problems

Typical problems / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Building heat losses						
Insufficient energy performance	X	X	X	X	X	
Thermal bridges	X				X	
Insufficient airtightness			X			
Thermal comfort						
Winter thermal comfort, local overheating, low temperatures (dysfunctional control system)	X		X			
Summer overheating	X		X		X	
Poor acoustic parameters				X	X	
HVAC system						
Large heat loses on heating system			X			
Insufficient ventilation	X	X	X		X	
Wear and failures						
Obsolete windows	X	X				
Chipped façade, old-fashioned look		X			X	
Waterproofing failures on balconies	X				X	
Water leakage around chimney	X					
Mould growth, condensation	X		X	X	X	

Special features

Historical (monumental) characteristics of the property: which historical / monumental characteristics need to be taken into account when considering nZEB retrofitting?	None of pilot buildings
Aesthetic characteristics of the property: which aesthetic characteristics need to be taken into account when considering nZEB retrofitting?	None of pilot buildings

Site plan

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Urban area	X	X	X	X	X	X
Shading objects nearby – some facades can be shaded	X	X		X		
Flat construction site	X	X	X	X	X	

Floor plans

Present state

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Unified apartments' layout			X	X	X	X
Various apartments' layout	X	X				

Design target

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
No changes in the floor plan		X	X			
Changes in the floor plan possible				X	X	
Lift addition	X					
New staircase built	X				X	
Newly glazed balconies	X					

Cross section

Present state

Characteristic / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
2-storey building			X			
3-storey building				X	X	X
4-storey building		X				
5-storey building	X					
Basement	X	X	X	X	X	

Design target

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
No changes			X	X		X
Floor addition planned					X	
Roof and attic change planned	X	X			X	

Façade and roof design

Present state

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Plain facade	X		X	X	X	X
Fragmented facade	X			X		
Segmented facade	X	X				
Curved facade				X		
Concrete surface	X					
Plaster surface		X		X	X	
Masonry/brick surface			X			X
Roof shape	flat	pitched	pitched	pitched	pitched	pitched

Design target

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Raised roof edges	X				X	
New dormers					X	
Replacement of old roof for additional floor with a new roof						

Complementary façade elements

Present state

Item / Country	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Open balconies	X				X	
Glazed balconies		X			X	

Design target

Target	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Opened balconies - refurbished					X	
Opened balconies - new					X	
Enclosed, glazed balconies	X					
Additional reading rooms - new					X	

Structural system

The constructional system present lateral masonry bearing walls.

Structural system	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Masonry wall	X		X		X	X
Concrete wall		X				
Hybird system				X		

Foundations

Present state

Foundation	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Reinforced concrete wall	X	X			X	
Reinforced concrete slab			X		X	
Reinforced concrete pile						X

Design target

No changes assumed at this point by any of partners.

Vertical structures

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Exterior wall thickness	270mm	280mm (180mm RC + 100mm TI)	380mm	260mm (150mm + 110mm)	450mm	-
U-value [W/(m^2.K)]					1,35	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
U-value [W/(m^2.K)]	0,08		0,18		0,12	0,21

Horizontal structures, floor slabs

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Floor slab thickness	220mm - 240mm			300mm	220mm	
U-value [W/(m^2.K)]				0,78	3,5	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
U-value [W/(m^2.K)]				0,3	0,32	

Openings

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
g-value	0,75	0,75	0,75		0,67	
U_w-value [W/(m^2.K)]	1,8	2,9	2,0	3,1	1,2	2,9
U_d-value [W/(m^2.K)]	2,0	2,9			1,4	2,9

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
g-value	0,67	0,67	0,67		0,5	0,67
U_w-value [W/(m^2.K)]	0,6	1,0	1,0	2,4	0,7	1,0
U_d-value [W/(m^2.K)]	1,0	1,0	1,0		0,8	1,0

Roofing

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Roofing	Bituminous waterproofing felt			Ceramic tiles	Ceramic tiles	Ceramic tiles
Slope	3°-5°	30°		33°	33°	40° – 50°
Free attic	no	yes	yes	yes	yes	yes
U-value [W/(m^2.K)]	1,1	(100-200mm of insulation)		0,94	3,58 (ceiling)	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
U-value [W/(m^2.K)]	0,06			0,32 (ceiling)	0,11 - 0,14	0,15
Attic utilization	no	no	no	no	Planned / possible	no

Heating

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Heating type	District heating	District heating		Local	District heating	
Heating elements	Cast iron radiators	Radiators	Radiators – single pipe system	Electric radiators	Cast iron radiators	
Gradient [°C]	75/60	80/60	75/60	-	80/60	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Heating type	District heating	No changes			Dis. Heating / to be adjusted	
Heating elements	new		Radiators – double pipe system		Air heating / electric radiator / radiator to be adjusted	
Gradient [°C]	70/55				-	

Cooling

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Cooling system	None					

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Cooling system	None – passive cooling measures: shading, increased ventilation assumed					

Ventilation

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Natural ventilation	X	X	X	X	X	X
Mechanical ventilation – suction boxes	X	X	X	X	X	X

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
New ventilation system	X	X	X	X	X	X
In-facade integrated syst.	X	X		X	X	X
Heat exchanger installation	X	X			X	X
Position of heat exchanger	roof	in flats?			loft / basement	loft

Electrical wiring

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Undue installation	X				X	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
No changes needed	X	X		X		X
New electric installation (separate task from M-C refurbishment)	?[1]				X	
New electric installation (integrated in modules)	?[1]					

[1] not clear

Water piping

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Undue installation					X	
Circulation control implementation	X				X	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
No changes needed		X		X		X
Refurbishment inside the building assumed	X		X[1]	X	X	

Connection to original system need to be done	X	X	X	X	X	X

[1] done by owners beyond M-C refurbishment

Drainage system

Present state

No problems were reported among any of pilot buildings.

Design target

No targets were set among any of pilot buildings.

Monitoring and control

Present state

Measured and controlled parameters, provided features	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Control system		(by district heating)	individual / flat	none	individual / flat	
Heat meter		central and individual			local	
Electricity meter		central			individual	
Water use meters		individual			individual	

Design target

Measured and controlled parameters, provided features	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Temperature	X		X	X	X	
Humidity	X		X	X	X	
CO_2	X		X	X	X	
Heat	X	X	X		X	
Individual Room Control unit	X				X	

Energy sources

Present state

Energy sources	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Individual gas boilers				X		X
Electricity (power grid)		X		X	X	X
District heating w. local DHW preparation	X	X			X	X

Design target

Energy sources	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
District heating	O	X			O	
Natural gas boiler (central)	O			X	O	
Biomass boiler (central)					O	
Photo-voltaic panels					X	
Photo-thermal panels					O	

O – optional

Acoustics

Present state

No parameters reported.

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Maximum noise from service systems [dB]	40 / 30 (25)	30	40 / 30 (25)	27 / 32	40 / 30	

Daylight

Present state

No problems reported. To be determined later.

Design target

Shading by very thick wall composition must be considered.

Air tightness/ventilation

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Air change ratio @ 50Pa	0,3 h^{-1}	0,5 h^{-1}	6,5 $m^3/(m^2.h)$	0,94 h^{-1}	0,3 h^{-1}	

Design target

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
Air change ratio @ 50Pa	1,5 h^{-1}	1,5 h^{-1}	3,0 $m^3/(m^2.h)$	0,55 h^{-1}	1,5 h^{-1}	

Moisture safety

Present state

	Estonia	Denmark	Latvia	Portugal	Czech Republic	The Netherlands
High moisture / mould growth reported	X	X		X	X	
Water leakage in the roof	X					

Integration of Renewables

Technology Overview

(D2.4)

Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions (MORE-CONNECT)

H2020-EE-2014-1-PPP (EE-01-2014)

Contents

1 Introduction

Due to the world efforts to tackle climate changes, the increase of energy efficiency strategies and the development of renewable energy solutions have been growing rapidly. Nearly Zero Energy Buildings (nZEB), buildings requiring zero or very low amount of energy have become an attractive solution when renovating the existing building stock. nZEB present high energy efficiency and its low energy consumption is to be covered by renewable energy sources produced on-site or nearby. There are several ways to integrate renewable energy technologies in buildings and the final solution will depend on many factors, such as the local climate, the building architecture or the building's energy demand.

The aim of this project is to reach nZEB and therefore renewable energy strategies are necessary. The two most likely options are photovoltaics for electricity production and solar thermal for domestic hot water (DHW) and partially heating. However, there are also other available technologies, such as small wind turbines, biomass boilers and geothermal heat pumps, which by themselves or combined with other can contribute to achieve the necessary renewable energy production. These technologies can be applied in buildings in two different ways: the renewable energy system is simply added to the building element (e.g. system mounted on the roof) otherwise the system is integrated into the building, replacing the conventional building materials and adapting their function (e.g. solar façade). In the first solution, the renewable energy system is a single technical element attached to the building, which is not directly related to the structure's functional aspects, and serves as an energy generator. In the second solution the system is a functional part of the building envelope and besides producing energy, it also ensures other functions like thermal and acoustic insulation, climatic protection shading or safety issues (Peng *et al., 2011*). By integrating the renewable technologies into the building itself, the efficiency and performance of the building is improved beyond what could be achieved if the technologies were simply employed as "add-on" features. The fact that renewable energy systems become a functional part of the building allows exploring synergetic effects, expanding the amount of space available, increasing the economic viability of systems and implementing high aesthetic value solutions.

This document, related with Task 2.4 – Integration of Renewables, describes the main renewable energy technologies that might be used when constructing and renovating buildings in order to reach nZEB level. It is intended to use such technologies in the different geo-clusters covered by the MORE-CONNECT project and therefore this section is crucial for the selection of favourable technologies for on-site production of energy from renewable sources on the pilot projects.

This task identifies a variety of options for renewable energy technologies and possibilities for their integration in buildings, hence appropriate solutions can be chosen for the implementation in the pilot buildings of the MORE-CONNECT project. Options may differ among others with respect to the following aspects:

- The **scope of the renovation**: the type of building elements included in the renovation project that will define the possibilities to integrate or apply (mount) the renewable energy systems;

- The **type of systems** for heating, cooling and domestic hot water (DHW) production that exist and/or will be installed in the pilot buildings;
- The **local constraints** (climate, availability of renewable resources, shading, for example) that will define the possible **on-site renewable energy technologies** (like PV, solar thermal, hybrid systems) that are suitable for the pilot buildings.

For the selection of favourable renewable energy technologies, this document intends to present different options for on-site renewable energy production technologies and also the technical and social barriers as well as the political context, associated to these technologies at a global and local level. It provides the necessary overview in order to carry out an informed decision on which renewable energy production technologies should be implemented in each geo-cluster.

The document firstly presents the terms and definitions (Chapter 2) followed by a technology inventory and review of available options for building integrated renewable energy production systems (Chapter 3). The technical and social barriers are presented in Chapter 4. Moreover, the political context, at the global and local level, are also explored and reviewed in Chapter 5. At last, in Chapter 6, different approaches of possible solutions for each pilot case are presented.

2 Terms and definitions

Nearly zero energy building – building with a very high energy performance. Nearly zero or very low amount of energy required should be, to a very significant extent, covered by energy from renewable sources, including energy from renewable sources produced on-site or nearby;

Biomass – biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste. Biomass can be in solid, liquid or gaseous state;

Building Integrated (BI) Systems (BIS) – systems which are integrated into the building; the most common being Building-integrated photovoltaics (BIPV) and Building-integrated solar thermal systems (BISTS). A system is considered to be building integrated if for a building component this is a prerequisite for the integrity of the building's functionality;

Building Added (BA) Systems – systems that are installed on the buildings as add-ons; the most common are building-applied photovoltaics (BAPV) and building-applied solar thermal systems (BASTS);

Building's energy consumption – amount of energy that encompasses the energy consumption necessary for heating, ventilation, cooling, lighting and hot water supply of the building;

Building's energy efficiency – comparison of buildings' energy consumption amongst similar type of buildings in areas with similar climatic conditions;

Cogeneration (Combined Heat and Power or CHP) – simultaneous production of electricity and heat in the same generating facility;

District heating network – heating network that distributes the heat generated in a centralized facility to a large number of buildings;

Heat pump – facility that relocate heat from a colder place to a warmer place. This process consumes energy as heat arbitrarily flows in opposite direction. Depending on the heat source, there are ground, air or water heat pumps;

Heat pump energy efficiency index (Coefficient of Performance) – ratio of the heat/cold delivered by a heat pump to the electric energy input required to operate the heat pump;

Heating boiler – facility designed to generate steam or to heat a portable heat carrier (e.g. water) for circulation through a building heating system;

Horizontal-axis wind turbine – wind turbine with a rotor shaft substantially parallel to the wind flow;

Low energy consumption building – building whose necessary energy consumption for heating is below a defined value;

Passive building – building with very low energy consumption where for the most part of year heating/cooling system for room temperature provision is not necessary. Necessary heat is mainly provided using existing internal heat sources and solar gains;

Photovoltaic (PV) modules – solid state devices that convert solar radiation directly into electricity requiring no fuel and creating virtually no pollutants over their life cycle;

Primary energy – energy from renewable and non-renewable energy sources that is neither recycled nor transformed;

Renewable energy sources – energy derived from resources that are naturally replenished in a human timescale and that, for all practical purposes, cannot be depleted. Types of renewable energy resources include moving water (hydro, tidal and wave power), thermal gradients in ocean water, biomass, geothermal energy, solar energy and wind energy. Municipal solid waste (MSW) is also considered to be a renewable energy resource;

Social barrier – barrier related to any restrictions that are caused by issues related to society and its attitudes towards features of building renewable energies;

Solar energy – energy obtained from the sun and transformed into usable energy using photovoltaic modules to produce electricity;

Solar heating – energy obtained from the sun and transformed into usable energy using solar thermal collectors to produce heat;

Solar thermal (ST) system – System that collects or absorbs solar energy for useful purposes. Can be used to generate high temperature heat (for electricity production and/or process heat), medium temperature heat (for process and space/water heating and electricity generation), and low temperature heat (for water and space heating and cooling).

Technical barrier – barrier related to any obstruction that affects building renewable energies due to issues related to mechanical problems or technological inadequacies in its inherent design;

Vertical-axis wind turbine – wind turbine with a vertical rotor shaft;

Wind energy – energy obtained from wind and transformed into usable energy, for example using wind generators to produce electricity or using windmill to produce mechanical energy;

Zero energy building – building with zero net energy consumption and zero carbon emission annually. Zero energy buildings can be operated autonomously from energy supply network, if energy is obtained in sufficient amount on the spot;

3 Technology overview

The renewable energy resources that can be used to cover the energy needs of buildings are, in general, water/tides, sunlight, wind, plants (biomass) and geothermal heat. Among them, the most common renewable energy resources used in buildings are the wind, biomass, geothermal and solar energy.

The common renewable technologies applied in buildings include solar thermal systems, photovoltaic systems, wind turbines, biomass boilers and combined heat and power (CHP) for cogeneration, geothermal heat pumps and hybrid systems (combining two or more technologies).

In any project, the selection of the technology to be used will depend on local constraints related not only to the availability of the renewable resource, but also the influence of surrounding elements, integration on the building, capacity of the existing building to support the system, legal constraints, aesthetics, acceptability, impact on site (e. g. visual, noise) and costs.

The advantages of adopting renewable energy systems (RES) towards achieving zero or nearly zero energy buildings are (Kalogirou, 2013):

- Offer local generation of heat and electricity therefore transmission losses are minimized;
- Usually the generation is done by RES, which are friendly to the environment;
- The building owner can install a high-tech system by taking advantage of subsidies when they exist (which often occurs);
- The energy consumption expenditure for the building is minimized or it is non-existent (for 100% coverage);
- The overall value of a property increases;
- The building can have a higher class in the energy performance certificate;
- As the energy performance certificate and the class of the building are usually related to the amount of rent requested, a higher income can result for the owner;
- There may be considerable income to the building owner by selling the electricity produced (for grid-connected systems) when this option is available. In some cases it can also lead to a reduction on the electricity price for own consumption.
- Different RES can be integrated together or even with existing conventional systems.

On the other hand these systems present disadvantages such as (Kalogirou, 2013):

- The initial expenditure for the building is higher;
- The owner usually has to pay at front the expenditure for the RES and then apply to get the refund from subsidies;
- Problems to install the RES on the building structure;
- Problems with respect to the space availability to install the RES systems required;

- Most RES systems will require periodic maintenance, which creates extra worries and costs for the building owner;
- On existing buildings, there may be disruption of existing services;
- Building integration may require specialist training for the installers.
- If the system is not properly designed, the overall efficiency can be very low.

3.1 Solar

The sun is a clean, unlimited and almost infinite energy source. Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy due to its ubiquity, abundance and sustainability. Proven technologies are able to transform its radiation into heat, electricity and even cold, and are now largely available at affordable prices (Frontini et al., 2012).

Solar energy resource can be explored through passive or active systems. In passive systems, solar radiation is used as a source of natural light and radiated heat through the windows and building envelope. Active systems capture and transform solar radiation into different forms of energy: photovoltaic (PV) modules convert solar radiation into electricity while solar thermal systems (STS) convert solar radiation into heat.

These two technologies are complementary and are commonly used together in a building. PVs can supply the electricity required to the building or generate electricity that can be fed or sold back to the grid. PV is usually preferred as the system does not require batteries for energy storage and in some cases might take advantage of higher electricity rates (an incentive) that can be obtained by selling the electricity produced to the grid. STS produce hot/cold water and can therefore supply thermal energy for space heating, cooling and the provision of hot water for the needs of a building (Kalogirou, 2013). Table 1 shows the solar technologies according to the building's energy needs.

Table 1 - Solar technologies according to the building needs (Adapted from Frontini et al., 2012)

Building energy needs	**Corresponding Solar Technologies**	
	Passive	**Active**
Domestic Hot Water	-	Solar Thermal
Space heating	Passive Solar	Solar Thermal
Space Cooling	Free Cooling	Solar Thermal/PV
Electric appliances	-	PV
Light	Day light	PV

Both types of solar modules are normally installed in the roof as an add-on (Figure 1). However, as the goal is to reach nZEB and roof space is limited, they can also be installed on vertical elements (façades), inclined (shading elements) or integrated directly into the building construction elements. Thereby replacing cover materials, such as in façades, roofs, shading devices, overhangs, balcony railings and curved/flexible façade and roof surfaces (Figure 2). However, they will need to meet the requirements that a standard module does not need to meet, such as thermal (e.g. U-value and g-value for transparent elements) and mechanical resistance.

Figure 1 - Photovoltaic modules (left) and solar thermal collectors (right) installed as add-on features on the roof.

Figure 2 - Photovoltaic modules (up left) and solar thermal system (up right and down) integrated on Portuguese buildings' elements (roof and façades).

A solar energy system is considered to be building integrated, if for a building component this is a prerequisite for the integrity of the building's functionality. Building integration must provide a combination of the following (Kalogirou, 2013):

- Mechanical rigidity and structural integrity;
- Weather impact protection from rain, snow, wind and hail;
- Energy economy, such as useful thermal energy, but also shading and thermal insulation;

- Fire protection;
- Noise protection.

The integration of RES in the building can present a number of problems that will need to be considered such as (Kalogirou, 2013):

- The amount of thermal energy collected and at what temperature range;
- The resistance to wind-driven rain penetration;
- The calculation of light and solar energy characteristics if the underlying base layer is transparent,;
- The calculation of thermal resistance and thermal transmittance characteristics of the construction (overall heat transfer coefficient);
- The fire protection classification and fire protection from hot components in contact with flammable materials;
- The noise attenuation.

The installation of a solar facility during the renovation of an existing building produces both synergies and savings. For instance, if a roof has to be completely recovered and a solar facility is installed, cost on tiling is saved in addition to energy generation.

The solar systems are influenced by the local solar radiation availability, tilt angle, azimuth, shadowing and temperature. High temperatures affect to a great extent the PV systems, for which the reduction of performance is more significant for crystalline silicon than for amorphous silicon. These aspects have to be considered in the design of building-integrated PV solar systems from the very beginning in order to allow the air to flow over the backs of the modules and to maintain a high performance.

For each geographic situation, there are different solar irradiation levels associated to different orientations. In order to maximize the annual energy yield, both PV and ST systems should ideally be south-facing when situated in the north of the equator. The optimum tilt angle of the module is equal to the latitude of the location with angle variations of 10 – 15°. A typical energy distribution for mid-Europe is shown in Figure 3.

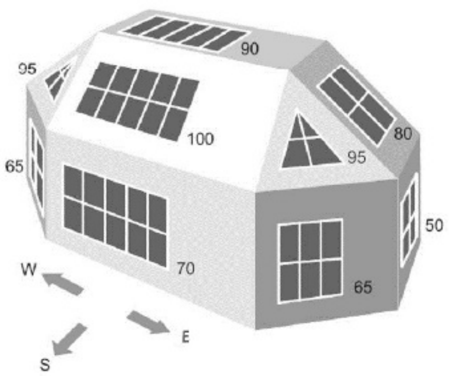


Figure 3 - Module yield vs. orientation (Source: PEA Project).

Regarding PV for tilted roofs oriented S-E to S-W, the production is close to the maximum (> 95%), while in the façades with the same orientations it is reduced to 65-

70% (less for regions close to the equator). In EU middle latitudes, where the solar radiation varies significantly during the year, the maximum summer production can be twice of what can be produced in the winter. To avoid summer overheating, tilted STS are usually undersized (solar fractions around 50%). A good way to increase the whole year solar fraction while limiting overheating risks is to mount the modules vertically, using the façade areas. The heat production would then be almost constant during the year, making it possible to design the system according to the real needs (solar fraction of up to 90%) while opening the way to building façades applications (Frontini et al., 2012).

3.1.1 Building integrated solar thermal systems (BISTS)

Solar thermal collectors are a particular kind of heat exchangers that transform solar radiation into internal energy through a transport medium. The major component of any solar system is the solar collector. This is a device made of a thin metal sheet with selective black coating which maximizes solar energy absorption while minimizing infra-red losses. After collecting solar energy, it converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) that is flowing through the collector. Thus, the solar energy is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days (Kalogirou, 2004).

There are two main categories of solar collectors: non-concentrating or stationary collectors, with same area of intercepting and absorbing solar radiation (flat plate collectors, stationary compound parabolic collectors and evacuated tube collectors) and concentrating collectors, usually a concave reflecting surface to intercept and focus the sun's radiation to a smaller receiving area to increase of radiation flux. Non-concentrating collectors consist also of single-axis and two-axis tracking.

The three most common solar thermal collector designs are the i) flat plate collectors (glazed or unglazed), ii) compound parabolic collectors (CPC), and the iii) evacuated tube collectors. All are hydraulic systems and use water (or water-glycol mixture) as a medium to transport and store the collected heat. Characteristics of the flat plates and evacuated tubes are summarized in Table 2. The CPC are further described.

Table 2 - Characteristics of the flat plates and evacuated tubes (Adapted from Frontini et al., 2012).

	Glazed flat plates	**Unglazed flat plates**	**Evacuated tubes**
Working temperatures	50-100 °C	25-50 °C	120 °C
Main applications	DHW, space heating	Swimming pools, low temperature space heating, DHW pre-heating	DHW, space heating, space cooling
Energy production (Switzerland, 6m^2 field)	400-600 kWh/m^2	300-350 kWh/m^2	480-650 kWh/m^2
BISTS application	Roof coverings, façade cladding, sun shading devices	Roof coverings, façade cladding, sun shading devices	Balcony eaves, sun shading elements, double roofs

Disadvantages	Overheating, maintenance	Back insulation needed, maintenance	Price, aesthetics, more complex building integration
Advantages	Lower cost, easily integrated in building envelope		Higher efficiency, well adapted for cold, windy and humid climates

The majority of these systems include a thermal storage with water capacity to supply 1 to 2 days demand of a household/building. Single-family systems have storage sizes ranging from 150 to 400 litres and the hot water is typically delivered at 50-60°C. Even though all these collectors are suited for DHW production and space heating, they have very different appearances, levels of efficiency and working temperatures (Frontini et al., 2012).

Glazed and unglazed flat plates are well adapted to replace parts of roof coverings or façade cladding (e.g. Figure 4). The insulation behind the absorber plate and the insulation of the building envelope can be merged to become one single insulation element either they can complement each other. The sun shading applications are also possible for flat plate collectors, but their thickness and water connections can present complexity. Flat plate collectors were developed for sunny and warm climates. Therefore their benefits are greatly reduced whenever the conditions become unfavourable for cold, cloudy and windy days. Furthermore, condensation and moisture will cause early deterioration of internal materials reducing the system performance as well as the system failure (COST Action TU1205, 2015).

Figure 4 - Flat plate collectors as façade cladding.

Compound parabolic collectors – CPC (Figure 5) have the advantageous capability of reflecting all the incident radiation to the absorber. They accept incoming radiation over a wide range of angles as reflections also reach the absorber surface. They are commonly covered with glass to avoid dust and other materials entering which could cause the reduction of reflectivity. These collectors can be stationary or tracking systems. If their long axis is oriented in north-south direction, the sun-tracking should be used, because stationary system is less efficient. If the long axis is orientated to east-west direction, only little seasonal adjustment may be required for greater efficiency. Thus, usually the long axis is placed in east-west direction.

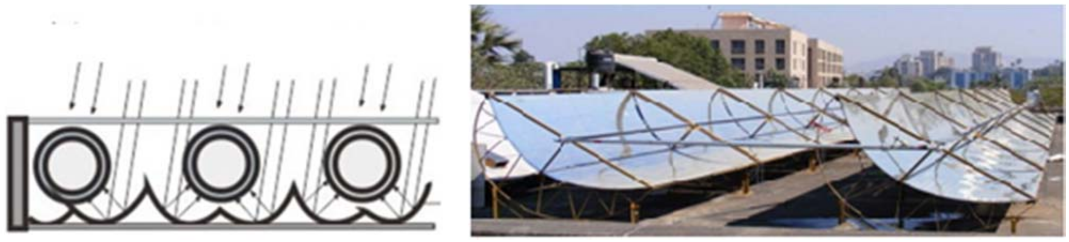


Figure 5 - Compound parabolic collectors' working principle (left) and example of a CPC installed on a roof (right).

Evacuated tube collectors have high levels of insulation and are therefore well suited for cold climates. Their structure and appearance somehow limit their possibility to be integrated into the envelope itself; however, their applications are possible in balcony eaves or sun shading elements (e.g. Figure 6).

Figure 6 - Evacuated tubes collectors used as glazed roof sun shading (left) and balcony eaves (right).

The STS can be used as combi systems, where the solar collectors are backed-up by auxiliary non-solar heat source (electricity/fossil fuel) connected to a storage tank for domestic hot water production as well as a storage tank for space heating for a heat distribution system. The space cooling is also a possibility if the solar thermal system is combined with a thermally driven absorption and adsorption chillers. These units are described later on.

Currently, a variety of systems are used in the integration of STS. The integration dictates the type and the way the STS are going to be designed and installed.

In case of an existing domestic water tank with a single heat exchanger, the STS can be connected in parallel to the existing conventional boiler. Thus, the solar collectors act as the primary system and the existing boiler as the back-up system. Due to common heat exchangers and heat transfer fluids, the solar collectors have to operate at the same or higher temperature than the temperatures provided by the boiler. In this situation, the evacuated tube collectors are mainly used since they are more efficient at high operating temperatures than flat plate collectors and are resistant to freezing in winter time due to the vacuum insulation around the collector pipes. These systems may also be used as solar assistance to space heating (with some extra connections to deliver the heat directly to the space heating loop).

When an entire conventional boiler is replaced (that provides hot water and space heating) due to aging or low efficiency, a combi system should be chosen and therefore integrate a STS in the building. A single storage tank can be used for water and space heating, whose installation will be easier since the distribution system already exists.

If renovating the STS in a multi-family building with a common heating system, the existing distribution system can be used with a low return temperature and a high solar yield. In case of multi-family buildings with decentralized domestic hot water storage solar collectors can be integrated every apartment through the façade or the balustrade of the balconies. In this case also, he existing distribution system can be used leading to a shorter collector loop piping, easier installation and lower heat losses.

3.1.2 Building integrated photovoltaics (BIPV)

Building integrated photovoltaics serve simultaneously as building envelope material and power generator. Like building integrated solar thermal systems, BIPV replace traditional cover materials, such as in façades, roofs or shading devices, therefore having to comply with the same requirements than traditional building materials (e.g. mechanical resistance). BIPV can improve the cost effectiveness of a project because the overall budget may be reduced by the avoided expenditure of the building materials and labour they replace.

The photovoltaic (PV) is a technology that generates electrical power by converting solar radiation into direct current (DC) electricity through the use of semiconductor technologies. The PV modules have to be combined with a set of additional application-dependent system components such as inverters, batteries, electrical components and mounting systems. Silicon is the most commonly material used in PV modules. The silicon materials types for solar cells are monocrystalline, polycrystalline and amorphous silicon. The monocrystalline silicon cells are made from pure monocrystalline silicon and have the highest efficiencies, but also slightly higher prices. The different available PV technologies are monocrystalline cells, polycrystalline cells and thin-film cells, whose comparison is presented in Figure 7 and Table 3**Error! Reference source not found.** On the other hand, the less common and so called non-silicon based PV materials are gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium diselenide (CIS) and copper indium gallium selenide (CIGS). on-silicon based PV materials are gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium diselenide (CIS) and copper indium gallium selenide (CIGS).

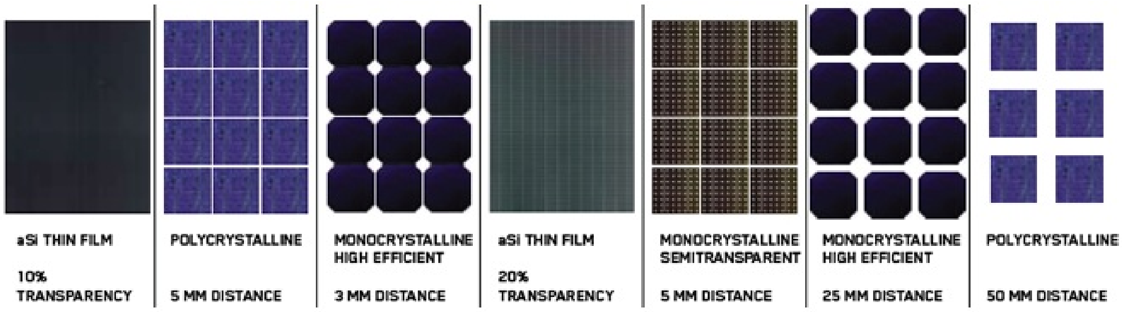


Figure 7 – Types of PV modules.

Table 3 - Comparison between monocrystalline, polycrystalline and thin-film technologies (adapted from Farkas et al., 2013).

Characteristics	**PV technology**			
	Monocrystalline	**Polycrystalline**	**Thin-film (amorphous silicon)**	**Thin-film (non-silicon) CdTe, CIS, CIGS**
Cell efficiency	17-22 %	14-18 %	4-10 %	9-18 %
Colour and texture	Dark blue/black - homogeneous	Dark blue/black – non-uniform	Brown/orange, purple, black – uniform	Dark green, dark gray, black – uniform
Space requirement	6-8 m^2/Wp	6-8 m^2/Wp	16-25 m^2/Wp	12-17 m^2/Wp
BIPV applications	Roofs (flat, pitched, curved, saw-tooth, tiles), façades (opaque, semi-transparent, translucent), indoor atria, glazing, sunshades, balcony parapets			
Main applications	**Electricity** for appliances, lighting, heat pumps, water pumping **Heat** for space heating (PV/T - back ventilation of PV façades)			
Advantages	Higher overall efficiencies		Better performance with high temperatures (no need of back ventilation), suitable for curved surfaces	
Disadvantages	Higher initial cost		Space requirement, lower efficiency	

Generally, the building function can be ensured either by a special photovoltaic component that performs as a system (PV tiles, Figure 8), composed by the PV module and the mounting system (e.g. replacing roofs or façades), or by a special photovoltaic module (e.g. replacing glazed surfaces, Figure 8) (Farkas et al., 2013). The families of products of specific PV technologies (crystalline and thin films) presenting the right specifications to be used in the substitution of building envelope elements are presented in Table 4. Figure 9 and Figure 10 present some example of building applied and building integrated PV.

Figure 8 – PV tiles on a roof and PV cells on a skylight.

Table 4 - Basic product families of specific photovoltaic modules to match and replace building components (Adapted from Farkas et al., 2013).

PV Technology	Specific modules and components		Building application
Crystalline (rigid)	Special modules	Glass-glass modules	Suitable to substitute parts of glazed envelopes
	Special components	Frameless modules equipped with a mounting system that ensures the technological integrability	Suitable to substitute roofs or façades (generally opaque)
Thin films	Special modules	Glass-glass modules	Suitable to substitute parts of glazed envelopes or cladding element
	Semi-industrialized laminated to integrate in building elements	Steel sheets	Generally used as roofs of industrial buildings (no special thermal requirements), or as part of prefabricated building systems, where they are the external layer
		Membranes	Generally used to replace the roof membrane (water tightness)

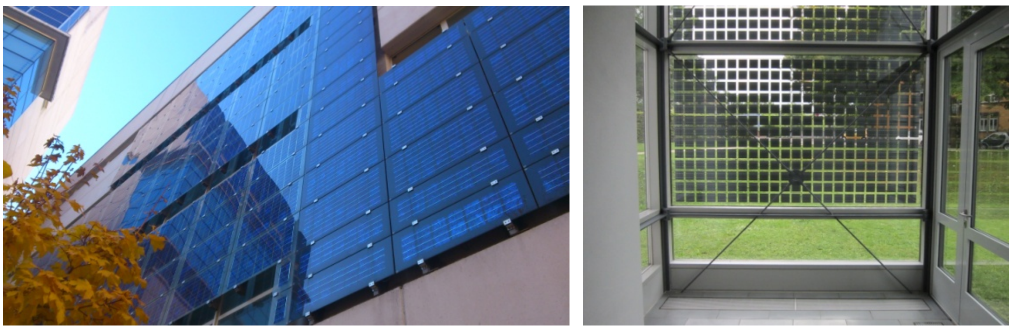


Figure 9 - Building-applied photovoltaics (BAPV) vs Building-integrated photovoltaics (BIPV).

The PV systems can be grid-connected (feed-in-tariff or net-metering model), or stand-alone (direct-coupled system or stand-alone system with batteries).

The feed-in-tariff presents a policy mechanism which offers long-term contracts and cost-based purchase prices to the producers for the energy that is produced and afterwards injected in the grid. The net-metering model results in offsetting the energy provided by the electric utility through the energy produced by the photovoltaics plant.

The stand-alone PVs are not connected to the electric grid, thus operating for own consumption of the energy generated by themselves. The direct-coupled system presents the system which provides instantly the energy produced to feed Direct Current (DC) load such as pumping systems. Whereas, the stand-alone system with a set of batteries results in providing instantly the energy produced as well as the possibility of storing part of it in the batteries to supply in a later time when it is required, the PV do not operate or the provided energy is not sufficient (such as at night or in case of cloudiness).

Figure 10 – Photovoltaic modules integrated in buildings (skylights, façades, shading systems).

The PVs can easily be installed in existing buildings, however cannot be easily substituted in structural components of the building and act as BIPV. Nevertheless, the solar potential of the installation site should be analysed in advance and consequently the benefit that will come up with the installation. Nowadays, in general the PV market is mature enough regarding the commercial type of PVs and can provide many solutions in order to be integrated in buildings.

3.1.3 PV vs STS

The issues related with the integration of PVs and STSs are often treated together. However, this simplification is not acceptable because they are fundamentally different.

For instance, one is designed to convert the solar radiation into electricity, while the other is designed to convert solar radiation into heat, thus, two different energies, with very different transportation and storage challenges. This brings different formal and operating constraints, leading to different building integration possibilities (Frontini et al., 2012). Table 5 summarizes the main differences between PVs and STS.

Table 5 - Main differences between PV and STS systems (Adapted from Frontini et al., 2012 and Basnet, 2012).

Parameters	**Solar technology**	
	Photovoltaics	**Solar Thermal**
Size	0.1 – 2 m^2	1.5 – 3 m^2
Shape	High flexibility	Low flexibility (due to hydraulic system)
Thickness[1]	0.4 – 1 cm	4 – 10 cm
Weight	9 – 18 kg/m^2	20 kg/m^2
Energy medium	Electricity	Hot water
Energy storage[2]	Batteries, grid	Water tank
Ideal operating temperature[3]	Lower	Higher
Shadow	Risk of modules damage (careful design of string and placement is needed)	Heat losses are proportional to shadow size
Building energy needs	Electric appliances, Lighting, Space heating/cooling	Domestic hot water, space heating/cooling
Efficiency	8-20%	65-70%

3.1.4 PV/T systems

For projects with ambitious energy targets or limited area availability for the installation of such systems, the solar thermal collectors and PV modules may be competing for the available space on the buildings' roofs and façades. This leads to hybrid photovoltaic–thermal (PV/T) modules, which generate electricity and heat simultaneously. The PV module is mounted on a solar thermal module and the residual heat is used to heat the liquid in the thermal system (Reijenga and Kaan, 2011). The dual functions of the PV/T result in a higher overall solar conversion rate than that of solely PV or solar thermal collector, and thus enables a more effective use of solar

[1] The thickness of solar thermal makes the sun shading application problematic and the use as cladding more delicate, especially in retrofits. This is also true, on a lesser degree, for the roof applications (Frontini et al., 2012)
[2] STS should be dimensioned according to the specific building needs and storage tank capacity, whereas PV can be dimensioned according to the size of available exposed areas or architectural criteria.
[3] PV modules should be back ventilated for a higher efficiency; solar thermal absorbers require back insulation to minimize heat losses.

energy (Zhang, 2012). Figure 11 shows some examples of PV/T systems integrated in buildings.

Figure 11 - PV/T modules integrated in buildings (Source: SolarWall®).

The PV modules convert only around 10–20% of the radiation to electricity, while the rest is reflected or dissipated as heat in the module (Good et al., 2015). The basic idea behind the PV/T technology is to utilize the incoming solar radiation by also harvesting the waste heat from PV modules. Since PV cell efficiency typically decreases with the increase of the cells temperature, the removal of the heat waste leads to an increase of the electricity output. Other benefits of PV/T systems are that they require less space than separate solar thermal and PV systems and can also provide a more uniform architectural appearance (Good et al., 2015).

There are several types of PV/T collectors and, in general, a distinction can be made between PV/T collectors with liquid heat transfer medium (PV/T-liquid), PV/T collectors with air as the heat transfer medium (PV/T-air) and concentrating PV/T collectors. In addition, the collectors can be made using PV technologies such as crystalline of thin film PV, and different solar thermal technologies such as flat plate collectors, evacuated tube collectors or heat pipes (Good et al., 2015). Table 6 presents a comparison between five different PV/T technologies.

Table 6 - Evaluation of the suitability for use in buildings of different PV/T technologies based on four indicators (Adapted from Good et al., 2015).

Indicator/Technology	**Ventilated PV**	**Air-based PV/T**	**PV/T liquid (covered)**	**PV/T liquid (uncovered)**	**Concentrating PV/T**
Building integration potential[4]	High	Medium	Medium	Medium	Low
Electricity output[5]	Increased	Increased	Decreased	Increased	N/A

[4] Estimation of how well the technology can be functionally integrated into buildings.
[5] Compared to a normal PV module without the use of thermal energy.

Thermal output[6]	Indirect	Direct/indirect	Direct/indirect	Indirect	Direct
Available products	<10	<10	<10	10-40	<10

A careful design is necessary as thermal applications often require higher operational temperatures, whereas the PV module efficiency is reduced with the increase of the temperature. The unglazed PV/T collectors are therefore particularly interesting in combination with heat pumps, whereas direct production of hot water requires glazed PV/T collectors with a somewhat lower efficiency in PV compared to independent PV modules (COST Action TU1205, 2015).

As other solar systems, these systems can be BAPV(T)-Building Added Photovoltaic Thermal systems, where photovoltaic modules are most commonly considered just as technical devices added to the building. The BIPV(T)-Building Integrated Photovoltaic Thermal systems correspond to a combination of solar collectors and photovoltaic functionality and their integration into the building envelope as constructive systems (roofs, façades, skylights, external devices), replacing traditional building components totally or partially assuring a cross-functional role.

3.1.5 Other Solar Thermal Systems

Besides the production of hot water and electricity, solar systems can also be used to heat air (Air Heating BISTS), and to be connected to other systems (such as heat pumps), and be used in conjunction with Thermal Energy Storage (TES).

Air heating BISTS are a type of building integrated STS, using air as fluid instead of water (the most usual) mainly for space heating. The major difference between air and water based collectors is the need to design an absorber that overcomes the heat transfer penalty caused by lower heat transfer coefficients between air and the solar absorber and the lower density of the air, which requires large volume of air to be circulated (COST Action TU1205, 2015). Figure 12 presents two examples of solar systems integrated in buildings and used to preheat air to be uses in the heating, ventilation and air conditioning (HVAC) system. Table 7 summarizes the main advantages and disadvantages of air heating BISTS.

[6] Direct use such as heating of DHW and indirect use such as input to a heat pump.

Figure 12 - SolarWall BIST in Canada (left) and SolarWall in Erlangen City Hall in Germany (right).

Table 7 - Main advantages and disadvantages of Air Heating BISTS (Adapted from COST Action TU1205, 2015).

Air Heating BISTS	
Advantages	**Disadvantages**
No need for protection from freezing and boiling Non-corrosive and free medium High degree of stratification inside the absorber can lead to lower collector inlet temperatures and higher efficiencies	Air handling equipment (ducts and fans) requires more space than liquid piping and pumps Pumps and air leaks are difficult to detect Higher parasitic power consumption (electricity used to drive air fans) compared to water systems

BISTS can also be linked with other systems such as heat pumps or thermally activated chillers. Technically, the scope of a BISTS integrated with a heat pump is not too different from BISTS technologies aiming the air or water heating directly. The only difference is the fact that through the use of a heat pump, a higher Coefficient of Performance (COP) can be attained compared to the case of a BISTS heating air or water directly. Even though there is an additional compressor in the heat pump system, the high efficiency makes it an attractive solution.

Thermally activated chillers (TAC) are heating and cooling heat operated devices which given their versatility in using various heat sources are especially popular when cooling loads are the predominant space conditioning load. They are particularly useful when coupled with either solar collectors or Combined Heat and Power (CHP) systems. Although various working principles exist, the most common commercially available TAC system is the absorption chiller which makes use of the affinity of two liquids (such as lithium bromide/water or ammonia/water) to produce a process similar to that of a conventional vapour compression heat pump cycle modules (COST Action TU1205, 2015). Moreover, adsorption chillers, which use solid sorption materials instead of liquid solutions (such as Silica gel/water and Zeolith/water), are also used.

Thermal energy storage (TES) is the technology that allows the storage of thermal energy (heat and cold) for later use (Cabeza, 2012). The principle of TES is related with the storage of heat or cold in a certain fluid (water, air, etc.) or material (phase change materials). TES can be classified as sensible heat storage (SHS) or latent heat storage (LHS). In the first case, the heat is stored in form of sensible heat due to the increase of temperature of a certain fluid or material. The most common SHS are the typical water tanks as presented in Figure 13. While for LHS, the heat is stored during the phase change of a certain material at almost constant temperature. The latter is usually associated to phase change materials (PCMs). LHS present much higher storage than SHS and therefore requiring less mass/volume for a certain target. Therefore, a wide range of LHS applications can be found in the literature using PCMs. Figure 13 shows an example of TES (using water tanks) integrated in buildings.

Figure 13 - Solar water tank integrated in a living room.

The TES allow overcoming mismatch between energy generation and use in terms of time, temperature, power or site (Mehling and Cabeza, 2008). Advantages of using TES in a SHS are the increase of the overall efficiency and better reliability, but it can also lead to better economics, reducing investment and running costs, and less pollution of the environment and less CO_2 emissions (Dincer and Rosen, 2002). The main advantage of using TES with BISTS is the success of converting an intermittent energy source in meeting the demand (usually also intermittent but at different periods of time) (Cabeza, 2012). In addition, TES components integrated into buildings can replace traditional components reducing overall costs.

3.2 Biomass

The biomass is an alternative solid fuel to the conventional fossil fuels and has an impact on carbon emissions that is close to neutral. Biomass is a material of biological origin excluding material embedded in geological formations and/or fossilized (EN ISO 16559). Organic material, plant or animal based, such as dedicated energy crops, agricultural crops and trees, food, feed and fibre crop residues, aquatic plants, algae, forestry and wood residues, agricultural wastes, processing by-products and other non-fossil organic matters might be used as biomass. The biomass energy systems are based on the combustion or more efficient conversion of the organic material to supply heat.

The solid fuels present many advantages. They consist of a small percentage of moisture and higher energy content because of their way of production (through compression). Thus, they present uniformity in their shape and size and therefore their transport and storage is facilitated. The burning solid biomass is a more efficient process than burning fossil fuels. However, biomass is only considered a renewable energy source if consumed appropriately. The CO_2 is absorbed in the carbon cycle phase and released when the plant is burned or dies. The balance is maintained if trees harvested as biomass are replanted as fast as the wood is being burned (as the new trees take up the carbon produced by the combustion).

For building applications the fuel usually takes the form of wood chips, logs, pellets and briquettes. The wood pellets are essentially high-density compacted wood with low moisture content, thus presenting a higher calorific value per unit volume or weight. The difference between pellets and briquettes is the size of the diameter, the pellets have a diameter of up to 25 mm while the briquettes have a diameter of more than 25 mm.

For modern low-energy houses the use of wood pellets in combination with grate furnace technology is used. The wood pellets and wood logs boilers are available with capacities from 10 kW upwards, while wood chips boilers are produced with capacities from 30 kW up to some MW. Therefore, wood chips boilers are commonly used for buildings requiring a higher heat demand and for district heating systems. Typical applications in buildings include: i) biomass boilers replacing standard gas- or oil-fired boilers for space heating and hot water (for individual buildings or district heating systems), ii) stand-alone room heaters for space heating, and iii) stoves with back boilers, supplying DHW.

The biomass boiler is easy to be installed in an existing central heating system (refer to Figure 14), since the same distribution system will be used. The only modification shall be the replacement of the conventional boiler to a biomass boiler. If the building does not present a boiler, the integration may be challenging due to the necessity of an exhaustion system for the smoke.

Figure 14 - Biomass energy system for space heating and hot water (left) and stand-alone room heater for space heating (right).

3.3 Geothermal

The geothermal technologies use the heat from the centre of the Earth, in the form of heat retained in shallow ground, hot water and rock located a few kilometres beneath the Earth's surface and the magma located deep in the earth. The available resource almost everywhere is in a shallow ground or at least at the upper 3 meters of the surface, as there it maintains a nearly constant temperature of 10°-16°C.

Geothermal heat pumps (GHPs) can provide very efficient HVAC system by using the ground to extract and reject heat (Figure 15). Through the use of the ground as a source and sink, the GHPs take full advantage from the fact that the ground temperature is often warmer than the air temperature in the winter and cooler than the air temperature in the summer.

In addition, as geothermal heat pumps exploit the nearly stable temperature of the ground, they have higher efficiencies than heat pumps.

The main advantages of these systems are the low operational cost and the system life that can reach 25 years for inside components and 50 years for ground loop. The disadvantages include a high initial cost and may present restrictions in case of integration in existing buildings.

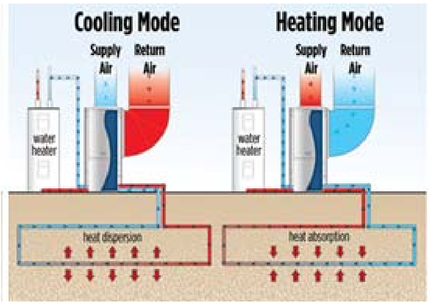


Figure 15 - GHP function diagram of heating and cooling mode.

There are different types of geothermal heat pumps: air to air (air heat exchanger in compressor and evaporator side); air to water (air heat exchanger in evaporator and water heat exchanger in the compressor side) and water to water (water heat exchanger in compressor and evaporator side). In a water-source heat pump the heat is extracted from the ground water or from a closed water circuit, ground heat exchanger, which transfers the heat to the heating medium.

A heat exchange fluid circulates in the ground collectors (coils) which transfers heat via a heat exchanger, to the heat pump. The different space configurations of piping are possible and the most appropriate to be applied in buildings depends on the climate, the soil conditions, the available land and the local installation costs.

The GHP can be categorized into two types: closed loop systems and open loop systems as presented in Figure 16.

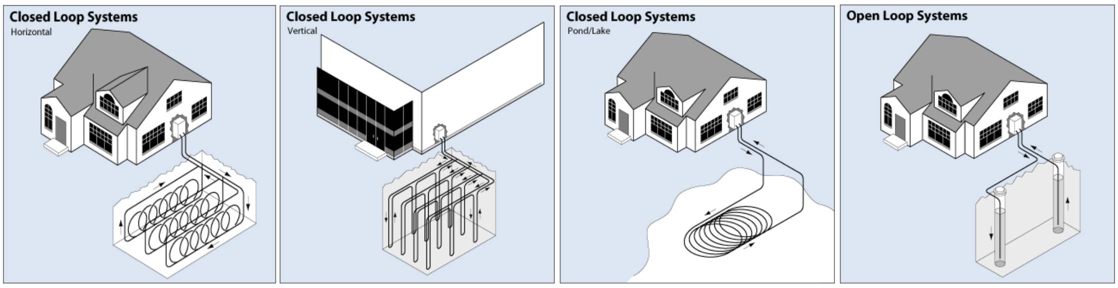


Figure 16 - Types of geothermal heat pumps (Source: U.S. Department of Energy, Geothermal Heat Pumps).

The closed loop usually consists of a loop buried in the ground or submerged in water. The heat exchanger transfers heat from the refrigerant to the ground or the water. The horizontal loop systems are generally more cost-effective for residential installations, especially in locations where there is sufficient available space, whereas the vertical loops are generally used in large commercial buildings when there is no sufficient land for horizontal loops.

The open loop system exploits the existence of a well or a surface body water and the heat exchange fluid that circulates directly through the geothermal heat pump system.

In case of integration in existing buildings, it should be examined beforehand the available space for its installation. In case there is not enough space, then the system presents restrictions, since only the vertical geothermal type can be installed (Figure 16). Moreover, in case there is no distribution system in the building (due to the existence of local heat pumps in every room), the distribution system should also be integrated in the building and connected to the existing building heating, ventilating, and air-conditioning system, which presents high complexity and cost.

3.4 Wind

The winds are caused due to the Earth's equatorial regions that receive more solar radiation than the Polar Regions, setting up large-scale convection currents in the atmosphere. Wind flow patterns and speeds vary to a large extent in the Earth's surface and are influenced by mountains, bodies of water and vegetation. Although global wind resource is very large and widely distributed, it requires a detailed assessment to quantify the resource in particular areas.

The wind power is the process through which the wind is used to generate mechanical energy or electricity. Wind turbines convert the wind's kinetic energy from mechanical energy collected by the rotor into electrical energy through the generator (Forsyth et al., 2015) (Figure 17). All types of wind turbines follow the same principle: the surrounding air moving and passing through the turbine blades create an aerodynamic lift, causing the blades to rotate. A generator inside the turbine converts the mechanical energy of the rotating blades into electricity.

Wind systems can be classified as grid-connected or stand-alone systems.

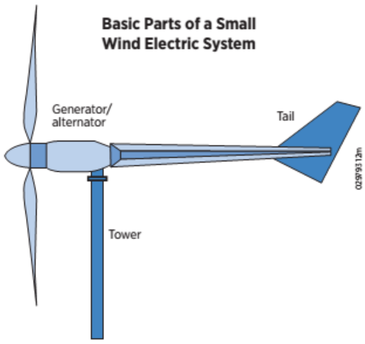


Figure 17 - Basic parts of a small wind turbine (source: Open Energy Information, 2015).

Wind turbines can be found in a variety of sizes and designs (Figure 18), usually categorised by whether they rotate around a horizontal axis (HAWT) or a vertical axis (VAWT). For instance, the VAWTs involve smaller space requirements and can be placed closer together than HAWTs. The generator is located at the bottom of the shaft – at ground level – making its maintenance easier for these turbines. However, the blades are also more vulnerable to damage by high winds than the HAWTs blades, which makes general maintenance in VAWTs higher.

Figure 18 - Examples of wind turbines (from left to right: VAWT, HAWT, VAWT).

However, because VAWTs operate at lower wind speeds, they generate less power than horizontal axis turbines. They also have lower capability of catching wind from all directions. Furthermore, they are also less efficient than the HAWTs due to the additional drag they produce when the blades rotate into the wind (Tummala *et al.*, 2016). On the other hand, VAWTs produce less noise than HAWT making them particularly attractive in residential and urban areas. HAWTs are far more common due to their better efficiency and generation capabilities. Although VAWTs may be preferred in locations with less available space, or where wind speed and direction are highly variable. Table 8 depicts the main differences between the two types of built-environment wind turbines (BWTs).

Overall, the wind systems require low maintenance and they are not pollutant as other renewables. To note that to be installed in urban areas, they should not produce significant noise. The VAWTs are preferred; however, they present lower efficiency than horizontal axis wind turbines.

Table 8 - Main differences between horizontal- and vertical-axis wind turbines.

	Type of small wind turbine	
Parameters	**HAWT**	**VAWT**
Starting wind speed	High (2.5 - 5 m/s)	Low (1.5 - 3 m/s)
Wind direction to generate power	Turbines must be pointed into the wind	Any (even vertically)
Blade rotation space requirements	Large	Small
Operation height	High elevation	Low elevation (more compact)
Rotating speed	High	Low
Noise	High	Low
Components location	Top of the tower	Ground level
Maintenance	Low	High

A small-scale wind systems can easily be integrated in existing buildings in order to improve the building to a nZEB level; however preliminary study needs to be carried out to assure there is enough wind potential in order to guaranty that the investment is feasible as well as to assure that there is enough space for the wind system to be installed in the building.

The built-environment wind turbines (BWTs) are wind turbines commonly located in an urban or suburban environment (Figure 19), although they are also classified as small wind turbines (SWTs), which have a rotor-swept area less than 200 m^2 and rated capacity of less than or equal to 100 kW (International standard IEC 61400-2).

Although SWTs operate with the same principle as large utility-scale turbines, small turbines operate lower to the ground level and at lower wind speeds than utility-scale turbines. At urban scale, there are four types of BWTs installations:

i) Building-mounted on the side of a building;
ii) Building-mounted on the roof of a building;
iii) Building-integrated wind turbine;
iv) Ground-mounted in building site.

Figure 19 - Example of integration of wind turbines in buildings or building sites.

The wind resource in urban environment is more turbulent and less predictable since it faces many obstacles and therefore comes from all directions. It depends strongly on the height and the orientation of the building and on the surrounding buildings. Therefore, during the design phase it is crucial to evaluate the wind resource in the specific area of interest.

The wind stream passes at an upward angle of 30-40 degrees from the leading edge over the roof of the building. Underneath that line there is only turbulence and no wind. Consequently, the turbine must be placed on a mast of sufficient height to bring it above the turbulence. Interestingly, a potential advantage arises since the wind speed directly above the turbulence layer is 20-40 % higher than prior to encountering the building (Ragheb, 2014).

3.5 Hybrid systems

In hybrid systems various technologies are combined, but one at least should exploit renewable resources. The most common examples are heat pumps and photovoltaics. In this case the heat pump receives the required energy for operation from the PVs. Another example is the absorption chiller and solar thermal system. In this case, the absorption chiller receives the required thermal energy from the absorption cycle.

Moreover, another example is the geothermal heat pumps and solar thermal systems for space heating, cooling and domestic hot water production.

3.6 Comparison of technologies

The buildings have different energy needs (heat, electricity) according to their application. As described in previous chapters, there is a broad range of possibilities to cover the different building energy needs. In order to reach nZEB and to be able to deliver the necessary renewable energy to cover the demand, it is necessary to select the most appropriate renewable energy system, which in most cases will be a combination of systems (hybrid system). An innovative and integrated approach in order to select the most effective solution has to consider: the building needs, the available renewable energy technologies and its architectural integration. In order to facilitate the selection of the available technologies, Table 9 gives an overview of each renewable energy technology based on relevant parameters that influence the selection.

Table 9 - Comparison of the building's integrated renewable technologies.

Parameters	Renewable energy technology				
	Photovoltaic systems (PV)	Solar thermal systems (STS)	Biomass boilers	Geothermal Heat pumps (GHPs)	Small wind turbines (SWTs)
Renewable energy resource	Solar energy	Solar energy	Biomass	Geothermal heat	Wind
Energy produced	Electricity/Heat	Heat	Heat	Heat	Electricity
Hybrid power system	Wind, batteries, Solar thermal,	Heat pump, biomass	Solar thermal	PV, Solar thermal	PV, diesel generator,

	GHP	boiler, PV			batteries
Type of system	Off-grid, hybrid systems, grid-connected	Off-grid, hybrid systems, district heating system	Off-grid, hybrid systems, district heating system	Off-grid, hybrid systems, district heating system	Off-grid, hybrid systems, grid-connected
Household application	Electrical appliances, lighting, water pumps, heat pumps, space heating	DHW, space heating, space cooling	Space heating	Space heating	Electrical appliances, lighting, water pumps
Building integration	Roofs (flat, pitched, curved, saw-tooth, tiles), façades (opaque, semi-transparent, translucent), indoor atria, glazing, sunshades,	Roof coverings, façade cladding, sun shading devices, balcony eaves, double roofs	Room installation and central heating system	Installed in basement, attic or storage room plus the installation of central heating system	Ground-mounted on site building-mounted (side, roof) building integrated (façade)

4 Technical and social barriers

The development of renewable energy technologies in buildings is affected by many factors such as: technological, economic, social, cultural, political and legislative. Some issues regarding these factors hinder their deployment and hamper their full development. The following sections discuss two important groups of barriers: the socio-cultural and the technical barriers due to their importance in the development of this project.

4.1 Socio-cultural barriers

The socio-cultural barriers are intrinsically linked to societal and personal values and norms that affect the perception and acceptance of renewable energy and may be slow to change. Perhaps the key social barrier is the lack of awareness and information among building owners, building users, architects, engineers, etc.. Users lack information regarding the efficiency of renewable energy technologies, their reliability, durability, maintenance needs, and investment and installation costs.

For instance, there is a poor accessibility to information on the financial incentive schemes provided by public authorities. The provided information is unclear and untargeted for different users and therefore not able to deliver effective support to users. This lack of transparency is a social barrier and may also become a barrier to market development. Regarding the integration of PV in buildings, there is a lack of knowledge and misleading statements that underestimate its added value (EPIA et al., 2008), such as:

- The advantages of PV are not clear for architects and clients;
- For some architects, BIPV is not attractive/aesthetical;
- Knowledge of planners, developers and architects about BIPV is limited;
- Change of behaviour and procurement criteria is needed from public authorities;
- Acceptance by architects, contractors, building developers and end-users of the need to integrate from the project inception through the whole construction process;
- Lack of awareness of the increasing role of electricity consumption in the value determination of a building;
- The perception of the PV technology is usually outdated which consequently leads to a bad image.

To note that many of the aforementioned barriers are not specific to PV and are similar for other renewable energy technologies.

An increasingly important social barrier for the further development of building integrated renewables is the tenancy and building ownership laws. Due to this barrier the following problems are found across Europe (ECORYS, 2010):

- Lack of interest in renewables by landlords as the immediate beneficiary is the tenant;

- Cost sharing difficulties between landlords and tenants regarding investment in renewable energy (also related to social laws protecting tenants);
- The use of renewables and energy efficiency is still not considered as a benefit in public regulations which makes it impossible for tenants to privilege energy efficient dwellings and reduces the willingness of landlords to invest.

Finally, the conservativeness of the construction industry, of architects and heating engineers is another relevant barrier, since they tend to slow down the penetration of technological innovations in the building sector (ECORYS, 2010).

4.2 Technical barriers

After decades of research and development on renewable energy technologies, the majority of the available technologies have reached maturity. Nevertheless and especially regarding building integrated technologies, there are still technical barriers that need to be overcome. For example, the challenge for BWTs can be summarized as a need to understand wind resource behaviour in the built environment, combined with a lack of measurements and model results to assist in the development of international design and test standards.

The building integration of renewables requires a careful planning and design in order to achieve the best combination of the different technologies, not only in terms of the balance between electricity and heat production, but also in terms of available space in building elements. Commonly, BWTs, BISTS and BIPV compete for roof space and therefore there is the need to integrate these technologies in other building elements. Table 10 and Table 11 summarize the main technical barriers for each building integrated renewable energy technology.

Table 10 - Technical barriers for building integrated renewable energy technologies.

Building integrated renewable energy technology	Technical barriers
Building integrated photovoltaics (BIPV)	• **Design phase** (lack of design consideration on how to facilitate maintenance and replacement, lack of specific design codes and standards, incorrect choice of BIPV systems, insufficient capacity of building structure to carry module weights, mechanical stress due to live loads, end users health and safety) • **Installation phase** (failure of fixings, wind-driven rain effects, cabling and connection issues, islanding) • **Operation phase** (lack of monitoring system, lack of warranties, lack of maintenance, difficulties to replace modules, galvanic corrosion)

Table 11 - Technical barriers for building integrated renewable energy technologies (cont.).

<table>
<tr><th>Building integrated renewable energy technology</th><th>Technical barriers</th></tr>
<tr><td>Building integrated solar thermal systems (BISTS)</td><td>Limited capacity to export or “bank” energy
Overheating protection needed
Building structure (roof weight, wind loading)
Wide development of PV sector (feed in tariffs) limited the diffusion of solar thermal systems
Obstacles in urban areas with landscape constraints
Solar mismatch (production vs consumption)
Missing standard for integrated façade collectors
Health risk (toxic materials exposed to rain and humidity, incubation of bacteria legionellae)
Fire risk</td></tr>
<tr><td>Biomass boilers</td><td>Greenhouse gases emission levels
Safety issues
Lack of knowledge on installation and plant dimensioning (biomass-solar integration)
Storage-logistics
Biomass supply and handling (especially in urban areas)
Heating measurement
Biomass markets reliability and quality standards
Competing use of biomass for electricity (high incentives available for electricity)</td></tr>
<tr><td>Geothermal heat pumps (GHPs)</td><td>High energy input of electricity (excessive amount) linked to inefficient heat pumps
Available land
Competent system designer to achieve high level of performance
Lack of operational understanding</td></tr>
<tr><td>Building wind turbines (BWTs)</td><td>Safety (fatigue resistance, braking redundancy, fail-safe features, strategies for ice- and part-shedding containment)
Wind resource (turbulence and directional variability, wakes, eddies, and separation zones, three-dimensional wind speed profile and distribution)
Turbine technology (control strategies to reduce vibration and noise, loads measurements and yaw rates, standard for BWT design and testing)
Building interactions (resonance frequencies, code compliance, mechanical and electrical integration)
Non-technical obstacles (hazards to personnel installing and servicing BWTs, outreach and education, economics)</td></tr>
</table>

4.3 Local barriers

In the previous sub-sections an overview on the social and technical barriers at global level has been given. Some of these barriers may be more relevant in one country than another and some specific for a given country or even city which are not relevant at the global level. It is therefore important to know the technical and social barriers affecting the deployment of building integrated renewable energies for each geo-cluster in order to evaluate a strategy to tackle and overcome those difficulties.

Table 12 - Overview of the current integration of renewables in buildings and its technical and social barriers, for each pilot case.

Country	Commonly renewable solutions integrated into buildings	Technical Barriers	Social Barriers
Denmark	Thermal solar collectors have been installed on houses in Denmark for more than 30 years but hasn't had a real breakthrough on social housing. Over the past 10 years, PV has installed on quite a large number of buildings – in the later years building integrated PV (BIPV) has become more used. As district heating is covering a large percentage of heating energy use in Denmark bio-fuel boilers and heat pumps are not often used for social housing, but the technologies are present and well-known	The main barrier for the renewable heating systems is the district heating networks. Because of the low CO2-emissons assigned to waste incineration that is covering a large part of the supply for the district heating in Denmark, it is difficult to compete on the environmental level and cost wise district heating is also often very competitive. For the PV-systems the main problem is low-prices paid today for the electricity sold to the grid. Electrical storage is becoming interesting for this reason, but they are still too expensive.	There are no real social barriers for implementing renewable energy on social housing projects in Denmark.
Estonia	PV-panels and solar thermal collectors are used mainly in residential sector. Awareness is raising but usage of renewable solutions is not yet a common practise in Estonia.	There are no restrictive technical barriers. Only limit for house owners is maximum inverter power 11 kW for PV grid connection.	The lack of knowledge among property owners and high investment need and relatively long payback periods of renewable solutions.

Table 13 - Overview of the current integration of renewables in buildings and its technical and social barriers, for each pilot case (cont.)

Country	Commonly renewable solutions integrated into buildings	Technical Barriers	Social Barriers
Latvia	There is a significant increase of PV and solar thermal panel use in single family houses. Produces electricity delivered into the grid and used back in off-production period. Solar thermal panels mainly are used in combination with wood pellet boilers. Use of on-site renewable energy sources is not common in multi-apartment buildings. There are only a few cases of installation of a heat pump and/or solar thermal panels in multi-apartment buildings.	Lack of knowledge among building planners and designers. Mandatory connection to the district heating network in case if building located in DH area. Strict requirements on supply/return temperature difference by district heating company. Lack of available infrastructure such as available electric power and connections, smart meters etc. Low natural gas price and extended pipeline network.	Lack of sufficient information campaign. Difficulty to get owner agreement on investments to their property. Skepticism on investment mechanisms, bank loans and ESCO companies.

Table 14 - Overview of the current integration of renewables in buildings and its technical and social barriers, for each pilot case (cont.).

Country	Commonly renewable solutions integrated into buildings	Technical Barriers	Social Barriers
Czech Republic	Use of renewables in large scale is not common in the multi-apartment buildings due to soft conditions of legal requirements on buildings and the lack of motivation to use subsidy programmes (low share of financial support) if compared the previous period. New installations of PV have decreased from 2014 when feed-in tariffs **have been practically stopped.** There is a shift from large PV land installations towards roof PV and façade Building Integrated Photovoltaics (BIPV) and towards electricity use for own consumption at the supply point. Biomass is continuously used especially as a retrofit of coal combustion in households. Use of heat pumps continuously grows mainly from economic reasons, independently from subsidy programmes.	The main barrier today is insufficient legal and financial support. Generally there not large barriers on the technical side or knowledge of designers. Under the current legislation isn't economically viable to sell the surplus power into the grid. The own consumption at the supply point matching energy profile of the building in combination with energy accumulation is much better option. Legal restrictions on size of the PV system connected to electric distribution network Usually multi-apartment buildings like the one in the Czech pilot project have quite often large roof areas suitable for the PV systems, PV system's size restrictions in place greatly reduce the chance for the building to become nearly Zero Energy Building (nZEB). Different complex technical solutions have to be applied to achieve nZEB by deep renovation despite the fact that large PV could be integrated into the energy mix. (Czech pilot building could have 56.16 kWp of the total system size, but only up to 30kWp can be connected to grid, for the rest of the system the galvanic isolation must be in place. There is a risk of penalties for unauthorised overflow of electricity back to the grid, technical issues of overflow elimination.	There are social barriers connected with the financing of renewable energy support (about 50% but for real systems about 35%). But in the case of coal boilers retrofit (a specific part of subsidy programme), even the investment subsidy reaching more than 80 % to change from old coal boiler to modern biomass boiler is not motivating for poor people which use the waste (anything) for combustion. Also, the excessive administration for the subsidy application is demotivating to people. Some level of scepticism related to use of photovoltaics in Czech society and prejudice against it due to the past turbulent solar boom and bust in the past. Relatively high initial cost of PV and BIPV installations for average household, no advantages of selling green clean energy back to the grid. The legal and financial conditions given by the state are not stable, which is a factor of demotivation for many investors.

Table 15 - Overview of the current integration of renewables in buildings and its technical and social barriers, for each pilot case (cont.).

Country	Commonly renewable solutions integrated into buildings	Technical Barriers	Social Barriers
Portugal	Besides the installation of STS on roofs, in recent buildings, biomass boilers are the most commonly installed renewable technology. PV modules are the least used technology. Geothermal heat pumps and wind turbines are not common at the building level. There are some examples of buildings with the integration of STS and PV, for the production of hot water, heating and cooling and electricity production, which are intended as showcases for the use of renewable technologies.	• Lack of knowledge among building planners and designers on the integration of renewable energy technologies in the building elements. • Installation as add-ons: solar thermal energy is the most frequent and better designed but PV systems lack some knowledge in the correct designing and dimensioning. • Little knowledge about the integration of wind small turbines in buildings. • Biomass boilers are increasingly becoming more common, although there is a lack of installation knowledge and the persistence of design issues. • Geothermal heat pumps are not commonly used, either because users/designers are not aware of the existence of this type of systems or because there is a lack of understanding regarding design, operation and installation. • Hybrid systems are not frequently installed due to lack of operational understanding among designers and users. • All technologies: lack of knowledge of the potentialities such as investment, maintenance and operation costs; durability; payback period of the investment.	• Users lack awareness of the existence of different renewable energy technologies • Users lack information of the efficiency of renewable energy technologies • Energy efficient dwellings and the use of renewables are not privileged in public regulations and are currently more expensive than regular dwellings • The two most well-known and accepted technologies across society are solar thermal systems and solar PV.

Table 16 - Overview of the current integration of renewables in buildings and its technical and social barriers, for each pilot case (cont.).

Country	Commonly renewable solutions integrated into buildings	Technical Barriers	Social Barriers
Netherlands	There is an increasing application in solar PV, especially in existing residential buildings and decreasing interest for solar thermal systems. For both new construction as renovation (especially ‘zero-on-the-meter’ concepts) increasing interest for heat pump concepts. For multifamily residential buildings sometimes interest for heat/cold storage (acquifers)	No specific technical barriers on simple component level (like PV systems). However, lack of knowledge among building planners and designers on more complex systems, especially local renewable energy infra structures in relation to buildings. Upskilling of ‘blue collar workers’ in renewable energy systems is still a point of attention.	No significant social barriers in terms of acceptance and appreciation of renewables. Sometimes architectural limitations for PV panels on (historic or iconic) buildings.

5 Political context

The integration of renewable energy in buildings is highly influenced by the political and legislative frameworks. They are fundamental to overcome cost and technical barriers. Fiscal incentives can help increase the use of renewable energy through benefits on the initial investment, reduction of its installation and operation costs, and contribution to overcome technical issues by introducing specific regulations and standards which facilitate the installation of renewable energies in buildings.

5.1 Global political framework

An increasing number and variety of renewable energy policies, motivated by many factors, have driven to the growth of renewable energy technologies in recent years. Government policies play a crucial role in accelerating the deployment of renewable energy technologies. Secure energy supply and environmental concerns have been the primary drivers in developed countries. Today, and in the context of EU policies (e.g. 2010/31/EU – nearly Zero-Energy Buildings), the integration of solar systems both in new buildings and during building renovation, is considered a priority in the development of a more sustainable built environment. The greater use of STS, particularly in the form of BISTS contributes to lower life-cycle costs and environmental impacts, thus contributing to the reduction of the overall life-cycle impacts of the building sector. The policies include regulations such as feed-in-tariffs, quotas, priority grid access, building mandates, biofuel blending requirements, and bioenergy sustainability criteria. Other policy categories are fiscal incentives such as tax policies and direct government payments such as rebates and grants; and public finance mechanisms such as loans and guarantees. The policies can be r specific by sector, implemented at the local, state/provincial, national and in some cases regional level, and can be complemented by bilateral, regional and international cooperation.

5.2 Local political context

Under this global context of supporting the growth of building integrated renewables, countries, cities and municipalities are developing plans to achieve energy efficiency and a zero carbon economy in the short and long term. Table 17 presents a summary of the legal regulations in force and existent financial incentives at the local level (national/city/municipality) regarding renewable energy production and the building integration of these technologies.

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Table 17 - Comparison of the regulatory framework of renewable energy production among the countries with pilot-cases.

Country	Legal regimes in force for renewable energy production in buildings	Financial incentives/surplus production sale	Regulation on the integration of renewables in buildings
Denmark	Law nr 744 of 01/06/2015 to advance the use of Renewable Energy, and about support to RE in production processes and law on electricity supply. BekenBEK nr 1114 of 18/09/2015 about price support for electricity produced on certain PV installations connected to the grid after November 2012.	There is no direct financial incentive for the installation of renewables on buildings. For the renewable electricity production by PV and wind mills special feed-in prices of electricity are used. The feed-in tariffs are higher than the net electricity production cost but has been reduced over the past few years and is steadily decreasing. Each owner has to apply for the feed-in tariffs in advance of the installation. Currently the feed-in tariffs for PV electricity sold to the grid is: 0,88 DKK = 0,12 €	The laws specify a certain amount of installed MW for each of calls for applications to be entitled to feed-in tariffs.
Estonia	Renewable energy production systems are like other building service systems must have permit from local municipality. Production of electricity is regulated with Electricity Market Act.	At the moment there is no financial incentive for the installation of renewables on buildings. When PV-panels is connected to the grid, the produced electricity can be sold to the electricity provider with the market price. Subsidy for electricity production (production power < 100 MW) from renewable sources is 0.0537 €/kWh.	Renewable solutions in buildings are defined as micro production and maximum inverter power limit for grid connection is 11 kW (3x16 A).
Latvia	No specific regulation on renewable integration within the building. Local district heating company can issue their own technical conditions for heat pump and/or solar thermal collector integration into building system.		

Table 18 - Comparison of the regulatory framework of renewable energy production among the countries with pilot-cases (cont.).

Country	Legal regimes in force for renewable energy production in buildings	Financial incentives/surplus production sale	Regulation on the integration of renewables in buildings
Czech Republic	The situation on renewable energy market In the Czech Republic compare to other EU countries has certain specifics. After one of the largest boom photovoltaic (PV) markets in the past due to massive government incentives (subsidies) and fixed purchase prices, there was a dramatic change in solar energy legislation. Act no. 1880/2005 Coll. put a 26% tax on photovoltaic plants producing over 30 kWp and a 28% levy for green bonuses. The PV industry was forced to a standstill. After the turbulent past, the new legislation changes in 2016 will try to bring some form of stabilisation to Czech PV market. The amendment to the Energy Act by Act no. 131/2015 Coll., Effective from 1 January 2016 and the amendment to Act no. 586/1992 Coll. the Income Tax Act (NZDP), from 1 January 2016 brings tax advantages for operators of photovoltaic plants (PVP) with an output of maximum 10 kWp and specify this new type of the photovoltaic system as a Mikrozdroj (Micro-source). One of the biggest benefits of the amendment is the fact that all new PV micro-source installations up to 10 kW can operate without a licence (normally granted by the Energy Regulatory Office). The operator will only produce electricity for their own consumption at the supply point and if some of the electricity will be supplied back to the distribution network unauthorised, then the penalty will apply in accordance with paragraph 3.28 Energy Regulatory Office (ERU). Law 406/2000 and consequent regulations which establish the legal framework for the building energy performance requirements and Law 165/2012 Sb. on supported energy production in general.	Czech Republic has a subsidy programme New Green for Savings, which supports the installations of solar systems (PV, solar thermal), heat pumps, biomass boilers, but also change to gas boilers. Because of administrative burden and low practical financial contribution there is not high interest as in previous programme (2009-2012). Feed-in tarrifs for PV systems has been practically stopped from 2014 and there are also legal limitations for installation connected to grids (penalty for overflow to grid). The situation leads to systems with high degree of self-consumption (PV water heating).	There is no specific regulation for building integrated renewables. Apart from size of the system. The,mico-source up to 10 kW without licence from ERU and with distributor`s agreement. From 10 kW to 30 kW with licence from ERU and agreement with energy trader, above 30kWp galvanic isolation must be in place. There is indirect regulation through energy labels to use the renewables to reach higher enrgy performance category. No specific regulation for envelope integration of solar systems.

Table 19 - Comparison of the regulatory framework of renewable energy production among the countries with pilot-cases (cont.)

Country	Legal regimes in force for renewable energy production in buildings	Financial incentives/surplus production sale	Regulation on the integration of renewables in buildings
Portugal	**Decree-Law 153/2014** establishes the legal framework applicable to the production of electricity for self-consumption from renewable sources (solar, wind, hydro, cogeneration, biomass and fuel cells using hydrogen). Two types of units are considered: i) small production units (< 250kW) selling the total of produced electricity to the grid, and ii) self-consumption units, connected or not to the grid, that may sell the exceeding production to the grid. **Decree-Law 118/2013** establishes the obligation of installing solar thermal systems for the production of DHW, for new buildings or major renovations. It requires a minimum area of solar collection on the basis of 1 m^2 of standard collector for each expected occupant (corresponding to the number of bedrooms plus one occupant). However, the regulation foresees the possibility of replacing the solar thermal systems by other equivalent renewable technology, as long as it guarantees an equivalent amount of energy on an annual basis. Since December of 2015 heat pumps can be used as a substitute for solar thermal collectors. It is possible to calculate the contribution of renewable energy from aerothermal, geothermal and hydrothermal heat pumps.	**Decree-Law 153/2014**: The selling price of the surplus electricity produced in self-consumption units is the average closing price of the Iberian Energy Market Operator for Portugal in a given month. The reference tariff for the small production units depends upon the type of renewable energy source used, being solar energy the most benefited of all with the higher tariff. If the owner of a small production unit also installs solar thermal collectors or a biomass boiler, it can access special tariffs. The producers have to offer discounts to the reference tariff in a bidding system and the final tariff will result from the higher discounts offered. There are no financial incentives available for the installation of heat pumps or biomass boilers for heat production.	Specific regulations/standards for building integrated renewable energies do not exist in Portugal. Therefore, the integration of renewable energy technologies in buildings must comply with the existent standards for building elements and meet its requirements for thermal and mechanical resistance.

Table 20 - Comparison of the regulatory framework of renewable energy production among the countries with pilot-cases (cont.)

Country	Legal regimes in force for renewable energy production in buildings	Financial incentives/surplus production sale	Regulation on the integration of renewables in buildings
Netherlands	Renewable energy production / application of renewables is not mandatory in the **Dutch Building Decree**.	There is no direct (national) financial incentives for the installation of renewables on buildings. However, for owners it is possible to retrieve VAT on PV panels (as being a private 'renewable energy company').	There are no specific regulations/standards for building integrated renewable energy systems. However, to reach a level of nZE in the national energy performance regulations (EPG), building integrated renewable energy systems are inevitable.

6 Pilot cases

In order to reach nZEB, the integration of renewable energy will be necessary to cover the energy demand. Furthermore, because both electricity and heat production are needed and roof space is very limited, it is fundamental to combine different renewable energy technologies to achieve the necessary energy production to achieve nZEB.

Table 21 – Characteristics of the approach for building integration of renewables in each pilot-case.

Country	**Building integration of renewables**					
	Renewables	**Produced energy on-site (kWh/m^2.a)**	**Space availability (m^2)**	**Building orientation**	**Solar radiation availability**	**Building elements with renewables (applied or integrated)**
Denmark	PV	7.4 kWh/m^2.a	The roof area (flat roof) is: 1123 m² – per block. That is 19 m² per apartment.	South	Figure 20 Figure 21 Figure 22	The PV is to be integrated in the roof – whether the roof is to be flat or tilted has not been decided yet.
Estonia	PV and solar thermal system	PV – 2.4 kWh/m^2.a ST – 9.4 kWh/m^2.a	Flat roof – 750 m^2	South	940 kWh/m^2 to 1010 kWh/m^2	PV and solar thermal system on the roof
Latvia	Solar thermal systems	<u>Solar thermal system:</u> 13,50 kWh/m^2.a	Façade (non glazed): N – 70 S – 70 E – 52 W – 56 Roof: South slope: 85 North slope:85	South	900 kWh/m^2 to 1050 kWh/m^2	Solar thermal system on roof

Table 22 - Characteristics of the approach for building integration of renewables in each pilot-case (cont.)

Country	Building integration of renewables					
	Renewables	**Produced energy on-site ($kWh/m^2.a$)**	**Space availability (m^2)**	**Building orientation**	**Solar radiation availability**	**Building elements with renewables (applied or integrated)**
Czech Republic	Photovoltaic systems	PV systems combined output of 56.15kWp, Main roof 29 panels two rows East, 29 panels two rows West, total of 58 PV panels 15.66kWp, Four flat roofs, 12 panels each per flat roof, total 48 panels 12.96kWp, South Façade 44 PV panels (landscape configuration) 11.88kWp	Main roof: 228 m^2 Small flat roofs 107 m^2 Facade 93 m^2	Main roof west azimuth 90°/east azimuth -90°, slope 32.4°, flat roofs 0° slope, façade south azimuth 0°, slope 90°	PVGIS estimate for exact location (in kWh/year for each 1 kWp installed): East: 778, West: 772 0°: 828 South 90°: 636	Standard PV systems on the roofs BIPV Façade without visible spacing, uniform design for high aesthetics

Table 23 - Characteristics of the approach for building integration of renewables in each pilot-case (cont.)

Country	Building integration of renewables					
	Renewables	**Produced energy on-site ($kWh/m^2.a$)**	**Space availability (m^2)**	**Building orientation**	**Solar radiation availability**	**Building elements with renewables (applied or integrated)**
Portugal	Solar thermal systems + PV system Solar energy resource is: • abundant in Portugal (Figure 28); • most privileged renewable resource in the Portuguese legal framework (Decree-Law 153/2014); • most frequent resource explored in buildings in the last decades. Solar thermal systems are: • technology better accepted among users and for which there is a reasonably good knowledge regarding installation, operation and maintenance; • mandatory to cover DHW needs, both in new buildings and major renovations.	PV system: 14.3 $kWh/m^2.a$ Solar thermal system: 10.4 $kWh/m^2.a$	Façade (non-glazed): 333.3 m^2 Roof: 159,5 m^2 Balconies: non-existent Shadings: non-existent Building site: no space available	South-West	Figure 28 Figure 29 Figure 30	PV system integrated in the façade and solar thermal system installed on the roof

Table 24 - Characteristics of the approach for building integration of renewables in each pilot-case (cont.)

Country	Building integration of renewables					
	Renewables	**Produced energy on-site (kWh/m^2.a)**	**Space availability (m^2)**	**Building orientation**	**Solar radiation availability**	**Building elements with renewables (applied or integrated)**
Netherlands	Pilot 1 Geothermal heat pump and PV Pilot 2 Solar thermal combined with heatpump And PV Solar Energy resource is sufficient in the Netherlands given the yields of both PV and Solar thermal. Compared to geo-thermal heat pumps and air/water heatpumps the heatpump combination with ST brings overall high cop (based on the average temp outside during heating season of ca 6 degrees) and still reaches cop of more than 2 on days with -10. ST related panels are relatively cheap.	Pilot 1 40 kWh/m.2a Pilot 2 PV 55 kWh/m2.a Solar Thermal heat pump Cop year average 4 Cop heating season 3 COP -10 2,5 Yearly need DHW; 3400 kWh (2 persons) 3400/105 kWh/m2.a	Pilot 1 151m2 6125 kWh/a Pilot 2 80 m2 per dwelling	Pilot 1 South/South /West Pilot 2 East	Pilot 1 1000 kWh/m2 Pilot 2 1000 kWh/m2	Pilot 1 PV on flat roof, not integrated Pilot 2 Integrated and applied. Applied is within and without in combi with thermal panels

6.1 Denmark

In spite of its northern location Denmark has considerable amounts of sunshine – most of which falls during the summer months. This is especially true for a horizontal surface. On 45° slope and vertical south facing surfaces the distribution becomes more even. See Figure 20 to Figure 22. These data are from the newest Danish Design Reference Year (DRY) based on a ten year period from 2001-2010 (Danish Meteorological Institute (DMI), 2013).

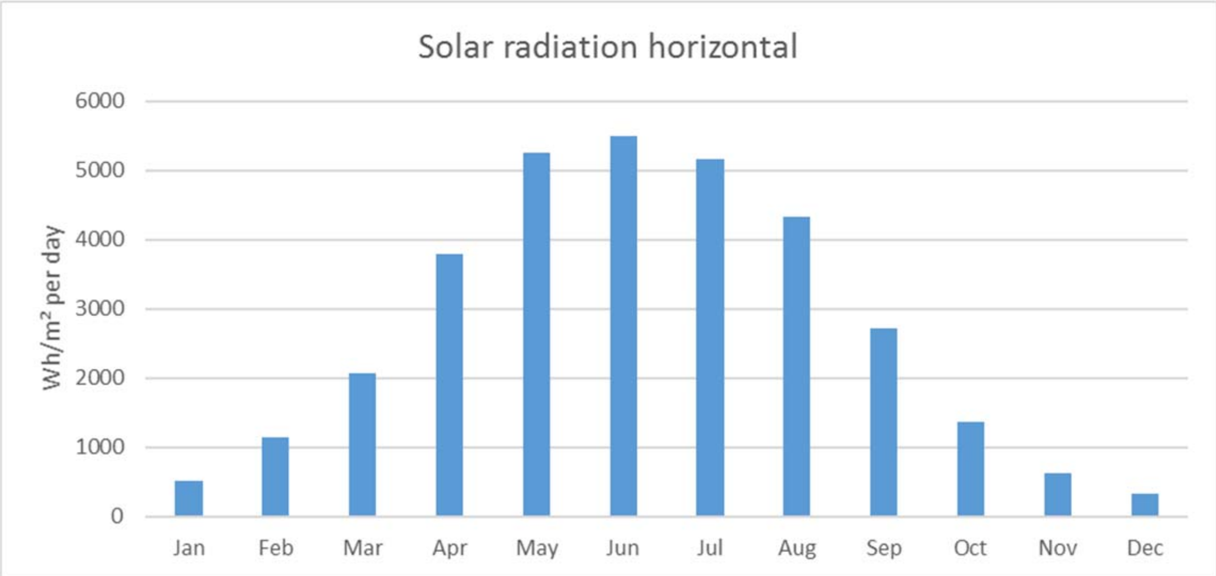

Figure 20 - Monthly global solar radiation in Denmark on a horizontal plane.

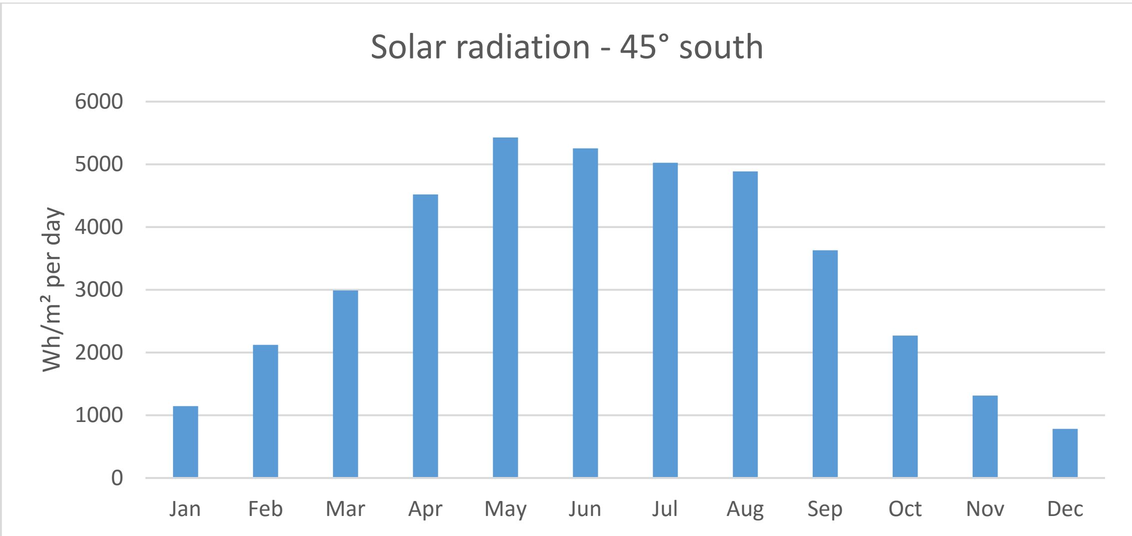

Figure 21 - Monthly solar radiation in Denmark on a 45° sloped surface (close to maximum for Denmark).

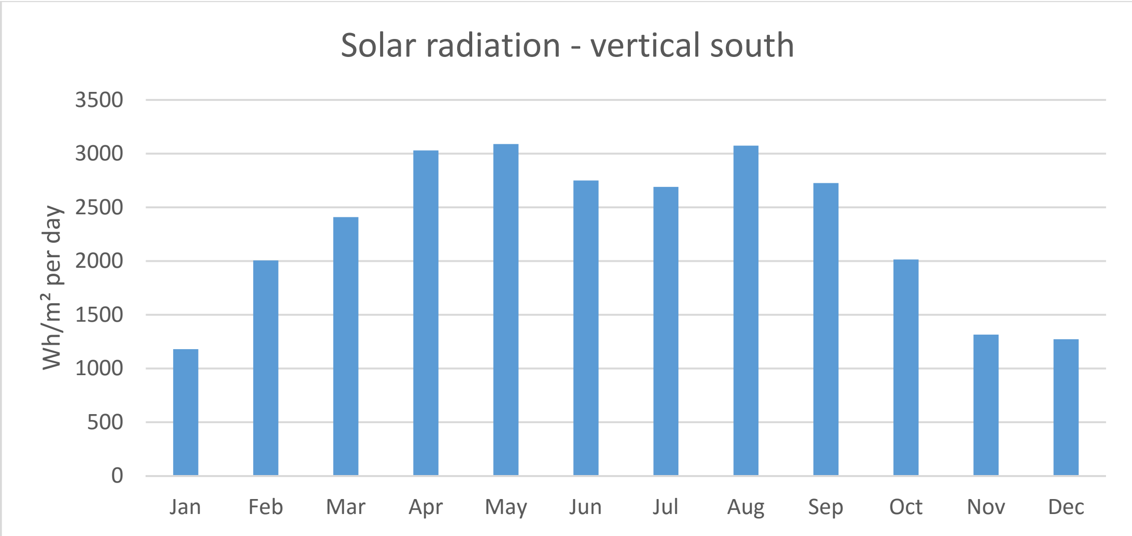

Figure 22 - Monthly solar radiation on a south-facing vertical surface.

6.2 Estonia

Most of solar radiation in Estonia is available during the summer months. In winter months, vertical surface has considerably more solar radiation than horizontal surface. Monthly solar radiation data is given in Figure 23 (Russak and Kallis, 2003.Handbook of Estonian Solar Radiation Climate)

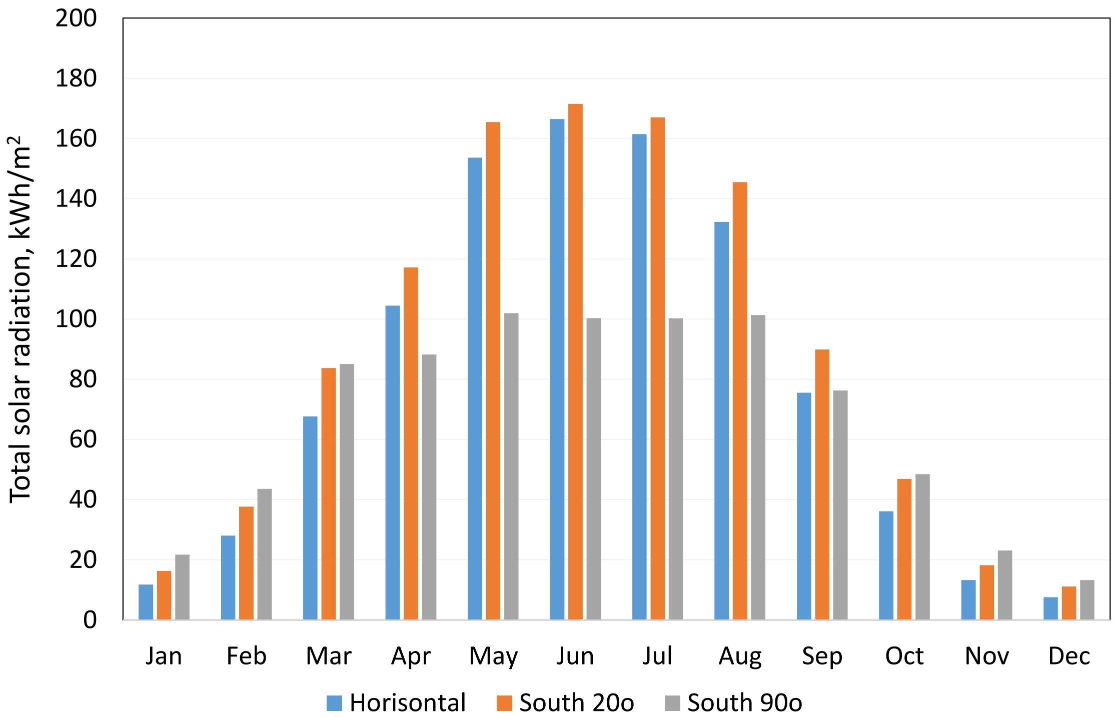

Figure 23 - Monthly solar radiation on surfaces with different slopes.

6.3 Latvia

The solar radiation varies from 900 kWh/m^2 to 1050 kWh/m^2 across the country. Use of solar energy is not mandatory in Latvia. However, building can be treated as nZEB only it case of on-site renewable energy production. The minimal amount of on-site produced renewable energy is not clearly defined.

The most popular are solar thermal collectors in combination with gas boilers, wooden pellets biomass boilers and electrical hot water boilers.

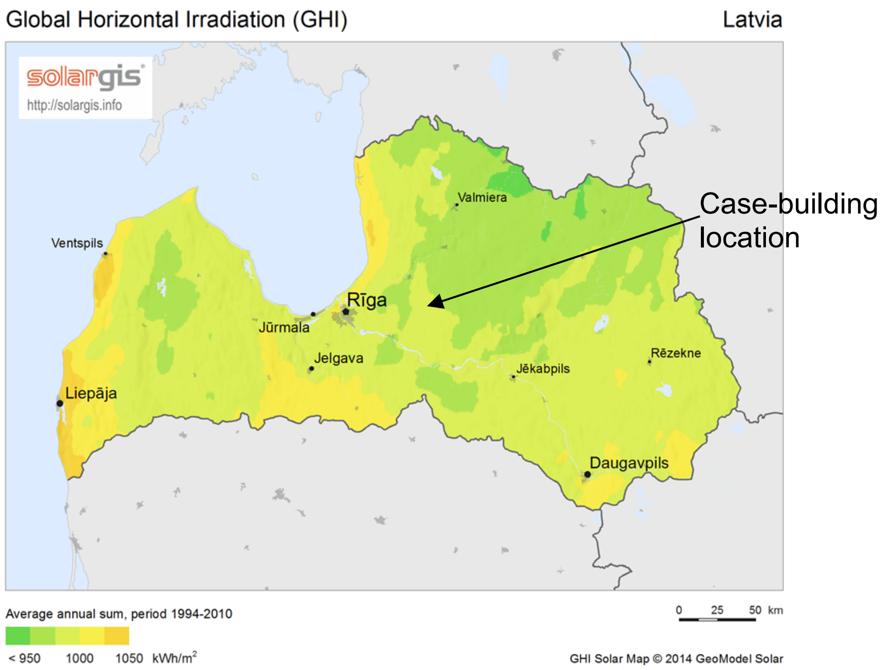

Figure 24 - Global horizontal irradiation in Latvia (kWh/m2) (Source: SolarGis).

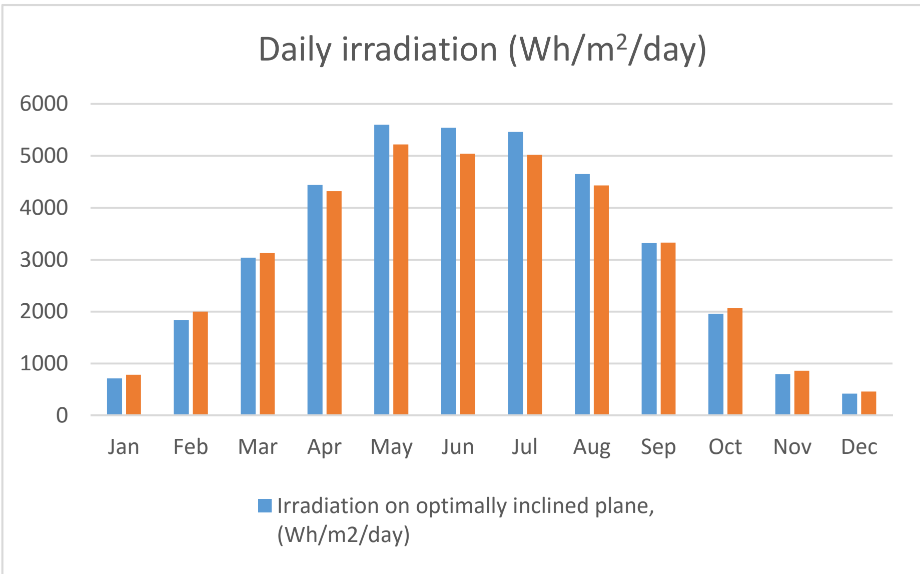

Figure 25 - Monthly irradiation on optimally inclined plane (39°) and inclined plane (55°), South orientation, for the location of the Latvian pilot building (Source: PVGIS).

Table 25 - Energy produced and area of collectors for the combination of renewables to be integrated in the Latvian pilot building.

	Renewable energy technology	
	PV modules	**Solar thermal system**
Produced energy on site ($kWh/m^2.a$)	N/A	13,5
Area of collectors (m^2)	N/A	8

6.4 Czech Republic

Czech Republic located in central Europe receives annually between 1000 and 1200 kWh/m2 of solar radiation energy. There are minor differences across the country, up to 10 % from southern Moravia to northern Czechia (see Figure 26). Data of daily irradiation shown in Figure 27 are reference climate data for building energy performance evaluation in Czech Republic.

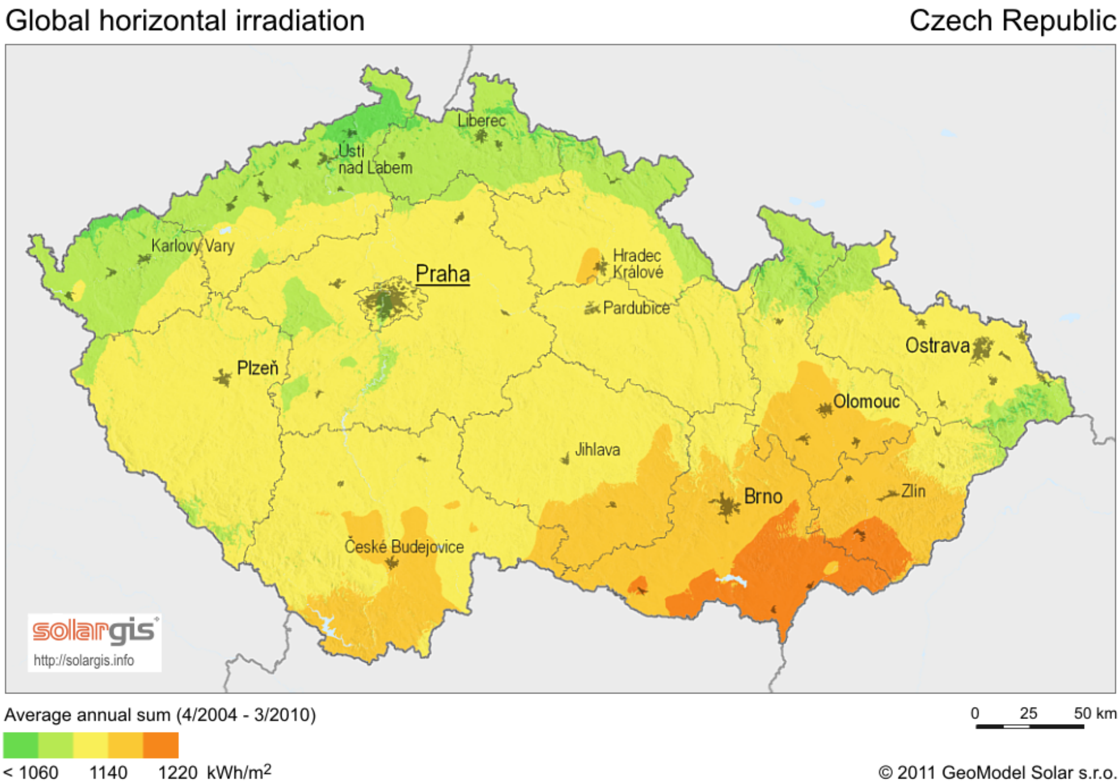

Figure 26 - Global horizontal irradiation in Czech Republic (in $kWh/m^2.a$) (Source: SolarGIS).

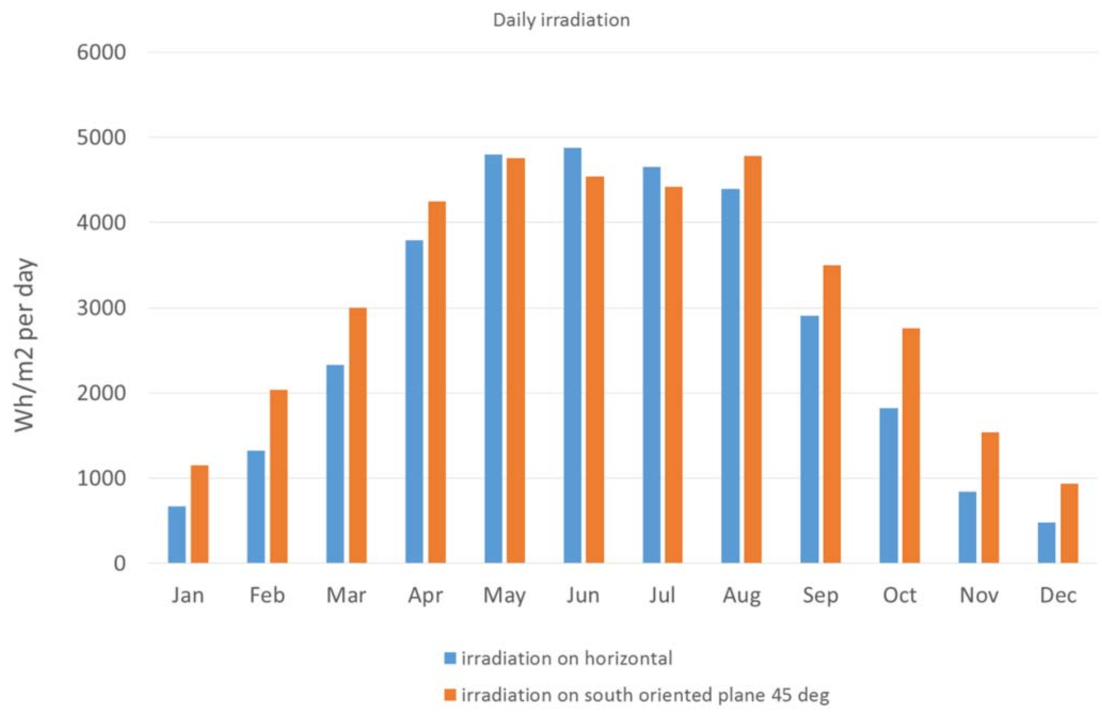

Figure 27 - Monthly solar irradiation on horizontal plane and south facing plane sloped 45 deg in Czech Republic.

6.5 Portugal

Solar energy resource is abundant in Portugal and it is the most privileged renewable resource in the Portuguese legal framework (Decree-Law 153/2014). The radiation varies from 1304 kWh/m^2 to 1872 kWh/m^2 across the country (Figure 28). For that reason, it is also the most frequent resource used in buildings since the last decades. Although there is a general lack of knowledge regarding the integration of renewable energy technologies in the building elements, solar thermal systems constitute the technology which is better accepted among users and for which there is a reasonably good knowledge regarding installation, operation and maintenance. Furthermore, solar thermal systems – or other equivalent renewable energy technology – are mandatory to cover DHW needs, both in new buildings and major renovations. Between 2006 and 2013 it was mandatory to install STS and, at the same time, an effort was made to increase its acceptability among users through the obligation of installation and maintenance (for a minimum period of 6 years) by a qualified technician. An additional advantage of the STS is their short payback which is, in general, less than 8 years.

Due to the fact that incentives for solar thermal systems privilege flat plate collectors, it is not usual to install evacuated tube collectors in Portugal.

Figure 28 - Global horizontal irradiation in Portugal (kWh/m^2) (Source: SolarGis).

Figure 29 and Figure 30 present the solar radiation available for the location of the Portuguese pilot building on the optimally inclined plane (35°) and for a vertical plane (90°). The first (Figure 29) represents the irradiation for systems installed on the roof and the second (Figure 30) presents the radiation available for systems integrated in the façade.

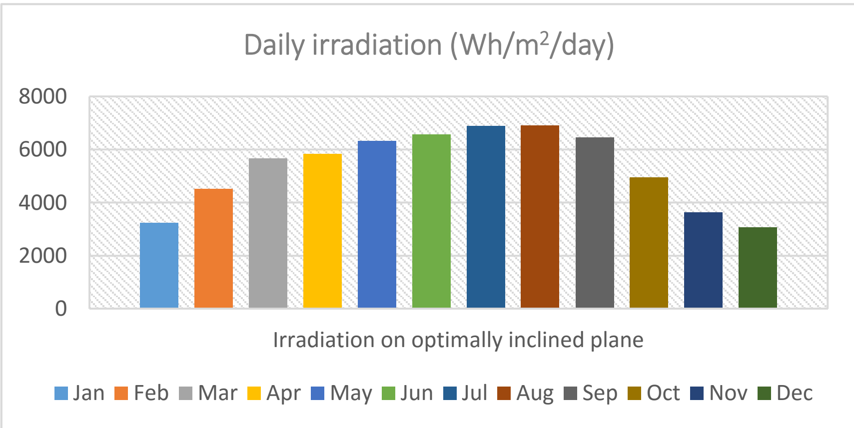

Figure 29 - Monthly irradiation on optimally inclined plane (35°), South orientation, for the location of the Portuguese pilot building (Source: PVGIS).

As mentioned before in Section 3.1, PV integrated in façades have a more homogeneous energy production throughout the year due to the available radiation on the vertical plane (Figure 30).

Consequently, at this stage, the approach considered for the Portuguese pilot is to mount STS in the roof in order to cover DHW and integrate PV modules in the façade, making part of the prefabricated module (non-glazed elements).

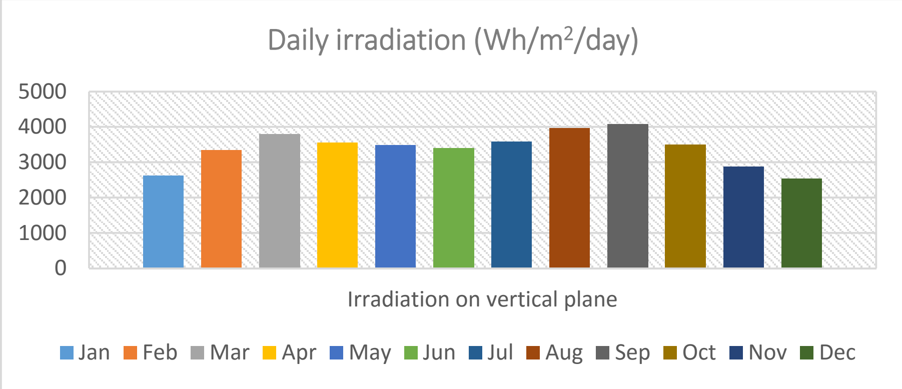

Figure 30 – Daily average irradiation on vertical plane (90°) with SW orientation, for the location of the Portuguese pilot building (Source: PVGIS).

Table 26 presents the area of PV and STS collectors as well as the produced energy on site, according to the simulation performed for the pilot building in order to reach ZEB.

Table 26 - Energy produced and area of collectors for the combination of renewables to be integrated in the Portuguese pilot building.

	Renewable energy technology	
	PV modules	**Solar thermal system**
Produced energy on site ($kWh/m^2.a$)	14.3	10.4
Area of collectors (m^2)	135	69

In order to guarantee continuous production of domestic hot water, a gas heater will work as backup system for the STS. A heat pump (COP=4) will be installed to cover the space heating demand.

6.6 Netherlands

The solar radiation in the Netherlands varies from 1000 kWh/m^2 (inland area) to 1200 kWh/m^2 (coastal area). Use of solar energy is not mandatory in the Building Decree and national EP regulation. However, for ZEB and nZEB on-site renewable energy production is the most important prerequisite. Depending on the building type or building site 25m^2 to 40 m^2 to make a house zero energy (or ‘zero-on-the-meter’). In almost all cases PV is preferred above solar thermal systems.

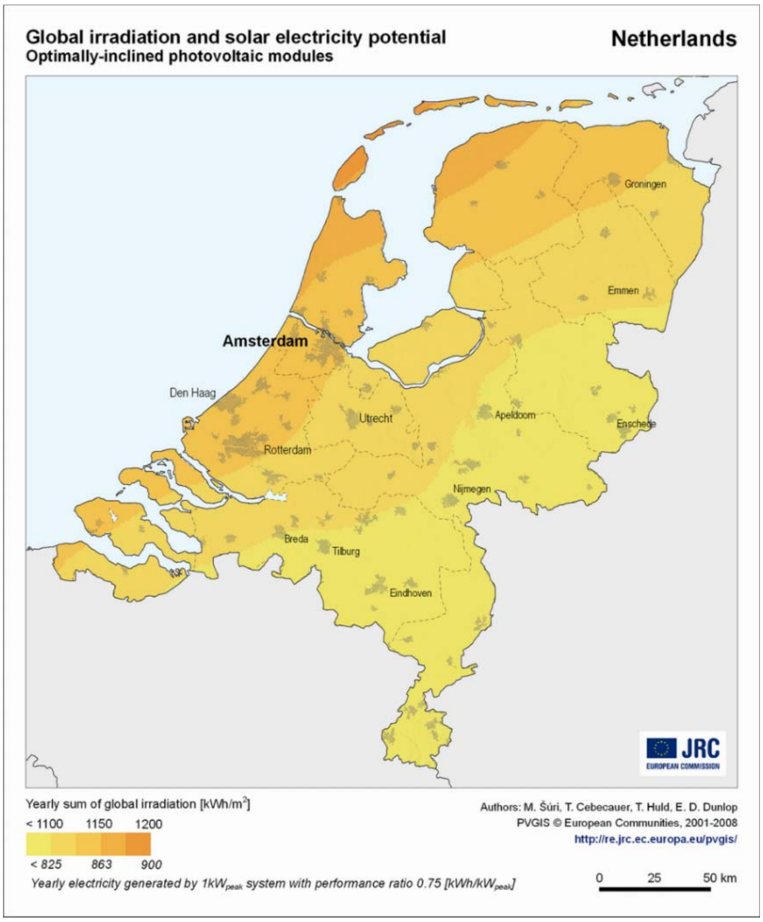

Figure 31 - Global irradiation for the optimally inclined plane in the Netherlands (kWh/m^2) (Source: SolarGis).

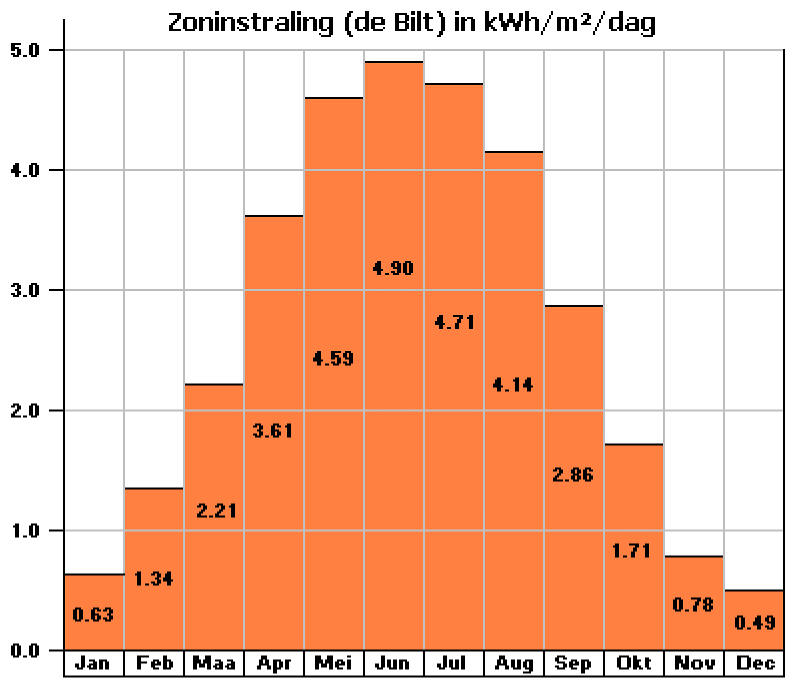

Table 27 - Relative yield as a function of orientation and inclination of PV collectors in the Netherlands.

Relative yield (%) as function of orientation and inclination					
	inclination				
orientation	0^0	30^0	45^0	60^0	90^0
S	87	98	97	94	74
SE and SW	87	95	94	85	70
E and W	87	84	78	73	56
N	87	65	52	42	33

6.7 Global analysis for the pilots

Table 28 presents a summary of the different approaches developed by each geo-cluster and to tackle the need of renewable energy technologies integrated in the pilot building in order to reach ZEB.

Table 28 - Summary of the strategy of building integrated renewables for each pilot building

Country	**Building integration of renewables**		
	Renewables	**Building elements with Renewables (applied or integrated)**	**Building Systems**
Denmark	PV	Roof	District heating
Estonia	PV and solar thermal	Roof	District heating
Latvia	Solar thermal	Roof	City district heating
Czech Republic	PV/BIPV	Roof/Facade	
Portugal	Solar thermal (ST) and PV modules	ST mounted on the roof and PV modules integrated in the façade (prefabricated module)	Gas heater as backup system for DHW production and heat pump for space heating
Netherlands	Solar thermal, geothermal, air/water thermal And PV	Air/Water; on the roof (kind of chimney)	Individual geothermal an air/water for row houses Collective geothermal for flats STS panels on roof

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Task 2.5 (D2.2c)

A review on super insulating materials (SIM)

MORE—
CONNECT

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H2020-EE-2014-1-PPP (EE-01-2014)

Table of content

1 Introduction

On the way towards a more sustainable environment, European Union (EU) sets high targets and ambitious goals in improving energy-efficiency of buildings, where increasing thermal insulation of buildings is one of the most common and cost-effective measures.

Especially the role of insulation is essential to achieve energy efficiency in renovated buildings and in nearly zero energy buildings following the requirements of the recast of the Energy Performance of Building Directive (2010/31/EU). An improved insulation in buildings will have a large impact on the reduction of energy consumption and CO_2 emissions at European level. It can also bring significant environmental, economic and social benefits both for the Member States and for the citizens. Although currently many materials are available on the market, there is a strong need for affordable advanced insulation materials which exceed the performance of presently used materials, and also respect strict sustainability principles.

In principle, application of thicker, traditional thermal insulation materials is required to satisfy strict EU energy-efficiency standards for buildings. Insulation layers of 20 to 30 cm thick have become daily practice in many European countries, especially in those countries where the passive construction concept is widely applied (Germany, Austria, and the Nordic countries). The main advantages of a high degree of insulation are: avoiding transmission losses, avoiding thermal bridges and in ensuring stable thermal comfort. Hence, increased thickness of building envelope is often not desirable due to a loss of internal floor area, an increased building footprint and a more complex building design. This shows a need for development of new materials supplying higher thermal resistance that can reduce unwanted extra building envelope thickness. The entry of super insulating material (SIM) commercial products in construction sector (for new buildings and retrofit) aims to achieve a reduction of energy use of buildings and solve space saving issues.

The objective of this report is to summarize the state-of-the art super insulating materials that can be used for building retrofitting by applying insulation solutions like:

- vacuum insulation panels (VIP),
- aerogel based products (ABP) and
- gas filled panels (GFP).

Figure 1: A comparison of the thickness of traditional insulation (mineral wool) and super insulation (VIP) having the same insulation performance (U-value).

These new generations of insulation materials present attractive alternatives that allow a reduction of the insulation thickness up to a factor of 2 to 5 [1]. However, the advanced SIM products currently available on the market are usually more expensive than traditional insulation materials.

Furthermore, there are several other issues related to the SIM properties. If these issues are not known or addressed properly before their application, there can be several risks during the construction and operation process. This review also presents an assessment of the relevant risks and additional costs when using different SIM products. It should be noted that in the recent years, the research on SIM accelerated dramatically and there are new products developed constantly, proving better physical performance and reduced costs. Already now, SIM often present most economically and technical feasible solutions when taking into account the cost of reduced floor area [2].

In order to evaluate the usability of the SIM commercial products for the purpose of MORE-CONNECT project, SIM products offered by different manufacturers and examples of practical application of SIM for building retrofit are presented. It is essential that the thermal performance is properly evaluated for potential thermal bridges and moisture problems. Furthermore, when installing SIM commercial products into the buildings, safety data sheets and instructions from the manufacturer should be followed carefully in order to obtain the desired high performance properties (not damaging the product, appropriate application etc).

One of the goals of MORE-CONNECT project is to select innovative and advanced components and products that allow for modular retrofitting and deep renovation leading towards nearly energy zero buildings. Therefore, this report aims to gather the knowledge on SIM, present state of the art solutions and prepare foundation for later application of SIM in the demonstration cases (when actual retrofitting takes place). The idea is to give an up to date summary of the present use of SIM. It should be noted that presented SIM products can be used both for new buildings and retrofit. Since MORE-CONNECT project focuses on solutions used in retrofitting, a focus is given on applicability of the SIM solutions for the renovation cases.

2 Characteristics of SIM

With the introduction of super-insulation materials (SIM), an entirely new generation of insulation materials emerged. Most of traditional insulating materials compose of cavities filled with air where such materials can reach a minimum value for thermal conductivity (λ) of about 0.029 W/(m K) [1]. However, as recognized by Fricke and Emmerling (1992) the use of the air as an insulator has reached its limit. A new technology approach was needed to acquire building insulation materials having lower thermal conductivities.

With applying SIM technology, this is possible. SIM products present attractive solutions when addressing above mentioned challenge. Thermal conductivity of SIM is commonly lower than 0.015 W/ (m K), having λ approximately twice lower than traditional materials [1]. Vacuum insulation panels (VIP) can offer even lower thermal conductivity value (of 0.007 W / (m K)).

Table 1 gives an overview of thermal conductivity values for the different insulation materials.

Insulation type	**λ** (W/m K)	Remarks
Mineral wool	0.035 – 0.050	
EPS/XPS	0.030 – 0.036	
PUR/PIR	0.023 – 0.028	
Resol foam (PF)	0.021 – 0.022	
VIP	0.007	Porextherm
Aerogels	0.012 – 0.019	Depending on the application
GFP	0.0074 (Xenon) 0.0108 (Krypton)	Based on Fi-Foil, 38mm panels

Table 1: Thermal conductivitiy values (**λ**) for different insulation materials.

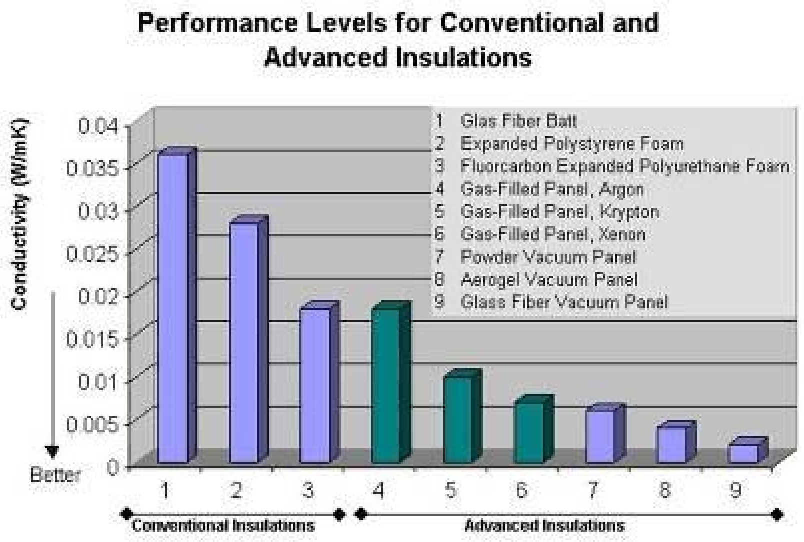


Figure 2: Thermal conductivity values (**λ**) for different insulation materials [3].

It should be noted that often the theoretical values (assessment done in laboratories) present lower thermal conductivities than are the actual measured thermal conductivities of the same insulation material applied in demonstration cases (prototypes or real scale applications) [4]. Over time (aging), thermal conductivity of SIM is increased either by water vapour or air diffusion through the material's envelope.

2.1 Thermal properties

The main thermal transport mechanism in SIM is through radiation (q_r), conduction through solid skeleton (q_{cd}) and heat transfer through the gas inside the material (gas conduction (q_g) and gas convection (q_{cv})) [5]. The total heat flow rate can be expressed as in Equation 1 [6];

$$q_{tot}\ (W/m^2) = q_r + q_{cd} + q_g + q_{cv} \tag{1}$$

The heat transfer through a material can be quantified according to the temperature gradient by the materials thermal conductivity λ_{tot} [6]; Equation 2.

$$\lambda_{tot}\ (W/m\ K) = \lambda_r + \lambda_{cd} + \lambda_g + \lambda_{cv} \tag{2}$$

All these parameters should be minimized to achieve a low thermal conductivity and this is currently the major challenge when improving the thermal properties of the building insulation materials. For further information on thermal conductivity aspects it is referred to the studies by Jelle et al. [7] and Jelle [8].

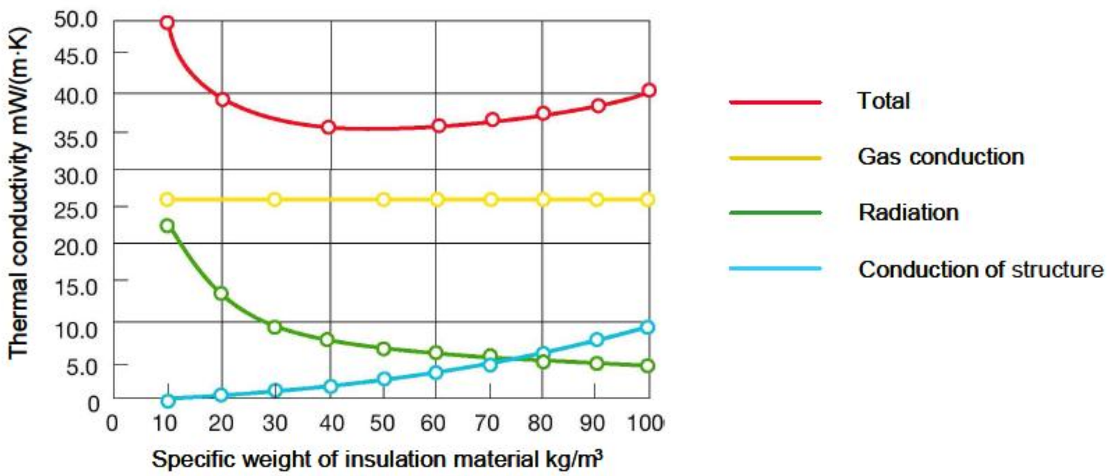


Figure 3: Transmission through a traditional insulation is determined primarily by conduction through gas (yellow line) [9].

As it can be seen from Figure 3, gas conduction (yellow line) has the highest impact on the materials total thermal conductivity [9]. Therefore, the most effective way of improving materials thermal properties is to reduce thermal conductivity properties of a gas. In general, a gaseous material presents much better thermal insulator than are solid materials. Applied gas medium in traditional insulation materials (such as glass and mineral wool) is air. A perfect vacuum would lead to a gaseous thermal conductivity λ_g=0 W/ (m K). To eliminate thermal conductivity due to convection of gas within the insulation material, also λ_{cv} should be equal to 0 W/ (m K). As represented by the blue line in Figure 3, a higher density of material leads to a higher proportion of heat transfer through the solid substance. Heat transfer by radiation and conduction of structure are in the same order of magnitude.

Following relationship (3) represents the impact of different parameters on gaseous thermal conductivity (λ_g):

$$\lambda_g = \frac{\lambda_{g0}}{1 + C \cdot \frac{T}{\delta \cdot p}}$$

(3)
Where:

λ_{g0} Heat transfer at standard conditions
T Temperature
δ Air cavities size
p Pressure
C Constant

A reduction in the gaseous thermal conductivity of an insulating material (λ_g) is achieved by:

- a gas having higher density than air (e.g. argon);
- reduced pressure; less particles in a given volume of space thus the mean free path between collisions of particles is increased;
- reducing the cavity size factor δ; introducing a nano-structured core material [10].

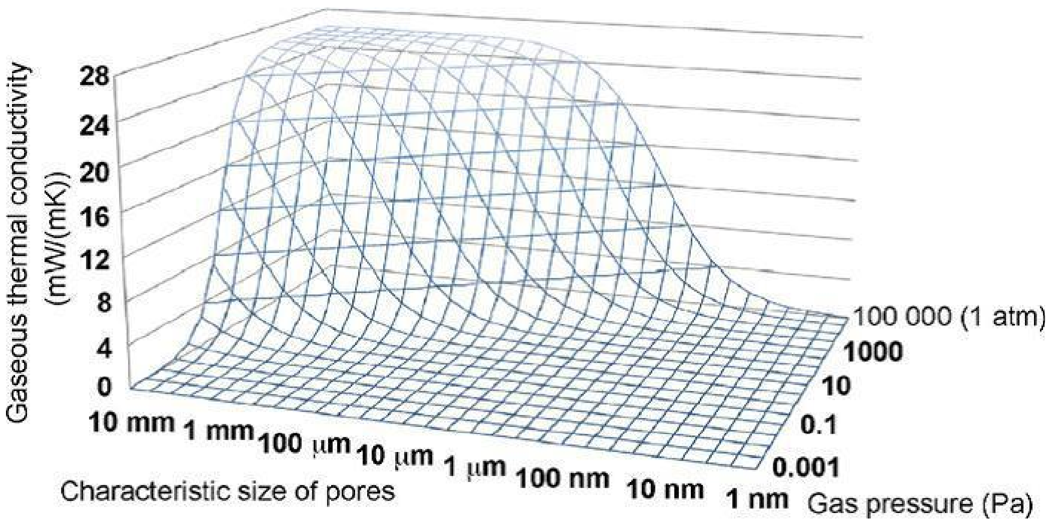


Figure 4: Gaseous thermal conductivity of air as a function of pore size and pressure [6].

As it can be seen from Figure 4 above, reducing the gas pressure and decreasing the pore diameter can efficiently reduce the gaseous thermal conductivity of the investigated material. By applying this approach, SIM materials were born.

When increasing the complexity for building industry production and due to the robustness in operation, nearly perfect vacuum is not feasible. A partial vacuum in combination with the micro-porous structure is more suitable for large scale applications of SIM insulation used in building industry.

2.2 Categorization of SIM

Three different technologies have been developed in order to achieve low thermal conductivities. The following figure (Figure 5) summarizes the products developed by applying these three technologies and can be categorized as SIM having low thermal conductivity.

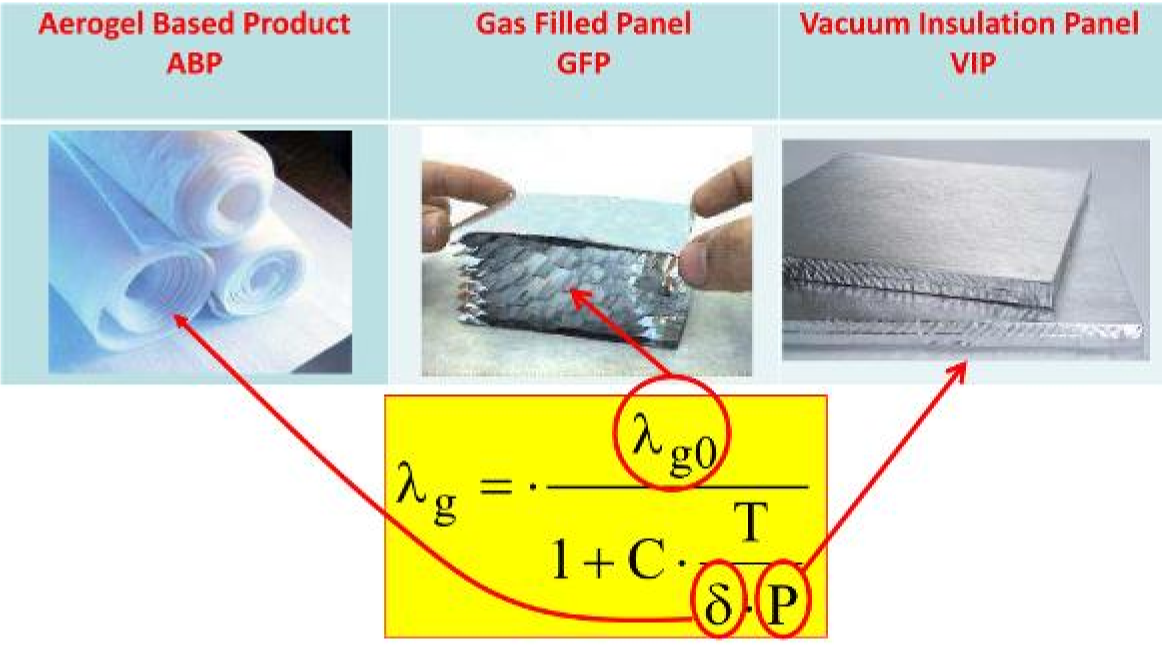


Figure 5: The basic principles for the three different SIM products: aerogel based product (ABP), gas filled panel (GFP) and vacuum insulation panel (VIP) [10].

- Shielding and vacuum insulation:

This method provides the lowest U values without an additional loss in internal floor area (having lowest thermal conductivity values). It requires a highly gas-tight envelope (shell) of the insulation which can maintain nearly perfect vacuum and at the same time minimizes thermal bridges.

The main issue for large-scale practical application is the production process, their vulnerability and especially the costs. Vacuum insulation technology process is much more expensive than production of traditional materials. However, when taking into account a thinner construction profile, vacuum insulation solutions quite often present the most economically attractive possibilities.

Products in the building industry are known under the name Vacuum Insulation Panels (VIP).

For VIP, the main principle is lowering the pressure (P): a low pressure is applied inside the evacuated foil-encapsulated envelope with an open micro-porous interior. By using vacuum, conductive and convective heat transfer is minimized leading to a low thermal conductivity
[4].

- Materials with nano-porous structure:

The heat transfer is reduced by gas if the pore sizes are smaller than the free path length of the gas molecules (i.e. the average path length of gas molecules for interaction with other gas molecules, about 70 nm). The so-called aerogels make use of this principle, and thus achieve a thermal conductivity between 0.012 - 0.019 W / (m K).

Products used in the building industry are known under the name Aerogel Based Products (ABP).
For ABP, high performance thermal insulation is achieved by reduced size of the pores (δ).A term nano-structure refers to a nano porous structure achieved via sol-gel processing (silica aerogel). The mean free path of the gas molecules reaches size values as the largest pores in the nano-structured core material. When the pore diameter of the material becomes less than the average free length of the path of gas molecules, the molecules will hit the pore surfaces without transferring energy, this is known as The Knudsen Effect (Figure 6) [5]. As a consequence, by decreasing size of the pores reduced thermal conductivity is obtained.

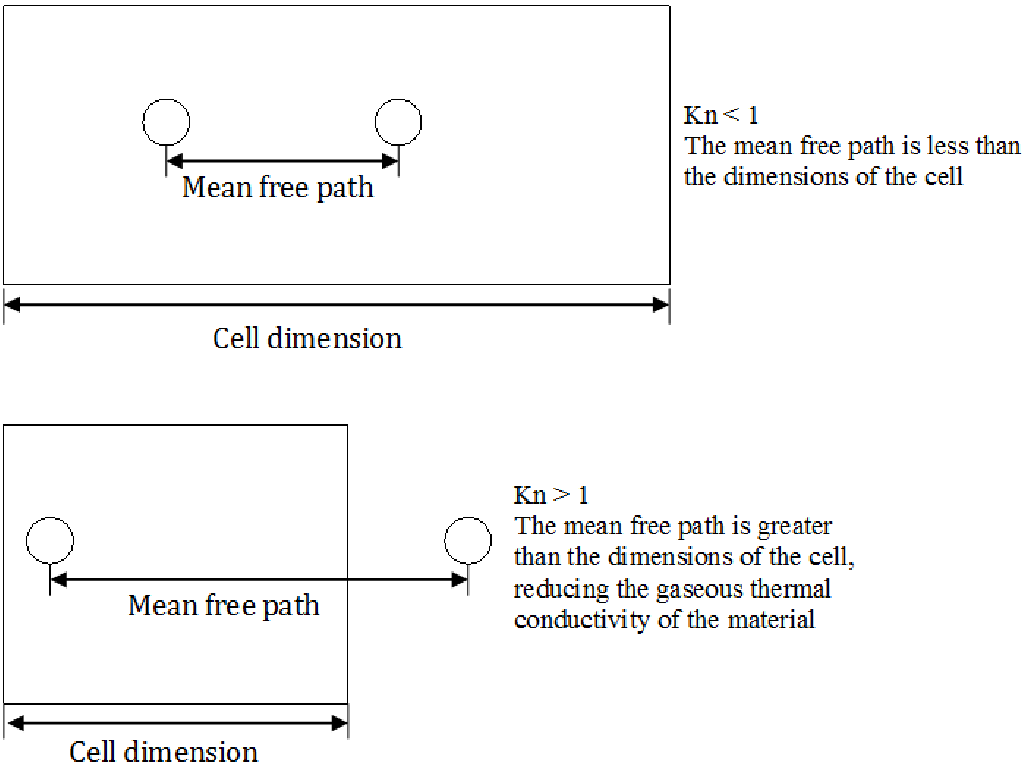


Figure 6: The Knudsen effect on gaseous thermal conductivity [5].

- Filling the pores with gas which has a lower thermal conductivity than air:

Instead a vacuum as in VIP, a closed pore structure filled with a non-harmful gas having a lower conductivity than air, e.g: argon (Ar), krypton (Kr) or xenon (Xe) is applied in this technique [4]. Surfaces are often covered with an aluminium foil to reduce the gas leakage.

Products in the building industry are known under the name Gas Filled Panels (GFP)
Better insulation properties are obtained for GFP filled with denser and heavier gases, generally these are the noble gases, having thermal conductivity around 0.020 W / (m K). Still, thermal

conductivities for prototypes (GFP) are still found rather high, 0.040 W / (m K) and therefore VIP is seen as a better choice (today and for the near future) [4].

3 SIM categories

3.1 Vacuum insulation panels (VIP)

3.1.1 VIP properties

Vacuum insulation panels (VIP) in façade panels were the first applications of super-insulating materials in the construction sector. Both single VIP as integrated VIP in the construction elements such as panels, doors etc. are currently offered by various manufacturers (Chapter 7). Still, VIP products remain a subject of many researches in order to improve its long-term performance and solve identified properties deficiencies.

Commonly, VIP consist of an open porous core of fumed silica protected by several metalized polymer laminate layers, and represent today's state-of-the-art thermal insulation with thermal conductivities ranging from 0.003 to 0.004 W/(m K) in intact earliest condition [4], leading to a thermal resistance about a factor of 10 higher than that of equally thick conventional polystyrene boards [5].

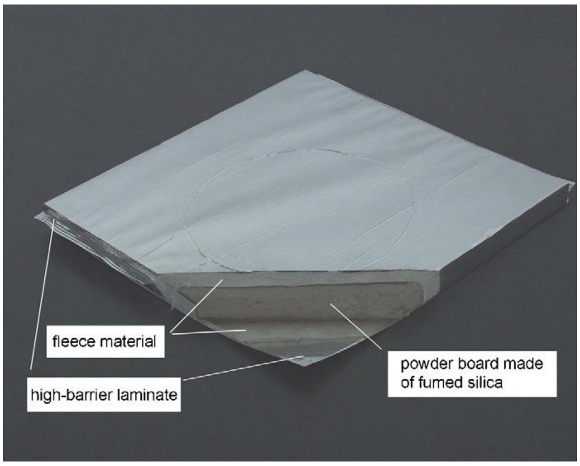


Figure 7: Vacuum insulation panel (VIP) [11].

Convective and conductive heat transfer is minimized by using a nearly perfect vacuum [5]. Filling material integrated in the flat VIP elements, which bears the atmospheric pressure load, reduces the requirements on the vacuum and increases the overall tightness.

The laminate is optimized for low air and moisture leakage rates and thus for a long service life. The evacuated silica kernel has a thermal conductivity of about 0.004 W / (m K) at a room temperature. As the kernel is nano porous, the gaseous thermal conductivity becomes noticeable only for pressures above 10 mbar. At about 200 mbar the thermal conductivity measures about 0.008 W / (m K). Such a gas pressure could occur after several decades of usage in a middle European climate. With VIP, slim yet highly insulating facade constructions can be realized. An U-value of 0.2 W / (m^2 K) can be achieved for a VIP thickness of only 2 cm; if the vacuum insulation core (fumed silica) and VIP envelope (barrier laminates) are carefully optimized as well as strict quality control is employed.

Two main components of VIP are:

- Vacuum insulation core

The basis for low gas thermal conductivity presents the core of VIP panel. The core also provides a certain degree of mechanical strength. The main requirements of the core that need to be satisfied are:
1) Small material pore diameter (10nm or less, gaseous conductivity = 0 W / (m K) at atmospheric pressure);
2) 100% open cell structure (to be able to be evacuated);
3) Stability: resistant material to compression (due to evacuated core) so that the pores do not collapse;
4) Resistant to infrared radiation (adding opacifers) [5].

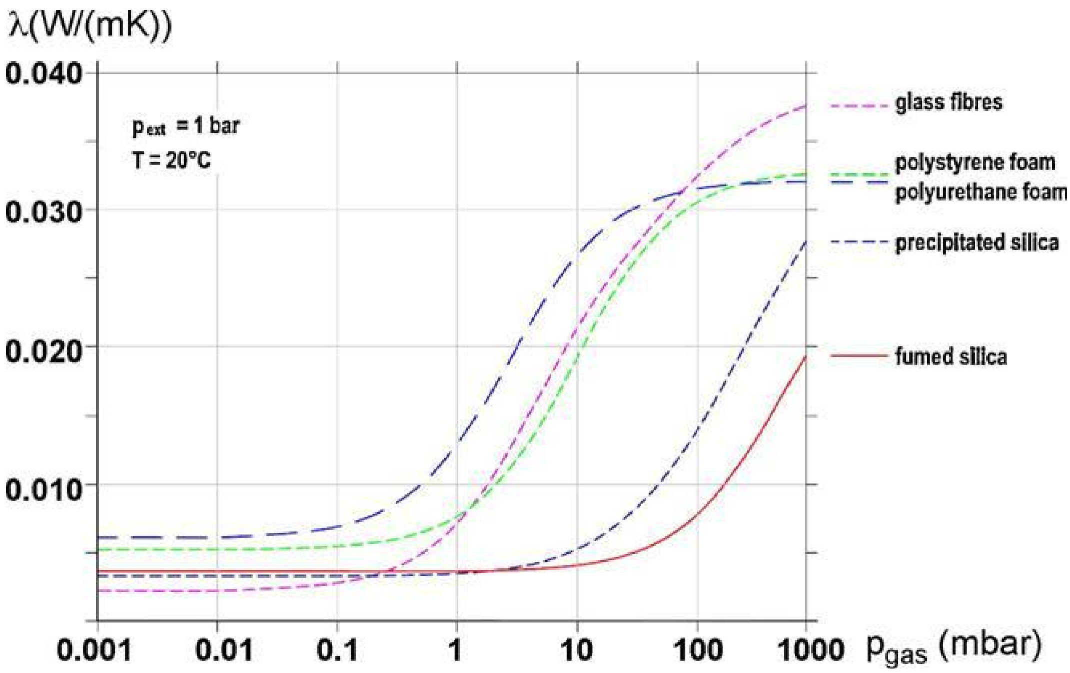


Figure 8: Thermal conductivity of different insulation materials at different pressures [12]. The heat conductivity of fumed silica starts to rise only above a gas pressure of more than 50 mbar.

If traditional materials are to be used as the core in VIPs (glass fibres, polystyrene foam), a very high standard of vacuum is required (0.1mbar) [5]. The envelope material must be of a higher quality to maintain the vacuum at such a high level, nevertheless, this results in a higher thermal conductivity. A good material that can be evacuated in the foil-encapsulated envelope and can satisfy all the above listed requirements is fumed silica.

Fumed silica consist of a cross linked structure of SiO_2 chains with a large number of air filled pores (high porosity) with a low pore size [5, 11]. Fumed silica pore sizes range from 5 to 70nm and this equates to 85–99.8% of the total volume of the aerogel [13, 14]. The fumed silica is evacuated to below 1 mbar and sealed in a high-barrier laminate, which consists of several layers of Al-coated polyethylene (PE) and polyethylene terephthalate (PET) [11]. Due to the thermal conductivity of the fumed silica core, the heat transfer at the centre of the panel is only 0.004 W/m K.

Furthermore, fumed silica or glass fibers are considered as non-combustible materials (acceptable range A). However, polymer barrier film is combustible therefore a layer of glass cloth should be added outside of the barrier film for fire safety protection [15].

1. VIP envelope

The outer coverage of VIP is the most critical component of VIP since it has to maintain the vacuum inside the core structure and prevent gas and water vapour permeation into the structure [12] therefore having high gas and water vapour resistance and thermal conductivity as low as possible. Thus, the outer envelope of VIP presents a critical element of the total structure. The internal structure and high thermal insulation properties are destroyed if moisture can penetrate into the VIP.

The VIP envelope is mostly represented by 3 types of materials that form the protection layers around the VIP core structure [16]:

- Metal foil: central laminated aluminium foil (6-12 μm), surrounded by plastic (PET) layers to protect the seams.
- Metallised films: three layers of aluminium foil coated PET films with an inner PE sealing.
- Polymer films: different plastic layers laminated together (e.g.: Mylar-polyether film), the materials used are polyether, polyamide, polypropylene and polyethylene. These polymers are less gas tight (more permeable) than the previous two types and therefore the envelope consists of multiple layers.

Multi-layered aluminium foils 100-200 μm thick are commonly used due to their low gas and water vapour permeation. The drawback, however, is that aluminium has a very high thermal conductivity (237 W/m K) and the aluminium envelope layer itself leads to creating thermal bridge. Envelope design needs to take into account the balance between achieving a sufficient seal and also minimising thermal conductivity at the panels' edges [5]. The thermal conductivity of the encapsulated micro-porous material within the aluminium foil envelope will have higher heat flux at its edges compared to its centre.

3.1.2 Benefits and drawbacks of using VIP

Even though VIPs have in general a great potential for building energy retrofitting (leading to energy savings while not obstructing internal floor area by offering slim elements), there are several drawbacks of VIP that need to be taken into account for building application. If these drawbacks are not recognized and properly addressed in the beginning, the overall usability and thermal performance of the elements can be diminished during the "service life".

The main advantage of using VIP as wall insulator is the significantly low thermal conductivity. The figure below shows how the same U-value is achieved for different insulation materials. It can be observed, that the VIP thickness of ¼ of the traditional wall insulation thickness (such as rockwool) is needed to achieve same thermal performance.

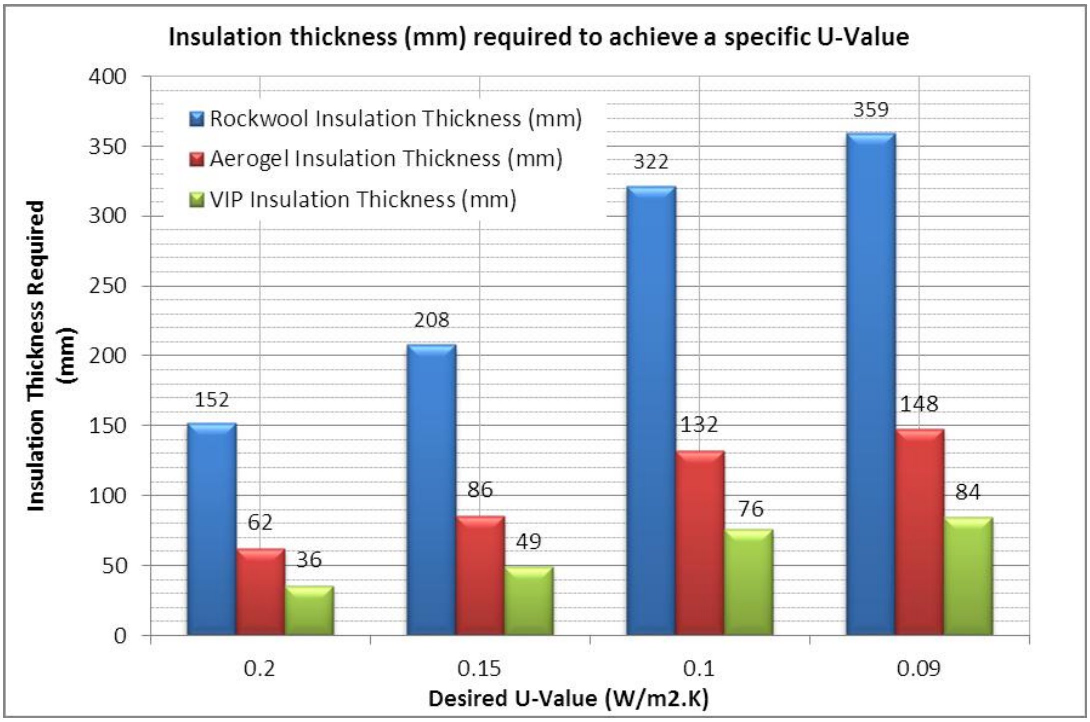


Figure 9: Insulation thicknesses required to meet predetermined U-Value targets [5].

The main challenge is on how to maintain vacuum inside a core material with a protective foil around the core. With current technology, thermal bridging due to the building envelope material and degradation of thermal performance through time occurs. Furthermore, VIP cannot be cut on site and the panels are fragile towards damaging [6]. After approximately 25 years, thermal conductivity is increased up to typically 0.008 W/ (m K) due to ageing, water vapour and air diffusion through the VIP envelope [4].

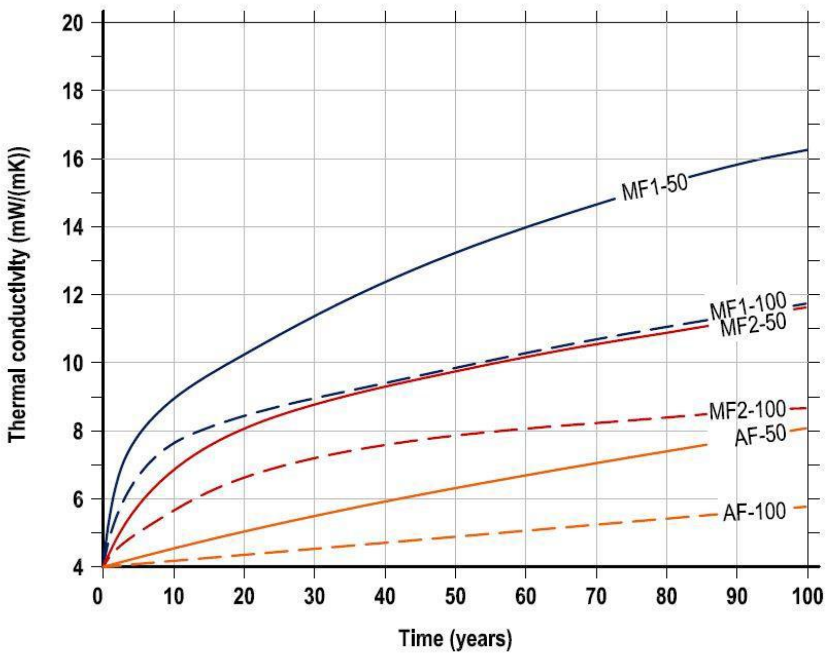


Figure 10: Centre-of-panel thermal conductivity for VIPs with a fumed silica core as function of elapsed time. For two different panel sizes of 50 cm x 50 cm x 1 cm and 100 cm x 100 cm x 2 cm, and for three different foil types AF, MF1 and MF2 as in [6]

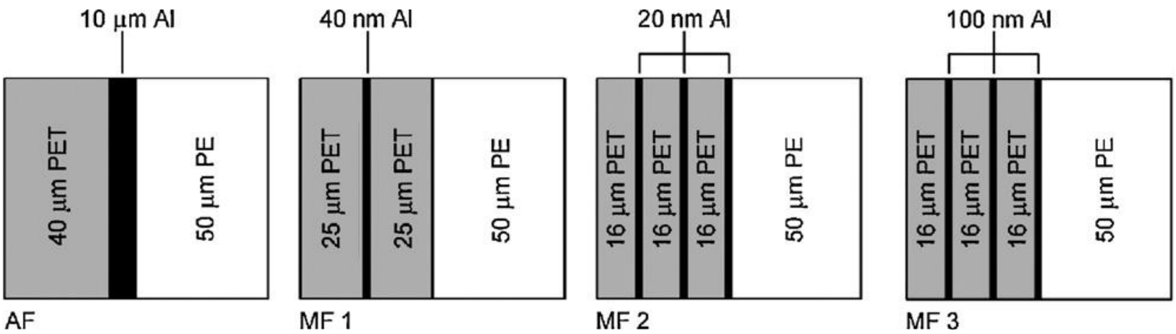


Figure 11: Study by Beatens et al. - Cross sections of some typical envelope materials for VIPs, commonly named AF (a metal film), MF1 (a single layer metallized film), MF2 and MF3 (both three-layer metalized films) [6].

Figure 10 above shows how thermal conductivity is after 50 and 100 years substantially higher for different types of VIP envelope. An increase in thermal conductivity from 0.004 W/ (m K) to around 0.020 W/ (m K) can be obtained if there is a situation with a total loss of vacuum (change in gas thermal conductivity).

To decrease the risk of loss of VIP performance, particularly for the decline of the vacuum and the VIP service life, the additives are added to increase VIP's service life. Getters are added to the VIP core to absorb gases (prevent an increase in internal gas) and desiccants to absorb water vapour (prevent an increase in vapour pressure) [5]. The internal gas and water vapour pressure will not increase until the capacity of the getters and desiccants are reached. Thus they prevent an increase in thermal conductivity of the panel and higher manufacturing costs even if there is an inclusion of gas and water vapour [6]. In addition, some core materials of VIP have a possibility to fulfil the function of getters or desiccants [15].

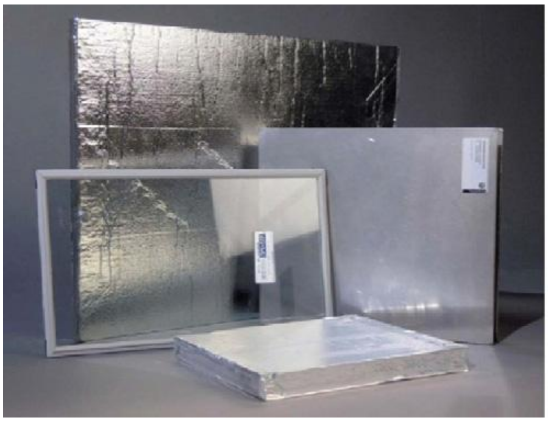
To reduce the radiant conductivity of a core material to a low level, opacifiers are added to the fumed silica in order to make it opaque to infrared. For fumed silica, a common opacifier is silicon carbide powder [6].

Advantages	Disadvantages
High thermal insulation performance and therefore not obstructing the internal/external floor area.	Fragility of the panels and protection against puncture of the foil (perforation vulnerability) is necessary.
Appropriate refurbishing of existing buildings with high restrictions.	Increased thermal conductivity through time. Limited service life may require replacement.
Can be used as 'thermal-bridge-insulation' on places where not much space is available.	Effective thermal performance will be reduced by thermal bridging of the VIP envelope.
Few cm of insulation is enough to meet (most of) national building regulations.	Increased structural thermal bridging due to the envelope.
Lower operating temperature increases thermal performances, which is beneficial in Nordic countries.	Inflexible: An on-site adaptation (cutting of panels) is not possible. Production inaccuracy of the panel sizes.
	Less suitable for traditional timber wall structures.

Table 2: Advantages and disadvantages of using VIP.

3.1.3 VIP service life-span and thermal bridges

Most VIP activity is still research and development projects with the application on the demonstration cases. A lot of research has been done on how to reduce the thermal bridging and on estimating the VIP products service life-span. Several manufacturers in EU (mostly Germany and Switzerland) offer different variations of panels with vacuum insulation panels (VIP) [12]. VIP needs to be seen as a system of different components, materials and properties and not only as single material. Baetens et al. [6] defines 3 sub-categories of VIP solutions that are currently available on the market: vacuum insulation panels (VIP), vacuum insulating sandwiches (VIS) or sheet-encapsulated vacuum insulation panels and vacuum insulating glazing (VIG).



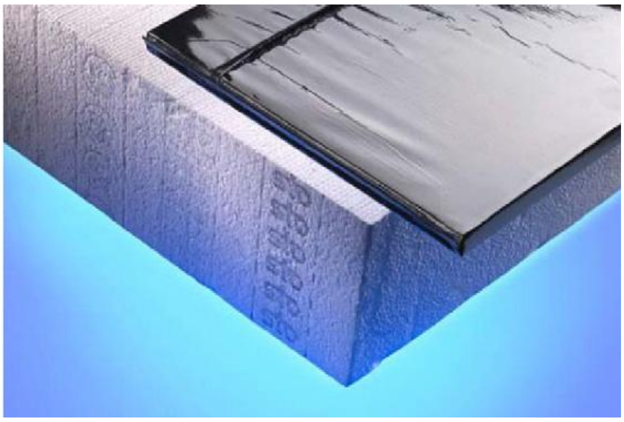


Figure 12: Vacuum technology as building insulation: VIPs, VIG and VISs (left) and a comparison between a vacuum insulation panels and conventional insulation with the same overall thermal performance (right) [6].

The general structure of VIP panel is: the packaging film of the vacuum insulation plate itself, the type of material inside the core and the material forming the plates (and edges). A VIP core is fixed between two outer protection skins with a spacer. The main common characteristic of these products is that they combine a small thickness with a high thermal insulation quality.

Figure 13: One of the first applications of façade panels insulated with VIP [16].

The outer plates protect the core insulation during the service life span. The main challenging part is the interaction between the applied core insulation and the required level of vacuum at the end of the life of the product. The thermal conductivity of the insulation material needs to be as low as possible and enough attention and detail design is needed in order to reduce the influence of thermal bridges.

Estimation of service life of VIPs

American standard Specification for Vacuum Insulation Panels (ASTM-C-1484-01) [17] defines a vacuum insulation board "service life-span", the time span within which the thermal conductivity is lower than 0.011 W/ (m K), applying following conditions: room temperature at 24 °C and relative humidity of 50 % RH. This result in a permissible maximum pressure in the vacuum plate that is dependent on the core insulation, namely: for micro porous silica max 270 mbar, for XPS 3 mbar and for mineral wool max 0.5 mbar. For architectural applications where long life is desired, there is a clear preference for core insulation of micro porous silica [30].

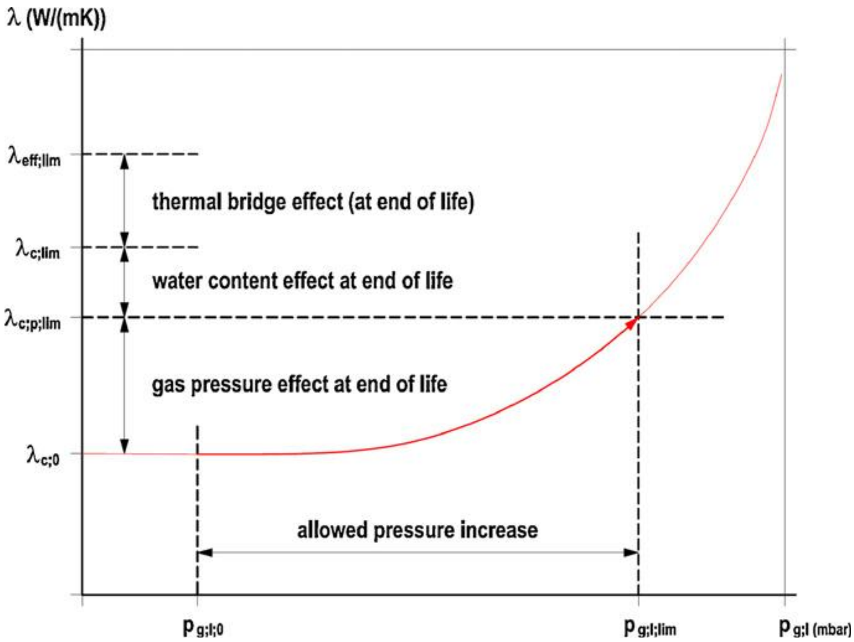


Figure 14: Service life definition of a vacuum insulation panel as in [6].

To estimate the service life-span of the VIP, different aging and durability mechanism can be assumed [6]. In first days after the VIP production, first failures can appear due to a low quality of seams with a rapid increase of the internal gas. This failure can be reduced by doing a quality control, storing the panels during a specified time (first 10 days) and therefore preventing the shipping and application of damaged VIPs in the building. Furthermore, often the damage of the VIP envelope is done during the installation and assembly on site (sand grains, bricks, other sharp objects etc.). After installation, failure risks are lowered. However, during the aging, the characteristics of VIP to withstand chemical and mechanical impacts become of great importance. During the operation phase, pressure can increase due to permeation of gas through the envelope (Figure 16). Water content is increased due to the intake of moisture through the surface (Figure 17). Both effects can be decreased by the additives (getters and desiccants) but still they increase the thermal conductivity of the core. These factors all define the service life of VIP products.

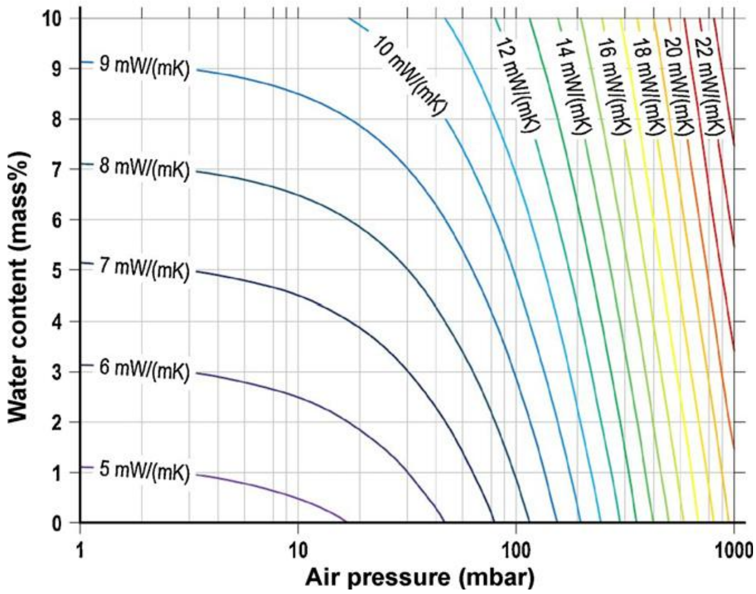


Figure 15: Thermal conductivity (mW/(m K)) of the common core material fumed silica as function of both the air pressure (mbar) with an external load of 1 bar on the sample and the water content (mass%), at a mean temperature of 20 °C as in [6].

Baetens et al. [6] did an experimental study where they calculated the increase of the total air pressure (Figure 16) and increase of the total water content (Figure 17) in VIPs for panel sizes of 50 by 50 by 1 cm^3 and 100 by 100 by 2 cm^3 and for three different foil types AF, MF1 and MF2 (Figure 11). The graphs were calculated using values for the envelope WVTRA determined at 23 °C and 75% relative humidity, i.e. 0.0006 (AF), 0.035 (MF1) and 0.0086 (MF2) $g/(m^2day)$ respectively [6]. Further calculation methodology can be found by Baetens et al. [6]. The inner air pressure is assumed to be zero at t_0 = 0 years whereas commercial products have an inner air pressure between 0.5 and 5 mbar. No getters and desiccants have been taken into account and one assumes that the VIP envelope properties remain the same, i.e. that no degradation will occur through time (which is not realistic) [6].

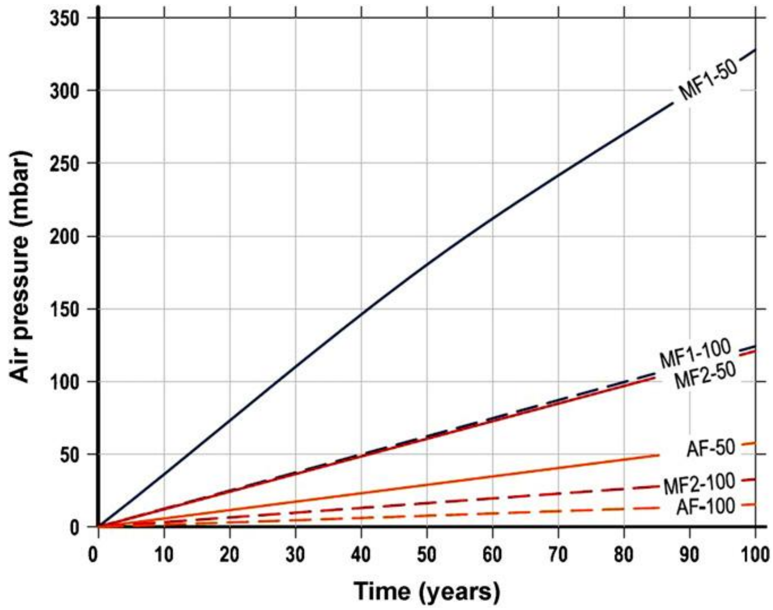


Figure 16: Study by Beatens et al. - Calculated increase of the total air pressure in VIPs for panel sizes of 50 by 50 by 1 cm^3 and 100 by 100 by 2 cm^3 and for three different foil types AF, MF1 and MF2 (see Figure 11) [6].

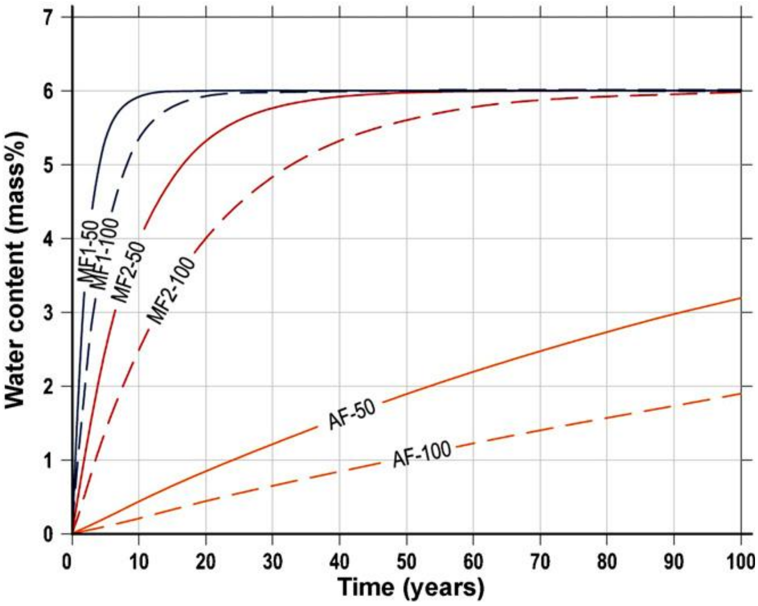


Figure 17: Study by Beatens et al. - Calculated increase of the total water content in VIPs for panel sizes of 50 by 50 by 1 cm^3 and 100 by 100 by 2 cm^3 and for three different foil types AF, MF1 and MF2 (see Figure 11) [6].

Thermal bridge effect due to VIP envelope

The linear thermal transmittance coefficient (Ψ_r) of edge construction (assuming linear thermal bridge) can be calculated using the methodology defined in European standard ISO 14683:2007, calculation method explained in EN ISO 10211 (Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations):

$$\Psi_R = \frac{\Delta\Phi}{L_{2D}} \quad \text{(W/ m K)}$$

(4)

Where:

$\Delta\Phi = \Phi m - \Phi c$ *in W*

$\Phi m =$ *Heat loss through a 2D model with length L_{2D} in W*

$\Phi c =$ *Heat loss through a 2D model without the linear thermal bridge (at the edge of construction) in W*

The point thermal transmittance in this model (4) is neglected, assuming that the corner thermal bridge effect is much smaller than the effect of the panel edge [6].

It shows that the linear thermal transmittance of the VIP envelope (Ψ_r), e.g. aluminium foil layered as packaging, depends on the core insulation's thickness (panel thickness), corresponding thermal conductivity value and the thickness of the aluminium foil and its thermal conductivity [6].

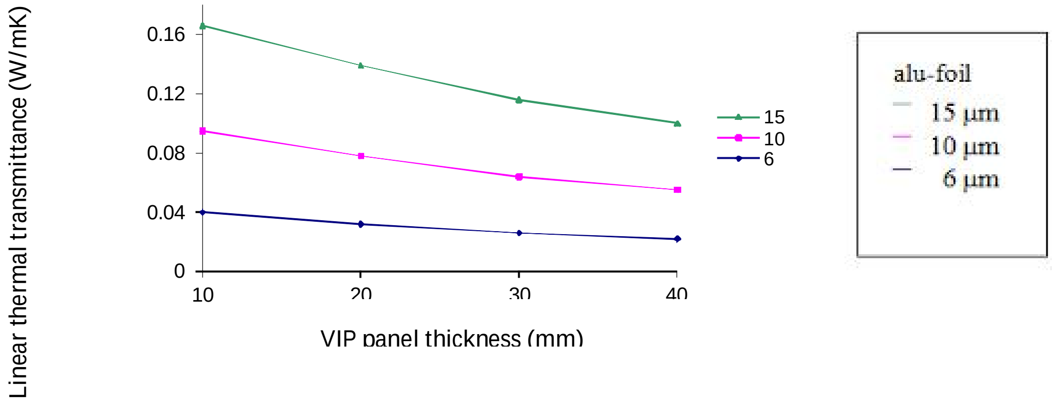


Figure 18: Ψ_r for different thicknesses of the aluminium foil as a packaging material and the thickness of the core insulation [16].

Figure 18 above illustrates how linear thermal bridges are increased when increasing the thickness of the aluminium foil layers (different colours) and the importance of the size of VIP panels. It can be seen that the effect of thermal bridges is decreased with the increased thickness of the vacuum panel. Furthermore, it shows that larger the panel, smaller the perimeter length and smaller is the influence of the linear thermal conductivity of the barrier envelope on the overall U-value of the insulation layer [6].

Figure 19a

Figure 19b

Figure 19c

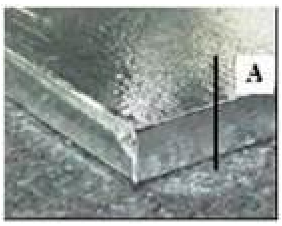


Figure 19d

Figure 19e

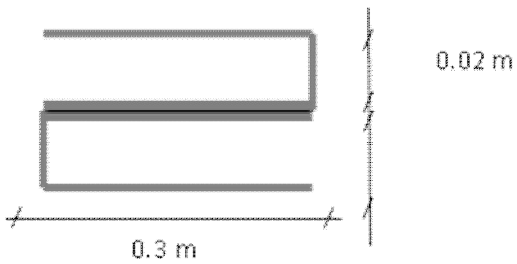


Figure 19f

Figure 19: Various possibilities of the glue line [16].

Figure 18 applies for an ideal packaging seam where it is assumed that only the thickness of the packaging film itself affects the linear thermal transmittance (see Figure 19d, thickness A). In practice, this seam looks different as Figure 19a-d show where Figure 19a shows the simplest seam. The adhesive flap is shown in Figure 19b and such open flap gives a chance for damage on a micro-level and thereby reduces the durability. A recent solution to the glue seam is presented in Figure 19c, the effect of thermal bridge is decreased with an increased thickness of the plates (the situation for which Figure 18 applies). As seen on Figure 19c and schematically on 19f at the glue connection, this glue seam is folded and protected with the two layers (on the half thickness of the total plate thickness).

The linear heat transmission coefficient can be also derived from equation (5) using simplified model [18, 19] where the assumption is that the thermal conductivity of the core material (λ_c) is equal to 0 W/ (m K) which is valid as long as λ_c or the ratio λ_c/λ_k is sufficiently small. This equals the assumption that the energy flux through the bulk material is zero and therefore every energy flux at the edge is caused by the thermal bridge of the barrier envelope [6].

$$\Psi_R = \frac{1}{\frac{Vd_p}{D\lambda_k} + \frac{1}{\sqrt{\alpha_1 D\lambda}} + \frac{1}{\sqrt{\alpha_2 D\lambda}}} \tag{5}$$

Where:

d_p = Insulation core thickness in m

λ_k = Equivalent thermal conductivity of core insulation in W/mK

D = Thickness of the packaging film (laminate) in m

α_1, α_2 = Heat transfer coefficient on the surface of the Panel in W/m² K

V = ratio between the thickness of the laminate and the thickness od the laminate at the panel edge an (if one packaging film thickness is V = 1)

Table 3 shows, for three values of λ_k, the comparison between the two methods of calculation for Ψ_R.

<table>
<tr><td rowspan="2">λ_k W/mK</td><td colspan="3">Ψ_R in W/mK</td></tr>
<tr><td>Comply with (4);
Computer model, Figure 6d</td><td>Comply with (5); Calculated,
Figure 6d</td><td>Comply with (4),
But in 2 layers with far-catching seams, Figure 6f</td></tr>
<tr><td>0.002</td><td>0.0221</td><td>0.0223</td><td>0.0086</td></tr>
<tr><td>0.004</td><td>0.0220</td><td>0.0223</td><td>0.0095</td></tr>
<tr><td>0.006</td><td>0.0216</td><td>0.0223</td><td>0.0106</td></tr>
<tr><td colspan="4">D = 7 μm α_1 = 7.7 m²K/W α_2 = 25 m²K/W λ_f = 225 d_p = 0.04 m</td></tr>
</table>

Table 3: Comparison calculation result of Ψ_R for different λ_k [30].

As it can be seen from Table 3, the VIP application shown in Figure 19f leads to approx. 60% reduction of the thermal bridges than in comparison with the application presented in Figure 19d, Table 3. Packaging film with a plastic vacuum coating alu-layer (thickness ca. 0.03 μm) or exclusively of plastic films exhibit a negligible thermal bridge effect.

Thermal bridge effect for different variations of VIP facade panels

The facade panels presently available on the market are based on the double glazing principle. Two outer sheets (panes) are fixed with a spacer and the vacuum insulation board fills the inner cavity (space between the panes). The outer sheets can be of different materials including coated sheet metal (aluminium, steel) or glass pane.

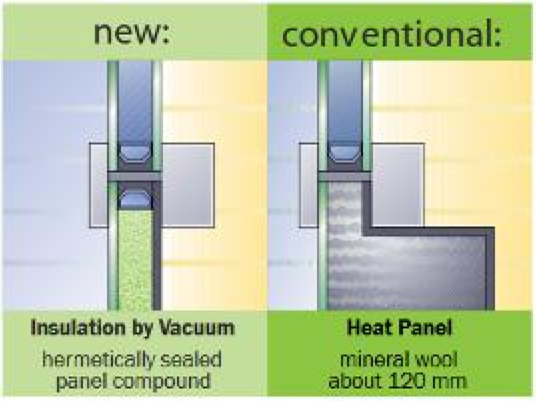


Figure 20: Example of VACUREX vacuum panels used as facade elements [20].

The effect of thermal bridging through the construction edges of metal facade panels is already known for a long time. The results show that the laminated aluminium foils (having a high heat transfer coefficient) have a great influence on the overall thermal quality of the VIP. For various constructions of VIP products, Table 4 shows the corresponding U-values.

Panel thickness (mm)	20	22	24	26	28	30	32	34	36
Inner plate	2	3	2	2	2	3	2	2	4
VIP insulation (mm)	16	16	16	16	24	24	24	24	24
Outside plate ALU Glass	 2 -	 3 -	 - 6	 - 8	 2 -	 3 -	 - 6	 - 8	 - 8
U-ideal	0.29 W/(m ² K)				0.18 W/(m ² K)				
Number	1	2	3	4	5	6	7	8	9

Table 4: Various configurations of facade panels with VIP insulation [16].

The linear heat transmission coefficient Ψ_{RP} of the panel edge is determined using the model and equation (4). Calculations are done for two VIP applications that is either a vacuum insulation board having aluminium-laminated packaging or plastic packaging film (Mylar). The results for Ψ_{RP} are shown in Figure 21. It can be concluded that:

- The choice of the envelope material on the outside has a great influence:
  ALU: Ψ_{RP} = 0.91-0.77 W/mK
  Glass: Ψ_{RP} = 0.37-0.38 W/mK
- The influence of the thickness of the alloy plating on the inside is limited and this also applies to the thickness of the VIP-insulation core material, which means that the heat is mainly transferred through the spacer.
- Application of the Mylar packaging of the VIP leads to a decreased linear heat transmission (with an average 13% lower Ψ_{RP} than when applying alu foil).

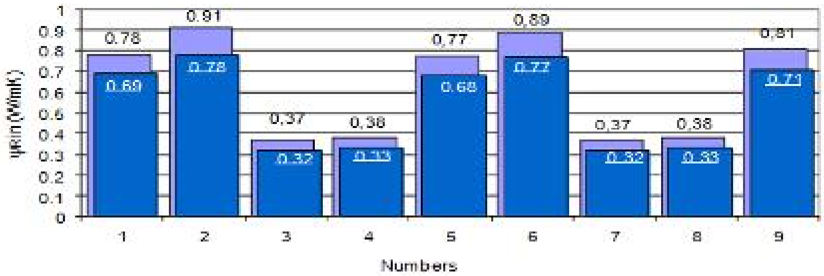


Figure 21: Ψ_{RP} for various configurations of the panel (alu foil, Mylar plastic packaging). The underlined values refer to the plastic packaging [16].

The average U-value of the vacuum insulated facade panel (U_p) and thus the influence of the thermal bridges on the total thermal quality can be calculated using Equation 6.

$$U_p = \frac{U_m A_p + \psi_{RP} l_{RP}}{A_p} \qquad (6)$$

Where:

U_p = *Average panel U-value W/m ² K*

U_m = *U-value for ideal diameter in W/m²K*

A_p = *Panel surface in m²*

l_{RP} = *Panel perimeter in m*

Table 5 below shows computations of U-value for two panel compositions (having alu foil or Mylar packaging as VIP envelope).

	Panel dimensions		
Packaging film	1 x 1 m²	1.4 x 1.4 m²	2.0 x 3.5 m²
Laminated alu	1.64	1.23	0.77
Plastic Mylar	1.44	1.09	0.69

Ideal U-value	0.19

Table 5: Average U-value of VIP Panel consisting of either 2 mm alu foil or 6 mm glass plate serving as VIP outer envelope, and VIP core thickness of 20 mm [16].

The results in Table 5 show that there is a great effect of the edge and the panel dimensions on the actual U-value. It can be concluded that calculating the heat loss using the U-value at the location of the ideal diameter is not permissible; this is not suitable even for large panel dimensions.

Thermal bridge effect on the scale of a building component

The spacer is needed whenever there is no structural (durable and strong) connection between the two outer (envelope) plates. Thermal bridges occur nearby such spacers due to the connection link between the inner part and the outer envelope. The glass industry is facing similar situation with glazing systems therefore they developed different spacer products that can be applied in VIP building applications.

Figure 22 below shows four edge spacer construction types: aluminium spacer of double glazing, folded edge construction, thermoplastic spacer and reinforced non-metallic tape. According to Baetens [6], lowest thermal conductivity of the spacer and therefore linear heat transmittance is found with a plastic spacer. If the outside plates are assembled as stand-alone construction units, the link (edges) can be protected with a plastic or reinforced tape and this is considered as a spacer (no structural link).

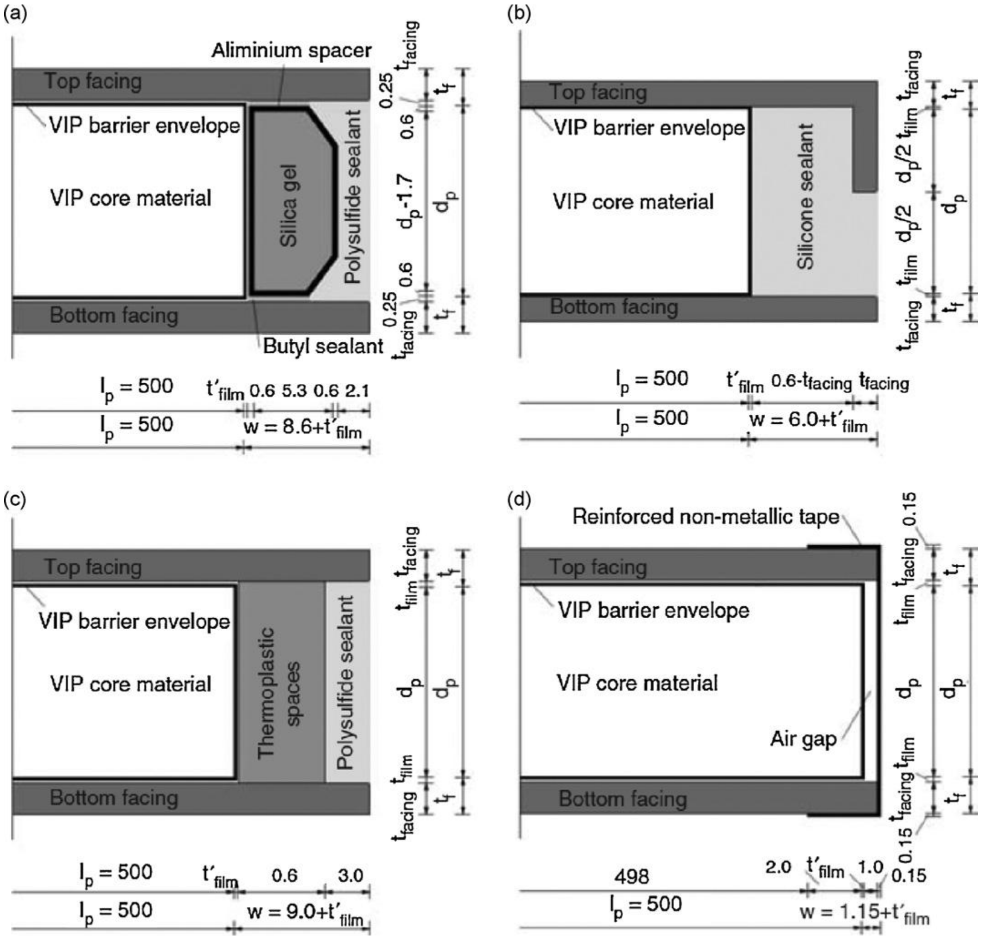
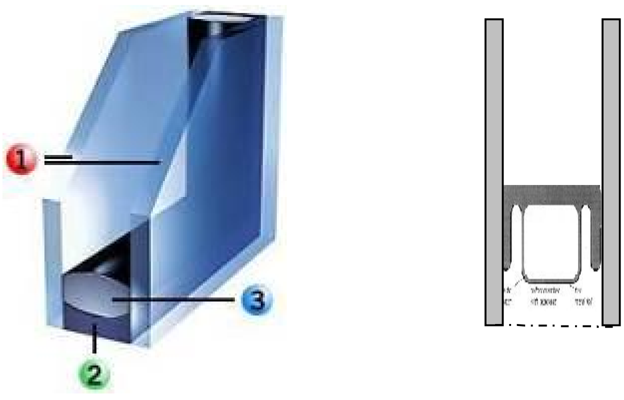


Figure 22: Four edge spacer construction types: (a) aluminium spacer of double glazing, (b) folded edge construction, (c) thermoplastic spacer and (d) reinforced non-metallic tape as in [6].



a b

Figure 23: Two example of thermo insulated spacers: (a) Tereson Henkel and Thermoplastic spacer and (b) Plastic spacer [16].

Figure 23 above presents two different plastic spacers leading to a significant reduction of the thermal bridge effect than in comparison with a metal spacer. The effect of the thermal improved spacer in comparison with a metal spacer is presented in Table 6 below, where it is shown the influence of replacing the alu spacer by a Trespa plate and how such a change leads to a reduction of the U-value for different panel size dimensions.

		U-value in W/m ² K	
Size	Packaging film	*Inner plate*	
		ALU 1.5 mm	Trespa 3 mm
1 x 1 m²	*ALU* *Mylar*	0.62 0.47	0.54 0.42
1.4 x 1.4 m²	*ALU* *Mylar*	0.5 0.39	0.44 0.35
2.0 x 3.5 m²	*ALU* *Mylar*	0.35 0.29	0.32 0.27
Outdoor Board: glass 6 mm VIP: 20 mm			

Table 6: Average U-values of sandwich panels with improved spacers [16].

Thermal bridges and other issues on the scale of the building

In general, structural thermal bridges have the biggest influence on the overall thermal performance of the assembly. The whole building element (VIP element) should be durable to withstand the basic load combinations (self weight, dead load, wind load etc.) as prescribed in national regulations. Beside the structural safety and overall stability also thermo-hygric behaviour (water intrusion) needs to be analysed. Studies on building details show that a special attention is needed to be brought to the joints and connections of VIP with other: higher chance of condensation damage due to possible low surface temperatures and air leakages [6].

3.1.4 Processing and implementation

Production of the VIP panels should be done with a similar amount of labour as for traditional insulation materials during the same time span. Presently, the manufacturing is still mainly hand-labour. It is important that VIP panels are not pierced or damaged during the production, transport, assembly (installation of the panels inside the building) and operation stage. Special measures should be taken when the product is installed in a harsh and/or outdoor environment in order to prevent the damage of VIP panels and therefore losing its performance qualities. If needed, relevant training of the construction workers on site should be done on how to install the VIP products. Easy replacement of poorly functioning VIP elements should be possible in case if high thermal properties of a specific VIP component are decreased (due to damage). As addressed earlier, possible thermal bridges need to be identified and properly solved (minimizing thermal bridges created by VIP application-building envelope, edge, spacer).

When using VIP as building insulation, acoustical properties are also important. As recognized by Baetens et al. [6], not much is known about VIP’s sound insulation properties. However, for the acoustical quality, factors such as sound absorption and noise banning for facade panels, and dynamic modulus for sprung floors should be addressed. The few studies done on acoustics performance of VIP by Lenz et al. [21], Cauberg and Tenpierik [22] and Maysenholder [23] showed that in general, due to the reduction of insulation thickness, acoustic performance needs to be improved with thicker and heavier facings in vacuum insulated (sandwich) elements.

The introduction of the vacuum insulation technology for space-saving constructions proved to be beneficial, however, due to the many identified weaknesses (and delicate system), a further development is needed. In order to improve the performance of VIP products and eliminate the main current drawbacks, new researches lead to a development of new solutions and insulation concepts.

3.2 Aerogel based products (ABP)

3.2.1 Aerogels properties

Aerogels present a second group of high performance thermal insulation products. Aerogels are dry gels with a very high porosity, high specific surface area and low density [5].

The first aerogels (silica aerogels) were made by S. S. Kistler in 1931 [24]. Later aerogels were produced on the basis of aluminium, chrome and tin oxide. Carbon aerogels were discovered in the 1980s. Nowadays, aerogels are produced by a sol–gel process followed by supercritical drying of the wet gel in an autoclave. Aerogels have a sponge-like, open-pore structure with a large inner surface. Silica aerogels stand for aerogels having a cross linked structure of silicon dioxide (SiO_2) and are the most commonly used aerogels. Usually, when the term aerogel product is used, it is referring to silica aerogels type of product. When using the term "organic aerogel", this normally refers to different aerogels composed by the organic polymers.

The main advantage of aerogels is reduced size of the pores and extremely low density, located between 0.0011-0.5 g/cm^3 (in comparison, the density of air is 0.0012 g/cm^3) [6]. Currently, this is the lowest density ever measured for a solid. The aerogels usually used have a density of 0.020 g/cm^3 or higher. Silica aerogels consist of cross-linked internal structure of $Si\text{-}O_2$ chains with a large number of air filled pores. The pores take from 85 up to 99.8 % of the total volume. Their porosity extends from about 1 to 100 nm, which is the reason why properly made aerogels can be highly transparent (refractive index of aerogels is between 1.0-1.05).

Figure 24: Transparent aerogel material (left) and example of aerogel blanket insulation (right; Aspen Aerogels).

Aerogels have very good thermal, physical, optic and sound properties due to its high porosity and small pore size. The thermal conductivities of commercially available state-of-the art aerogels (at the ambient pressure) are between 0.013-0.014 W / (m K) (approx. 2.5 times lower than traditional Rockwool insulation) [4]. The gaseous thermal conductivity can be reduced by decreasing the pore size and by adding the gas or vacuum in the aerogels [6]. At the pressure of 50 mbar, they can reach thermal conductivities as low as 0.008 W / (m K). By adding a component that suppresses the infrared radiation (e.g. carbon black), thermal conductivity can be decreased up to 0.004 W / (m K) [4]. The thermal conductivity of silica aerogels is not affected by temperatures coming up to 200 °C, however it is reduced dramatically with a slight intrusion of water. To prevent such degradation of the aerogel properties, the surface is treated for hydrophisation (CH_3) to remove the moisture.

Although they are load-bearing with high compression strengths, they have low mechanical and tensile strength which makes them fragile [6]. However, this can be improved by incorporation of aluminium silicate fibre or carbon fibre matrix. Aerogels can be produced as opaque, translucent or transparent, the desired optical property can be influenced during the sol-gel part of the synthesis process [25]. Silica aerogels consisting of $Si\text{-}O_2$ and a CH_3 hydrophone are non-reactive and non-flammable (depending on a type of aerogels: flame-retardant or fire-resistant).

3.2.2 Synthesis process

In general the aerogel synthesis can be divided into three main process parts where more complex synthesis process description can be found in the review done by R. Baetens [25].

1. Gel preparation: by traditional low-temperature sol-gel process;
2. Ageing: of the gel in its mother solution to prevent the shrinking of the gel during drying process and;
3. Drying: of the gel under special conditions to prevent the gel structure to collapse (supercritical and ambient pressure drying) [25].

3.2.3 Benefits and drawbacks of using aerogels

Currently, the state-of-the-art aerogel products show the highest potential among the novel high performance thermal insulation materials though the production costs are still high. Recently, the periodical *Science* has rated aerogels as one of the top ten scientific and technological developments.

Figure 25: Aerogel in its basic form.

As already described, the main advantage of the aerogels is their low thermal conductivity. Similar as for VIP, reduced thickness of the insulation (10-20 mm) is needed to reach the same thermal insulation performance of the building element as when using traditional insulation material (e.g. rockwool). Furthermore, since aerogels have high compression strength, they can withstand different mechanical surface loads (pressure). Under different load combinations, their thermal insulation performance stays intact (up to temperature of 200 °C).

In comparison with VIP, thermal bridging is not as significant with aerogels (especially when used as blanket like design). Aerogels are made of a single homogeneous material and therefore the heat flux through the material is continuous. Due to its flexibility and robustness, they can be cut and fitted on site which makes not only the installation process easier, but also allows more installation possibilities that can help in minimizing the thermal bridges.

The biggest disadvantage that halts a fast penetration of the aerogels on the market is the high cost. The production and aerogels synthesis process (super-critical drying process and needed equipment) is expensive and therefore currently aerogels cannot be competitive to the traditional insulation materials. However, a significant breakthrough was achieved by Aspen aerogels who developed aerogel form of a flexible blanket (their Spaceloft Product) [26].

Production process of aerogels takes a relatively long time period (±6 days) in comparison with the production of traditional insulation materials (e.g. mineral wool). When assembling the aerogel insulation products on site, the sheets can create fine dust which can cause certain level of throat and chest irritation. However, the International agency for Research on Cancer (IARC) classified synthetic amorphous silica as not carcinogenic [25]. Furthermore, when the surface is treated for hydrophisation (CH_3), CH3 hydrophobe can cause drying and irritation of eyes and skin if it comes in direct contact with the human. Therefore, proper protective clothing should be used (goggles, mask, gloves and coat) in order to reduce the risks mentioned above. Once the aerogel products are assembled on site, the risk is reduced to minimum (occupants not exposed directly to the surface of aerogel products).

Advantages	Disadvantages
Low thermal conductivity leading to a decreased	Expensive production process and equipment.

insulation thickness to achieve low U-value.	Relatively long production process.
Robust, bulk material (can be cut on site, less significant problem with thermal bridges, compression strength).	Possible health risks at exposure: can cause chest and throat irritation (should be treated with caution, workers wearing appropriate clothing).
Translucency and possible transparency (potential for window products).	
Non-flammable and non-reactive (suitable for building applications).	

Table 7: Advantages and disadvantages of aerogels.

3.2.4 Building applications

Aerogels used for building insulation applications can be categorized into two groups:

- Insulation materials only used due to the high thermal performance of silica aerogels (opaque products);
- Insulation materials which also use translucency and transparency properties: granular aerogel based translucent insulation materials or transparent monolithic aerogels [25].

Opaque products

Spaceloft product by Aspen Aerogels,

Aspen Aerogels, Inc from US seems to be currently a leading manufacturor in the field of aerogel insulation materials used for commercial products [26, 27]. Their innovative breakthrough solution presents a textile-like aerogel blanket (5 or 10 mm thickness, 0.013 W / (m K) at 0 °C) which is very flexible and this allows various insulation application possibilities (main insulation material, insertion in places where high chance of thermal bridges), can be cut on site and is relatively robust [5]. The reason for textile-like form lies in the production process where fibres are added to a pre-gel mixture which makes the product flexible instead of fragile as are the rest of monolith silica aerogels [25]. Hence, the main disadvantage of this product is still the high cost.

Figure 26: Aspen Aerogels Spaceloft blanket insulation product [26].

A case study by Aspen Aerogels [26], showed a 44 % reduction of the thermal transmittance which resulted in a reduction of 900 kWh/year energy use when a retrofit of a public housing apartments was done where they used the Aspen Aerogels insulation product (Spaceloft).

Two layers of Spaceloft aerogel insulation (2*10 mm) were placed together and were fastened to a building facing board. This was screwed directly into the internal surface of the building and the mounting process was twice faster than when comparing to the retrofit with traditional insulation material since no framing was needed. The total module had a 30 mm of thickness which consequently presented a cost-effective solution when taking into account the thinner final construction (second option would present three times thicker solution).

Figure 27: Aspen Aerogels Spaceloft aerogel used for building retrofit (wall insulation) [26].

Recently has Aspen Aerogels also engaged in the development of reinforced but highly translucent, monolithic aerogel panels for 'aerogel window' applications (still under development).

Cabot Corporation

Cabot Corporation is one of the main competitors to Aspen Aerogels in US, also offering silica-based aerogel products available in the form of flexible blankets or granular material. Granular translucent aerogel materials are in general much easier to handle since they can be poured like a powder. Cabot Corporation developed a family of silica aerogels under the trade name Nanogel (now Lumira) [28].

Figure 28: Cabot aerogel granulate filled Scobatherm glass fiber composite panels used for transparent daylighting roof construction application in the school Buchwiesen in Zurich (2003) as in [29].

Recently two eastern competitors Nano Hi-Tech from China [30] and EM-Power from Korea [31] started supplying sol-gel based super insulating materials.

Bluedec

Bluedec is a Dutch company producing aerogel-based insulation sheets (5 or 10 mm thick). Similar as Aspen Aerogels, Inc, they produce highly flexible sheets that insulate heat and cold 2 to 8 times better than other traditional insulation materials. Using patented nanotechnology, their insulation combines a silica aerogel with reinforced fibers to deliver industry-leading thermal performance in an easy-to-handle products. Their products are used in building industry (new buildings or retrofit: insulation of walls, floors, roofs, framing, and windows) [32].

Aerogel Composite

Another company from US Aerogel Composite, Inc. produces carbon aerogel supported platinum nano-composites, which are used as an electro catalyst in polymer electrolyte membrane fuel cells. The company's products are used as catalysts, electro catalyst for fuel cells, sensors, absorbents, and chromatographic packing.

Translucent products

Airglass A.B.

A Swedish company Airglass A.B. was one of the first manufacturers of aerogel filled double paned windows in the world [33]. The company is a contractor of the European project for the development of aerogels high insulating windows: HILIT+. They produce batch quantities of monolithic, crack-free and flat aerogel plates 60*60 cm^2 of 1, 2 or 3 cm thickness. The thermo-optical properties of the window are: low thermal conductivity (0.017 W/ (m K) under ambient conditions), high transparency ratio (TR of 90 %) and a very low extinction coefficient ($E < 10m^{-1}$) [33].

The HILIT+ window was developed in combination with the technology of vacuum glazing (pressure between 1-10 mbar). An overall U_{window} of 0.66 W/ (m^2 K) was measured for an evacuated glazing with 13.5 mm thick aerogel. Furthermore, a noise reduction of 33 dB was measured for the glazing. Increasing the aerogel thickness to 20 mm results in U_{window} of 0.5 W/ (m^2 K) while the solar transmittance stays 0.75 [25]. For a Danish climate (elaborated at DTU), simulations showed an energy saving of 19 and 24 % for 13.5 and 20 mm thick aerogels insulation respectively [34]. Due to scattering, the windows should be avoided direct sun therefore are HILIT+ windows more suitable for north facing windows (in EU). Furthermore, the processing of these silica aerogel plates appears to be difficult and the plates are mechanically weak.

Figure 29: Example of super-insulating aerogel glazing developed within the frame of the HILIT+ European project based on the use of silica aerogels plates from Airglass AB as in [34].

Okalux

Furthermore, two commercial types of such aerogel-based daylight systems (Scoba-lit and Okagel windows) are manufactured by Okalux [35].

ZAE Bayern

A granular aerogel based window was developed by ZAE Bayern in Germany where two types of granular aerogel were used: semi transparent spheres with a solar transmittance T_S of 0.53 for a 10 mm packed bed and highly translucent granulates with a T_S of 0.88. This granular aerogel is stacked in a 16mm wide polymethylmethacrylate (PMMA) double skin-sheet, between two gaps (i.e. of either 12 or 16mm in width and respectively filled with krypton or argon) and glass panes [29].

3.3 Gas Filled Panels (GFP)

3.3.1 GFP properties

A third type of SIM presented in this report is gas filled panels (GFP), which represent an opaque thermal insulation technology. Even though the GFP panels are one of the promising super insulation materials, there are not yet many available GFP commercial products that can be used in building insulation industry at the moment.

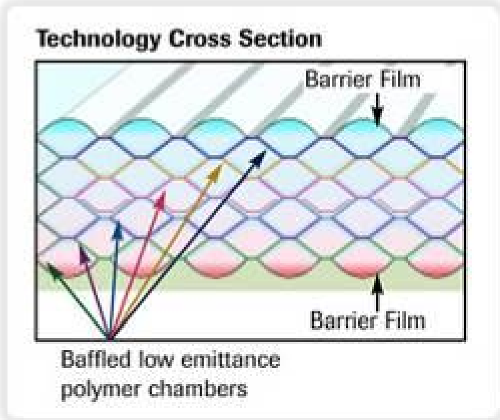


Figure 30: Structure of GFP (Fi-Foil) [3].

The panels consist of an outer (barrier) envelope and a gas filled in-between the reflective layers (baffle). The heat transfer for GFP is minimized by using low-conductive gases having lower thermal conductivity than air [6]. In general, gases that have low thermal conductivity have a higher molecular weight. Furthermore, mono-atomic gases (inert noble gases: argon, krypton and xenon) have even lower thermal conductivity compared to polyatomic gases with the same molecular weight [36].

The barrier panels are kept gas-tight by using low diffusion gas barrier foils. These panels can be made stiff or flexible and this depends on a type of foils used for the structure. Metalized films are used in a tied cellular structure (baffle) which suppresses convection and radiation. By constructing these chambers (low emissivity baffle structure), convective heat transfer of the gas and gas radiation are decreased. These metalized sheets constructing the multilayer cavities are relatively cheap on the market [36]. Low-diffusive gas barrier foil (envelope) helps to decrease radiation through the envelope.

The quality of GFP barrier is defined by their (inner) gas transmission rate where it is needed to distinguish between different types of gases. Still acceptable is 0.1 vol% per year of gas transmission loss [36].

Concerning the economic cost and the thermal performance, an optimal number of baffle layers is found by taking into account specific gas type filled in the chambers, thickness and temperature difference. According to studies and calculation model done by Baetens et al. [36], effective thermal conductivities for different GFP structures are presented in Table 8. The effective thermal conductivities are calculated according to the baffle thickness, number of cavities, thermal conductivity of the foil material and on the type of gas inserted.

Panel thickness	Effective thermal conductivity, λ_e [W/(m K)]		
	Air	Argon	Krypton
25 mm	0.0350	0.0213	0.0106
50 mm	0.0380	0.0226	0.0106

Table 8: The effective thermal conductivity λ_e for an optimal number of cavities based on the lowest marginal cost of the fabrication of the gas filled panels, adapted from Baetens et al. [6].

3.3.2 Benefits and drawbacks of GFP

As it could be recognized from Table 8, GFP panels achieve low thermal conductivity values. However, not many practical demonstration cases are presented on the market that would address the effectiveness, durability and practical usability of GFP for building applications.

Nothing is known about the effect of climate factors (chemical environment, thermal shocks, ultraviolet light, high energy radiation) on the polymer degradation inside GFP products. High temperatures and mechanical damage (pressure, nail penetration) can damage relatively fragile GFP and reduce their thermal qualities. To ensure handling of GFP, the panels should not be delivered as standalone solutions on the site but should be integrated as part of more durable and robust building elements [36]. However, no harm effects for home and building owners were found (no itchy fibbers, inerted gases (argon, xenon, krypton) are not harmful and safe for the environment) [3].

3.3.3 Building applications

Only one commercial product using this technology was identified: Fi-Foil [3], which is a product developed under the grant from the U.S. Department of Energy, researchers at the Lawrence Berkeley National Laboratory. As discovered during the review, the Lawrence Berkley National Laboratory is one of the leading (if not only) teams working in the field of GFP solutions for building applications.

The envelope (barrier) of Fi-Foil GFP panels consists of very thin layers of aluminium foil-laminate polymer and presents a critical component since maintains the filled gas and protect the structure from the intrusion of outdoor air and moisture. The baffle consists of five internal low-emitting films with an aluminium coating. When filled with gas, the structure can expand due to the flexible envelope (outer panels) with a honeycomb structure of approximately 38 mm. The sealed gas-tight inner cavities include gas filling which can be air, argon, krypton or xenon; high thermal performance achieved with noble gases (higher R-value). Figure 31 below shows different thermal resistance values of Fi-Foil GFP insulation panels according to type of gas inside the panels. Different tests done in accordance with international ASTM standards showed a good thermal performance (maintaining R-value) over a wide temperature range [3].

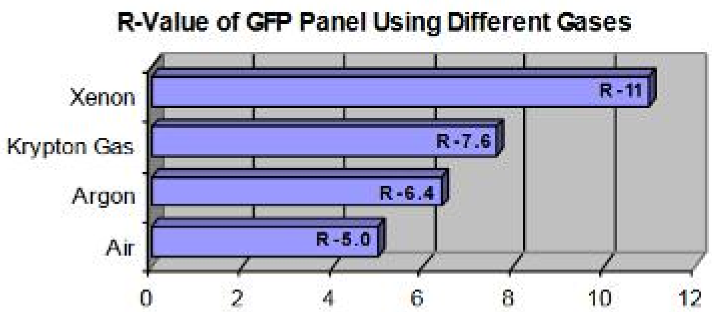


Figure 31: Thermal resistance (R-values) of Fi-Foil 1.5 GFP Insulation panels with different types of inserted gas [3].

The Fi-Foil panels have a certain degree of flexibility; they can be shaped according to the needs (different thickness and length). Usually they are applied in places with little or no potential mechanical damage (no direct exposure to additional loads). The Fi-Foil products can be used for insulation of buildings, construction elements (e.g. doors or facade panels) as for devices. With insertion of noble gases, there is no danger for emission of harmful gases and no dust or fibers are spread during the mounting process (as with aerogel based products). In addition, the panels are resistant to moisture and mould.

If the panels become damaged (for example by perforation), the high thermal performance is lost only in the damaged cells (now filled with air) and is not lost for the whole product. The panels themselves retain their thickness and their honeycomb structure.

Figure 32: Example of an application of Fi-Foil GFP's applied for the insulation [3].

A study done by Yarborough et al. [37] presented a full scale renovation of attic with air-filled and argon-filled panels (GFP). It was shown that only slightly lower thermal conductivity was obtained for argon filled panels (0.04 W/(m K)) than in comparison with air-filled panels (0.046 W/(m K)). However, GFP panels are much more expensive than air-filed panels. For more detailed description of the case study, it is referred to [37]. The GFP applicability for building sector (retrofit) is questioned when much cheaper traditional insulation leads to the same thermal performance.

4 Recognized risks and challenges when using SIM

Presented SIM solutions are facing certain risks that need to be recognized and addressed correctly and in this way mistakes and certain failures can be avoided once the SIM solutions are integrated as part of building elements during the building retrofit.

Currently, SIM are not truly competitive to the traditional insulation materials due to the high price of SIM products. It is believed that costs of the SIM solutions will be reduced in near future with a further development of these materials and new products will be offered presenting more cost-effective possibilities for building retrofit.

4.1 Durability and service life-span

The development of SIM technology is still relatively young and only during a last decade commercial products have been available on the market. Many SIM products are available as a part of the building system incorporating SIM insulation materials. Most of the reviewed articles and present research is focused on the analysis of super insulation material composition and their material (thermal) properties. However, not much is known about the long-term building applications of these products, their durability and their performance during building's operation (aging). This information is still limited and there is a need for more testing and evaluation procedures to prove the suitability of SIM for wider building application in practice.

The main issues identified for the 3 SIM categories:

- VIP: The maintenance and durability of the vacuum core:

Due to fragility, VIP products can be easily damaged leading to a loss of high thermal performance (loss of vacuum). The building components have a life-span of 30-50 years and therefore VIP products used for building applications should have better thermal properties through time. As a general rule, the pressure within a VIP (vacuum core) should not rise above 100 mbar after 30-50 years of operation [38], however, current products are more vulnerable for the penetration of outdoor gases (air) during the building's operation time span. It was noted, that most of the first applications of VIP covered integration of VIP as part of equipment and components having a relatively short life span. Nevertheless, VIP used in the building industry should have much longer life-span.

- Aerogels: The moisture behaviour of the material under different conditions:

Although aerogels themselves are resistant to moisture, little is known about the aerogel based products moisture behaviour under varying conditions and during a longer-time period (life span of a building component).

- GFP: Questionable usability and effectiveness of GFP for building applications:

There is currently one available commercial product on the market offering GFP solutions for building applications. However, more practical studies need to be done in order to see whether this new SIM technology presents better solutions than currently traditional building materials.

Presently, other two types of SIM solutions (aerogels and VIP) seem to present more promising solutions for building retrofit.

In particular, a new Annex of IEA (started in the middle of 2014, finishing in 2017); Annex 65 Long Term Performance of Super-Insulating Materials in Building Components & Systems is focusing on actual performance of SIM in building components and systems during time and under varying conditions.

4.2 Vulnerability

Due to the fragility of VIP panels and GFP, these SIM products are highly vulnerable to mechanical pressure and point loads (nail penetration, human force). This can result in decreasing or even losing the high thermal performance characteristics of these products.

However, for GFP a damage only in a certain area of the panels (nail penetration) means a loss of gas and therefore a loss of low thermal conductivity properties only in this particular area (inside damaged cavities now air). Normally, when SIM panels are damaged, this does not lead to a complete loss of vacuum. The thermal conductivity rises up to 0.02 W/ (m K) at the atmospheric pressure which is still better than most of the traditional insulation materials.

Aerogels are less vulnerable than VIP and GFP. However, depending on a type of aerogel based products (ABP), different level of fragility is applied. For example, textile-like form of aerogels (Aspen Aerogels, Inc) presents very flexible products where fibres are added to a pre-gel mixture which makes the product flexible instead of fragile. The rest of monolith silica aerogels are still fragile. Adding fibres during the synthesis process can be applied when a flexibility is desired. Higher silica content (up to 60 %) can also increase the strength and firmness of aerogels.

4.3 Thermal bridges

Possible thermal bridges should be analyzed closely and enough attention should be brought to the building details and connections, i.e. local thermal bridge effects (around reveals of window frames during retrofitting). High degree of insulation in combination with the thin insulation layer thickness can result in a challenge around the connections where it is increased heat/cold-flow. As recognized, with traditional insulation thicknesses it is easier to avoid thermal bridges, however the thick construction profiles are not desired due to space saving. The better the insulating ability (lower thermal conductivity of material), the stronger are the heat/cold-flow effects around the connection surfaces. This can result in reduced surface temperatures with increased risk of condensation if not properly tackled.

When using SIM in building applications, all connection details should be analyzed with calculation models taking into account three dimensional thermal bridges. For the calculations presented in Chapter 5, computational program TRISCO version 12.0 Physibel's was used. With this calculation program, 2 and 3-dimensional thermal bridge computations are possible according to:

- Thermal bridges in building construction: heat loss calculation, surface condensation (ISO 10211) /FDIS;

- Thermal transmittances of building components and elements (EN ISO 6946);
- Thermal performance of windows, doors and shutters (EN ISO 10077-2).

4.4 Costs of SIM products

Beside the overall thickness of the construction profiles and insulation thermal performance, one of the most important aspects when choosing building insulation is costs. Due to a relatively new development of SIM, these products still present relatively costly solutions that can hardly compete against traditional insulation products. However, they present cost-effective solutions where space saving is an important aspect during the planning of building retrofit.
Following Figure 33 presents a simplified relationship between insulation performance, cost and market share. It can be seen, that the traditional insulation products present most representative products used on the current market (best performance per unit cost) [29]. The developed super insulation products offer better thermal performance, however, at a remarkably higher cost. On the other hand, low-cost products present poor performance and durability insulation products for a very low price. It can be concluded that super insulation and low cost products have similar market shares. The red arrows symbolize the expected development of each area in the near future.

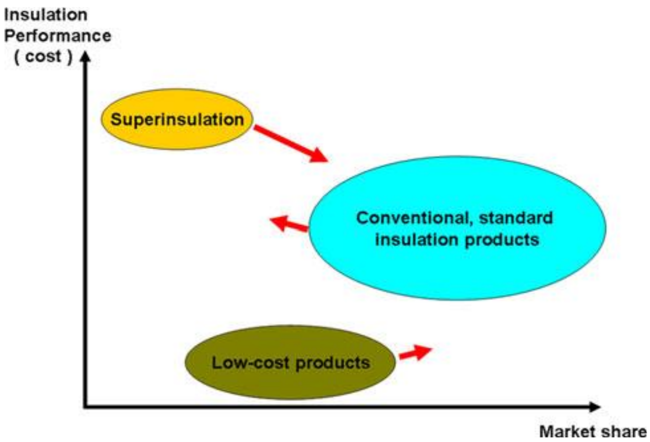


Figure 33: Market share displayed by cost and performance. The red arrows symbolize the expected development of each area in the future as in [29].

SIM solutions are often applicable due to achieving surprisingly low U-value of the building envelope with just few extra cm of additional insulation. This can result in lower building cost per m^2 and lower rental price per m^2 (especially in dense cities).

For the comparison, VIP panels are 5-10 times more expensive than traditional insulation products (mineral wool). Production process of aerogels requires expensive equipment and it takes relatively long production time period (approx. 6 days). Expensive devices in combination with the time-consuming process results in expensive ABP solutions: 1 m^3 around 3500-5000 €. Due to a lack of commercial products available in the field of GFP, the costs of the products at the European market cannot be compared. The prices of GFP depend on the type of filled gas. The estimated cost of GFP is located between the 600 € and € 700/m^3 based on argon filling.

It is expected that in next few years, the price of aerogel and VIP products for building applications will drop due to their high potential for retrofit (high thermal performance with space saving). The cost of the raw materials is not the main issue; what makes the SIM products expensive is currently the production process of the product. Optimization of the production process can therefore lead to a lower cost. A number of new FP7 research projects aims to achieve that by developing new concepts and alternative solutions (see Chapter 6).

Beside the investment costs, the energy savings obtained throughout the building life cycle should be taken into account (assuming the same life-span of the installed SIM product and the building).

Figure 34 below shows average annual costs when 50 years of operation is considered. It can be seen that with longer operation period (50 years) super insulation material can be competitive to costs of traditional material (mineral wool). It should be noted that around 30-50 mm of super insulation material is optimal thickness to achieve desired thermal performance (building envelope having lower U-value than 0.2 W/ m^{2}K).

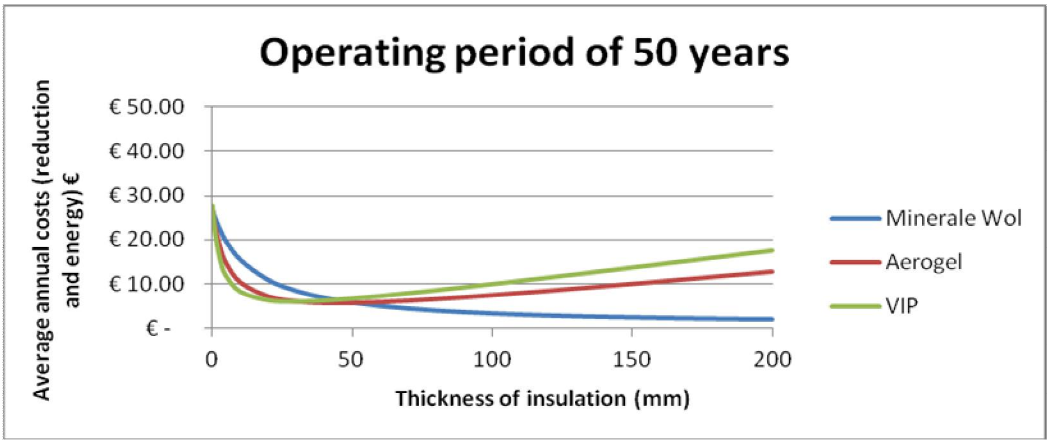


Figure 34: The life cycle costs for traditional insulation, aerogels and VIP.

The following table gives an overview of the relationship between the insulation costs, thermal conductivities and costs per thermal transmission resistance for the different insulation materials:

material	insulation-costs for d=100mm	thermal conductivity	costs per thermal transmission resistance
	e_{HI} [EUR/m^3]	λ [W/(m·K)]	$K_{R,spez}$ [EUR/m^2(m^2·K/W)]
glass wool 16 kg/m^3	88.44	0.036	3.18
glass wool 40 kg/m^3	155.10	0.033	5.12
glass wool 70 kg/m^3	168.30	0.034	5.72
glass wool 80 kg/m^3	237.60	0.032	7.60
mineral wool 32 kg/m^3	80.52	0.036	2.90
mineral wool 50 kg/m^3	146.52	0.036	5.27
mineral wool 75 kg/m^3	174.90	0.036	6.30
mineral wool 100 kg/m^3	232.32	0.034	7.90
expanded polystyrene 20 kg/m^3	135.96	0.037	5.03
expanded polystyrene 30 kg/m^3	217.80	0.035	7.62
extruded polystyrene 33 kg/m^3	373.56	0.032	11.95
polyurethane 30 kg/m^3 mat-clad	262.02	0.028	7.34
polyurethane 30 kg/m^3 alu-clad	279.18	0.024	6.70
polyurethane sandwich panel	302.94	0.023	6.97
foam glass 130 kg/m^3	345.84	0.040	13.83
wood fibre insulation board 170 kg/m^3	221.10	0.040	8.84
cellulose insulation board, 70 kg/m^3	135.30	0.039	5.28
cork 120 kg/m^3	303.60	0.042	12.75
coco fibre insulation board 66 kg/m^3	198.00	0.045	8.91
VIP A	4'290.00	0.008	34.32
VIP B	4'290.00	0.005	21.45
	e [EUR/m^2]	U [W/m^{2}K]	[EUR/m^2(m^2·K/W)]
glazing 2-IV	76.56	1.200	176.20

Table 9: Insulation costs, thermal conductivity and costs per thermal transmission resistance for various insulation materials (traditional and VIP) [39].

The Table 9 shows that the high costs of SIM products can be partly compensated by the good heat resistance. However, this table does not include costs for ABP and GFP products. The cost of Spaceloft products by Aspen Aerogels are approximately 3300 €/m^3 or 43 €/m^2. The cost of GFP (Fi-Foil product) is estimated to approximately 700 €/m^3 or 12.6 €/m^2.

In Figure 35, an integrated cost comparison between mineral wool and VIP is presented. It shows that the overall cost of mineral wool is similar to VIP costs when beside material costs also space cost is included.

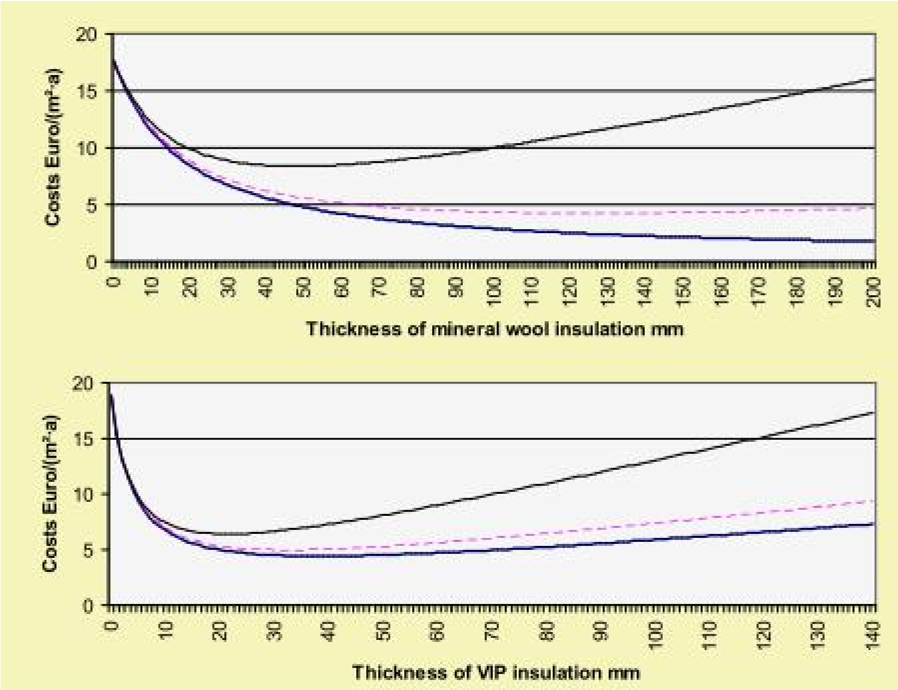


Figure 35: Optimal insulation thicknesses for mineral wool and VIP's including :

Only insulation and energy costs: ______________

Insulation, energy, land costs: _ _ _ _ _ _ _ _ _ _

Insulation, energy, land and building costs: ______________ as in [9].

Assumptions for this comparison:

Insulation on 15 cm brick wall;

Mineral wool: λ = 0.036 W/mK; life span 80 years, cost € 100/m^3;

VIP: λ = 0.008 W/mK; life span 50 years, cost € 4000/m^3 + 60 €/m^2;

Land cost: 400 €/m^2 (maximum utilization 0. 4 m ^{2}/m ^{2} land);

Space rental costs 200 €/(m^2 year).

5 Possible building application of SIM for retrofitting

5.1 Introduction

Further development of SIM products, improvement of their material properties and cheaper price are needed before the SIM will present common competitive products to traditional insulation.

Hence, there are several high-quality and reliable SIM products already available on the market that can be used for building retrofit and present cost-effective solutions where space saving is desired. Chapter 7 presents an overview of several manufacturers offering VIP based products that can be used for building applications.

VIP products present attractive solutions for renovation and retrofit. Especially for prefabricated modular renovation (MORE-CONNECT project), the SIM products present attractive possibilities and high exploitation potential. With prefabrication, super insulation materials can be integrated as part of a construction element (e.g. facade panel). In this way, vulnerable and fragile vacuum insulated panels (integrated as part of a construction element) are protected by the construction envelope (external surface of the module). Furthermore, the prefabrication and modular design also leads to a reduction of the production costs and several dimensions and sizes can be offered to the potential customer.

Subdivision according to the area of building application is done:

- Application for critical places, for example where the available space (thickness) is critical and limited;
- Application at (partial) interruption of insulation layer, for example by installation components in multifunctional building parts;
- Full application, for example in (prefab) façade panels.

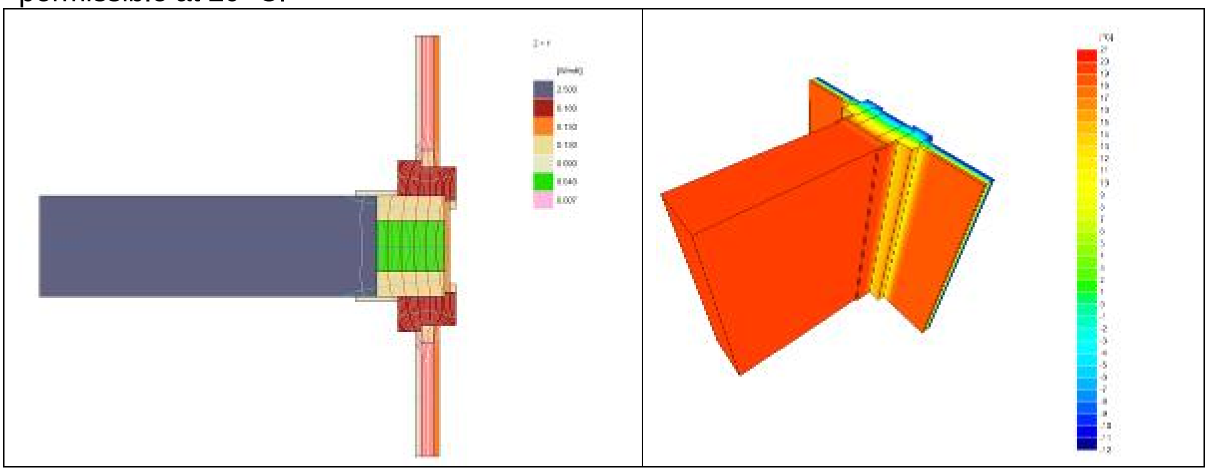
5.2 Application for critical places

Insulation of critical places where the thickness of the construction detail/profile is limited can be done by integrating SIM solutions. Those are the places where thermal bridges occur, such as reveals of window frames and beam edges. A common critical detail is shown in Figure 36 showing the connection of the window frame (outer wall) and the inner wall separating two adjacent apartments.

Figure 36: Example of a critical place where thermal bridge occurs (connection of outer wall with the inner wall separating two adjacent apartments).

Below is an example on how to solve such a critical detail. The first situation presents an insulation panel with cantilevered slabs applied. The temperature factor f-factor is 0.701, i.e. a maximum relative humidity of up to 56% is permissible at 20 °C (critical).

An insulation panel with integrated super insulation panel (λ for traditional mineral wool of 0.04 W/ (m K) changed to SIM having λ of 0.007 W/ (m K)) gives an increase in temperature factor (f-factor 0.796), i.e. a maximum relative humidity of up to 68% is permissible at 20 °C.



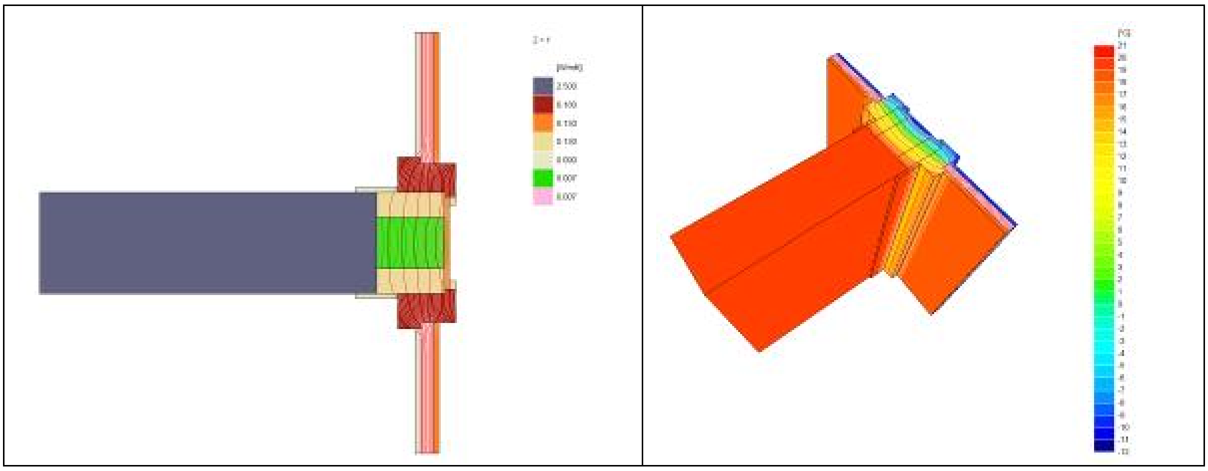
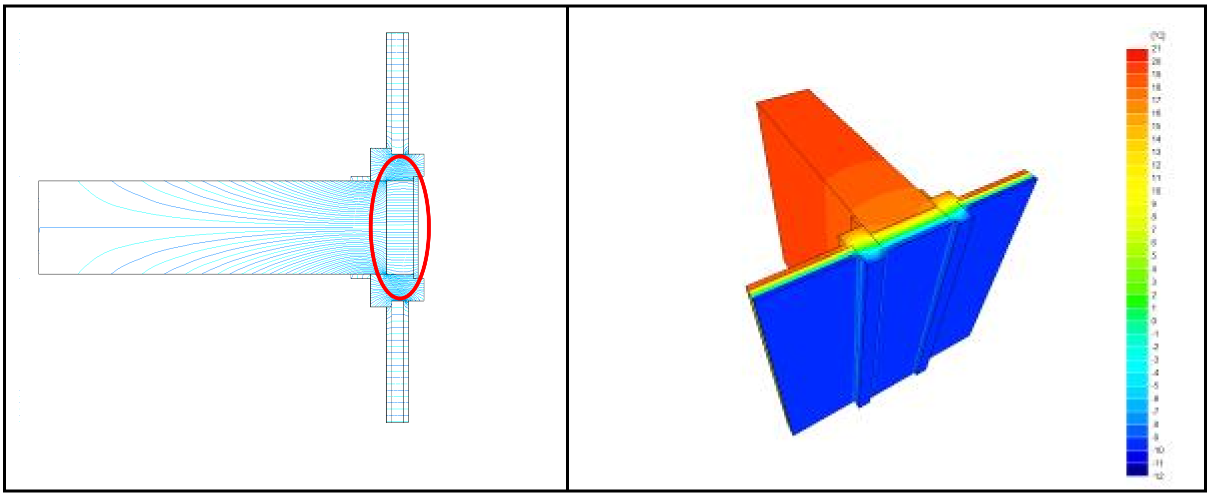


Figure 37: Thermal bridge and heat flow for wall detail without SIM (above) and with SIM (below).

Following Figure 38 shows a solution where a space between the outer facade and the separation wall is insulated for two alternatives (red marked circle). First solution (above) presents a traditional solution with conventional insulation (thicker profile). Second solution (below) shows insertion of SIM which requires a lower insulation thickness to obtain the same U-value of the connection detail. Now, the remaining area around the inserted SIM plate allows an inner insulated space where channels, pipes or other installations can be placed with a required level of insulation.



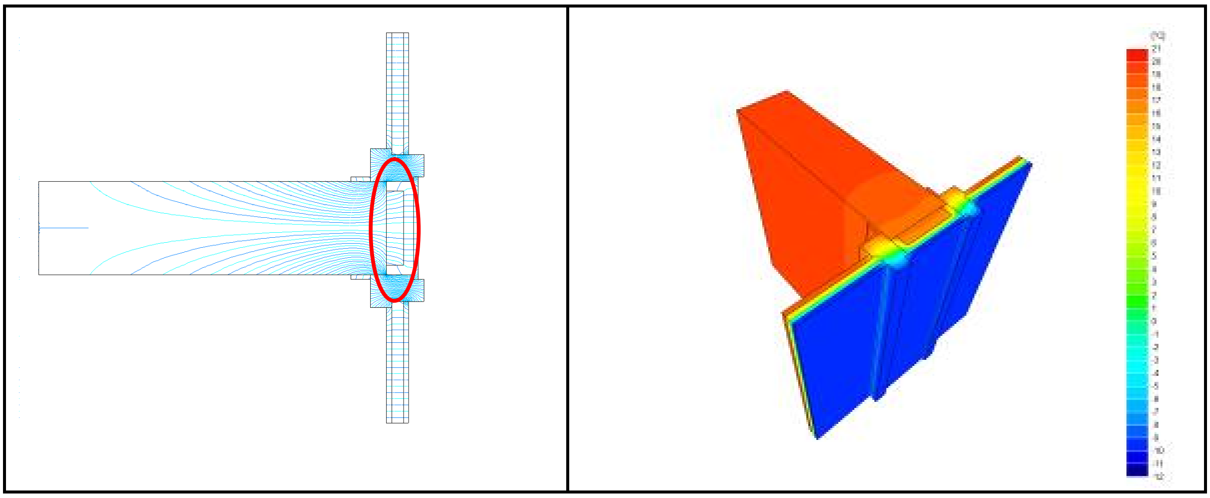


Figure 38: Two insulation solutions of connection detail. Second solution (below) presents inserted SIM plate where a space is created for installation components (pipes).

5.3 Application at break insulation layer

The aim of the Modlar project supported by the European Regional Development Fund (ERDF) was to present “one-stop shop” concept where the building owner chooses his renovation solutions that will lead to affordable energy neutral renovation of his building. The basic idea is that the renovation is paid by the energy savings over a period of 15years. New solutions and techniques in the field of smart and modular renovation were developed where super insulation materials play an important role.

In multifunctional building design, certain installation components are combined and integrated into building parts such as precast facades and roofs. The required space for the installations is accommodated by applying SIM insulation instead of traditional insulation. In this way, space saving is obtained and the unused area can be used for the ducts (for heating and ventilation system) which are built into the facade elements (MODLAR concept, see Figure 39).

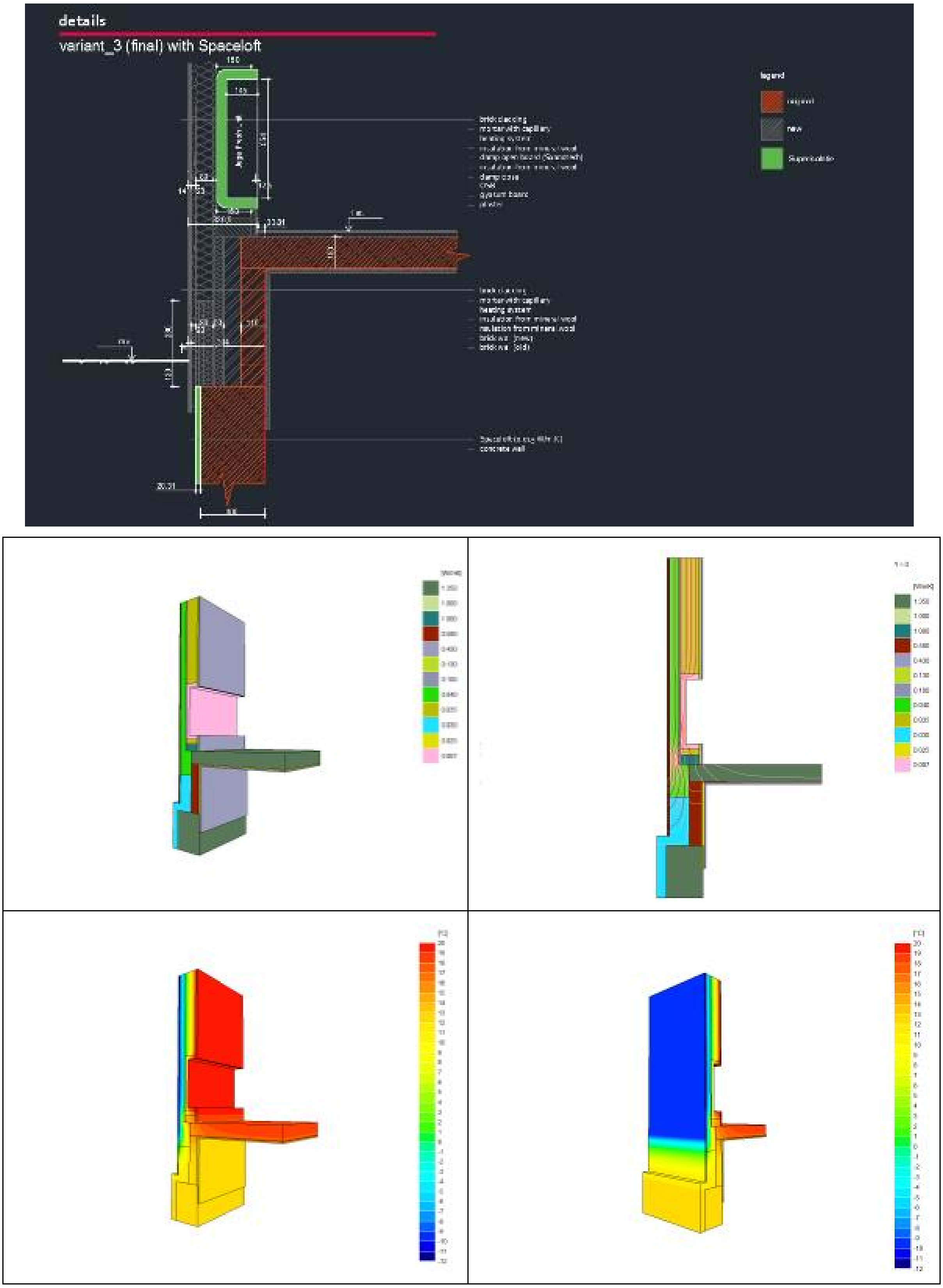


Figure 39: Improving R_c value when insulation break is solved with applying SIM.

The target value for the heat resistance of the prefab Modlar facades is $R_c = 6.0$ m^{2}K/W. For the façade elements having connections between convectors and ventilation units (Jaga), the thickness of the insulation layer is limited and the desired heat resistance of the Modlar facade R_c value may be achieved by applying SIM. By inserting VIP plate with a thickness of 3 cm or ABP (aerogels) with a thickness of 6 cm can be obtained such thermal insulation performance.

5.4 Full application

Total insulation of a building with SIM is almost always possible but needs to be balanced against the additional costs of the SIM products. When the available space is very limited, SIM can offer a cost-effective solution. An example of such potential renovation situation can be seen for the building type shown in Figure (apartment building with gallery flats).

Figure 40: Apartment building suitable for renovation with modular prefabricated facades.

Applying thick layers of insulation can be problematic for the retrofit of the building presented above (Figure 40), neither inside nor outside. Figure 41 shows a typical detail of a light panel from the 1960s where it can be seen that the available additional space (where insulation can be inserted during the retrofit) is only about six centimetres.

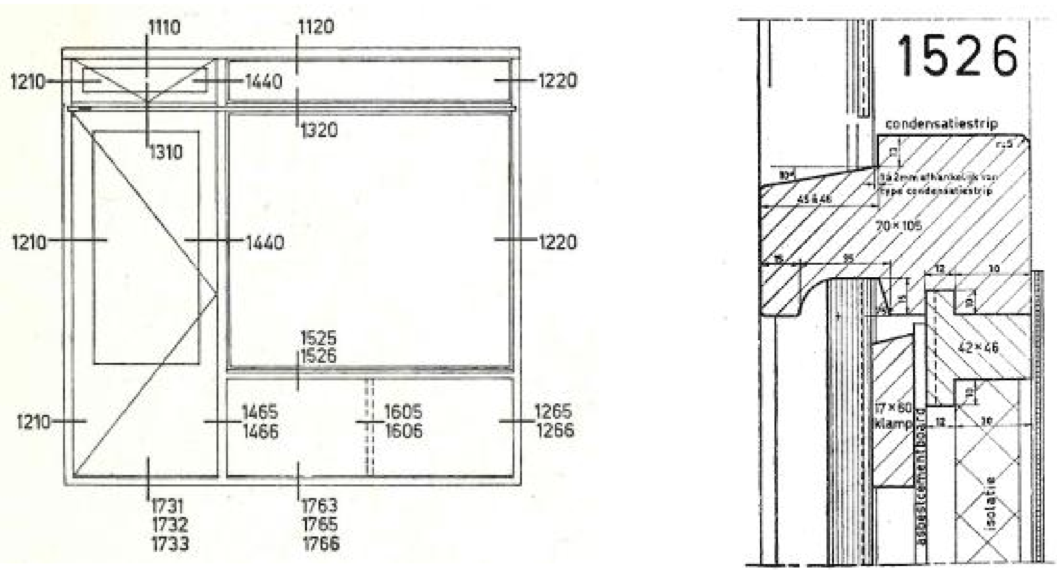


Figure 41: Standard detail of facade panels from 1960s.

With aerogel blankets (Spaceloft) having a thickness of 60 mm, a R_c value of approximately 4.5 m^2K/W can be obtained. Insertion of a VIP panel of 50 mm thickness can lead to a R_c value of over 7 m^2K/W. It can be seen, that high insulation performance can be achieved without additional loss of space. If modular prefabricated panels are done in the factory, VIP plates are protected against mechanical damage (direct pressure, nail punctuation) and therefore fewer risks appear during the assembly and actual retrofitting process.

5.5 Application in 3 D printing

Within the framework of the MORE-CONNECT project partner INVELA, Denmark developed the Robot At Work 3D facade solution on site with Multipor facade insulation system.
Robot At Work's 3D facade solution is a fusion of a known insulating material with a new finishing method performed by the robot, which makes it possible to create a 3D facade, with the focus on high quality building envelope.
The Mulitpor insulation panels is installed traditionally by craftsmen from the lift.

After this, Robot At Work's robot solution is performing the remaining work, such as trimming/ 3D milling and spraying plaster and facade paint, ending with a high quality finished building envelope, with or without 3D design.

Multipor insulation system is built on capillaraktive mineral Multipor insulation panels with associated system components.

5.5.1 Embedded system components

Facade insulation: Multipor - capillary active mineral insulation sheet of aerated concrete Lambda value: 0.045 W / mK and with a density of about 100-110 kg/m3 Thicknesses: 120, 140, 160, 180 and 200 mm.
Larger thicknesses can be specially produced depending on the design.

<u>Window frame Insulation:</u>
Multipor frame panels - capillary active mineral insulation panel of aerated concrete Lambda value: 0.045 W / mK and with a density of about 115 kg/m3 thicknesses: 20, 30 and 40 mm
<u>Base profile:</u>
Ytong Base profile - Plastic profile for the closure of Multipor insulation above ground.

Drip Nose profile:
Ytong Drip Nose Profile for drainage of rainwater away from the socket profile.

The alignment and glue of insulation:
Multipor Light Mortar - is an special mineral mortar for Multipor insulation system having a density of 0.77 kg/liter and a particle size up to 2 mm.

Corner protection:
Ytong Corner profile with net - for border protection of all outbound sharp corners and folding frames.

Dowels plastic fasteners:
Multipor dowels - System approved special dowels for extra security of Multipor insulation against wind uplift.

Reinforcing layer:
Multipor Light Mortar - same as above plus reinforcement fibers embedded of very high quality.

Facade plaster:
Ytong end plaster: mineral structure plaster for final rendering, with an average grain size of 1.5 mm.

Paint:
Ytong Facade paint white - Permeable Silicone paint.
Colour: White

All incoming components in Multipor insulation system MUST be from Xella.

5.5.2 Execution

The work must be performed by a trained Multipor Insulation Specialists or other qualified personnel who have experience with assembly of Multipor insulation system.
Robot At Work's robot must be controlled by qualified personnel from Robot At Work.

Preparation:
Do not work at temperatures below 10 ° C. Always work in the shade.
All retracted joints are filled with a suitable k/c mortar.
The surface must then be permeable, sustainable, clean and dry.
In the project the described base solution is performed, with either Ytong Socket and Ytong Drip Nose Profile, or XPS insulation applied to a suitable reinforced socket plaster. Multipor insulation should not be used below ground.

The insulation work:

Multipor Light Mortar is applied in a thin layer on the back wall. Afterwards the Light Mortar will be applied on the insulating boards with a 10 mm notched trowel.

The mortar is only glued at the back and NOT in the spigot- and bearing grout. Subsequently, the insulation is pushed into place, on the rear wall (across the adhesive stripes). Making sure that the plates are glued and in full contact with the back wall.

Apply also 10 mm. Multipor Light Mortar on both Multipor window frame plates and in the clearing before pushing the plates into place. DO NOT bond in spigot- and bearing grout.

5.5.3 3D design and surface grinding

After the gluing of the insulation panels is dry, the surface can be sanded and milled in 3D, with Robot At Work's robot solution.
Using a local lift where both craftsman and collaborative robot can work freely, the craftsman will be able to perform the desired design on the 3D surface by means of a control system which will guide him through all tasks needed.
Excess material from the grinding / milling will be sucked away and collected in big bags ready to be 100% recycled at Multipor.

After milling the desired design in 3D, Multipor insulation boards is fixed with Ytong dowels according to the project description. There should be no dowels in or near the panel joints. The dowel holes can leave small indentations
in the surface, these should be filled with Ytong light mortar immediately after fitting the dowels.
The surface after the filing of the indentations should follow the desired design. The surface is brushed free of dust.

5.5.4 Reinforcement and spraying

Robot At Work's robot solution will inflict Multipor light mortar with reinforcing fibers in one operation.
Employ a local lift where both craftsman and collaborative robot can work freely. The craftsman will be able to carry out the reinforcement layer on the surface by means of a control system which will guide him through all tasks needed.

Reinforcement layer is carried out with Multipor Light mortar and reinforcing fibers. The reinforcing layer will have an approximate total thickness of 7-10 mm. Ytong Corner profiles is installed manually on all sharp external corners and reinforced diagonally with Multipor Light mortar.

Furthermore Ytong Drip Nose Profiles is installed in all the base frames.

Finish rendering with 2-3 mm Ytong Final plaster white, which is also sprayed on with Robot At Work's robot solution. DO NOT use foamboard for further manual trimming and finishing touches.

Drying time: 1 day per. mm plaster on. 20 ° C

5.5.5 Surface

The surface can be finished with 1-2 layers of Ytong Facade paint and must always be kept permeable. Facade paint is sprayed like plaster layers with Robot At Work's robot.

5.5.6 Dimensions and tolerances

The surface should appear without holes with a smooth surface and with no unintentional dominant rough boundaries.

5.5.7 Overall description of benefits, traditional vs. robot solution

Robot At Work	Traditional performed
- New 3D design opportunities, cultural and social boost to the building and area. - Less hard manual labour on site. - The Robot performs mortar envelope on the 3D design which is not otherwise possible. - The Robot performs 100% compared to the craftsman 30% efficient work. - The envelope is performed with higher precision and with brand new control and quality assurance capabilities. Moist, temperature, weather etc. - No Scaffolding needed, less hazards to residents. - Direct communication from the Architect/ building control to the craftsman onsite.	- Traditional 2D/ even surfaces - Severe tough on craftsmen doing plaster work. - Many man hours spent on site. - Craftsmen works effectively 30% of the actual execution and 70% on logistics and preparation, etc. - Scaffolding placed long periods in the facade, even during bad weather.

6 New concepts, ideas and studies

6.1 Introduction

SIM present relatively new technology approach where the SIM products are most often developed for various high-tech applications. Application of SIM for building industry (new construction, retrofit) is most often not the primary area of SIM development; however, it does offer a particularly interesting market perspective with many advantages and application possibilities. Especially, when tackling the challenge to build energy neutral buildings.

A number of new innovative researches and development projects are focusing on solutions that can help elaborating energy neutral buildings, improve their production process and cost effectiveness and therefore deepen a long-term sustainability. New application possibilities focus mainly on the application of aerogels as a composite building materials and products based on aerogel granulate and powders. Examples include the application in mortars, paints and insulating materials themselves (for example, EPS).

Aerowool product from Rockwool presents a lightweight insulation board made by compounding aerogels granulates with mineral wool and resin based binders having thermal conductivity of 0.020 W/ (m K) [40]. Swiss Federal Institute for materials Science and Technology, Empa, together with the Fixit group developed application of high performance insulating plaster and rendering system where the render consists of more than 80 % silica aerogel granulate in volume and can be sprayed and applied on walls with conventional industrial machine based projection systems [41, 42]. Ratke [43] developed ultra lightweight concrete by mixing sand, cement and up to 70 % of silica aerogel granulate by volume achieving high mechanical strength and low thermal conductivity.

The European Commission supports several projects (under FP7: EU 7th framework programme) that aim to improve the super insulation practical application, improve their materials properties (fragility) and to gain more insight into SIM long-term performance and behaviour under dynamic conditions.

6.2 FP7 HIPIN

European research project HIPIN covered development of High Performance Insulation based on Nanostructure encapsulation of air (project ended in March 2015). In particular, the main objective was to develop cost-effective technology approach leading to a robust aerogel that can be used as an insulation material in buildings (coating).

This covered a development of new affordable building products based on aerogel (paint, plaster, panel) suitable both for retrofit as new buildings. HIPI Aerogel is based on sol-gel technology with high silica content (60 %) followed by a method for supercritical drying and surface treatment. The main objectives of the HIPIN aerogel process technology are:

- Manufacturing route to a robust silica aerogel;
- High silica content (58% silica) precursor;

- Cost-effective surface treatment for hydrophilic and hydrophobic silica (Separex);
- Optimisation of processes for incorporation into:
    - water-borne systems (paint, plaster);
    - composite polymeric matrix (panels).

The aim was to incorporate these aerogels granules into

- HIPIN plaster: having a λ value of 0.034 W/mK;

Figure 42: Plaster formulated with HIPIN aerogel.

- HIPIN Decorative Paint: having a λ value of 0.49 W/mK (standard paint 0.64);

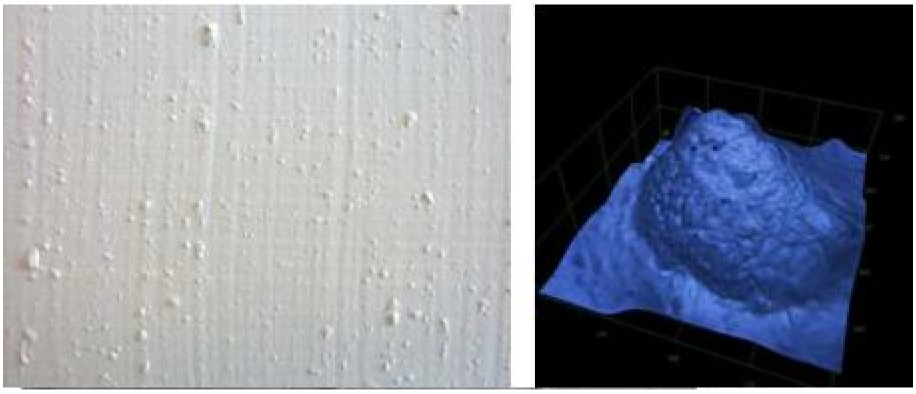


Figure 43: Appearance of hydrophobic aerogels in paint.

- HIPIN aerogel-based panels: having a λ value of 0.025 W/mK, approximately 25 % improvement compared to best EPS solutions available on the market;

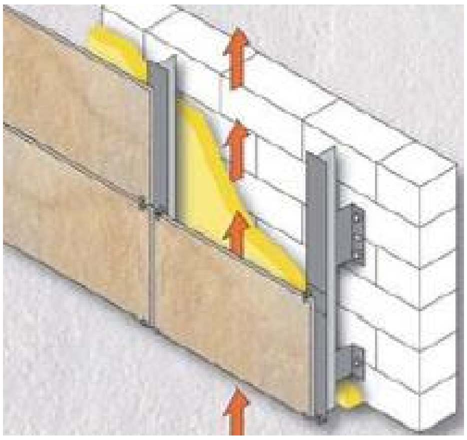


Figure 44: Mixing of EPS with HIPIN aerogels basis for the HIPIN aerogel based panels.

Techno-economic analysis showed that price of aerogels comes down with growing demand and by using less material for plaster (low U-value achieved with less thickness). Furthermore, lower costs are calculated for the transportation and application (even though the material itself more expensive than the traditional plasters).

Website: http://www.hipin.eu/ [44] (Final presentation can be found on the website.)

6.3 FP7 NANOINSULATE

NanoInsulate project focuses on a development of robust, durable and cost-effective opaque and transparent vacuum insulation panels (VIPs) incorporating new nanotechnology-based core materials (such as nanofoams, aerogels and aerogel composites) and high-barrier films. The overall goal is to produce vacuum insulation panels that are up to six times more energy efficient than current solutions.

Initial building simulations based on the anticipated final properties of the VIPs indicate reductions in heating demand of up to 74% and CO_2 emissions of up to 46% for Madrid, Spain and up to 61% and 55% respectively for Stuttgart, Germany for a building renovation which reduces the U-value of the walls and roof from 2.0 W/m.^{2}K to 0.2 W/m.^{2}K [45].

According to the project website, this reduction could be achieved with NanoInsulate products only 25 mm thick, giving a cost-effective renovation without the need of changing all the reveals and ledges. Similarly, significant reductions in U-values of transparent VIPs (from 3 W/m^{2}K to 0.5 W/m^{2}K) are shown by substituting double glazed units in existing building stock [45].

Website: http://www.nanoinsulate.eu/ [45]

6.4 FP7 AEROCOINS

AEROCOINS project focuses on a development of new super-insulating aerogels and their widespread integration into building industry. The main technical and scientific goal is to optimize the chemical processes for the preparation of super-insulating base of silica aerogel-like materials for mechanical reinforcement and to promote multi functionality without compromising the very low thermal conductivity. The goal is to overcome the two major obstacles that prevented a wide use of silica-based aerogel insulation components in the building industry [46]:

- Strengthening of silica aero-gels by cross-linking with cellulosic polymers or the incorporation of cellulose-based nanofibres;
- Lowering the production cost of monolithic plates or boards of composite/hybrid aero-gel materials via ambient drying and continuous production technology.

This leads to [46]:

- the development and optimization of a robust and efficient subcritical ambient drying process of super insulating aerogel based materials;
- production of robust and highly efficient super insulating aerogels plates and building components (design, scale-up and manufacturing);
- the design and manufacture of new super-insulating building components for the renovation;
- demonstrating and validating the cost reduction of the developed products .

Website: http://aerocoins.eu/ [46]

6.5 FP7 FOAM BUILD

The FoAM-BUILD project covers a development of Functional Adaptive Nano-Materials and Technologies for Energy Efficient Buildings. It is focusing on a development of thermoplastic particle foam using newly developed raw materials, additives and process set-ups. A nano-scaled structure is used for the particle foam cell morphology in order to achieve the targeted insulation behavior. The project covers also development of new polymer blends and nano-scaled nucleating agents in combination with a new high pressure drop rate expansion process in order to obtain the nano-cellular foam. The objectives of the project as described on the project's website [47] are:

- Higher insulation properties than conventional insulation materials; 50% lower thermal conductivity.
- Cost and energy-efficient, industrial-scale processes that are used for EPS production.
- Recyclability (100% of the foam due to thermoplastic material).
- Same properties as conventional ETICS (ETAG 004) in terms of insulation properties, mechanical resistance and stability health environment etc.

During the project, the new particle foam will be implemented into insulation panels that are lighter, thinner and more cost-effective than conventional panels. Active monitoring and control of moisture: a control system will be developed based on a sensor network to measure moisture and liquid water [47].

Website: http://www.foambuild.eu/ [47]

6.6 IEA EBC Annex 39: High Performance Thermal Insulation (HiPTI)

Annex 39 [12, 39] was the first international research that was focusing on improving thermal insulation properties by lowering the thermal conductivity of the insulation material. Such approach could enable more efficient building retrofits if the insulation thickness is effectively be reduced. The development of HiPTI is particularly important in situations where the available space for additional insulation is limited, for example in the case of renovation, for underfloor heating, doors, flat roofs, interior insulation, window extension, installations and pipes.

The general objective of the project was to develop reliable components for buildings based on HiPTI (High Performance Thermal Insulation). 'HiPTI systems' (e.g. façade elements, doors, water heaters etc) should cover building products that present competitive products, having high exploitation potential and are available on the market. The technologies presented in the Annex 39 are mostly focused on Vacuum Insulation Panels (VIP), which consist of a nanoporous core material, packed in a gas tight envelope that has been evacuated to a pressure of less than 1 mbar [12, 39 In conventional thermal insulation is dominating the heat transfer by gas. To reduce this, the energy transfer between gaseous molecules should be reduced. This can be achieved by reducing pore size, reducing the air pressure or replacing it with heavy gases (argon, krypton or xenon).

Annex 39 is divided in three research areas [48]:

- Basic concepts and materials
- Practical application and system development
- Demonstration and dissemination of knowledge

Website: http://www.ecbcs.org/annexes/annex39.htm [48]

Downloads:

- Vacuum Insulation Panels-Study on VIP Components and Panels for Service Life Prediction or VIP in building Applications
- Vacuum Insulation in the building Sector-Systems and Applications
- Vacuum Insulation: Panel Properties and Building Applications – Summary
- High Performance Thermal Insulation Systems-Vacuum Insulated Products (VIP) Proceedings of the International Conference and Workshop

6.7 IEA EBC Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components & Systems

The new generation of super-insulating materials (VIP, ABP, GFP) is slowly finding its way to the building insulation market. The available SIM commercial products present attractive alternatives that can significantly reduce the final thickness of the construction profile (compared to traditional insulation). However, in addition to excellent insulating properties, these products are available at high costs and their long-term durability and behaviour under different working life conditions (high temperature, humidity, deformation etc.) is not yet well investigated.

The main purpose of Annex 65 is to develop necessary knowledge, tools and networks to improve confidence of end users regarding super insulating materials and to foster a wider public integration in the near future. The annex focuses on investigating long-term benefits and risks of the super-insulating products available on the market and to develop guidelines of appropriate applications of SIM and their installation methods [49].

Website: not yet available.

7 Products available on the market

This chapter presents a number of manufacturers who nowadays offer commercial SIM products. However, it should be noted that SIM (VIP, Aerogels and GFP) technology is still under development and new improved SIM products are being developed constantly. Therefore, this state of the art review should soon be updated with the new market products.

7.1 Aspen Aerogels Spaceloft

Aspen Aerogels, Inc has been manufacturing Aerogel materials since 2004. Aspen Aerogels has developed a product where fibres are integrated during the synthesis process of aerogels making the end product (text-like blanket) more flexible and less fragile. Their products meet low thermal conductivity values, breathability (no damp), good performance with aging (50-60 years of reliability) and good fire safety (non-combustible; Spaceloft PET fibres: Euro fire class C, s1, d0 and Pyrogel Glass fibres: Euro fire class A2, s1, d0). Their products are vapour permeable but hydrophobic (in accordance with EN ISO 846, mold growth =0). Their products are normally applied in buildings: roof, floor and terrace, eliminiation of thermal bridges and for protection of the internal heritage [50, 51].

Spaceloft is a very strong, durable, thin and flexible material as it can be seen from figure below. It has a thermal conductivity of 0.0131 W/ (mK) and is 2 to 4 times better than traditional insulation materials. Spaceloft comes in thicknesses of 10 mm and R_c value of 0.763 m^2K/W.

SPACELOFT

Spaceloft is ideal for renovation applications where preservation of the usable floor area is essential (minimal space loss) and there is a limited disturbance of the residents. Spaceloft has payback of about 5 to 12 years depending on the specific application situation. Two options are available:

- Cryogel for applications where a damp-proof construction is desired;
- Pyrogel for fireproof designs (application to 650^{0}C).

The following properties have been recognized for Spaceloft product [51]:

- Low thermal conductivity λ of 0.0131 W/m.K.
- Very good fire safety
- Moisture and mould resistant
- Non-absorbent and liquid repellent
- Low energy and CO_2 emissions production
- Durable
- Easy and fast mounting, easy processable
- Available in mats with thicknesses of 5 or 10 mm

- Available in damp open, dam close and fire/heat-resistant implementation
- Suitable for insulation of all types of installation components such as channels and pipes, boilers, fittings.

PYROGEL

Pyrogel presents another product produced by Aspen Aerogels suitable for high temperature applications (insulating pipes, equipment, tanks etc.). Pyrogel XT-E presents a high-temperature insulation blanket that is formed of silica aerogel and reinforced with a non-woven, glass-fiber batting.

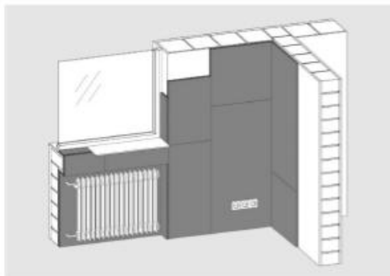
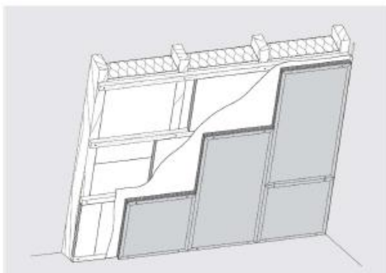
Website: http://www.aerogel.com/

7.2 Rockwool Aerowool

Rockwool is specialized in rock wool insulation products and has developed the product Aerowool as an interesting hybrid form of rock wool and Aerogels, having a lambda value λ of 0.019 W/ (m K). The first application of Aerowool was offered in combination with a drywall and a vapour barrier, under the name Aerorock. Aerorock presents a solid board with a glass veil on both sides, containing stonewool fibres, aerogel and binder. It is specifically developed to be applied where (extra) insulation on the inside part of the structure is needed. The product is certified according to Euro fire class B, s1, d0 [50, 52].

Products for indoor insulation [52]:

- Aerorock ID-VPL is used for window reveals and radiator niches (L x W x T = 1200 x 60 x 20 mm^3)
- Aerorock ID-VP is available as a standard board in dimensions L x W x T = 1200 x 600 x 30 (50) mm^3.
- Aerorock ID-VPK is used as a wedge board for linked walls and ceilings L x W x T = 1200 x 600 x 26 (14) mm^3.

Following properties are known for Aerowool products [52]:

- Unique combination of the mineral wool and aerogel properties in a single insulation product
- Very good thermal insulation: thermal conductivity $\lambda = 0.019$ W/(mK)
- Low insulation thickness, used for extremely thin structures
- Pressure resistant insulation material
- Space-saving and efficient
- Easy to process
- Available in thicknesses of 20 and 50 mm
- Not suitable for insulation of channels and pipes, water heaters; (though possibly for flat installation parts).

Applications:

- Wilhelmshaven, Germany: Restaurant Pier 24 [50];

- Baden Baden, Germany: parish office [50]:

About the product:

http://www.rockwool.com/about+the+group/media/corporate+news/news+viewer?newsid=2995

7.3 Kingspan insulation

Kingspan Insulation presents a leading UK producer of high performance rigid insulation products and building insulation systems. The products including VIP technology are known under the name: OPTIM-R and premium performance rigid insulation under the name Kooltherm (having λ of 0.018 W / (m K)).

The Kingspan OPTIM-R External Wall System provides solutions for external walls where insulation thickness is an issue and high thermal insulation can be achieved with thin elements due to te thermal conductivity of 0.007 W / (m K). This product is available in length 300 – 1200 mm, width 300 – 600 mm and thickness 20 – 60 mm [53].

OPTIM-R comprises a rigid vacuum insulation panel which is evacuated, encased and sealed in a thin, gas-tight envelope, giving outstanding thermal conductivity and the thinnest possible solution for insulating external walls. The vacuum insulation panels accompanied are protected by rigid insulation infill panels which can be cut to fit around penetrations, reveals and where fixtures and fittings need to be installed.

These products are suitable for insulation of walls (cavity, solid), roofs (pitched, flat), framing (timber, steel), externally insulated cladding system, externally insulated render systems floors and also insulation of ducts [53].

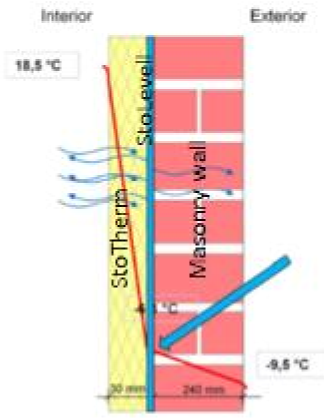
About the product: http://www.kingspaninsulation.co.uk/Products/OPTIM-R/OPTIM-R-External-Wall-System/overview.aspx

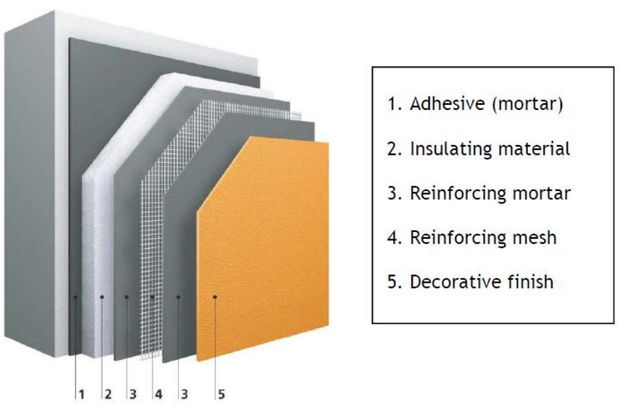
7.4 StoTherm In Aevero

The manufacturer Sto developed a superinsulating board that consists of aerogels in corporation with Cabot. The product EIFS/IIFS Sto (Exterior/Interior Insulation Finishing System) consists of an aerogel core with fibreglass on the sides serving as a protection of the aerogel core. IIFS (Interior) system is specifically designed for the indoor insulation of buildings and is particularly suitable for renovation.

Sto Aevero insulation boards are available in dimensions L x W = 580 x 390 mm and in thicknesses of 10. 15, 20. 30 and 40 mm. The side boards' main functionality is to ensure a good attachment to a rougher structure with the adhesive mortar and reinforcement.

The challenging issue is the water uptake. As seen in figure below, insulation may take up moisture in case of open IIFS. Hence, Sto Aavero unlike other diffusion open systems, stay drys by not being not capillary active which present a quite innovative solution.





The sheets can be easily applied and simple cutting (no special tools) on site is possible.

Following properties apply to their products [54]:

- High quality Aerogel-based insulation board with λ = 0.016 W/(mK)
- No need for a vapour barrier
- Pressure resistant insulation material
- Effective space saving
- Matching system components
- Easy to process
- Available in thicknesses of 10 to 40 mm

Applications:

- Solving window detail (possibility of curved reveals) [50]:

- With other capillary active systems [50]:

Website: http://www.stocorp.com/

7.5 Aerogel-based rendering (Fixit)

Aerogel-based rendering is the name of a technique that insulates the building with the insulating plaster on the outside. It is a technique used by EMPA in Switzerland and has been specially developed for insulating historical buildings where it is important that the appearance of the building stays the same as much as possible. The basis for this technique is a mixture of aerogel granules with a mineral binder. They are available in layers of 20 to 60 mm. The first tests showed that the mortar could reach a thermal conductivity of 0.025 W/mK. The currently available product on the market by Fixit produced by this technique has a thermal conductivity of 0.028 W/mK [50, 55].

This material is relatively soft and should therefore be finished with a protective low reinforcement layer of 8 mm applied on the insulation stucco layer. The fine plaster (stucco) can be applied either by hand or mechanically by spraying technique.

Although the technique was initially developed as outdoor insulation of buildings (historic) it can be also applied indoors. Another interesting application is insulating thermal bridges at balconies and galleries.

Features [55]:

- Product was recently offered on the market by Fixit
- $\lambda = 0.028$ W/(mK)
- Water repellent
- Acoustic dampening
- Non-combustible and heat-resistant
- Resistant to algae, fungi by the mineral components
- Available in thicknesses from 20 to 60 mm, applied both manually and mechanically (painting)

Company website: http://www.fixit.ch/aerogel/?w=start&lng=en

7.6 Poroxtherm

Porextherm is one of the leading companies in the field of micro porous insulation materials and silica based VIP. Their VIP products are available on the market under the product names Vacupor or Vacuspeed. Vacupor can be used in different forms, dimensions and finishes with a choice of different protection layers [56].

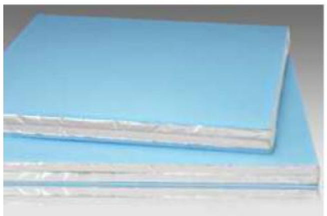
There are five product types available:

- Vacupor ® NT-B2-S: standard B & C VIP, unprotected

- Vacupor ® RP-B2-S: protected with rubber granulate mat, mainly floor applications

- Vacupor ® PS-B2-S: protected with an EPS layer, mainly wall applications

- Vacupor ® XPS-B2-S: protected with an XPS sheet, mainly for finishing of reveals of window frames and Tambour door cabinets



- Vacupor ® TS-B2-S finished with a sound-insulating layer in particular, floor and ceiling applications

Vacupor has summarized following properties:

- All types have a λ = 0.007 Vacupor W/(mK)
- Vacuspeed has a λ = 0.693 W/(mK)
- Plates can be cut in various desired dimensions and shapes
- Specific example details of different applications on URhttp://www.bau-vip.de/en/download-invitation-to-tender-text.html
- Pressure resistant insulation material

Company website and their products: http://www.porextherm.com/en/products.html

7.7 Variotec

Variotec is a medium-sized company that in recent years got recognized for their passive house construction techniques and products. Among other, Variotec produces VIP under the name QASA. Several different variations are offered according to different shapes and dimensions [57].

The VIP panels are available with a core thickness from 10 to 50 mm. The corresponding U-value lies between the 0.625 W/m^{2}K (10 mm) and 0.137 W/m^{2}K (50 mm). Plates are placed in a specific pattern and the seams are finished with tape.

Variotec also offers passive door and window systems equipped with VIP panels The U-value ranges from 0.63 to 0.94 W/(m^{2}K), depending on the size and thickness of the doors.

Following properties are known for Variotec products [57]:

- Variotec VIP panels λ = 0.007 W/(mK)
- Available in core thicknesses of 10. 15, 20. 25, 30. 40 and 50 mm

VIP-Dicke	Lambda-Wert VIP	Gesamt-Dicke	U-Wert VIP
VIP 10 mm*	0,007 W/(mK)	16,5 mm	0,625 W/(m²K)
VIP 15 mm*	0,007 W/(mK)	21,5 mm	0,432 W/(m²K)
VIP 20 mm	0,007 W/(mK)	26,5 mm	0,330 W/(m²K)
VIP 25 mm	0,007 W/(mK)	31,5 mm	0,260 W/(m²K)
VIP 30 mm	0,007 W/(mK)	36,5 mm	0,220 W/(m²K)
VIP 40 mm	0,007 W/(mK)	46,5 mm	0,170 W/(m²K)
VIP 50 mm	0,007 W/(mK)	56,5 mm	0,137 W/(m²K)

- Plates can be cut into the desired dimensions and shapes
- Specific example details of different applications on URhttp://www.bau-vip.de/en/download-invitation-to-tender-text.html
- Pressure resistant insulation material

Company website: http://variotec.de/hp358/Startseite.htm

7.8 Microtherm

Microtherm is a world leader in the field of specialized micro porous insulation materials production, used both in extreme and ambient temperatures. Although Microtherm specializes in high-quality insulation, high temperature and special industrial applications, they recently put on the market products used in construction industry, in particular integration of VIP panels into building construction elements (façades, coverings of reveals, balconies and doors). New concepts and products are currently under development in a partnership with Promat International within the new business unit Promat High Performance Insulation [58].

Microtherm:

http://www.microthermgroup.com/low/EXEN/site/hightemperature-insulation.aspx

Promat in collaboration with Microtherm:

http://www.promat-hpi.com/en-us/technologies/overview

7.9 Weber

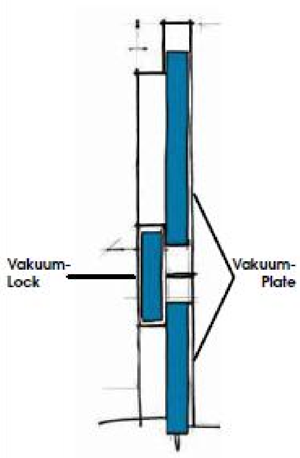
Weber is part of the Saint Gobain Group and is particularly known for mortar products.

In 2014, Sodamco Weber presented a solution for external wall, insulation system on patented super insulating mortar, super insulation mortar. This products has several advantages: fire resistance, high durability, weatherproof, absence of hollow sound and good sound insulation.

Weber also brings outdoor insulation systems on the market under the name ETICS: External Thermal Insulations Composite Systems, where mostly EPS is incorporated. New development has been done by Weber-Terranova, Czech Republic, where a product was developed where instead the EPS plate, a plate of 10 mm VIP was used. The U-value of such panel was found at 0.15 W/m² K. The plates can easily be mounted (bonding on surface). Because the VIP plates are fully integrated in the construction, the risk of damage due to outdoor factors (pressure, punctuation) is decreased [59].

Weber presents several case studies (link below) on how to renovate historic buildings where better insulation properties are achieved having the almost the same aesthetics:

http://weber-cultural-heritage.com/external-insulation-masonry-facades



Company website: http://www.e-weber.com/

7.10 va-Q-tec

Va-Q-tec offers vacuum insulation panels for construction applications which are fire resistant (inflammable; Construction materials class DIN 4102-B2). There are different modifications done according to the aim of application: va-Q-vip B, va-Q-vip F, va-Q-vip EPS and va-Q-vip GGM. All four building applications have rectangular edges and corners obtained through an edge folding technique "va-Q-seam" which allows joining the elements almost seamlessly. All 4 applications can be used for for interior insulation applications for ceilings, walls, floors, flat roofs, top floor ceilings, exterior insulation behind panelling or insulation in wood frame constructions [60].

va-Q-vip B

Va-Q-vip B is covered in a high barrier film and an additional black glass fibre textile for mechanical shock protection.

va-Q-vip F

Va-Q-vip F can be used for interior insulation applications of ceilings, walls, floors, flat roofs, top floor ceilings, exterior insulation behind panelling and insulation in wood frame construction.

va-Q-vip F-EPS

va-Q-vip F-GGM

Va-Q-vip GGM was designed especially for its application on flat roofs, terraces and floors.

Company website: http://www.va-q-tec.com/en/

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