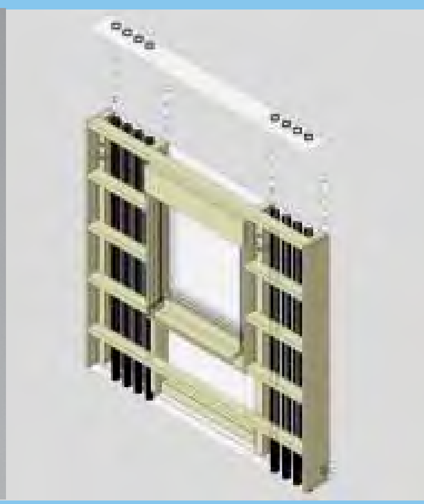
IEA ECBCS Annex 50
Prefabricated Systems for Low Energy Renovation of Residential Buildings

Retrofit Module Design Guide

March 2011


International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

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Retrofit Module Design Guide

March 2011

This report documents results of cooperative work performed under the IEA Programme for Energy Conservation in Buildings and Community Systems, Annex 50 “Prefabricated Systems for Low Energy Renovation of Residential Buildings”

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Retrofit Module Design Guide

IEA - International Energy Agency
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Annex 50 – Prefabricated Systems for Low Energy Renovation of Residential Buildings

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-eight IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA co-ordinates research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research.

The research and development strategies of the ECBCS Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Building Forum Think Tank Workshop, held in March 2007. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in three focus areas of R&D activities:

- Dissemination
- Decision-making
- Building products and systems

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by *):

Annex 1: Load Energy Determination of Buildings*
Annex 2: Ekistics and Advanced Community Energy Systems*
Annex 3: Energy Conservation in Residential Buildings*
Annex 4: Glasgow Commercial Building Monitoring*
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities*
Annex 7: Local Government Energy Planning*
Annex 8: Inhabitants Behaviour with Regard to Ventilation*
Annex 9: Minimum Ventilation Rates*
Annex 10: Building HVAC System Simulation*
Annex 11: Energy Auditing*
Annex 12: Windows and Fenestration*
Annex 13: Energy Management in Hospitals*
Annex 14: Condensation and Energy*
Annex 15: Energy Efficiency in Schools*
Annex 16: BEMS 1- User Interfaces and System Integration*
Annex 17: BEMS 2- Evaluation and Emulation Techniques*
Annex 18: Demand Controlled Ventilation Systems*
Annex 19: Low Slope Roof Systems*
Annex 20: Air Flow Patterns within Buildings*
Annex 21: Thermal Modelling*
Annex 22: Energy Efficient Communities*
Annex 23: Multi Zone Air Flow Modelling (COMIS)*

Annex 24: Heat, Air and Moisture Transfer in Envelopes*
Annex 25: Real time HEVAC Simulation*
Annex 26: Energy Efficient Ventilation of Large Enclosures*
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems*
Annex 28: Low Energy Cooling Systems*
Annex 29: Daylight in Buildings*
Annex 30: Bringing Simulation to Application*
Annex 31: Energy-Related Environmental Impact of Buildings*
Annex 32: Integral Building Envelope Performance Assessment*
Annex 33: Advanced Local Energy Planning*
Annex 34: Computer-Aided Evaluation of HVAC System Performance*
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT)*
Annex 36: Retrofitting of Educational Buildings*
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx)*
Annex 38: Solar Sustainable Housing*
Annex 39: High Performance Insulation Systems*
Annex 40: Building Commissioning to Improve Energy Performance*
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)*
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)*
Annex 43: Testing and Validation of Building Energy Simulation Tools*
Annex 44: Integrating Environmentally Responsive Elements in Buildings*
Annex 45: Energy Efficient Electric Lighting for Buildings*
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)*
Annex 47: Cost Effective Commissioning of Existing and Low Energy Buildings*
Annex 48: Heat Pumping and Reversible Air Conditioning*
Annex 49: Low Exergy Systems for High Performance Buildings and Communities*
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings*
Annex 51: Energy Efficient Communities
Annex 52: Towards Net Zero Energy Solar Buildings
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods
Annex 54: Analysis of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)
Annex 56: Energy and Greenhouse Optimised Building Renovation

Working Group - Energy Efficiency in Educational Buildings*
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings*
Working Group - Annex 36 Extension: The Energy Concept Adviser*
Working Group - Energy Efficient Communities

* completed

Annex 50 "Prefabricated Systems for Low Energy Renovation of Residential Buildings"

Energy conservation is largely dominated by existing buildings. In most industrialized countries new buildings will only contribute 10% - 20% additional energy consumption by 2050 whereas more than 80% will be influenced by the existing building stock. If building renovation continues at the current rate and with the present common policy, between one to over four centuries will be necessary to improve the building stock to the energy level of current new construction.

Currently, most present building renovations address isolated building components, such as roofs, façades or heating systems. This often results in inefficient and in the end expensive solutions, without an appropriate long term energy reduction. Optimal results can not be achieved by single renovation measures and new problems could arise, including local condensation or overheating.

The objectives of this Annex have been the development and demonstration of an innovative whole building renovation concept for typical apartment buildings. The concept is based on largely standardised façade and roof systems that are suitable for prefabrication. The highly insulated new building envelope includes the integration of a ventilation system.

The concept is focused on typical apartment buildings that represent approximately 40% of the European dwelling stock. The advantages include:

- Achieving energy efficiency and comfort for existing apartment buildings comparable to new advanced low energy buildings (30-50 kWh/(m²·y);
- Optimised constructions and quality and cost efficiency due to prefabrication;
- Opportunity to create attractive new living space in the prefabricated attic space and by in-cooperating existing balconies into the living space;
- A quick renewal process with minimised disturbances for the inhabitants.

The deliverables of the project are:

Retrofit Strategies Design Guide
A building retrofit strategies guide [II] documenting typical solutions for whole building renovations, including prefabricated roofs with integrated HVAC components and for advanced façade renovation. The report is supplemented by the **Retrofit Simulation Report** [IX] and an electronic **'Retrofit Advisor'** [V] that allows a computer-based evaluation of suitable renovation strategies.

Retrofit Module Design Guide
Guidelines for system evaluation, design, construction process and quality assurance for prefabricated renovation modules [III]. This publication includes the technical documentation of all developed renovation solutions.

Case Study Building Renovations
Case studies of six demonstration buildings in Austria, Netherlands, and Switzerland [IV].

Technical Summary Report
A summary report for a broad audience, demonstrating the potential of prefabricated retrofit [I].

Additional publications are:

- Annex 50 Fact Sheet, offering a short overview of the project and its achievements
- Building Typology and Morphology of Swiss and French Multi-Family Homes [VI], [VII], [VIII]

Home Pages: www.empa-ren.ch/A50.htm, www.ecbcs.org/annexes/annex50.htm

Participating Countries: Austria, Czech Republic, France, Netherlands, Portugal, Sweden, Switzerland

Abstract

Buildings have a considerable impact on the implementation of a more sustainable development. Within this context "IEA ECBCS Annex 50 – Prefabricated Systems for Low Energy Renovation of Residential Buildings", focuses on the most important sector of multi-residential buildings. A large number of these buildings have an urgent renovation need. The project aims to provide whole building renovation concepts and standardised renovation solutions in order to facilitate this process. It aims at contributing to quality control and standardization based on prefabricated modules and advanced retrofit strategies. The project focuses on prefabricated and factory-assembled roofs, façades, and HVAC systems for multi-family houses.

Concept of prefabricated systems

For the development of prefabricated retrofit systems, the following three fundamental aspects were considered:

- The modules are **standardised in construction**, layers, and joints
- The modules are **flexible in architecture**, form, and cladding
- The modules **can be combined** with each other and with non-prefabricated (conventional) retrofit options

Façade and roof modules with a large application potential were designed based on a building typology. So far, the prefabrication technology for façade and roof modules has been developed and tested. Special attention was given not only to building physics, but also to fire protection and logistics. There are two different approaches for retrofit module design: One is a fully prefabricated solution, the other concentrates on prefabrication at the window area as being the area with the highest density of details. Modules for roofs and balconies are developed in the same way.

Completely prefabricated

Semi prefabricated with F4.1 modules

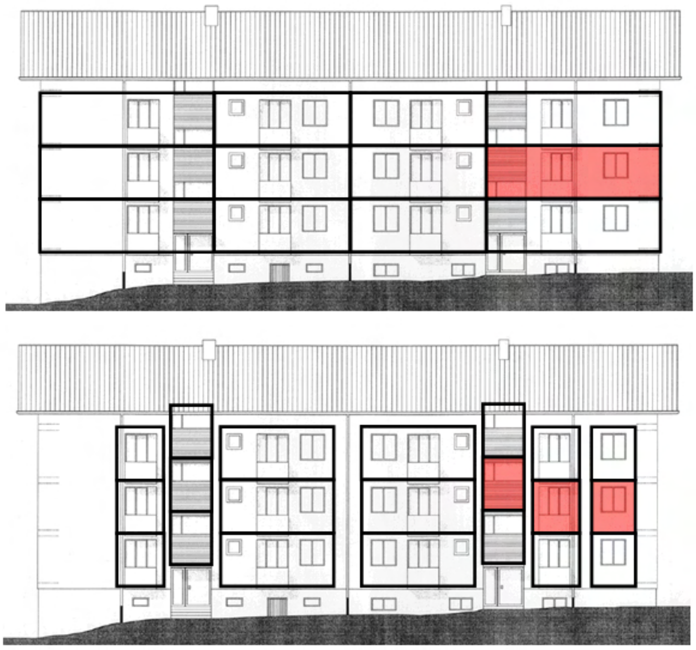


Figure 1: Two design and construction approaches for modular retrofit systems

Fundamentally, the module consists of:

1) An equalizing layer mounted on the existing outer wall,
2) A load bearing construction with insulation layer and integrated ducts,
3) A second layer of insulation material. The thickness of the insulation can be chosen depending on the desired U-value and
4) A cladding layer that can be prefabricated and delivered with the module, or mounted on site.

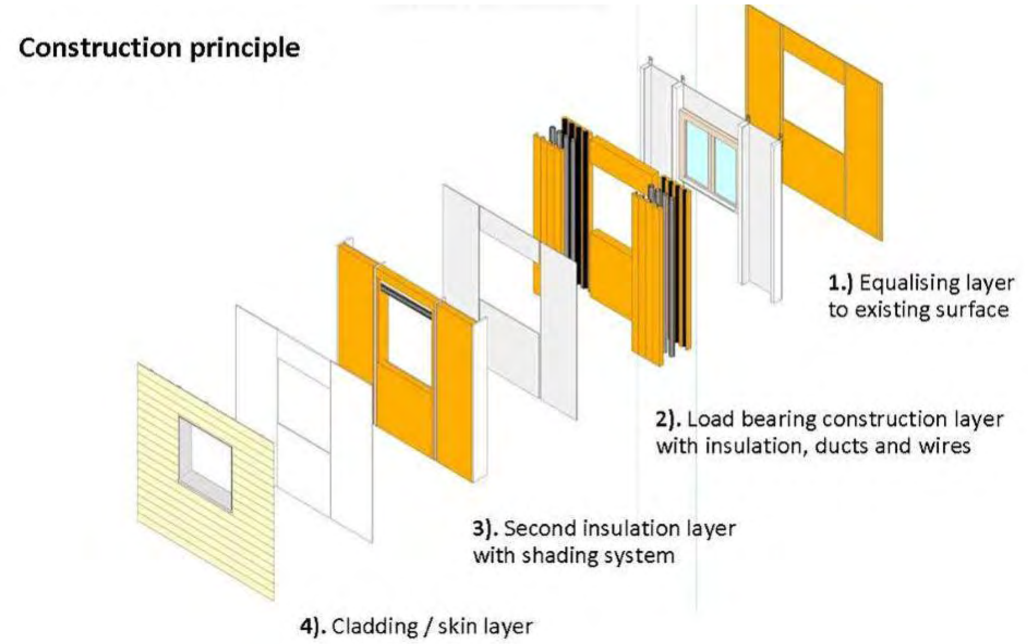


Figure 2: Assembly of the Swiss module (© René L. Kobler, FHNW)

The approaches to renew and as far as possible to prefabricate energy efficient new envelopes for existing buildings can be very divers. This is not only because buildings themselves are divers. Even for identical buildings, there are various options to achieve practical solutions for retrofitting and to find a way to produce prefabricated modules for façades and roofs. For example, the integration of a ventilation system can be very differently addressed and will strongly influence the whole planning process. Also the country specific and well established process chains should not be bypassed. They set basic conditions from planning to working on site.

This report shows four different approaches on how prefabricated renovation modules could be designed and produced. The concepts presented have been developed by national teams from Austria, France, Portugal and Switzerland. They had tried to consider the specific needs and possibilities of each country and to apply different materials. They are presented in four separate sections:

- Part A
  The Swiss solution is based on small modules with a high degree of standardisation. The prefabricated façade modules concentrate on the window area as the area with the highest concentration of technical details, whereas the plain façade parts are insulated traditionally. Also the façade finish – ventilated cladding or rendering – is done on site. This concept has also been used for the development of roof elements, for flat or sloped roofs.

- Part B
  The Austrian solution is based on large glazed façade modules, which are fully prefabricated. They are as high as the building story and up to 12 m long. They have been already tested at various demonstration buildings in Graz.

- Part C
  The French development was focussed on large vertical façade elements with metal under-construction. Special attention was given to the avoidance of thermal bridges. Prototypes were produced and tested.

- Part D
  The Portuguese study concentrated also on fully prefabricated but smaller sized modules. They are based on easy mountable metallic and of course insulated façade panels.

The project provides with these four approaches a variety of options that cover various possible ways to retrofit buildings in Europe. They represent concepts, which still may be varied and optimised for future applications. This documentation should support manufactures and designers to evaluate the possibilities for efficient refurbishment of existing buildings. It covers only the design and construction of renovation modules. The general development of a renovation strategy and the documentation of renovated case study buildings are documented in separate Annex publications [II], [IV].

The renovation modules have been classified by module types. **F-type** modules stand for **Façade elements**, **R-type** for **Roof elements**. These categories have been subdivided in following categories and may be further subdivided (i.e. F4.1):

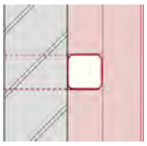
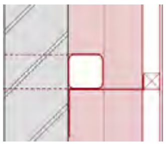
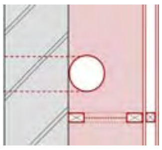
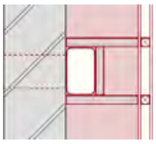
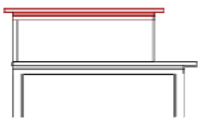
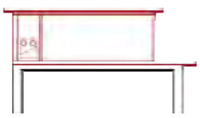
Code	Module type	Description
 **F1**	Compact façade insulation	Conventional compact insulation with polystyrene or mineral wool insulation, plaster finish
 **F2**	Ventilated façade insulation	Mineral wool insulation and ventilated cladding, fixed with mounting system, mounting and cladding system prefabricated.
 **F3**	Fibre insulated façade cladding	In situ or factory filling of cavities with loose fibre insulation (e.g. cellulose fibres)
 **F4**	Prefabricated façade module	Mineral wool, foam or vacuum insulation in frame construction and ventilated cladding, full system prefabricated, incl. windows and duct system
 **F5**	Room extension	Prefabricated light weight façade constructions, suitable for integration of balconies
 **R1**	Insulated steep roof elements	Large insulated roof elements, prefabricated
 **R3**	Attic steep roof space module	Complete light weight attic extensions
 **R8**	Attic flat roof module	Prefabricated roof solutions for new attic spaces
 **R9**	Attic flat roof space module	Completely prefabricated light weight attic extensions (flat roof). They may offer additional living space, space for technical installations or both.

Table 1: Typology of façade and roof renovation modules

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Part A

Retrofit Module Design Guide

Part A: Semi-Prefabricated Standardised Retrofit Modules

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Basel / Muttenz, March 2011

The participation in IEA ECBCS Annex 50 was funded by the
Swiss Federal Office of Energy FOE
and
Swiss Innovation Agency CTI
3003 Berne

Industry partners in research project

Façade and roof modules	Bächi Holzbau AG, Rietweg 7, CH-8424 Embrach, www.baechi.ch
Windows and balcony doors	4B Gruppe, an der Ron 7, CH-6281 Hochdorf, www.4b-gruppe.ch
	EgoKiefer AG, Schöntalstrasse 2 CH-9450 Altstätten, www.egokiefer.ch
	Ernst Schweizer Metallbau, Bahnhofplatz 11 CH-8908 Hedingen, www.schweizer-metallbau.ch
Windows	swisswindows AG, Haltelhusstrasse, CH-9016 Mörschwil, www.swisswindows.ch
Thermal insulation	Flumroc AG, CH-8890 Flums, www.flumroc.ch
	isofloc AG, Soorpark, CH-9606 Bütschwil, www.isofloc.ch
	Saint-Gobain Isover SA, Route de Payerne 1, CH-1522 Lucens, www.isover.ch
	swisspor AG, Bahnhofstrasse 50, CH-6312 Steinhausen, www.swisspor.ch
Vacuum insulation	Neofas AG, Falkenstrasse 7, CH-8317 Tagelswangen, www.neofas.ch
	ZZ Wancor AG, Althardstrasse 5, CH-8105 Regensdorf, www.zzwancor.ch
Façade cladding, PV	Eternit, CH-8867 Niederurnen, www.eternit.ch

Table of Content - Part A

1. Introduction and procedure

Older residential buildings exhibit a much higher heating energy demand than new-build accommodation. This legacy has major implications for the future energy performance of the built environment and its contribution to achieving the national vision of a "2000 Watt society". The refurbishment backlog is due to various reasons. Adopting an integral approach, the IEA project on "Prefabricated Systems for low Energy Renovation of Buildings" sets out to identify potential solutions to assist in the sustainable refurbishment of residential buildings.

Part A of this report sets out the results of the façade and roof construction research module undertaken in Switzerland in collaboration with Swiss industry partners. It focuses on the use of largely prefabricated units with integral ventilation ducts for external retrofitting to the existing building envelope to achieve a significant reduction in heating energy demand. The aim is to cut energy consumption to a level between the values specified in the Swiss MINERGIE and MINERGIE-P energy efficiency standards.

The learning processes undergone and information gathered during the research phase provide the basis for useful models applicable to both the design and construction phases of building projects. The aim is not to put forward a comprehensive set of recipes containing solutions to every conceivable detailing problem, but to present a conceptual tool that "smoothes the path" for those facing the complex task of refurbishing an older residential building and upgrading the building envelope. The concept entails no change to the traditional organization of and relationships between the different project team members – i.e. client, architect, specialist designers and contractors – nor to their respective duties. On the contrary, the provision of a common basis for design and construction is intended to promote collaboration and facilitate the project development process.

The aim of the overall IEA project on "Prefabricated Systems for low Energy Renovation of Buildings" is to identify methods of refurbishing existing residential buildings in order to achieve levels of energy efficiency at least between 30 – 50 kWh/(m²·y). The related Swiss national project covered the fields of technical development, typology and socio-economic forecasting (Figure 3). The participating research institutes were: the Swiss Federal Laboratories for Materials Science and Research (Empa) in Zurich, University of Applied Sciences Northwestern Switzerland (FHNW), Lucerne University of Applied Sciences and Arts (HSLU), Swiss Federal Institute of Technology Zurich (ETH-Z), Swiss Federal Institute of Technology Lausanne (EPFL) and Paul Scherrer Institute (PSI).

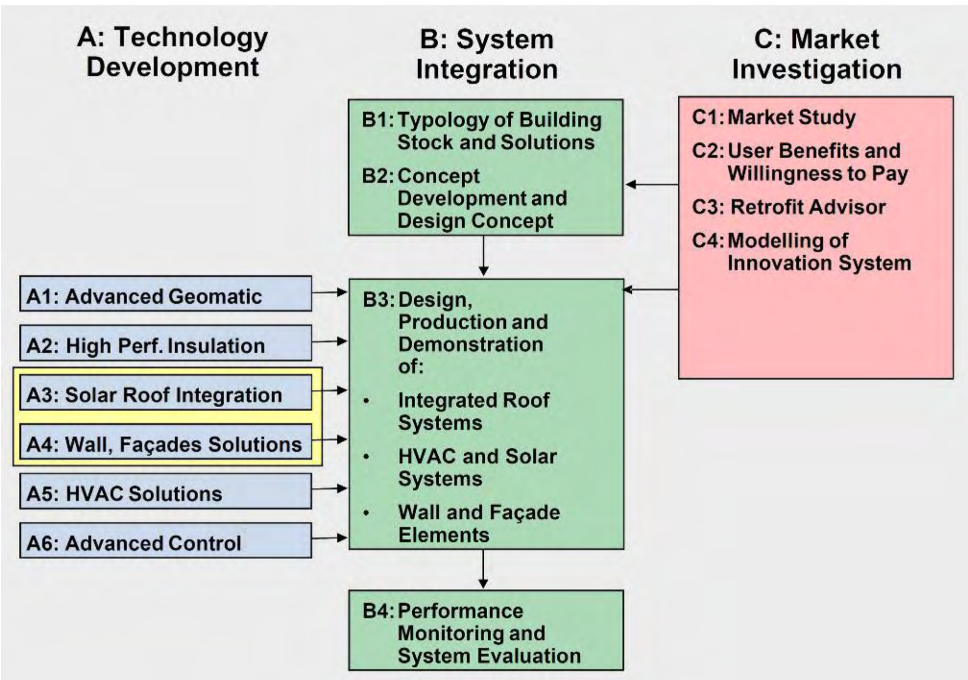


Figure 3: Summary of overall research project showing the context of the research modules A3 and A4 (diagram by Empa)

The proposed renovation concept is simple and consequent: A new, largely standardised and prefabricated building envelope is laid around the existing building (Figure 4). It allows improving the façades, to add room extensions or a new attic floor. This new building envelope has the quality of a new building construction. It is perfectly insulated, physically sound and it offers an excellent comfort. A new mechanical ventilation system with heat recovery is integrated in the façade and roof modules. Optimised constructions, efficient construction processes, high quality standards and reliable budgeting are important features of this concept.

This report focuses on the technical development of largely prefabricated façade and roof units specified for research modules A3 and A4 (Figure 3). With the examined systems, the ventilation ducts do not run inside the building, but within the prefabricated units. This means that refurbishment of the building exterior must be permissible. In other words, the findings of this report are not applicable, for instance, to listed buildings whose external appearance must not be altered.

Following the principle of maximum prefabrication, research modules A3 and A4 target the development of façade and roof units that can be delivered to the site as far as possible in pre-assembled form – with components such as windows, ventilation ducts, blinds, thermal insulation, solar energy systems and possibly other utility services pre-installed in the modules.

A pivotal role in the development of the façade and roof modules is played by the *industry partners* and their instinctive grasp of the practicability of both general development directions and detail solutions. These industry partners are involved in the later stages of construction and their products provide the component parts for the façade and roof units.

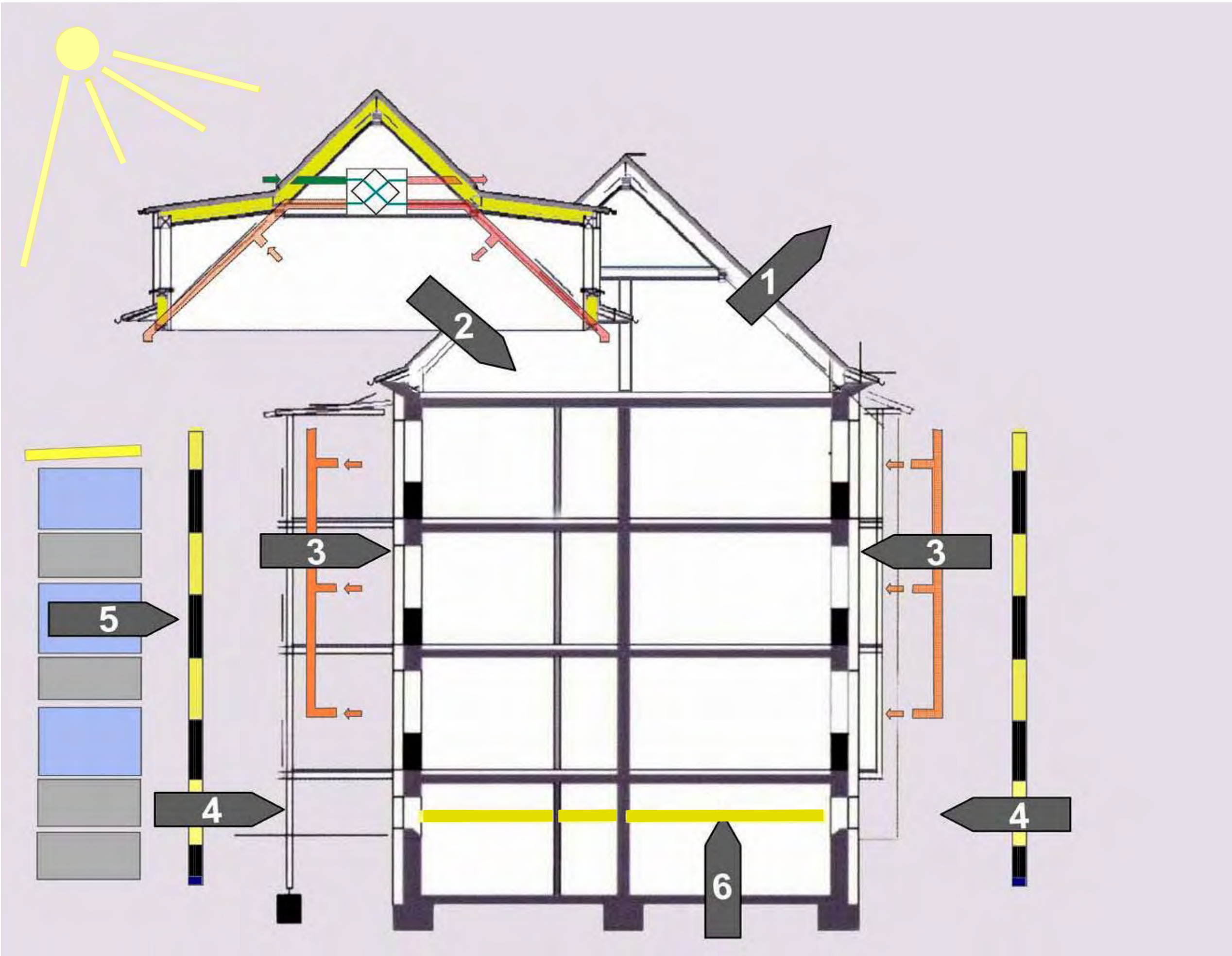


Figure 4: Renovation approach: Exterior renovation with maximized prefabrication of façade and roof module: Replacement of old roof (1+2), mounting of ventilation system from outside (3), mounting of façade modules (4+5), insulation against basement (6) (diagram by Empa)

The integration of our industry partners' products in the façade and roof units guarantees the market availability of the necessary products and components in the required quality. We wish to take this opportunity to express our gratitude and appreciation to all industry partners for their constructive participation in the project work and the valuable know-how they contributed during the various discussions. This research project could not have been undertaken without their help. The collaboration was promoted by the CTI[1].

The procedure adopted in research modules A3 and A4 for the development of the façade and roof modules can be summarized under six general headings:

- Systematic cataloguing of industry partner products relevant to façade and roof modules (integration of industry partner products)
- Identification of complementary products needed for construction of façade and roof modules
- Determination of requirements regarding energy-efficiency targets in terms of Swiss MINERGIE
- Systematic identification and representation of design and constructional interfaces at walls, roofs and windows, as well as junctions with existing buildings (Figure 5)
- Development collaboration with industry partners, integration of know-how
- Preparation of "handover document" for construction industry

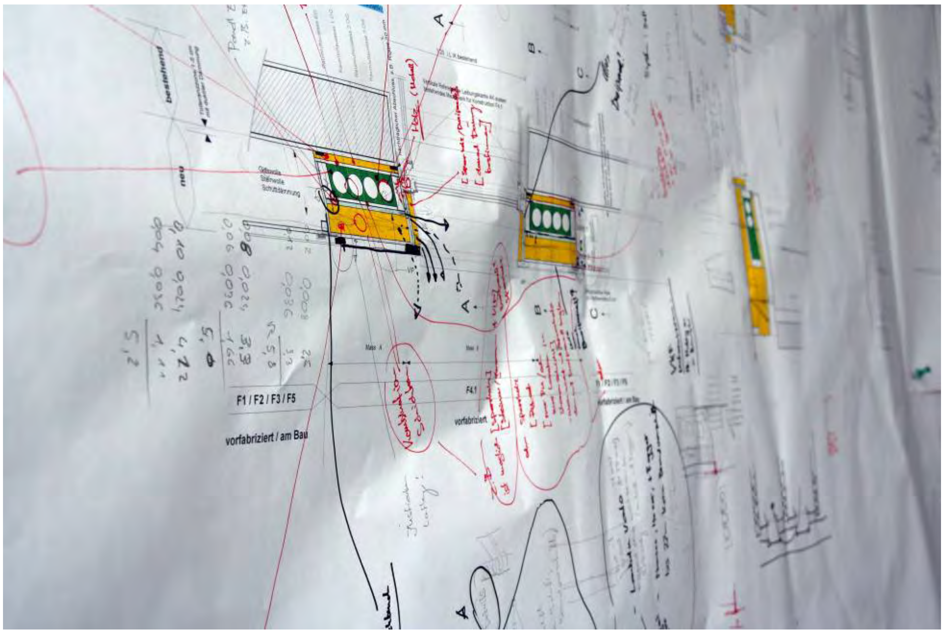


Figure 5: Development of details based on expertise provided by industry partners, with detail solutions worked out during design phase and not on site

[1] The Commission for Technology and Innovation (CTI), the innovation promotion agency of the Swiss Confederation, supports the transfer of knowledge and technology between companies and universities.

2. Façade modules

2.1. Partial or full prefabrication?

Prefabrication is commonly associated with full prefabrication, i.e. – in the case of advanced retrofit – the installation of large-size units over the entire surface of existing buildings (Figure 6). This technique has already been implemented with some success. For a fully prefabricated retrofit, the unit sizes are governed by both the façade dimensions and logistical constraints. In Switzerland, units of around 3.5 m width and 10 m length are easily transportable. The transportation of larger units is possible, but may require a police escort and/or night time transportation. The storey height and a width not exceeding 10 m offer a convenient size for horizontal arrangement of the modules. Depending on the specific façade arrangement, these dimensions will result in a grid similar to that pictured below.

Figure 6: Possible façade subdivision into large-size units with maximum size of 10 m x 3.5 m

The use of large-size units is a possible option for residential building retrofits. At the same time, the low-energy renovation of residential buildings to an energy efficiency level between the Swiss MINERGIE and MINERGIE-P standards is a challenging task requiring in-depth knowledge and experience on the part of the designer, backed by a practised team of contractors. In particular, the following factors and issues demand close attention[2]:

- Considerable effort involved by on-site measurement
- Processing of sizes in factory
- Tolerances, including those at junctions between large-size units
- Weight of large-size units
- Alignment and suspension
- New potential sources of error
- Little repetition of details, higher amount of project-specific detailing
- Unclear basis for design team co-ordination with regard to routing of building service installations

[2] See also [II] and Part B

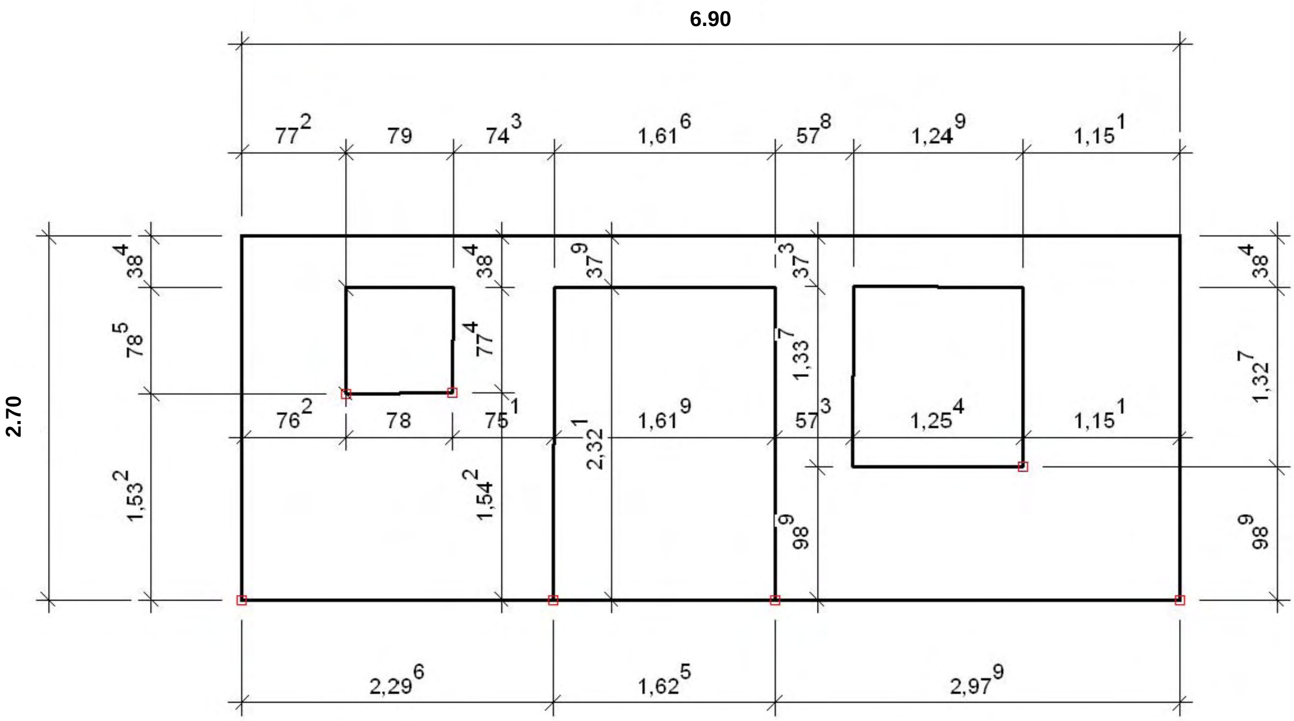


Figure 7: Example of measurements taken for a large-size unit

Although the grid adopted for the large-size modules may be clearly dimensioned, provision is still needed to accommodate the features of the existing envelope. In this case, the fitting process is done within the modules themselves. At least in case of more complex units, this necessitates a accurate specification of unfamiliar sizes, tolerances and angles, which creates a further potential source of error (Figure 7). The problem arises:

> *"Because something new must be built crookedly to fit neatly onto something old and crooked."*

Given the huge number of residential buildings that are candidates for refurbishment –some 106.000[3] in German-speaking Switzerland – an alternative to large-unit construction may prove to be more effective. The research project developed a concept that focuses on the window area as the "focal point of detailing" (Chapter 2.2.1). This facilitates the design and construction process through standardization while significantly reducing the problems with tolerances. The industry partners support this concept because it simplifies and structures the construction processes.

2.2. Base module F4.1

The Swiss retrofit module development focussed on the "base module 4.1". This module concentrates the important construction details, the technical installations and the interface solution around the window area. The result is a small size module renovation module, approx. 2.8 m x 2.8 m, which is highly standardised. The concept behind this "Base module 4.1" and its construction are described in chapter 2.2.

2.2.1. "Focal point of detailing"

A completely different approach arises from a consideration of the amount of time needed to discuss the various façade details. Only little time is used for discussing and detailing the opaque wall sections. The associated calculations, fixings, material specifications and other parameters appear to be more clear-cut

[3] P. Schwehr, 2010 [V]

and warrant less discussion. This is probably a reflection of the large number of tried-and-tested opaque façade systems already on the market. If it is true that these façade sections need less discussion because they are more straightforward, then it is also fair to conclude that the opaque areas are not the core problem on advanced retrofit schemes.

Discussions are more clearly focused on the detailing at windows, reveals, junctions, fixings, ventilation ducts, penetrations, blinds, fixtures and the like which – purely in terms of location – are all centred on the window area.

This observation serves as the starting point for an alternative concept to support the design and construction processes. In the context of a particular project, this basic framework can then be fleshed out with the necessary additions by the relevant experts in the project team.

In this regard, consideration should at least be given to the following factors:

Design requirements:

- Good thermal insulation performance and low-thermal-bridging assembly, use of high-grade windows
- Handling of building services that are integrated in renovation module
- Penetration of building envelope by ventilation ducts and any necessary electrical installations
- Provision for responding to external climate/temperatures to minimize heat losses from ventilation ducts to outside
- Provision for dealing with moisture/humidity from interior
- Repetition of details – principle behind details geared to multiple reuse
- Maximum design freedom for external skin (finish) – avoidance of "prefabricated look"
- Principle design principles applicable to entire building envelope, i.e. also applicable for prefabricated roof units

Fabrication requirements:

- Straightforward and reliable connection of ventilation ducts incorporated in adjacent units
- Airtightness between unit and existing masonry
- Motorized blinds with optional automation
- Possible provision for sensor cables at windows
- Use of generally available construction materials/products
- Use of materials/products with simple geometries
- Clearly defined layers (of envelope enclosing building), wherever possible
- Efficiency gains through recurrent processes in design and prefabrication

Transport and mounting:

- Consideration of maximum consignment sizes on roads
- Inherent stiffness of units to facilitate shipment and installation
- Fixing to existing external walls
- Provision for accommodating irregularities in existing masonry

The "focal point of detailing" concept can be graphically illustrated as follows:

1: Observation
It can be observed that far less time is spent discussing the opaque façade sections than details such as window junctions, blinds etc.

2: "Focal point of detailing"
Most of the discussions centre on the areas "around windows". A useful approach could entail grouping together, as far as possible, all key details within a predefined zone and systematically developing solutions for these details. The shaded area is that part of the existing façade to be clad with a new, prefabricated unit incorporating built-in solutions to most of the problems. This is the **F4.1 base module** that is central to the retrofit system.

3: Application to entire column of windows
The same base module can essentially be applied to a full vertical line of existing openings.

4: Application to as many openings as possible
Ideally, more or less the same base module can be applied to all existing openings in a façade. This automatically deals with many of the problem zones in the façade.

Figure 8: Illustration of "focal point of detailing" concept

The procedure from factory production of the F4.1 base module up to on-site erection is as follows:

At factory
Ordering of final window based on reference sizes from existing structure and from contractor drawings

Start of assembly of F4.1 base module, structural frame, including integration of ventilation ducts, windows and other materials in layer 1 (see Figure 10)

Installation of thermal insulation, completion of layer 2 (see Figure 10), possible application of external skin (finish) or solar panels/collectors

On site
Preparatory site operations, e.g. removal of window sills, apron wall, façade cleaning, fixing of (temporary) support beams etc.

Installation of prefabricated F4.1 base module, including window, ventilation ducts, utility services, insulation, possibly with solar panels/collectors or external skin

The remaining opaque façade sections can be constructed in the normal way using standard façade systems. Here too, the use of prefabricated units is a possible option. The concept leaves this open and allows project-specific solutions.

The following modules are used for the opaque sections:
F1: Rendered façades
F2: Rear ventilated façades
F3: Façades with loose-fill insulation

Finishing works to external façade layer and interiors (removal of existing window, airtight sealing, and drillings for ventilation duct penetrations etc.)

Figure 9: Façade construction procedure

2.2.2. Design and assembly

The F4.1 base module can essentially accommodate all window sizes and various numbers of ventilation duct runs[4]. The following drawing shows a relatively large assembly with four ventilation ducts on either side. Basic information on the routing and dimensioning of the ventilation ducts is available at the design stage due to their generally vertical arrangement, fixed positions within the assembly and individual component sizes. This duct arrangement and its assembly automatically meet fire-safety requirements provided the relevant minimum sizes and material specifications are observed.

The sizes of the individual components follow a pattern. Although the exploded drawing (Figure 10) appears complex at first sight, this merely reflects the attempt to collect and tackle many "problems" simultaneously within a single base module. All components shown below can be factory-assembled. The assembly procedures were tested using a full-scale working model.

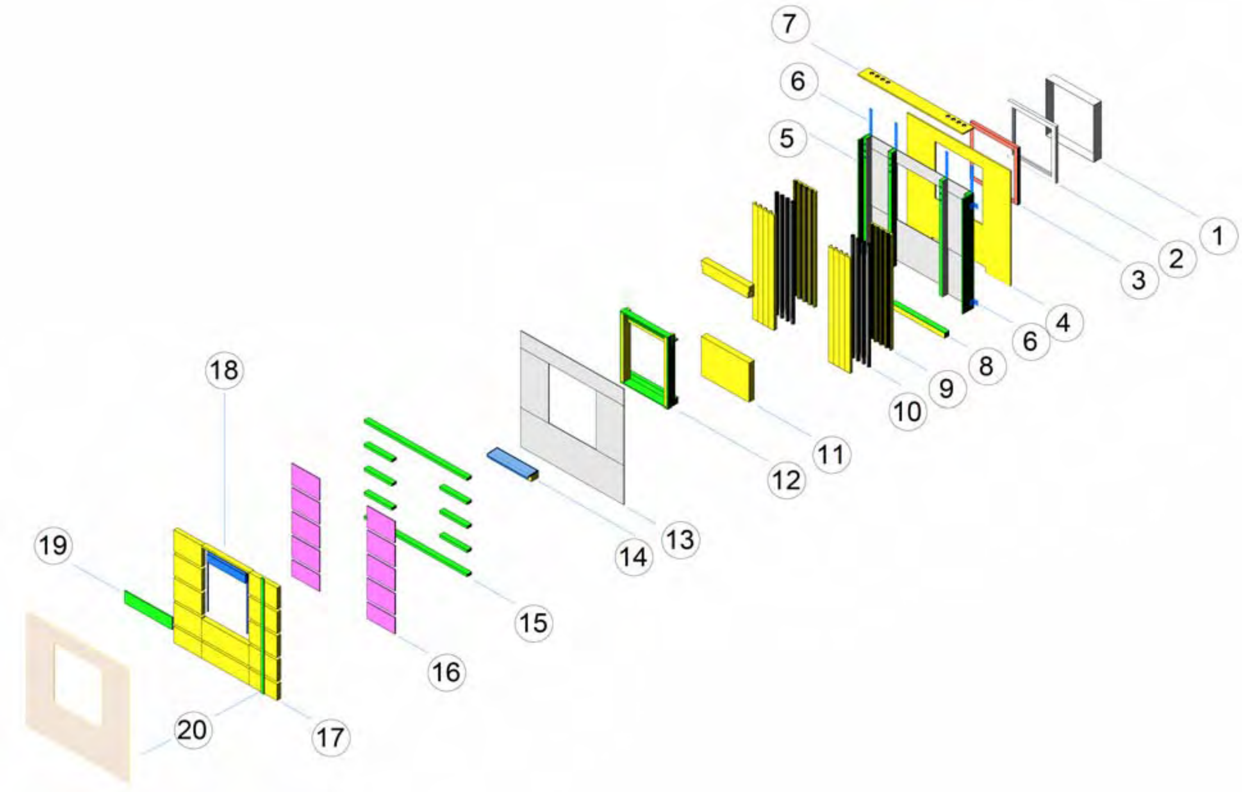


Figure 10: Exploded drawing showing the components of F4.1 base module. Layer1: components 1-13, layer 2: components 14-20

Components 1-13 form layer 1. Its thickness depends on the diameter of the integrated ventilation ducts:

- Layer 1 thickness for D internal = 80 mm: 30 mm+15 mm+140 mm+15 mm = 200 mm
- Layer 1 thickness for D internal = 100 mm: 30 mm+15 mm+160 mm+15 mm = 220 mm

Components 14-20 form layer 2. Its thickness depends on the necessary insulation thickness over the ventilation ducts and the total U-value (thermal transmittance) required. The example shown incorporates 20 mm thick vacuum insulation panels (VIP) and 100 mm glass wool or rock wool. Here, then, layer 2 has a total thickness 120 mm (without external skin). The overall assembly thickness relevant to the U-value – excluding the external skin and levelling layer in contact with the existing masonry – thus totals 200 mm + 120 mm = 320 mm. Added to this are the values for the levelling layer and existing masonry, together with a small value for the external skin. This assembly also provides a low-thermal-bridging solution for the blind box as this is located entirely within layer 2 and can be covered internally by thermal insulation – either a standard product or VIP.

[4] A survey conducted by the Competence Centre for Typology and Planning in Architecture (CCTP) at Lucerne University of Applied Sciences and Arts [V] showed that the F4.1 base module would be applicable to some 2.3 million openings in 106.000 residential buildings in German-speaking Switzerland.

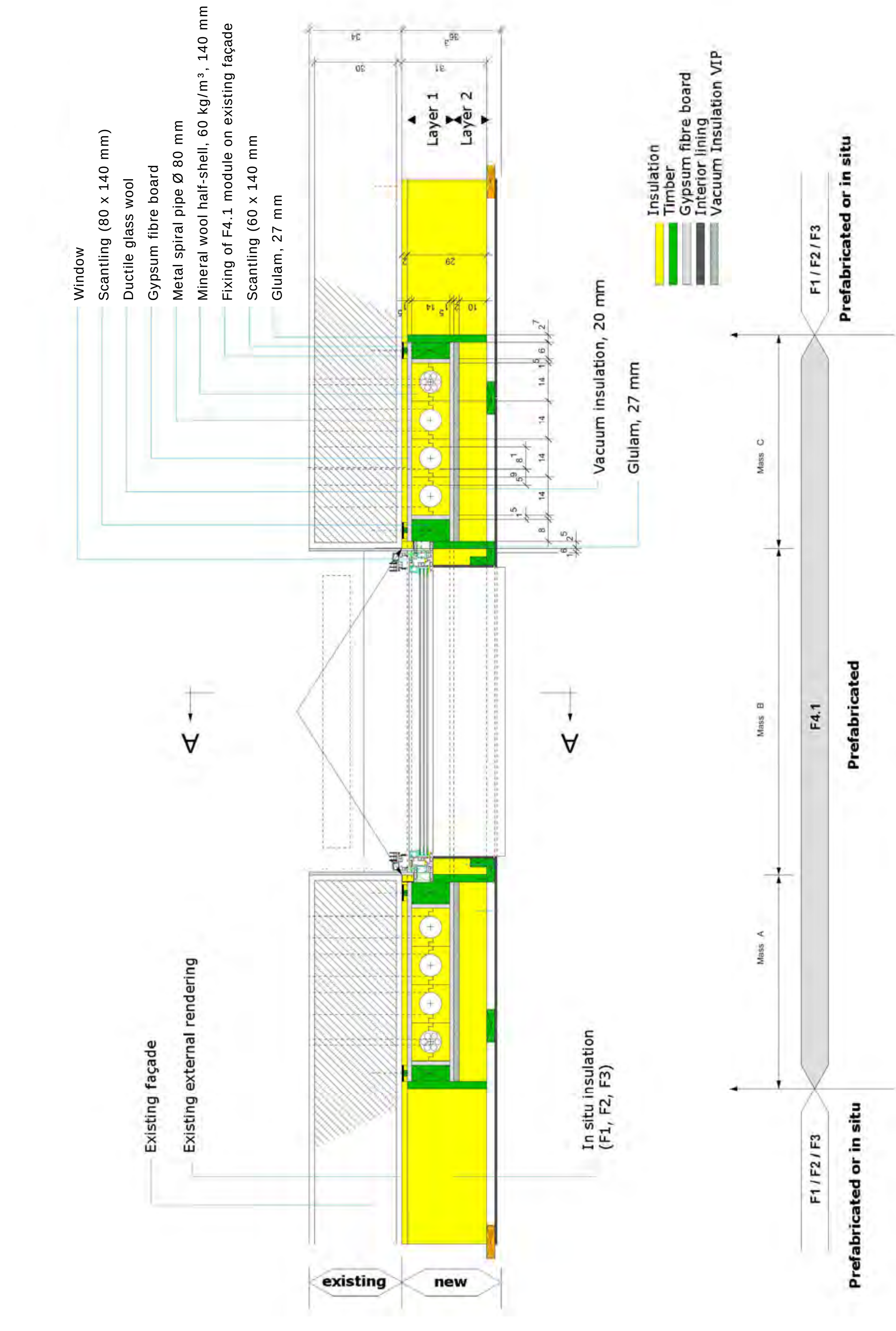


Figure 11: Plan view of installed F4.1 module

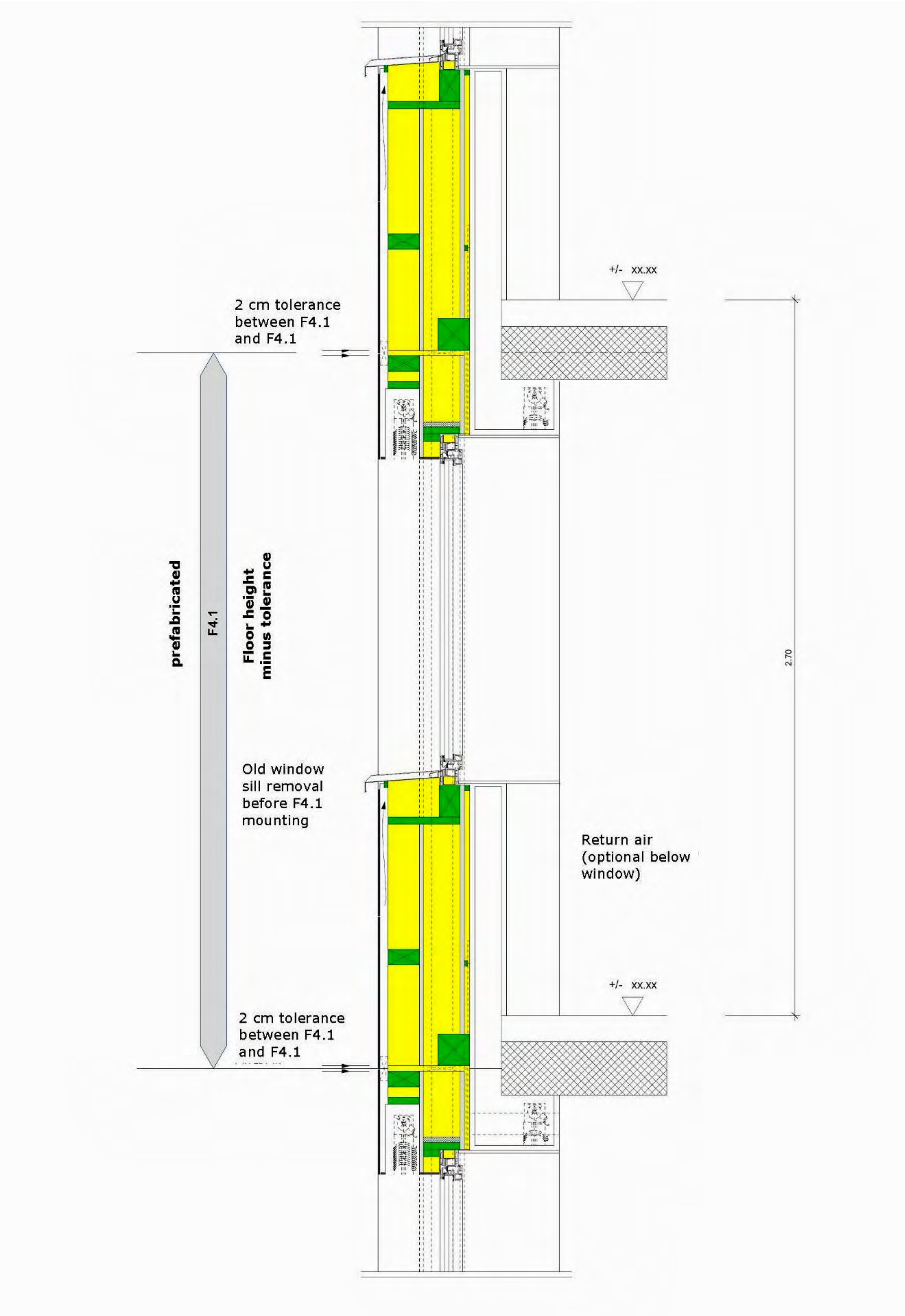


Figure 12: Cross-section of F4.1 module

Base module 4.1 component description

1 Airtight seal

The air sealing is bonded around the window frame during prefabrication and projects from the F4.1 module. It is bonded on site to the existing outer reveal and covered e.g. by 10 mm gypsum plasterboard (to become new internal reveal – see procedure described below).

The sheet can also double up as a vapour barrier. Some existing window products can be supplied with the sheet ready-bonded to the window frame.

2 Window

Triple-glazed units with a U-value of at least 0.7 W/(m²·K) are recommended. The size of the opening in the F4.1 module – and with it the window size – is adaptable to the clear opening in the existing wall. The following should be considered during window selection:

- Opening action (tilt-and-turn or side-hung only)
- Sound-reduction index to outside better after retrofit than before
- Possibility of blind-free solutions (blinds integrated in window)
- Pivot point of window and implications for enlargement of clear opening size
- Positioning of window handles in lower part of window, accessibility due to larger inner reveal, kitchen windows, reachability from wheelchair etc.
- +/- 2 mm tolerance on either side for factory installation, front window stop min. 10 mm wide, screwing to structural timberwork, NO screw fixing behind seal (risk of damage to VIP)

3 Insert

Integration of a levelling layer is required between the window and the area of the window stop. As a rule, this should take the form of a vapour proof and airtight joint seal (e.g. using film tape). Its main function is not to improve airtightness, but to fill the gap between window and window frame given the tolerance needed for integration of the window.

4 Levelling layer between F4.1 module and existing wall, vapour barrier

While the new F4.1 modules have a plane rear face (gypsum fibreboard) the existing masonry may be uneven. Compressible (ductile) insulation can be used to accommodate the tolerances between the new module and the existing wall. Compression of the insulation material slightly affects the U-values. This levelling layer, comprising a glass wool product manufactured by ISOVER, has a minimum thickness of 30 mm.

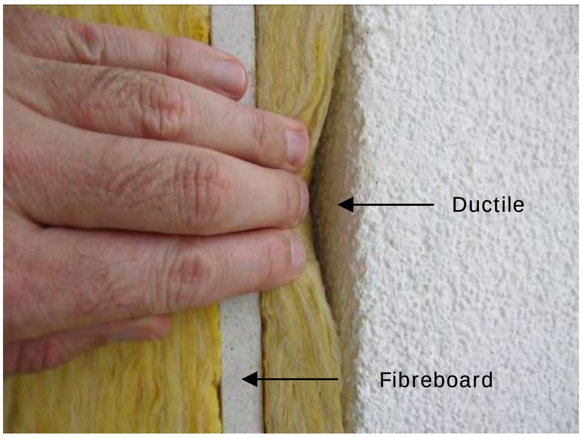


Figure 13: Compressible insulation between gypsum fibreboard and existing wall

The possible requirement under Swiss standard SIA 180 for a vapour check or barrier should be investigated. Any necessary vapour check/barrier can then be inserted between the rear gypsum. fibreboards and the levelling layer. This should be bonded to the sheet providing an airtight seal at the window.

5 Gypsum fibreboard and timber uprights in layer 1

Factory production begins with the assembly of the rear gypsum fibreboards, square timber uprights in layer 1, edge boards and metal flats.

Gypsum fibreboards:
All boards are 15 mm thick. To stiffen the entire base module, the boards must be cut so as to provide horizontal continuity (horizontal joints) when assembled (the same applies for component no. 13). Holes must be drilled at those positions where ventilation ducts branch off into the interior and the duct factory-fitted with a bend (or sound attenuator). For fire-safety reasons, the gypsum fibreboards fixed on the internal side of the timber uprights facing the ventilation duct must also be 15 mm thick to achieve an EI30 nbb rating. (See also plan view of F4.1 base module below).

Timber uprights in layer 1:
The height of the timber uprights is equal to the existing storey height minus a tolerance of around 2 cm. This eliminates any structure-borne sound transmission between storeys where timber uprights are vertically aligned. The depth of the uprights is determined by the size of the sectional pipe insulation (component no. 9), which in turn depends on the ventilation duct diameters.

Ventilation duct D internal = 80 mm: Outer face of sectional insulation 140 mm x 140 mm
Ventilation duct D internal = 100 mm : Outer face of sectional insulation 160 mm x 160 mm

For fire-safety reasons, the timber uprights adjacent to the window must be at least 80 mm wide. A width of 60 mm suffices for the two outer uprights.

Edge boards:
The edge boards terminate the unit at the junction with the opaque F1, F2 and F3 façade modules while also laterally stiffening the F4.1 module. The front face could also serve as the base for fixing any necessary expansion joint strips. The edge boards facilitate the transmission of loads to the timber uprights in layer 1.

If not structurally necessary, the edge boards need not be carried up flush with the outer face of the timber crosspieces in layer 2 but only e.g. up to mid-thickness. Linear thermal bridging can then be reduced by means of covering insulation.

6 Metal components

Metal flats:
The F4.1 base module is suspended from the existing wall, thereby obviating the need for any additional foundations. While a vertical arrangement with units placed on top of each other is theoretically feasible, its implications for settlement and structure-borne sound transmission would be much more difficult to predict.

The metal flats used to suspend the units are around 10 mm thick and 60 mm wide, the length – up to over half the storey height – being determined by structural requirements, depending on the strength of the existing masonry. The flats are made from rustproof steel or aluminium and provided with one slotted hole and one or more round holes. The number of holes and their spacing are dictated by the pull-out strength of the anchorages and the pull-out behaviour of the individual masonry units. Several holes may also be needed for the through fixings used to screw the metal flats to the gypsum fibreboards and layer 1 timber upright at the rear. Their number and spacing are based on the specifications of the structural engineer.

The whole assembly is thus suspended from the timber uprights. The vertical forces are mainly transmitted within layer 1. Layer 2 is structurally connected to layer 1. The fact that the fixings are wholly contained within layer 1 and covered by layer 2 eliminates any point thermal bridges to the outside.

The metal flats are through-bolted to the timber upright behind the gypsum fibreboards. The bolt head or nut is countersunk in the upright as this will later receive the second, front gypsum fibreboards. All remaining cavities in the timberwork must be packed with insulating material to prevent the creation of any voids.

The metal flats may also serve as easily identifiable suspension points for the units in the factory or during loading, unloading and on-site erection – thus eliminating the need for provisional suspension devices which have to be removed on site.

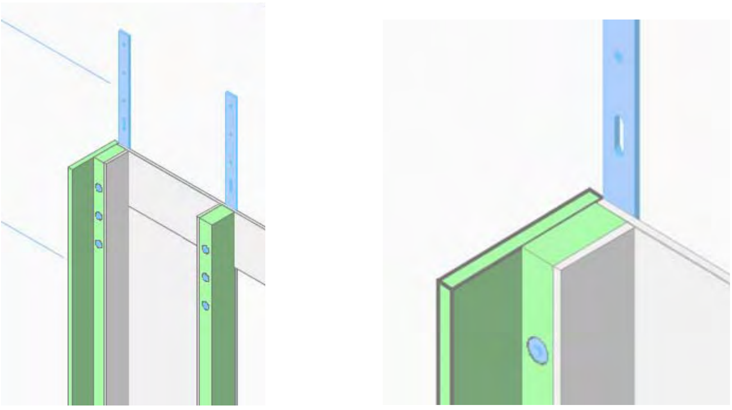


Figure 14: Rear gypsum fibreboard, metal flats, timber uprights, edge board, inner gypsum fibre-boards

The metal brackets secure the assembly e.g. against wind loads, thereby preventing displacement towards or away from the existing wall. At least one, or preferably two, must be fixed on either side. The brackets also allow adjustment of the distance from the masonry. Additional metal brackets can be provided to accommodate higher loads. To prevent any risk of damage to the installed VIP, the brackets should be screwed to the timber uprights roughly along the centreline.

The metal flats and metal brackets allow a clear-cut allocation and transmission of the total vertical and total horizontal loads.

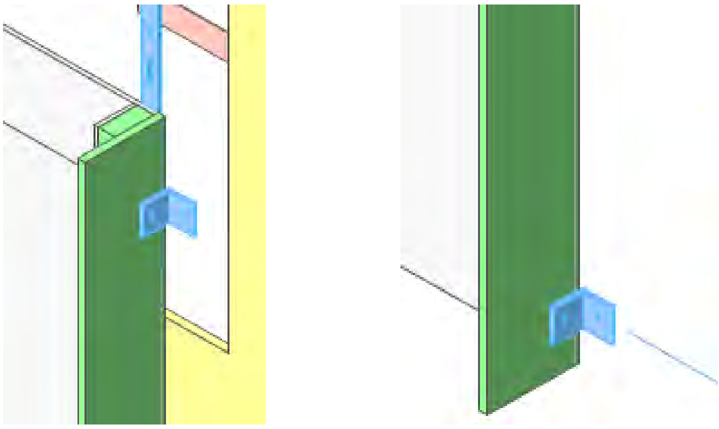


Figure 15: Minimum bracket provision

The anchor holes in the masonry must be drilled without percussion. All anchorages and fixings must comply with the state of the art.

7 Tolerance area between vertically adjacent F4.1 modules

This intermediate component, made from compressible thermal insulation (as used for component no. 4), is inserted between two vertically adjacent F4.1 modules to accommodate the required 2 cm tolerance described above.

All gaps between vertically adjacent F4.1 modules (i.e. the tolerance area) are insulated on site (component no. 7). Apart from preventing heat losses, this is also important for stopping the transmission of outdoor sound to the ventilation ducts as well as any noise transmission between ducts.

8 Support beam

It is possible to suspend the modules from a crane and directly screw them to the existing wall. The erection process may be simplified through the use of a support beam. Essentially, however, this is not intended as a permanent structural member but only as an aid to installation. On site, it provides a base onto which the module can be placed in order to facilitate alignment.

Should the support beam be designed as a permanent load bearing member, it must span the entire width of the F4.1 module so as to accept the loads transmitted from the inner uprights (adjacent to the window) and outer uprights in layer 1 (as specified by the structural engineer).

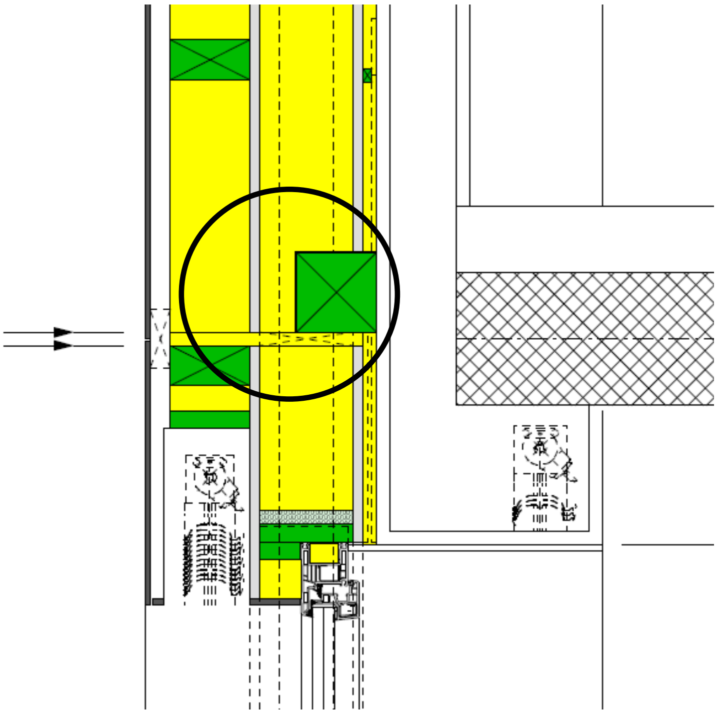


Figure 16: Support beam for F4.1 module

9 Rockwool sectional insulation

All ventilation ducts are encased by sectional insulation. This dispenses with the elaborate process of installing ventilation ducts with pipe brackets and of packing the voids between ducts with insulating material (one exception being the corner areas at changes of direction – see below). The insulation sections are sized such as to achieve an EI30 nbb fire rating between the ventilation ducts.

Sectional insulation is available for various duct diameters, e.g. for 80 mm or 100 mm internal diameters and in various densities, starting from 60 kg/m³.

Figure 17: sectional insulation for ventilation ducts (Flumroc, Switzerland)

10 Ventilation ducts

A generally vertical arrangement is adopted for the ventilation ducts in the façade (conceptual approach developed by Gerhard Zweifel, HSLU, in research module A5). The ventilation ducts must be easy to join together on site. The use of special products, which allows instant push-fit connection of ventilation ducts is required (Lindab, Switzerland).

Pull-out telescopic duct | Alignment | Push-fit | Repeat for other ducts

Figure 18: Connection of ventilation ducts

Figure 19: Model at Swissbau 2010 construction trade fair (Bächi Holzbau). Here, the façade is designed with timber rainscreen cladding. F4.1 module with push-fitted ventilation ducts

The above picture shows how the upper unit is positioned above the lower unit and the ventilation ducts push-fitted together. Here, the next step would be to install component no. 7 and complete the connection operation by further lowering down the upper F4.1 module from the crane.

11 Thermal insulation at lintel/apron, layer 2

The vapour-permeable thermal insulation products specified in the table below can be used. In some cases, these may need cutting to size and shape prior to installation.

12 New frame at reveal with thermal insulation

The timber frame also incorporates the window stop and the base for the new outer reveal, which is thermally insulated.

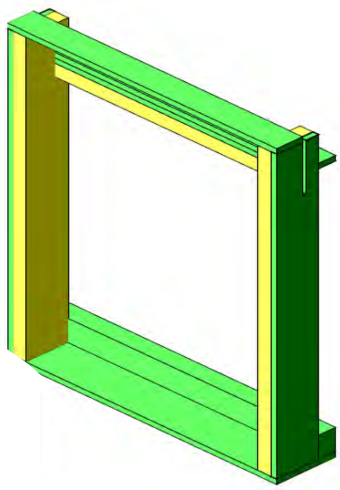


Figure 20: Insulated frame as outer reveal and for fixing window

13 Front gypsum fibreboards

The 15 mm gypsum fibreboards terminate layer 1. In combination with the rear gypsum fibreboards (in component no. 5), they lend the F4.1 base module its torsional stiffness, which is also important for transportation.

14 Window sill

E.g. in metal, always thermally insulated on the underside

15 Timber crosspieces in layer 2

Square timber crosspieces, e.g. 60 mm high. Depth = insulation thickness of component no. 16 (VIP) + insulation thickness of component no. 17.

Fitted between the timber crosspieces are the vacuum insulation panels (component no. 16). A clear distance of 50 cm should be provided between the crosspieces to allow direct insertion of standard-size panels, e.g. 50 x 60 cm. The width of the vacuum insulation panels must exceed the width of all the sectional insulation units (i.e. must be greater than 4 x 140 mm for four ducts). Any remaining voids adjacent to the edge boards (see components no. 5 and 12) must be packed with other thermal insulation. These voids allow any differences from the standard VIP sizes to be accommodated (although any size is normally available on request).

The external face of the timber crosspieces can serve as a base to fix wood fibreboard as a rendering background, vertical battens for rain screen façades or solar panels/collectors (always vapour-permeable assemblies). Structural loads are transmitted at the intersections with the timber uprights in layer 1. In cases of doubt, moments can be reduced, for example, through the additional integration of triangular fillets.

16 Insulation over ventilation ducts

Optimization of thermal insulation using vacuum insulation panels (VIP). A more detailed discussion of possible heat losses from ventilation ducts is presented in Section 2.2.4.b. The integration of VIP offers an effective remedy to any excessive thermal transmission potentially resulting from long, linear thermal bridges between ventilation ducts and the exterior environment. This has no effect on the thickness of layer 2.

17 Thermal insulation in layer 2

A wide variety of insulation products can be used.

18 Sun shading

Electric blinds, fabric roller blinds etc. for summertime thermal control, reduction of heat losses in winter. Clear internal size for blind box depends on aggregate size of components no. 15, 16, 17, 19 and 20. Possible integration of control components (cable, remote control)

19 Blind box trim, optional

Blind box requires no separate trim e.g. where cement fibre board is used.

20 External skin (finish)

Standard materials can be used to provide a vapour-permeable external skin. The options include an ETICS (external thermal insulation composite system) with rendered finish, a timber or metal back-ventilated rain screen façade (vertical batten for cement fibre board shown in exploded drawing) or installation of solar panels/collectors etc.

Whether this external skin is prefabricated or applied on site (e.g. due to alignment of joints with adjoining opaque façade sections) can be specified on the basis of project-specific factors.

In the process of developing details for the façades, it emerged that the two basic façade systems – timberwork and metal/glass – necessitate different approaches. The production of large-size units (incorporating ventilation ducts) equivalent to the 10 m x 2.7 m panels that are possible with timberwork systems is not yet practicable for metal/glass assemblies. Though no doubt technically feasible, any such developments would be uneconomical. Moreover, large metal panels would require an elaborate solution to meet the stringent requirements regarding the prevention of thermal bridging.

The purely timber assembly adopted for the F4.1 base module is pictured below. The timber components are in colour, with the other parts shown as 3D wireframe objects. In this example, the timber components account for a total volume of around 0.23 m^3.

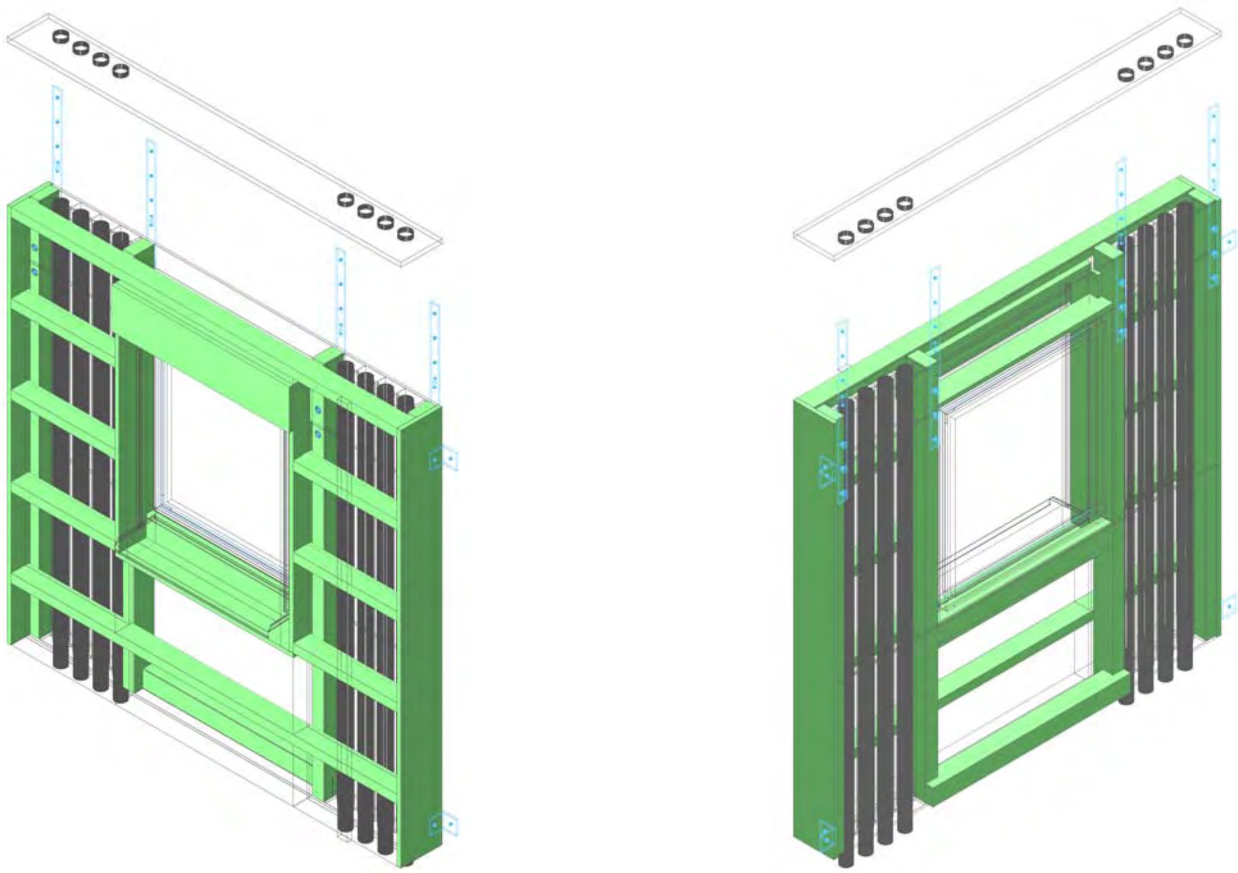


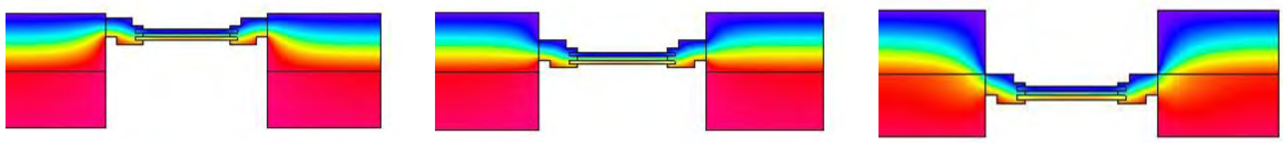
Figure 21: Isometrics showing timber components in F4.1 base module, front view on left, rear view on right

2.2.3. Background to window position

The determination of the window position on plan is governed by several criteria. Those discussed here relate to thermal transmission losses, transportability of the base module, and the need to strike a balance between the internal and external reveal depths. Specification of the window position is a prerequisite for the development of further details within the F4.1 base module. While the position proposed below may, theoretically, be shifted outwards, this will always entail the reworking or adjustment of the relevant detail solutions and renewed fine-tuning to minimize thermal transmission losses.

A simplified model can be used to demonstrate that, purely in terms of geometry, the window position has an impact on thermal transmission losses. The following sequence simulates the relocation of the window from the outside inwards and computes the associated transmission losses. The analysis embraced 15 positions. The diagram shows the two extremes and the centre position, for constant temperatures $T_{outside}$ = 0°C and T_{inside} = 20°C, with a thickness of 20 cm assumed for both masonry and thermal insulation.

The calculations are intended to provide general guidance. The temperature patterns also depend on other assumptions. The U-value of the existing wall may, for instance, play a role: the lower the thermal conductivity of the existing wall, the closer the window should be placed to this wall (starting from the centre of the new insulation layer, though still remaining within this layer).



Window practically flush with building exterior and fully enclosed in new insulation layer

Centre position

Extending into existing reveal

Figure 22: Temperature patterns for different window positions

2.2.4. Ventilation ducts as critical path

On both new-build and refurbishment schemes, ventilation ducts are commonly located in the building interior. This research project, however, focuses exclusively on situations where the ventilation system is housed within the new external wall. Here too, various problems arise regarding design team co-ordination and constructional detailing. Ready-made solutions to most of these are designed into the F4.1 base module. The task of incorporating ventilation ducts in a prefabricated unit is so challenging and overriding that these merit the status of a "critical path".

This entailed, among other things, the provision of two distinct layers (layer 1 and layer 2) in the F4.1 base module. The aim is to locate the ventilation ducts at a maximum distance from the cold outside air in order to prevent the creation of very long thermal bridges and rule out any risk of cooling of the fresh air supply. Moreover, any unnecessary cooling of exhaust air will automatically lower the output of the heat recovery system. This is particularly critical e.g. in regions where winter temperatures of -20°C prevail for weeks on end. It is thus important to create "favourable ambient conditions" or at least the means of optimizing the ventilation duct arrangement within the system – whether in terms of thermal performance or with regard to planning, design or operational criteria.

The concept must permit the full, detailed design of service runs while providing adequate flexibility for subsequent project-specific adjustments/refinements, e.g. the use of a pipe-in-pipe system for heat recovery.

The model pictured below, showing the planned refurbishment and vertical extension of a two-storey residential building using the F4.1, F2, R8 and R9 modules, clearly illustrates the layout of the new ventilation ducts. In this case, the ventilation plant (here serving a cascade ventilation system) would be located on the rooftop at the point where the ducts converge. A building of this size is likely to require roughly one kilometre of ventilation ductwork.

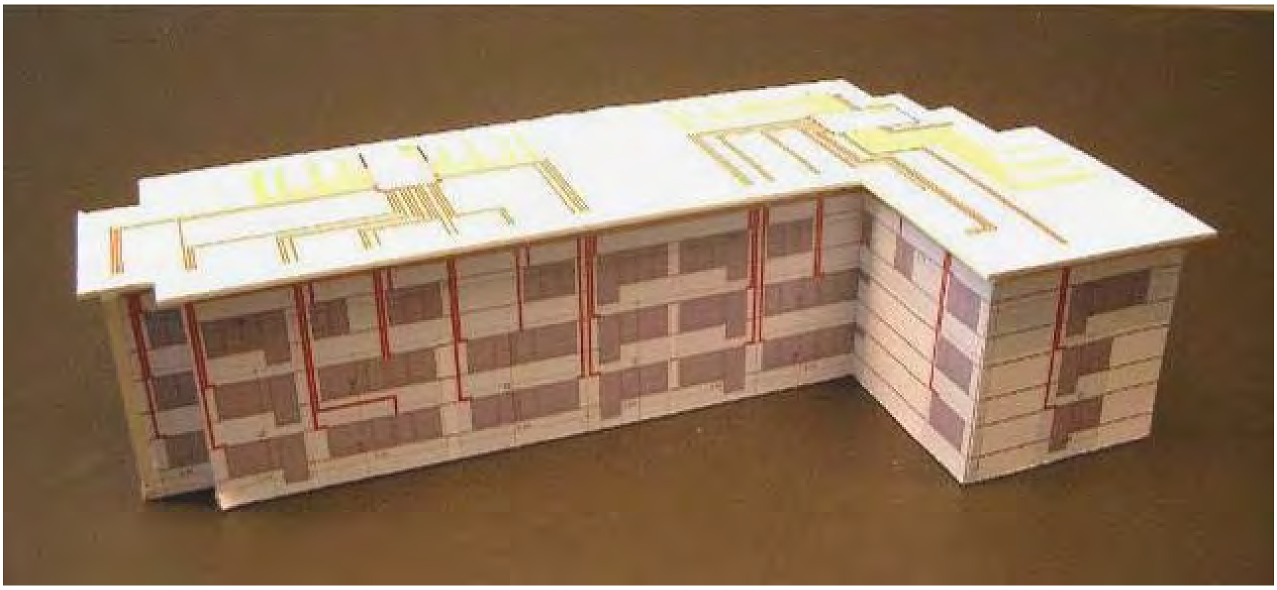


Figure 23: Model of Glatt 1 pilot and demonstration project in city of Zurich illustrating ventilation design, produced by Zurich-based architectural practice BAUART (photo: BAUART Zurich)

Fire protection
For ventilation ducts, compliance with fire regulations becomes a particularly important issue e.g. where ducts from different dwelling units run next to each other. Given the approx. 106.000 residential buildings that may be fitted with ventilation ducts in the future, it should be a key aim of the product development process to include passive fire protection as an inherent system.

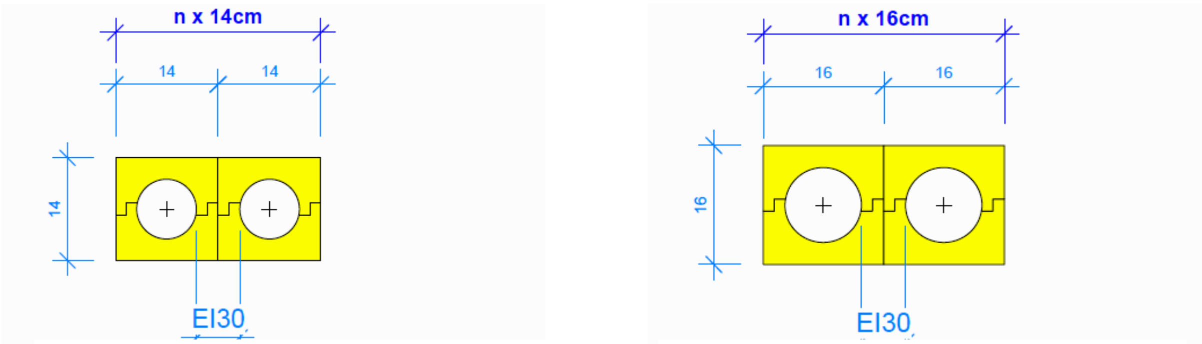
Provision of a common basis for communication offers a useful means of simplifying co-ordination and boosting efficiency in the design, planning application and construction processes. A good practice standard, to which contractors and authorities can refer, can provide a reliable starting point for meeting the required fire ratings while also achieving overall savings in project time. The aim is to issue a good-practice paper, which will then become mandatory. For the ventilation ducts – which must be made of metal – the following fundamental points need to be observed regarding the minimum distances between ventilation ducts serving different apartments and those between ducts and combustible material in the façade and roof modules. The examples illustrate two situations: that where ventilation ducts serving different apartments lie adjacent to each other (EI30[5] nbb[6]) and that where enhanced requirements apply, e.g. where a kitchen extract runs alongside a ventilation duct serving another apartment (EI60 nbb). One option that allows the EI60 nbb variant be dispensed with is to convert the kitchen extract into a recirculation system.

The following material specifications apply to the examples below: metal ventilation ducts, 15 mm gyp-sum fibreboard, mineral wool sectional insulation, 60 kg/m³ mineral wool:

EI30 nbb rating between adjacent ventilation ducts:
- Mineral wool insulation section + mineral wool insulation section
- 60 mm mineral wool

Adjacent mineral wool insulation sections (see component no. 9 in exploded drawing, Figure 10) in façade and roof modules achieve an EI30 nbb rating.

[5] Fire protection classification for 30 minutes
[6] nbb = not inflammable



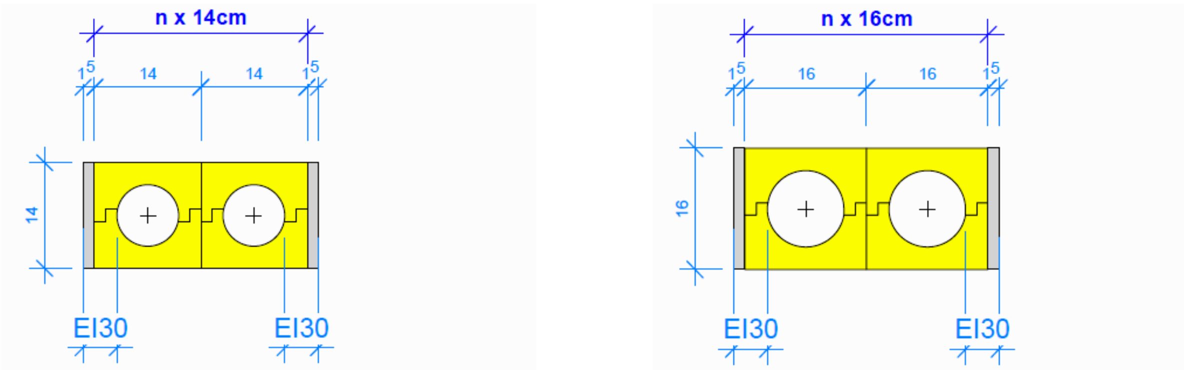
Half-shells for Ø 80 mm air ducts Half-shells for Ø 100 mm air ducts

Figure 24: EI30 nbb, between adjacent ventilation ducts serving different apartments

EI30 nbb rating to timber

- Mineral wool insulation section + 15 mm gypsum fibreboard
- 60 mm mineral wool

To achieve an EI30 nbb rating, a gypsum fibreboard must be fixed at the side of the rock wool insulation section.



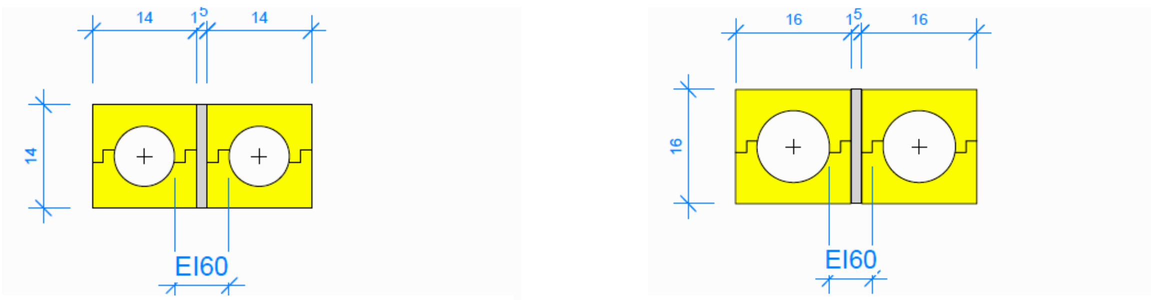
Half-shells for Ø 80 mm air ducts Half-shells for Ø 100 mm air ducts

Figure 25: EI30 nbb, to other adjacent components

EI60 nbb rating between adjacent ventilation ducts

- Mineral wool insulation section + 15 mm gypsum fibreboard+ rock wool insulation section
- Mineral wool insulation section + 2 x 15 mm gypsum fibreboard
- Mineral wool insulation section + 30 mm rock wool + 15 mm gypsum fibreboard
- 90 mm rock wool

An EI60 nbb rating is achieved, for example, by inserting a 15 mm gypsum fibreboard between the mineral wool insulation sections.



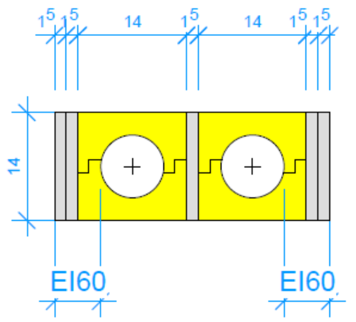
Half-shells for Ø 80 mm air ducts Half-shells for Ø 100 mm air ducts

Figure 26: EI60 nbb, between adjacent ventilation ducts

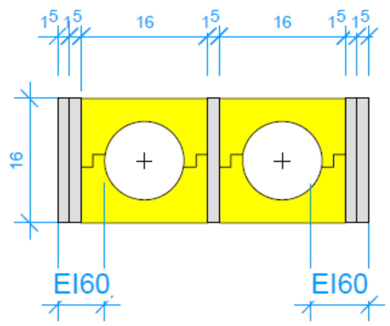
EI60 nbb rating to timber

- Rock wool insulation section + 2 x 15 mm gypsum fibreboard
- Rock wool insulation section + 30 mm rock wool + 15 mm gypsum fibreboard
- 90 mm rock wool

To achieve an EI60 nbb rating, two gypsum fibreboards must be fixed at the side of the rock wool insulation section.



Half-shells for Ø 80 mm air ducts



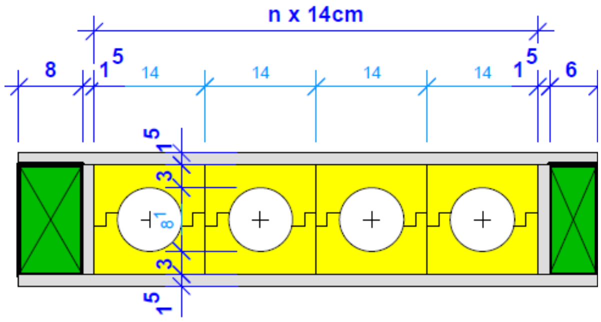
Half-shells for Ø 100 mm air ducts

Figure 27: EI60 nbb, to other adjacent components

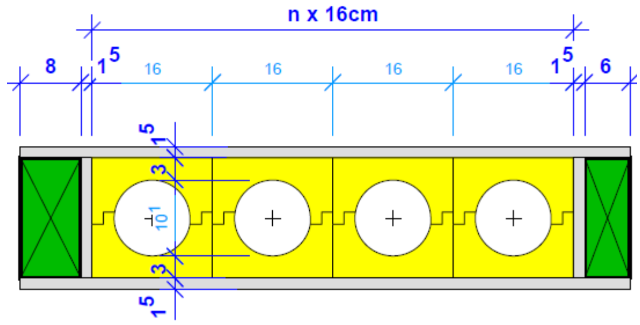
Concrete application with EI30 nbb rating in F4.1 base module

- rock wool insulation section + rock wool insulation section
- rock wool insulation section + 15 mm gypsum fibreboard

An EI30 nbb rating between adjacent ventilation ducts serving different apartments is reliably achieved by the following assemblies. The gypsum fibreboards facing the existing wall (at top in diagram) or the external skin (at bottom) are not strictly required to meet fire regulations. Yet, as they are needed for structural reasons (to stiffen the module), adequate fire protection is automatically provided and any type of material can then be applied on the external skin side.



Half-shells for Ø 80 mm air ducts



Half-shells for Ø 100 mm air ducts

Figure 28: Achievement of EI30 nbb fire rating for F4.1 base module

The F4.1 base module itself must not encroach upon the area of fire (party) walls. Moreover, compliance is always required with all other fire regulations governing façades and roofs. The same applies for lightning protection. Consultation with the fire authorities is recommended at a sufficiently early stage.

Laying of sectional insulation:
A staggered layout – both on plan and in cross-section – should always be adopted for the sectional insulation for both fire-safety and sound-control reasons. Unnecessary waste through offcut from the 1 m long insulation sections can be avoided by using this as a starter piece in the next row.

Figure 29: Mounting of half-shells

Calculations

In many cases, the ventilation engineer will be able to specify ventilation ducts with an internal diameter of 80 mm. An example with this internal diameter will now be used to highlight the key issues relating to thermal behaviour. An analysis of these in conjunction with the local conditions will enable the building physicist to specify or confirm the sizes and thermal conductivities λ_D,W/(m·K) or U-values required of the assembly for the thermal insulation between the outer face of the ventilation duct and the outside air.

Given that the supply air temperature should approximate to the required inside temperature (unless supply air is explicitly used for heating or cooling), the impact of thermal action from the outside on the temperature of the supply air flowing through the ventilation duct should be minimized. The ventilation ducts are located in layer 1. The thermal insulation on the internal side, i.e. the assembly between ventilation duct and existing external wall, comprises 30 mm rock wool + 15 mm gypsum fibreboard+ approx. 30 mm glass wool. On the other side, the design of the thermal insulation between ventilation duct and exterior environment must be such as to prevent any major linear thermal bridging between duct and outside air. In the example shown below, the required thermal insulation performance is achieved by using 30 mm rock wool + 15 mm gypsum fibreboard+ 20 mm VIP + 100 mm glass wool or rock wool.

Caution is required when considering only the temperature differences between entry into the ventilation duct after the central ventilation plant and discharge from this duct into the building interior. These temperatures differences may well be small, but it would be wrong to conclude that hardly any energy has been lost during circulation. Small differences may be simply attributable to a sufficiently high airflow rate. Accordingly, the temperature differences e.g. for a 30 m³/h airflow rate may remain slight even where the assembly between ventilation duct and outside air exhibits a poor U-value. The loss of energy to the outside is offset by energy transmitted from the inside, i.e. the poorer the U-value between ventilation duct and existing wall, the greater the compensation of energy losses to the outside, relative to the air temperature in the duct. This link with the interior thermal environment may impact the building's overall energy performance, particularly if it contains hundreds of metres of poorly insulated ventilation ductwork.

The proposed integration of VIP in the system at least creates the possibility of addressing this issue. This is particularly important in cold, high-altitude regions, where external temperatures of -20°C can persist for long periods during the winter months.

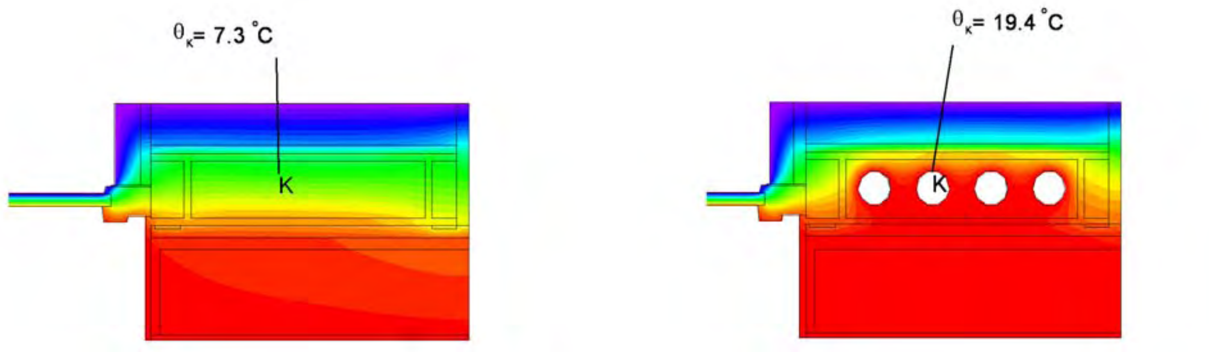
By the same token, retrofits in warmer areas can completely dispense with the VIP or alter the VIP thickness to 20 mm, 40 mm or more, as required. For the approx. 106.000 candidate residential buildings, it will also be important to investigate the implications of the covering insulation for heat recovery and other issues such as condensation inside ventilation ducts and to make the necessary adjustments.

The diagram below (based on a purely static/non-dynamic model) shows the impact of VIP with thermal conductivity λ_D = 0.008 W/(m·K). Here, the assumed air temperature in the ventilation duct is 20°C and the assumed surface coefficient between air and internal face of the metal duct is 17.85 W/(m²·K). The ventilation ducts are "linked" to the building's interior thermal environment through heat flows in both directions.

The following model may serve as an aid to understanding:
An F4.1 module is built, though without integration of the ducts, the resulting voids being filled with standard insulation. At point K, within the insulation and immediately in front of the metal duct, the

temperature would equal 7.3°C (for $T_{outside\ air}$ = -10°C and $T_{inside\ air}$ = 20°C). The U-value between the duct position and outside air totals 0.16 W/(m²·K) in both the module with and without ducts.

In an initial phase, the environment around the ventilation duct is "heated up". Given a specific heat capacity of something over 1000 J/(kg·K) for the sectional insulation, the low volumes and accordingly low mass, significant amounts of energy are not required. This leads to the situation shown in the second diagram. The aim now is to minimize the amount of heat energy escaping from this area around the ventilation ducts to the outside.



F4.1 base module without ventilation ducts F4.1 base module with ventilation ducts

Figure 30: Temperature distribution around ventilation ducts

The following section, which forms part of *research module A5 "Building services"*, is intended for specialists. The computational method for analysing heat losses from ventilation ducts plus associated discussion was drawn up by Gerhard Zweifel, HSLU, in 2010.

Computational method:
The underlying differential equation describes the pattern of air temperature ϑ over its path length x as a result of the heat transfer between the airflow and two sides (inside and outside) with different, though constant temperatures. The equation is as follows:

$$\dot{m}\rho c_L \frac{\partial \vartheta}{\partial x} = b\left[U_i\left(\vartheta_i - \vartheta\right) + U_a\left(\vartheta_a - \vartheta\right)\right] \quad (1)$$

Where

$\dot{m}$ Mass flow rate of air

ρc_L Density x specific heat capacity of air

b Width allocated to ventilation duct within which heat transfer takes place with thermal transmittances U_i and U_a

U_i Thermal transmittance between interior environment and airflow

U_a Thermal transmittance between exterior environment and airflow

ϑ_i Inside air temperature

ϑ_a Outside air temperature

The thermal transmittances are determined by means of two-dimensional heat transfer computation.

The solution of equation (1) is:

$$\vartheta(x) = \vartheta_{L,ein} + \left(\vartheta_{L,\infty} - \vartheta_{L,ein}\right)\left(1 - e^{-b\frac{U_i + U_a}{\dot{V}\rho c_L}x}\right) \quad (2)$$

where

$$\vartheta_{L,\infty} = \frac{U_i\vartheta_i + U_a\vartheta_a}{U_i + U_a} \quad (3)$$

, air temperature for infinitely long ventilation duct

$\vartheta_{L,ein}$ air entry temperature

Discussion:
Temperature $\vartheta_{L,\infty}$ represents the equilibrium temperature between the heat flows from the inside to the airflow and those from the airflow to the outside. As can be seen in equation (2), where the air entry temperature is equal to this equilibrium temperature, there will be no change to the air temperature over the length of the duct.

The outside temperature, of course, does not remain constant throughout the year. Yet, what does remain constant is the ratio of the temperature differences between inside temperature and $\vartheta_{L,\infty}$ and between $\vartheta_{L,\infty}$ and outside temperature. The same applies for supply air preheated by means of a heat recovery system with constant temperature efficiency. From this it can be inferred that, here, the ideal plane for routing the supply air will be that for which the ratio U_{tot}/U_a is equal to the temperature efficiency of the heat recovery system. In this case, the equilibrium state of heat flows in the wall will be maintained. This effect can be exploited by optimizing the distribution of the thermal insulation components.

The above does not, of course, apply where the relevant air temperatures remain constant year-round, e.g. as with exhaust ventilation ducts or reheated supply air. The effect in these cases can be calculated using the above equations (2) and (3) (Zweifel 2010).

Responsibility for airtightness

Ventilation ducts:
The concept entails little, if any, change to the division of responsibilities between client, designer and supplier. For contractors, however, there is a shift in responsibilities regarding the ventilation duct assembly. As the ducts are integrated in the prefabricated module, they are generally installed by the module manufacturer and not by the ventilation contractor. The integration of ventilation ducts in the rock wool insulation sections and the telescopic push-fit connections offer a reliable solution. While the producer guarantees airtightness class C (to EN 12237), the system reportedly surpasses class D requirements by 10% in practical applications (according to Lindab, 2009). Provision is nonetheless required for checking the airtightness of ventilation ducts at certain stages of construction. This is important for the contracting company, which, under the Swiss Code of Obligations, is required to provide a warranty for the works (defects liability provisions).

Essentially, the responsibilities are subject to negotiation. One option would be as follows:
The supplier of the modules (e.g. F4.1, R8, R9) accepts responsibility for both the ventilation ducts within the modules and the junctions between modules. The main interface between module supplier and ventilation plant supplier is at that location where the ducts meet and are connected up to the ventilation plant. Responsibility can then be assigned by determining the position of any leakages. Use of a leakage tester (e.g. LT 510 by Lindab) or similar devices is recommended for testing purposes. This produces a printed report on site, which can then be signed e.g. by the site supervisor as a further precaution.

Building envelope:
The F4.1 base module is delivered to the site with a perimeter sheet for airtight sealing (see component no. 1 in exploded drawing). The embedment of this sheet between the existing reveal and the newly fixed 10 mm board is one area of responsibility either fully borne by the façade/roof module contractor or which requires clarification between this contractor and the plasterer (see diagrams showing procedure for airtight sealing of F4.1 module).
Similar clarification is required for the packing of voids between the ventilation duct and drill hole in the existing wall – also in respect of fire protection – at the inlet/outlet positions (branches from F4.1 module to interior). This list of potentially overlapping responsibilities is not exhaustive and detailed clarification is required with the contractor following concrete design of the module.

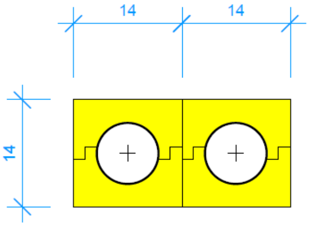
Sound control

The following discussion is limited to aspects of sound control directly related to the façade and roof modules. The design of sound attenuation measures for the central ventilation plant remains the responsibility of the ventilation engineer.

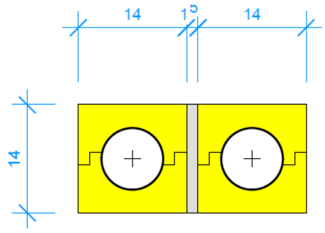
Sound transmission between ducts:
The fact that the ventilation ducts are enclosed by mineral wool sectional insulation eliminates the need for mechanical fixing. In terms of air and structure-borne sound transmission, then, this may be viewed as an essentially discontinuous construction. Should specific factors dictate the need for higher sound-

reduction indices between ducts, these can be achieved by means of either sound attenuators (e.g. Lindab SLFA25) or intermediate layers directly installed in the modules. The positioning of sound attenuators must also take account of cleaning and replacement requirements.

Provision for an intermediate layer of 15 mm gypsum fibreboard will automatically achieve an EI60 nbb rating (e.g. kitchen extract and fan noise). It is also possible to select mineral wool sectional insulation of a different density (e.g. 100 kg/m³ instead of 60 kg/m³).



Normal arrangement, EI30 nbb



Enhanced sound insulation, EI60 nbb

Figure 31: Sound control between parallel ventilation ducts

Sound control for vertical extensions:
Vertical building extensions (e.g. using the R8 and R9 modules – see later section) may result in sound transmission to other apartments on the same storey or to a lower storey via the ventilation ducts in the ceiling of the topmost storey.

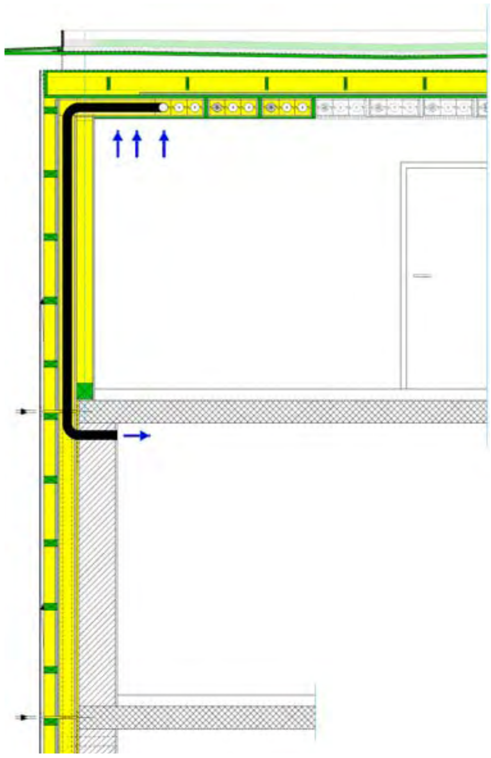


Figure 32: Possible sound transmission between apartments

Theoretical computations for sound control purposes are difficult in this situation and, as yet, no experimental verification is available. However, assuming that the assembly on the ceiling underside comprises at least 15 mm gypsum fibreboard with mineral wool channel and metal ducts, preliminary computational estimates suggest that no problems are likely to arise. If necessary, the aforementioned sound attenuators could be used to provide an economical remedy.

Other parameters and assumptions may also affect the above assessment. For example, where a sound source in the upper space generates a sound level of 90 dB, structure-borne sound transmission may prove a more relevant factor in the existing assembly.

Outdoor sound:
Neither the F4.1 base module nor the roof modules are vulnerable to problems caused by sound transmission into the ventilation ducts from the exterior environment. Inaccurate workmanship at the junctions between modules or – typically for façade assemblies – at windows is likely to cause more significant problems.

A general remark should be made about the relative nature of internal noise perception: even if the level of internal noise remains constant, it will be perceived more sharply due to the improved outdoor sound insulation brought about by the additional thermal insulation and higher-grade windows. Estimates/assumptions regarding sound levels are beyond the scope of the façade and roof module package and are the interior designer's responsibility.

Additional integration of utility services

The sectional insulation can also accommodate other building services installations, e.g. wiring for new electric blinds or any sensors needed for the windows. These service runs, which require mechanical protection, should be run through the first insulation section next to the window to prevent them from crossing any other installations. While the inclusion of water pipes is also feasible, the attendant risks, e.g. water damage to the façade through leakages, should be weighed up very carefully. Pipe-in-pipe solutions may provide additional safety in such cases. To minimize thermal losses, the packing (e.g. with loose-fill insulation) of any remaining voids is always recommended.

2.2.5. Thermal transmittance (U-values)

Buildings in Switzerland erected in the last century before 1975 exhibit (at a very rough estimate) façade and roof U-values between 2.6 W/(m²·K) and 0.8 W/(m²·K). The corresponding values for buildings completed since 1976 range from 0.8 W/(m²·K) to under 0.1 W/(m²·K) for more recent schemes. The spread is thus very large. Although the new overall U-value will also depend on the existing masonry, it will be mainly dictated by the new module and a figure of around 0.10-0.15 W/(m²·K) be targeted. The assumptions made for the purpose of identifying the critical locations in terms of thermal transmittance will, of course, vary in line with project-specific factors.

The calculations set out below are subject to the following assumptions for thermal conductivity in W/(m·K) or heat transfer in W/(m²·K):

Rock wool	0.036	Lime mortar	0.870	VIP	0.008
Gypsum board	0.250	Lightweight brick	0.450	$Alpha_{ext}$	25.00
Gypsum rendering	0.350	Wood	0.130	$Alpha_{int}$	7.700
Glass U=0.8	0.030	Plywood	0.170	$Alpha_{air\ duct}$	17.85
Glass wool	0.034	Steel	60.00		

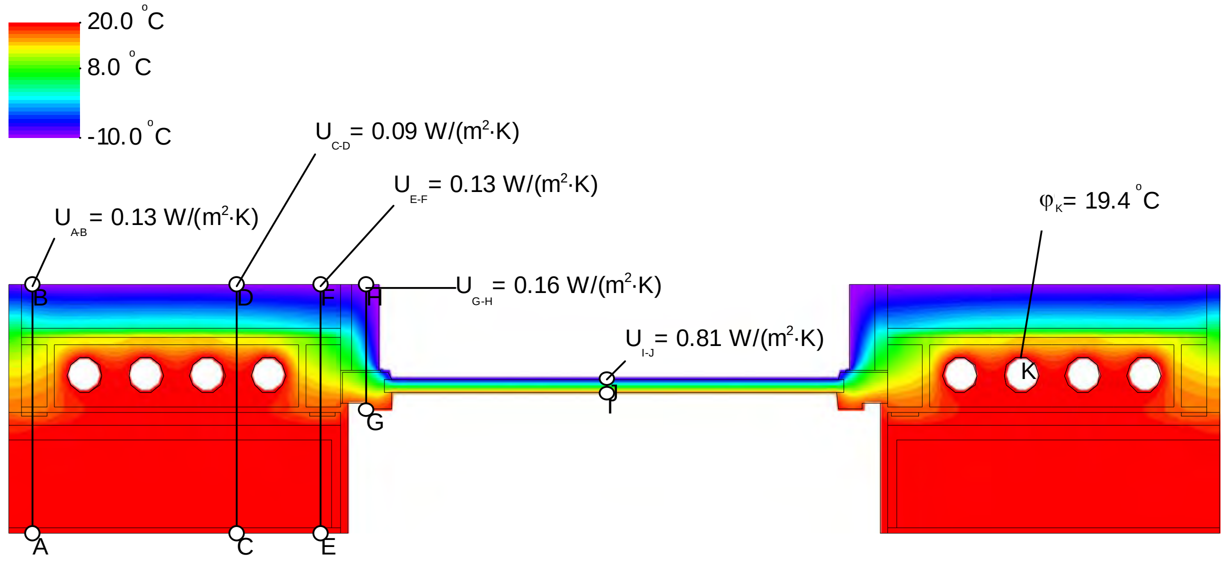


Figure 33: Temperature distribution in F4.1 base module

The best U-values, totalling 0.09 W/(m²·K) including the assumed existing wall, are achieved at C-D. At E-F, which crosses the timber uprights in layer 1 (see component no. 5 in exploded drawing), the value falls to 0.13 W/(m²·K). The U-value from point K to the outside air is 0.16 W/(m²·K).

Provision can be made in layer 2 to adjust the U-values: they can be improved either through the use of thicker VIP (total thickness of layer 2 remains constant) or thicker insulation board (thickness of overall assembly increases). The use of thicker insulation board would, among other things, necessitate adjustment of the timber crosspieces in layer 2.

Of course, a reduction of the overall U-value is also possible. A more interesting option, however, is to reduce the size of layer 2 through the use of thicker VIP (e.g. 40 mm or more) while maintaining good U-values. The resulting extra space can then be reserved for the possible integration of solar panels/collectors. It should be noted that layer 2 thicknesses of less than 13 cm may have implications for the installation of standard blinds (minimum size requirements).

2.2.6. Examples of optional features for F4.1 base module

The possibility of alterations to the F4.1 base module was mentioned at a number of points in the above discussion. The concept aims, among other things, to provide a base unit amenable to modification. The F4.1 base module is also adaptable in terms of function. Minor amendments allow the building to accommodate additional requirements without the need for any fundamental changes to the system or wholesale reinvention of details.

Functional adaptation of opening

Optional French balcony:
The F4.1 base module can also be produced as a prefabricated unit featuring a French balcony. The F4.1 base module allows existing windows to be converted into **door openings** incorporating suitable doors that open onto new balconies. The above also applies to external doors opening onto the terrace of a penthouse apartment.

Adaptation of unitization:
Theoretically, the production of a "stacked" variant comprising several vertically arranged base modules is also conceivable. However, points that are likely to necessitate adjustments include: structure-borne sound transmission from timber upright in layer 1 (part of component no. 5 in exploded drawing) to next storey, nature and sizing of wall fixings, fitting to existing, possibly slanting walls etc.

Adaptation to fully prefabricated large-size unit – F4.2 module:
The F4.1 base module concept by no means rules out the possibility of a fully prefabricated façade solution. The opaque sections can be straightforwardly attached following minor adjustments. The base module can thus be expanded into a large-size unit (designated as an F4.2 module). The maximum size is dictated by its transportability on Swiss roads. Possible dimensions would be storey height (less than 3.5 m) by approx. 10 m length. The contractor can also provide advice on the most economical solution and the viability of full prefabrication in a particular case. The design concept remains unchanged. The solutions for junctions between large-size units can be similar to those for roofs (see Section 3.2).

Conversion into structural element:
The F4.1 base module can also be converted into a **load bearing system** for use in vertical (and possibly horizontal) extensions (e.g. through adaptation of the timber uprights in layer 1 – see component no. 5 in exploded drawing, Figure 10). This option (R8 module) is described in a later section.

A further potential variant might focus on maximizing the slenderness of the F4.1 base module. In this case, the insulation in layer 2 would exclusively comprise VIP (e.g. for ground-floor locations requiring set-back from pavement).

To summarize, at least the following adaptations are always feasible:

- Adjustment of U-values
- Adjustment of heat transfer between ventilation duct and exterior environment

- Adjustment to structural requirements
- Dimensional adjustment, e.g. to accommodate different window sizes
- Adjustment of number of incorporated ventilation ducts
- Use of ventilation duct run to accommodate other building services installations
- Functional adaptations
- Aesthetic adjustments to external skin (finish)
- Integration of solar energy systems

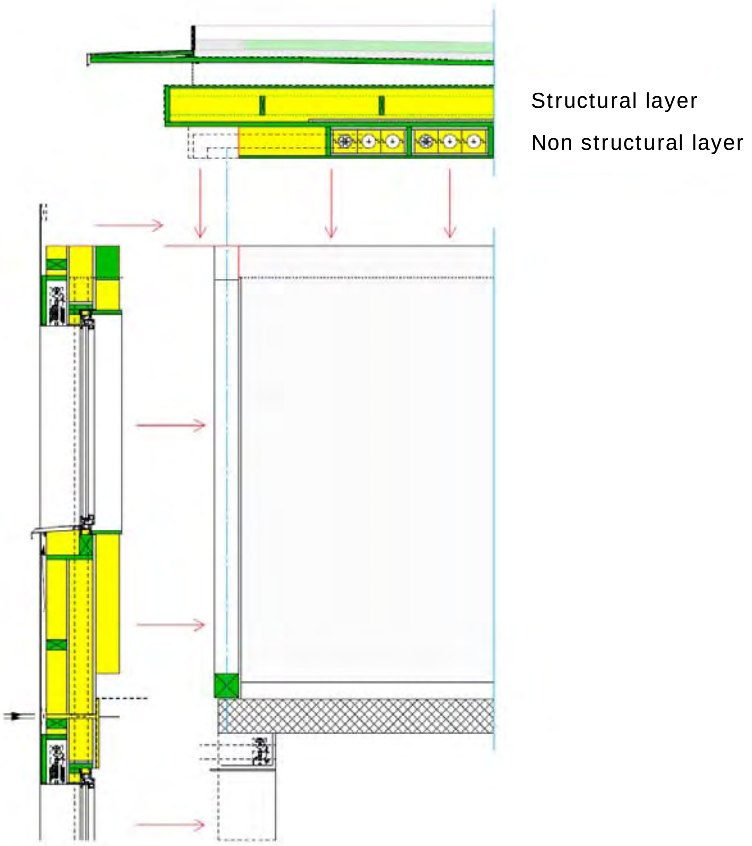


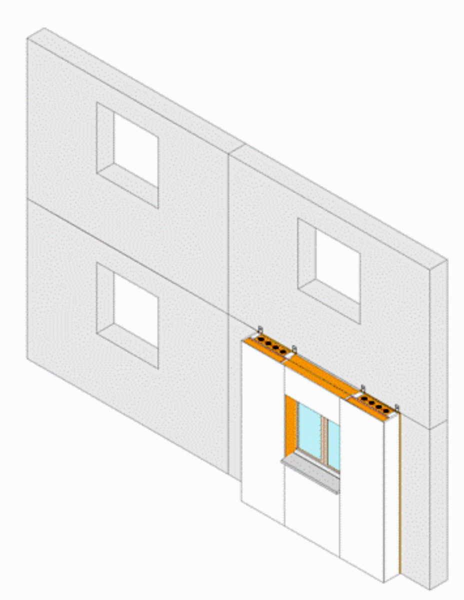
Figure 34: F4.1 as load bearing system

2.2.7. Installation on existing wall

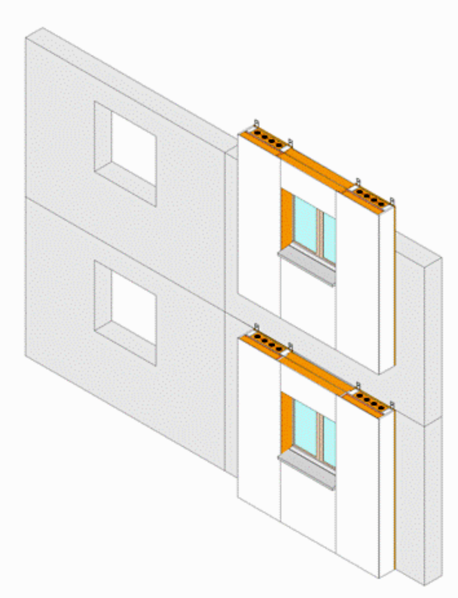
The following section outlines the procedure for installing the F4.1 module and thereby covers further aspects of specialist erection practice.

Prior to erection of the F4.1 base modules, the window reveals are either unchanged (those of existing structure) or have been newly constructed and rendered (where the openings have been widened). The window sills will also have been removed and the exposed parts of the building shell similarly made good and rendered.

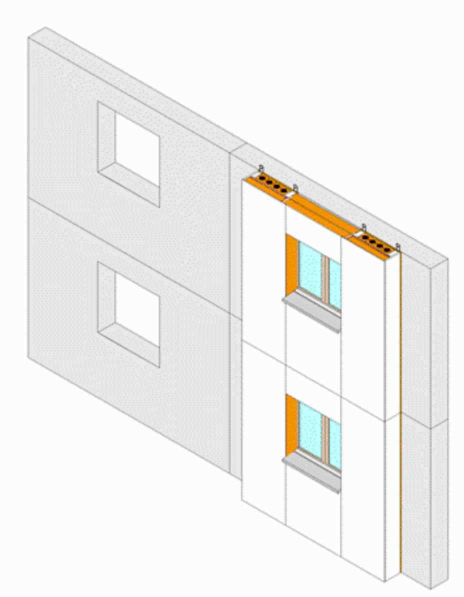
Scaffolding is provided for the erection process. Although it is feasible to install the modules by truck-mounted crane, this solution should be reserved for cases where only fully prefabricated façade modules have to be mounted (see Part B). As regards the scaffolding, it is possible to work with cantilevered platforms (projecting up to 1 m) that can be dismantled during erection. Under Swiss SIA standards, any alterations to the scaffold must be performed by specialist contractors. The setback of the scaffold from the wall, excluding cantilever, will depend on the thickness of the new modules and the necessary spacings between wall, new module and scaffolding. The installation period of the scaffold should be properly co-ordinated with the programmes for the other trades, e.g. fitting of exterior basement wall insulation.



The first F4.1 module is positioned (possibly with prefixed support beam for all F4.1 modules placed on top – see component no. 8 in exploded drawing). The unit is laterally secured by metal brackets (see component no. 6 in exploded drawing).



Prior to definitive placing of the upper F4.1 module, the ventilation ducts (and any other utility services) must be connected up.



Compressible insulation (component no. 7) is incorporated in the tolerance area between units and the upper module definitively fixed in place. The same procedure is adopted to install the modules on the other storeys.

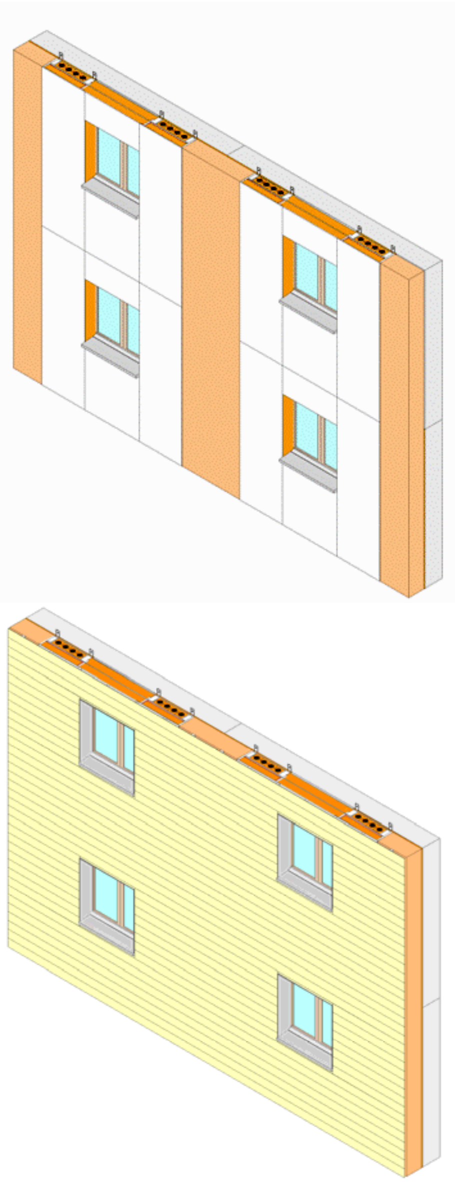


Figure 35: Installation of F4.1 module

The remaining opaque wall sections can be constructed in the normal way using standard façade systems. Here too, the use of prefabricated units is a possible option, depending on project-specific factors.

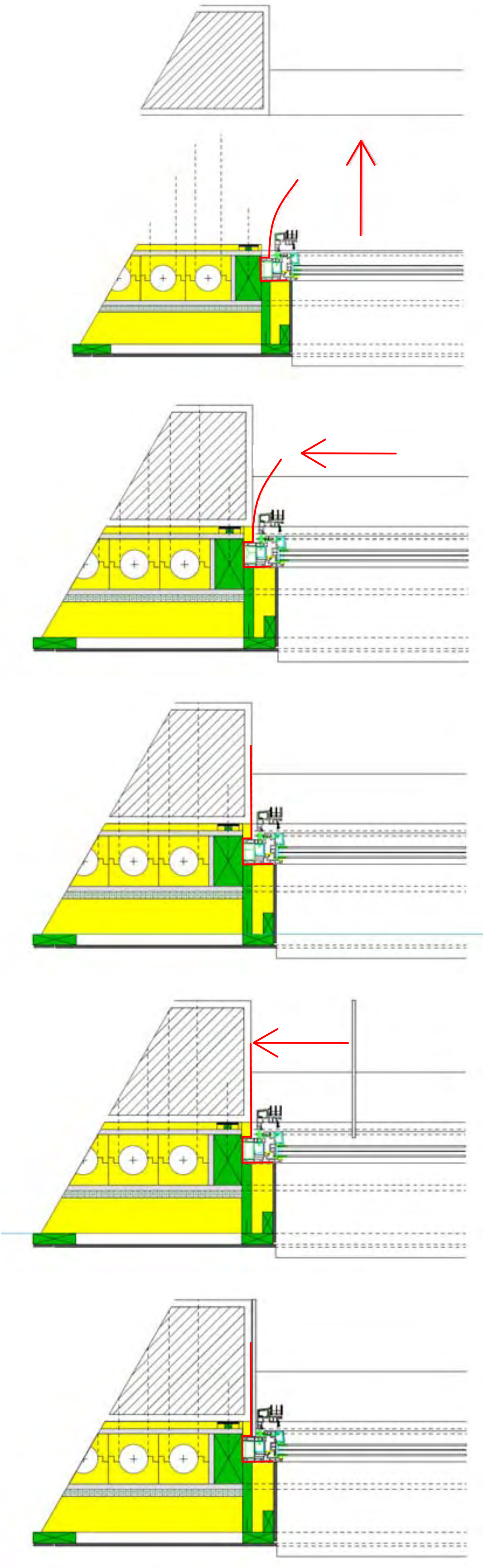
The modules used for the opaque sections are:

F1: Rendered façades
F2: Back-ventilated rainscreen façades
F3: Façades with rear loose-fill insulation

Finishing works to external façade layer and interiors. These comprise:

- Removal of existing window
- Bonding of sheet providing airtight seal/vapour barrier between F4.1 module and building
- Drilling of holes in wall to carry ventilation ducts from module into interior and for associated fixing
- Window board/ledge, cosmetic interior finishes, plastering, painting etc.

The procedure for the interior finishing works is as follows:



After the F4.1 base module is fixed in place, the airtight seal must be installed between wall and window.

This is provided by the airtight sheet (or vapour barrier) that projects loosely from F4.1 base module (see comments on component no. 1 in exploded drawing, Figure 10). Any small remaining voids must be packed with insulation.

The airtight sheet is bonded to the existing wall.

The bonded sheet is then covered by a suitable board (e.g. 10 mm thick gypsum baseboard for later plastering of reveals).

Possible installation of window boards/ledges. The finished assembly can now be plastered and cosmetic works performed to the edges and possibly the internal face of the wall.

Figure 36: Procedure for airtight sealing around F4.1 module

2.3. F1, F2 and F3 modules

The opaque façade sections or wall systems serve as the "infill" between the F4.1 base modules. The existing façade and thermal insulation systems of the industry partners can generally be adopted, without any major changes, for the F1, F2 and F3 modules.

Fundamentally new solutions for the opaque wall sections are neither necessary nor in any way useful. Suitable design-friendly systems with a proven track record are already available on the market and can be readily adopted. The available range of products also allows designers to tailor their solutions in line with various criteria (free market, costs, embodied energy, thermal conductivities, assembly thicknesses, supporting structures, eco-efficient alternatives etc.).

Use of the F4.1 base module in conjunction with the F1, F2 and F3 modules amounts to a combination of full prefabrication and on-site construction. The on-site component represented by the F1, F2 and F3 modules significantly eases tolerance problems by simplifying the adjustment of thermal insulation between two F4.1 base modules.

There are no constraints on the design of the visible parts of the façade (external skin): both rendered finishes and back-ventilated rainscreens made from any material (timber, metal, fibre cement etc.) are possible. The opaque façade sections can also accommodate solar panels and collectors. In terms of aesthetic impact, the F1/F2/F3 modules and the base module can be provided with the same or different exterior finishes. A decision is also needed as to whether the F1/F2/F3 modules should be flush with the F4.1 base module or whether certain modules should stand proud (e.g. spatial impact of façade, expansion joints).

While, theoretically, the F1, F2 and F3 modules could also carry ventilation ducts (or utility services), such solutions should only be considered in exceptional cases. All points in the above discussion of the ventilation duct as a critical path equally apply in this context.

Summary of opaque façade modules:

- F1: Rendered façades, e.g. standard external thermal insulation composite system (ETICS)
- F2: Back-ventilated rainscreen façades with insulation in cavity and any type of external skin, e.g. fibre-cement panels, timber weatherboarding, metal cladding, also integration of solar energy systems etc.
- F3: Façades with rear loose-fill insulation. On-site or prefabricated façade cladding with blown loose-fill insulation (applied on site or in factory)

2.3.1. F1 Module

The F1 module essentially reproduces the external appearance of a rendered façade, making it technically feasible for the new exterior to resemble the old. Provision is required for an appropriate rendering background, depending on the system (direct application to thermal insulation, wood fibreboard fixed to supporting frame etc.). The expansion joint between F4.1 and F1 modules demands particular attention. The edge board described in component no. 5 can serve as a base for fixing any necessary expansion joint strips. The module's construction and physical properties correspond to those of standard render systems. While it is theoretically possible for this module to carry ventilation ducts or other utility services (as described for the 4.1 modules), this should only be considered as a last resort in exceptional cases. Technical services should be concentrated in the 4.1 base modules.

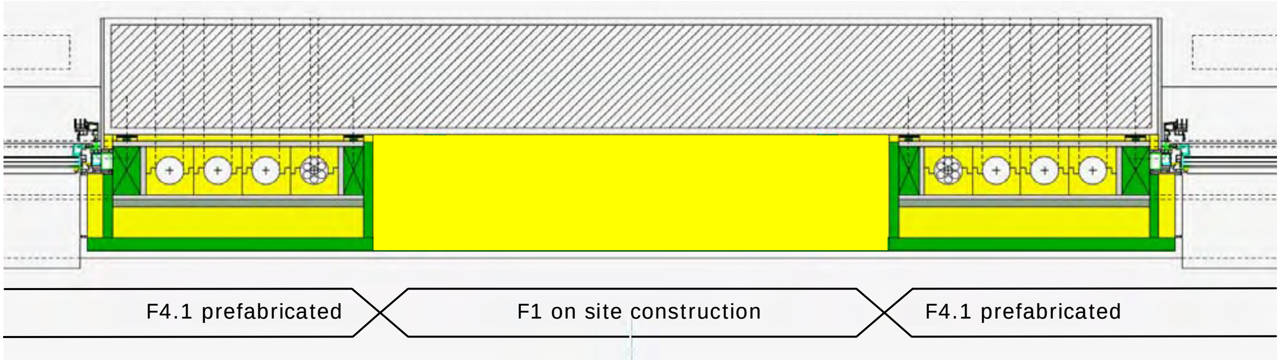


Figure 37: module, between prefabricated F4.1 modules

2.3.2. F2 Module

The F2 module is modelled on the conventional back-ventilated rainscreen façade. Here too, the application methods and physical properties of the standard systems apply. Insulation thicknesses of up to around 300 mm (e.g. in conjunction with Swisspor's LAMBDA Vento) are currently accommodated by spacer screw systems. The company is, however, set to supply longer fasteners to meet the market demand (according to information provided by Rogger, 2010). The new PHOENIX façade system recently developed by Isover represents a further option.

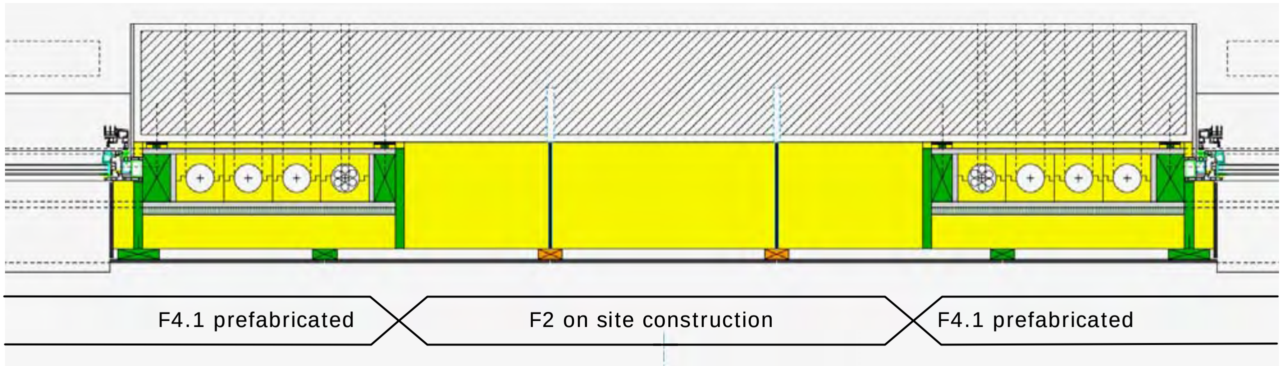


Figure 38: Module, between F4.1 prefabricated modules: back-ventilated cladding, e.g. fixed with spacer screws system. Here, fibre-cement board is used for the external cladding.

2.3.3. F3 module

The F3 module is a cladding solution for opaque façades incorporating rear loose-fill insulation. The "voids" remaining between the F4.1 base modules can be closed off at the front to create cavities for blown-in loose-fill insulation. As a result, the insulation thicknesses are no longer governed by 2 cm increments. Where suitable measures are taken to prevent settlement (e.g. cellulose fibres, with horizontal batten approx. 1/5 width of total insulation thickness fixed at each storey), this solution is capable of providing a void-free insulation layer, regardless of how uneven the existing masonry is. Various options are available for the external skin (rendered, cladding), though this must be vapour-permeable. New developments will allow robotization of the blowing-in process on prefabricated units. Various tests have shown there to be no risk of settlement of the loose-fill insulation during shipment.

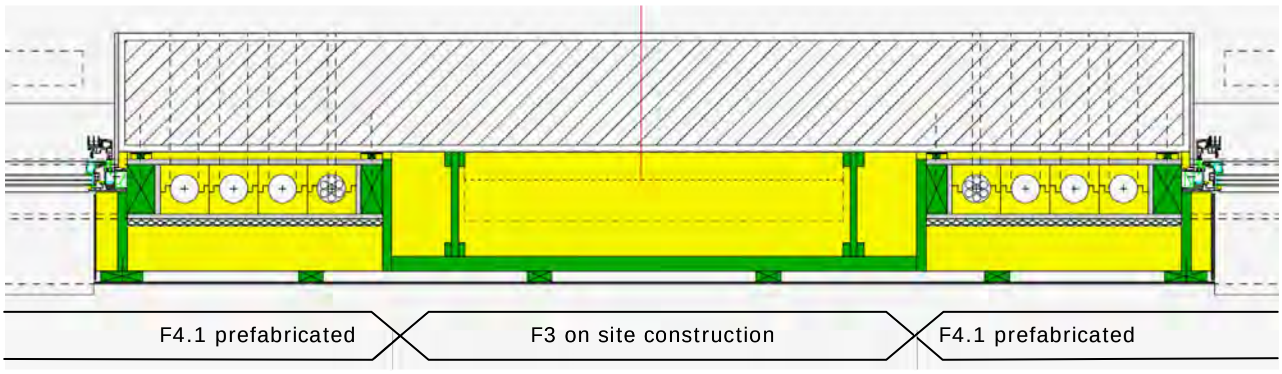


Figure 39: F3 module, between prefabricated F4.1 modules, here with rainscreen

3. Roof modules

The following discussion of roofs, like that of façades, sets out to provide project team members – architects, specialist designers and contractors – with a common understanding of the underlying concepts. It assumes knowledge of carpentry and timber engineering for roof assemblies and will provide no special background on these subjects. The details and processes shown here may be directly adopted or, where appropriate, altered, expanded or refined in line with project-specific requirements. The construction industry has also to ensure that site supervision has equal importance as that of the design.

The listed modules cater for the following roof solutions:

- Existing roof structure (purlins, rafters) to be retained (R1 module)
- New flat roof unit (R8 module)
- Wall unit for vertical extension (R9 module), normally in conjunction with R8
- Complete pitched roof space module (R3 module)

Other variants are also feasible, e.g. the R1.1 module (R1 module with integral dormer window). Yet, such options are not further examined here as they primarily entail the application of standard carpentry know-how. As with the façade units, the technical novelty of incorporating ventilation ducts in the roof modules necessitates a consideration of the following issues:

- Sizes and routing of ventilation ducts, including sectional insulation and gypsum fibreboard (critical path)
- Fire protection
- Impact of penetrations
- Ease of assembly on site

3.1. Application of façade details to roofs

The F4.1 base module already makes some provision for its application at roof level, and certain roof details proceed automatically from a proper understanding of the concept and its options. The underlying aim is to abolish, as far as possible, the need for one-off solutions and to design the entire building envelope using more or less the same repertoire of details. Although façades and roofs are clearly distinct in terms of construction, some important commonalities exist, e.g. the difficulties surrounding the critical path of the ventilation duct. Here too, the "layer principle" encourages a structured arrangement of ventilation ducts, which avoids numerous headaches, e.g. unnecessary and unfeasible penetrations or inscrutable structural and thermal bridging problems. The details included under Section 2.2.2 are also applicable here.

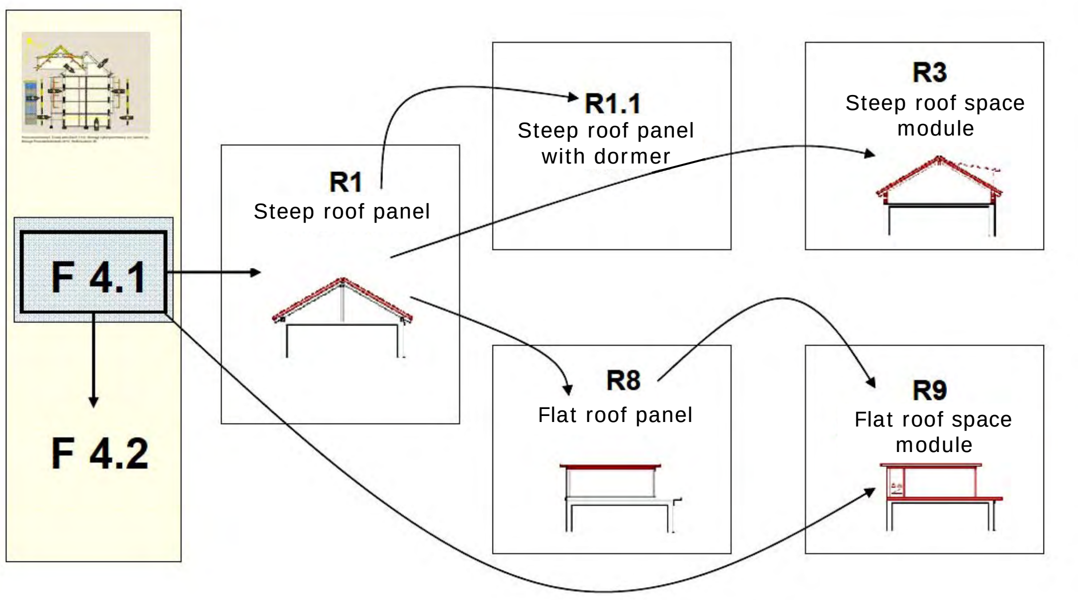


Figure 40: Application to roof units of relevant detailing concepts from F4.1 base module

3.2. Layer arrangement and junctions

The junctions between façades and roofs are of crucial importance, e.g. as the location of key ventilation duct connections (changes of direction). Ventilation ducts incorporated in prefabricated units must be easy to join together on site, e.g. where a flat roof unit is placed on top of a wall unit.

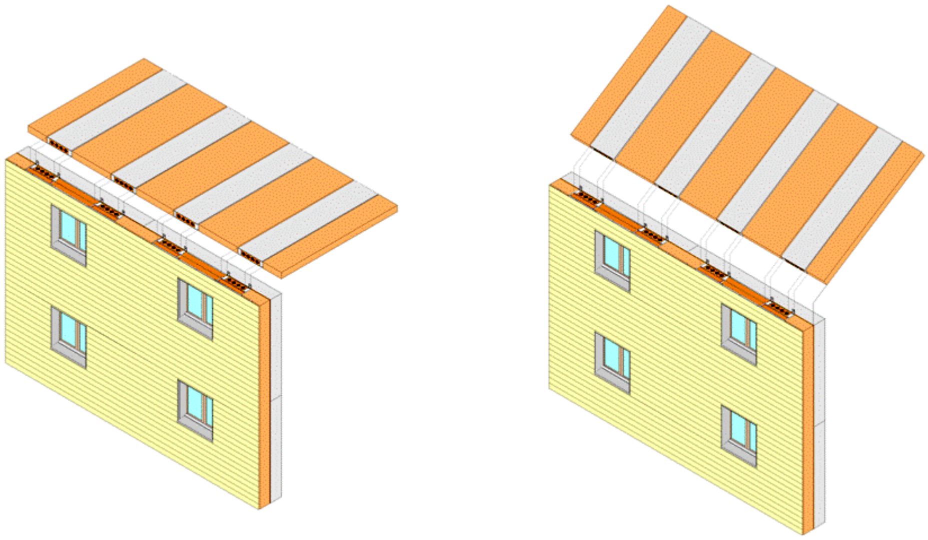


Figure 41: Change of direction and layer principle for ventilation ducts at wall/roof junction

Layers in roofs

Various questions recur in connection with the integration of ventilation ducts in the modules. Where should they best be positioned so as to create a suitable basis for detailed design and the systematic repetition of details? Key issues include:

- Perpendicular penetrations through structural members: Neither purlins nor rafters, nor any beams or girders supporting flat roofs, e.g. I-joists, can be randomly penetrated as this would soon compromise their structural performance. Beams penetrated by multiple drillings each measuring around 140 mm x 140 mm (external face of sectional insulation for 80 mm internal duct diameters – or even 160 mm x 160 mm for 100 mm diameter ducts) are no longer able to accommodate the vertical shear loads. This is an important consideration due to the inevitable concentration of ductwork around the central ventilation plant.
- Heat losses to/gains from outdoors: Location of the layer carrying the ventilation ducts too close to the exterior environment will result in unnecessary heat losses/gains.
- External noise: Location of the ventilation ducts on the very outside might lead to sound transmission to the interior from outdoors.
- Crossovers between ventilation ducts result in minimum cross-sectional heights of 280 mm (2 x 140 mm) and should be avoided as they may inflate the overall roof thickness.

The above factors militate against the inclusion of ventilation runs within the structural layer (one exception relating to the existing rafters of a pitched roof is described below). They must for the most part be housed in a dedicated layer which must not lie close to the exterior environment. A layer arrangement similar to that for façades thus appears appropriate, with:

- the upper layer for the structural members, and
- the lower layer for the ventilation ducts.

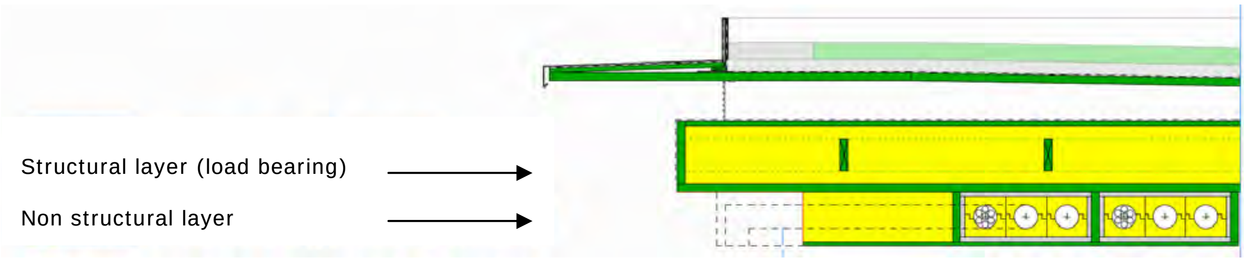


Figure 42: Layer arrangement in roof, illustrated for flat roof (R8 module)

This arrangement also provides a basis for the development of further details, as described in the following section on wall-roof junctions. The layer concept should not, however, be rigidly applied as situations may arise where alternatives are more appropriate. It nonetheless helps to systematize the detailing process and rationalize effort through the repetition of details, which ultimately boosts both design and construction efficiency.

Wall-roof junctions

The diagram below shows an example of a ventilation duct arrangement at the junction between façade and flat roof, as seen from the outside. The drawing is pared down to the relevant timber components so as to emphasize the routing of the ducts. In this case, the vertical ventilation ducts from the F4.1 module are carried through the timber head plate of a studwork assembly to a position between the lower face of the structural layer and underside of the ceiling. Here, the penetration through the head plate passes through the "nodal point"[7]. The nodal point is the point where the ventilation duct changes direction at the façade-roof junction (see also later cross-sections, Figure 52). This area is significant and recurs in both flat and pitched roofs. It is often here that the vertical forces from the structural layer of the roof are transmitted to the walls (see figures 46, 47, vertical extension to flat roof). The forces from roofs must not be transmitted beyond the external face of the existing wall to the suspended F4.1 modules.

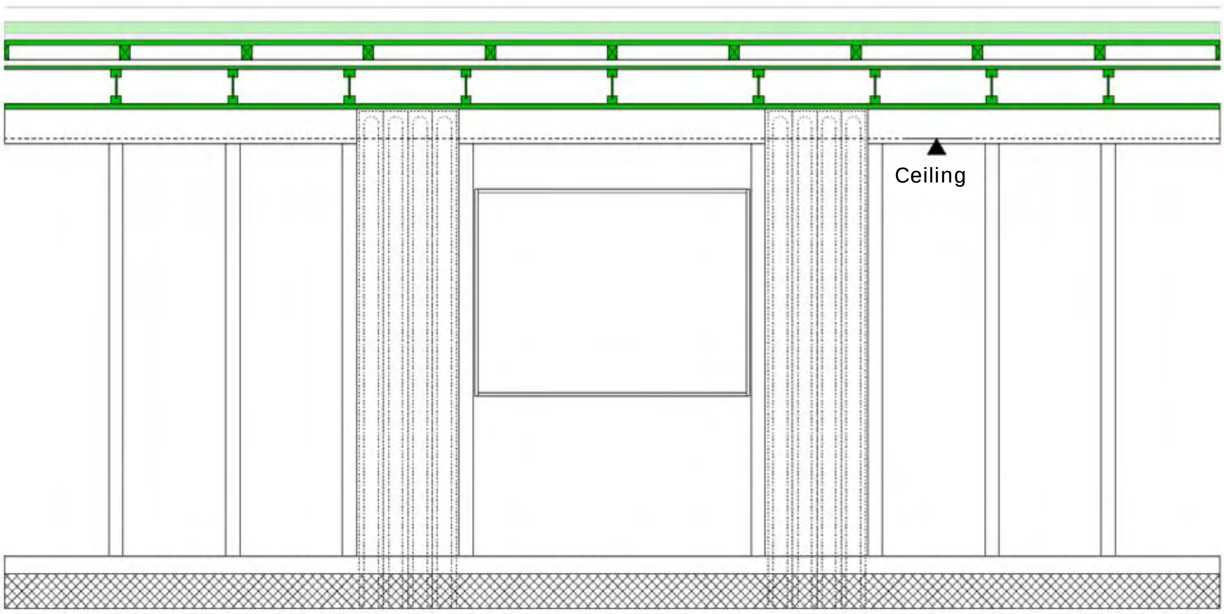


Figure 43: Elevation showing routing of ventilation ducts from façade to flat roof below structural layer

Roof-roof junction

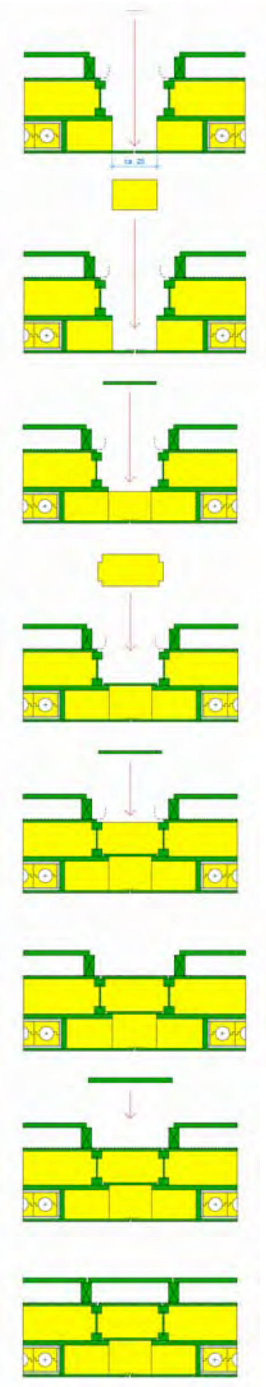
Flat roof:

Prefabricated flat roof units can measure up to e.g. 3.5 m x 10 m (logistical constraints). To cover the entire roof surface, several units must therefore be joined together on site at predetermined junctions.

[7] The term "nodal point" is borrowed from photography and denotes a point around which everything rotates.

Roof units are not usually separated by opaque sections, as is the case with façade constructions (F4.1 modules separated by F1, F2 or F3 modules). Consequently, the junctions themselves must make the necessary provision for tolerances, airtightness and the possible routing of service runs outside the sectional insulation. Solutions of this kind may also be applicable at the junctions between F4.2 modules, for fully prefabricated façades.

The following diagrams show the on-site assembly procedure for a cold flat roof construction (which is similar to that for pitched roofs – see below). A similar solution can also be adopted for warm roofs. The bottom layer is non-loadbearing and contains the ventilation ducts. The structural layer lies on top of this. The uppermost layer is the roof covering.



Provide airtight seal at joint

Make any necessary cross-connections between ventilation ducts (telescopic system identical to that for façade), pack voids with thermal insulation (optionally install additional service runs)

Fix timber board to stiffen assembly

Pack voids with thermal insulation
(optional installation of additional service runs, ventilation ducts only in conjunction with VIP to ensure adequate thermal insulation against external temperatures)

Fix timber board

Bond waterproof membrane

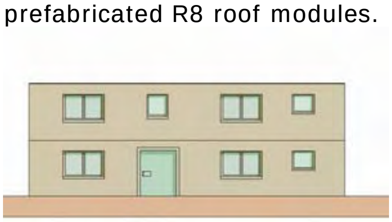
Additionally install OSB

Completed assembly, finishing works to covering layer (water proofing layer will be installed on top)

Figure 44: Procedure for assembly at junctions between roof units on flat roof

3.3. Concrete illustrations of R8 and F4.1 modules

Vertical extensions are an interesting option in that they may increase the building's value (in economic terms) and/or at least partly offset the additional cost of the overall building refurbishment. Further benefits include a more favourable envelope/floor area ratio (proportionately lower heat losses) and an economical use of land through urban densification (efficient spatial development). Both vertical extensions and rooftop penthouses can be constructed using F4.1 base modules in conjunction with prefabricated R8 roof modules.



An existing two-storey residential building is to be vertically extended. The top layers of the roof assembly are removed down to the upper face of the concrete deck, together with any roof edge constructions.

The new storey can be built in standard masonry or using a lightweight construction. A penthouse with roof terrace is a further alternative. The example shows the addition of a full storey constructed in masonry. The external face of the new masonry is flush with the external face of the existing wall or, strictly speaking, the render finish.

The roof is covered using prefabricated flat roof units (R8 modules). (Prefabricated flat roofs can also be fixed after the façade, because of better connecting of the ventilation ducts).

The F4.1 base modules are then similarly installed at the existing openings.

The remaining opaque wall sections can be constructed in the normal way using standard façade systems. Here too, the use of prefabricated units is a possible option, depending on project-specific factors.
The modules used for the opaque sections are:
F1: Rendered façades
F2: Back-ventilated rainscreen façades
F3: Façades with rear loose-fill insulation

Finishing works to external façade layer and interiors.

Figure 45: residential building to be vertically extended

The cross-section cuts through the area of the ventilation ducts. The positioning of the ducts (shown in black) within the system is such that the telescopic section of the ventilation duct in the F4.1 module (dashed lines in upper cross-section) can be extended shortly before placing and inserted into the R8 module duct. The prefabricated flat roof unit can then be definitively mounted on top of the F4.1 module.

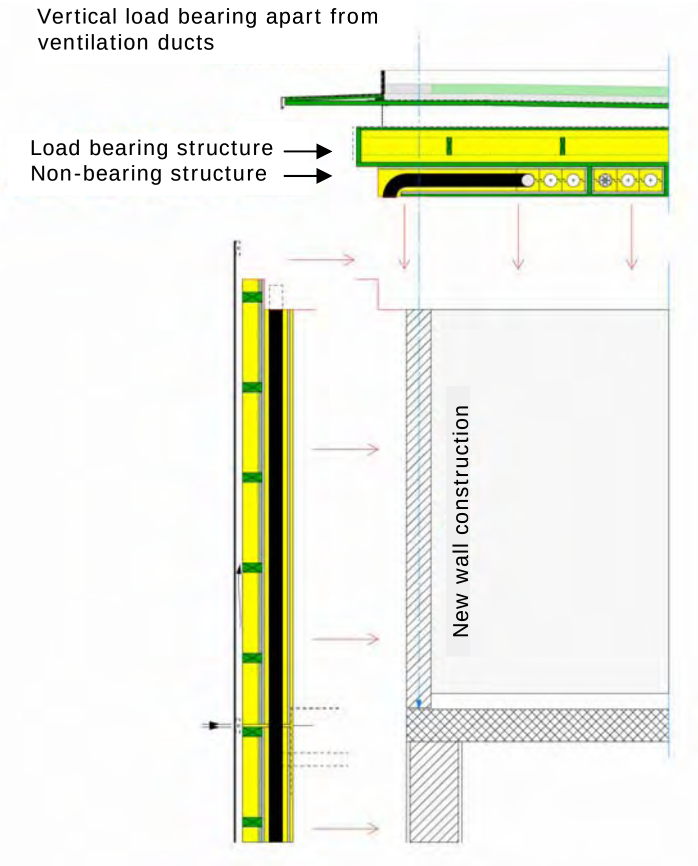


Figure 46: Joining of prefabricated F4.1 and R8 modules at ventilation duct connection

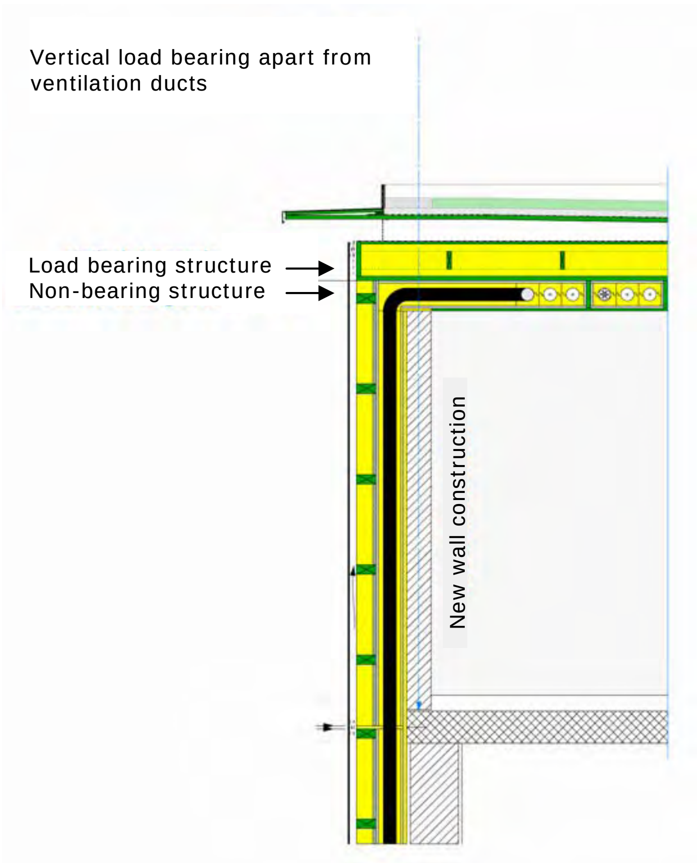
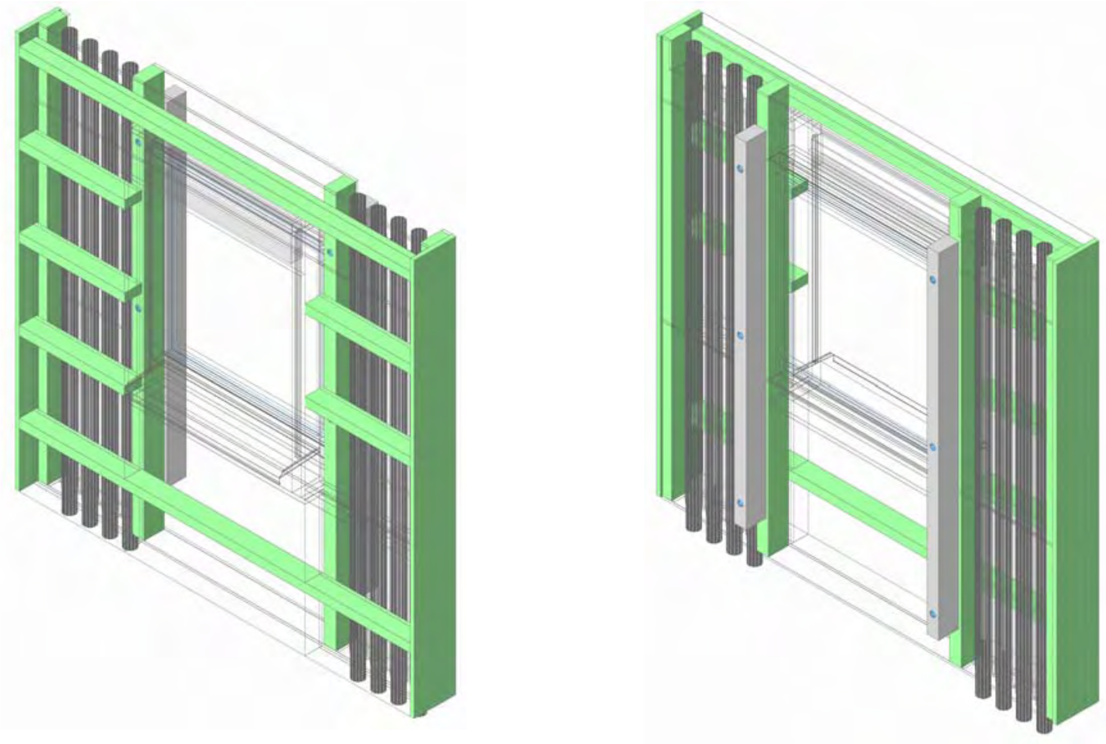


Figure 47: Joining of prefabricated F4.1 and R8 modules at ventilation duct connection

Example of lightweight construction for vertical extension using R9 and R8 modules

Where a lightweight solution is needed for the vertical extension (e.g. to prevent overloading of the existing foundations, to allow fast-track construction, to avoid building moisture or mixing heavy/lightweight assemblies etc.), a full prefabrication approach can be adopted. For this purpose, the F4.1 base module can be converted through minor adaptation into a load bearing wall (designated as an R9 module). The alterations are largely confined to the "timber uprights in layer 1" (see component no. 5 in exploded drawing). In terms of materials, the same industry partner products can be specified as for the F4.1 base module.

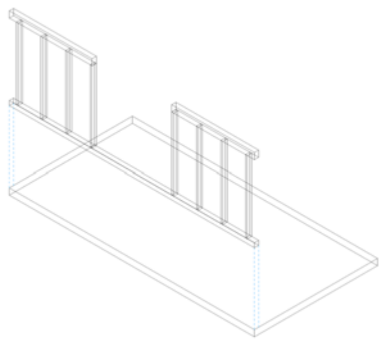


Front view: no changes needed

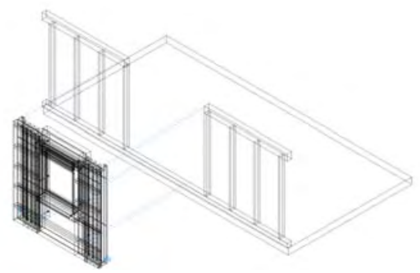
Rear view: the members shown in grey represent the main alterations

Figure 48: Conversion of F4.1 base module into R9 module

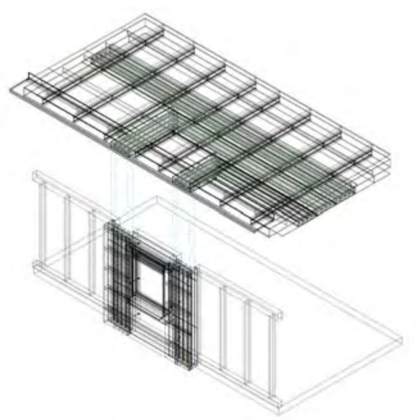
The following diagrams outline a possible procedure for on-site assembly:



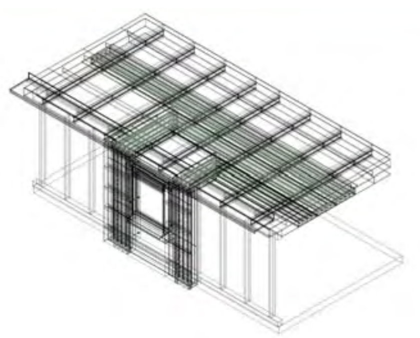
Erection of studwork on existing concrete slab



Installation of R9 module (one possible variant of converted F4.1 base module)



Installation of prefabricated flat roof unit (R8 module). Connect up ventilation ducts using telescopic system prior to placing roof units.



Erected modules. Complete opaque wall sections of studwork assembly (insulation, interior lining) if not also prefabricated.

Figure 49: Procedure for assembly of lightweight vertical extension on existing flat concrete roof

The procedure is shown below in cross-section. The F4.1 base modules on the lower storey are already in place. The prefabricated R9 module is then installed, followed by the R8 module.

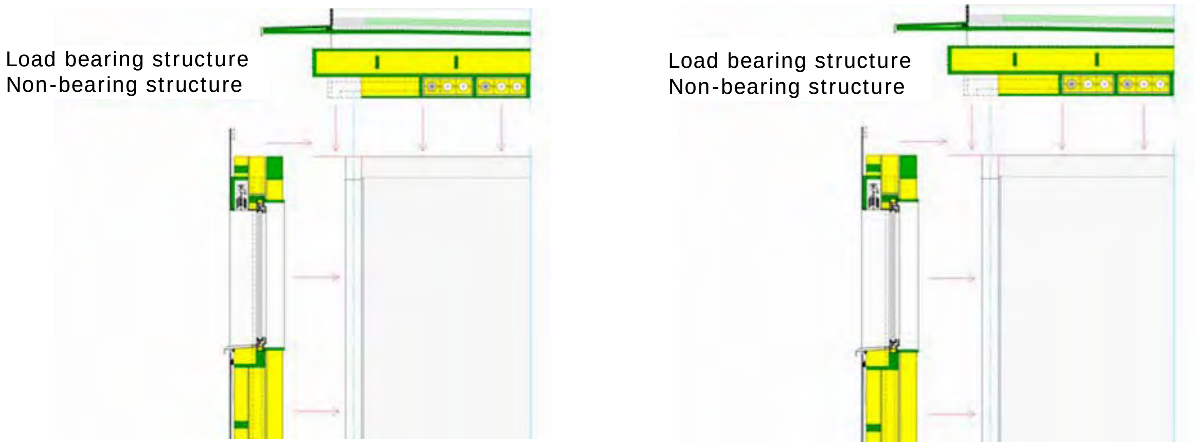


Figure 50: Cross-sections showing assembly of façade and flat roof units for lightweight vertical extension, through window and ventilation duct areas

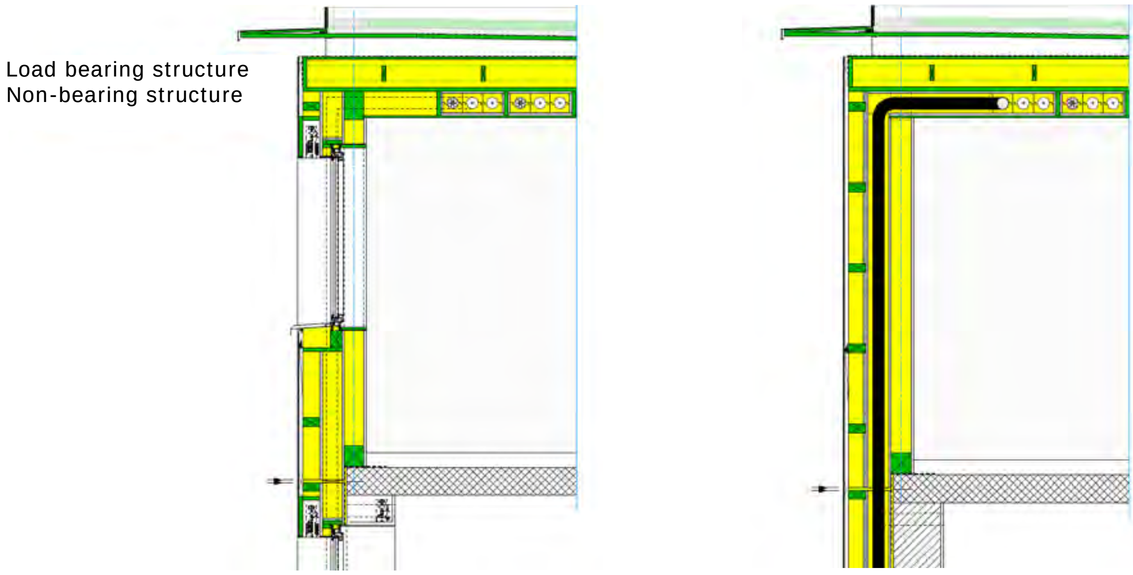


Figure 51: Cross-sections showing R9 and R8 module and installed studwork

Options for R9 module

The F4.1 base module can be converted into various different R9 modules. Hardly any modification is required to create a solution for the walls of a new penthouse apartment built on top of a roof. The recommended balcony doors can be installed in place of windows to provide access to the terrace. Any necessary service runs on the terrace can be designed in accordance with the principle described below for the N modules (see illustrations regarding "Routing of ventilation ducts on concrete deck"). Protection of the ventilation ducts against heat losses/gains can be enhanced by the use of additional VIP.

A further potential solution for vertical extensions could take the form of a fully prefabricated space module, comprising external walls (R9), roof (R8) plus internal walls. The 60 mm and 80 mm minimum sizes specified for the "timber uprights in layer 1" (see component no.5 in exploded drawing) merely reflect the fire safety requirements. If at all necessary, these components could be widened to meet structural demands. The order of cost for this type of integral space module depends on various factors, such as the associated road and building site logistics, object geometry and available factory facilities.

However, to prevent any extra heat losses, it is essential to minimize any additional thermal bridging caused by bracing components needed only for safe transportation.

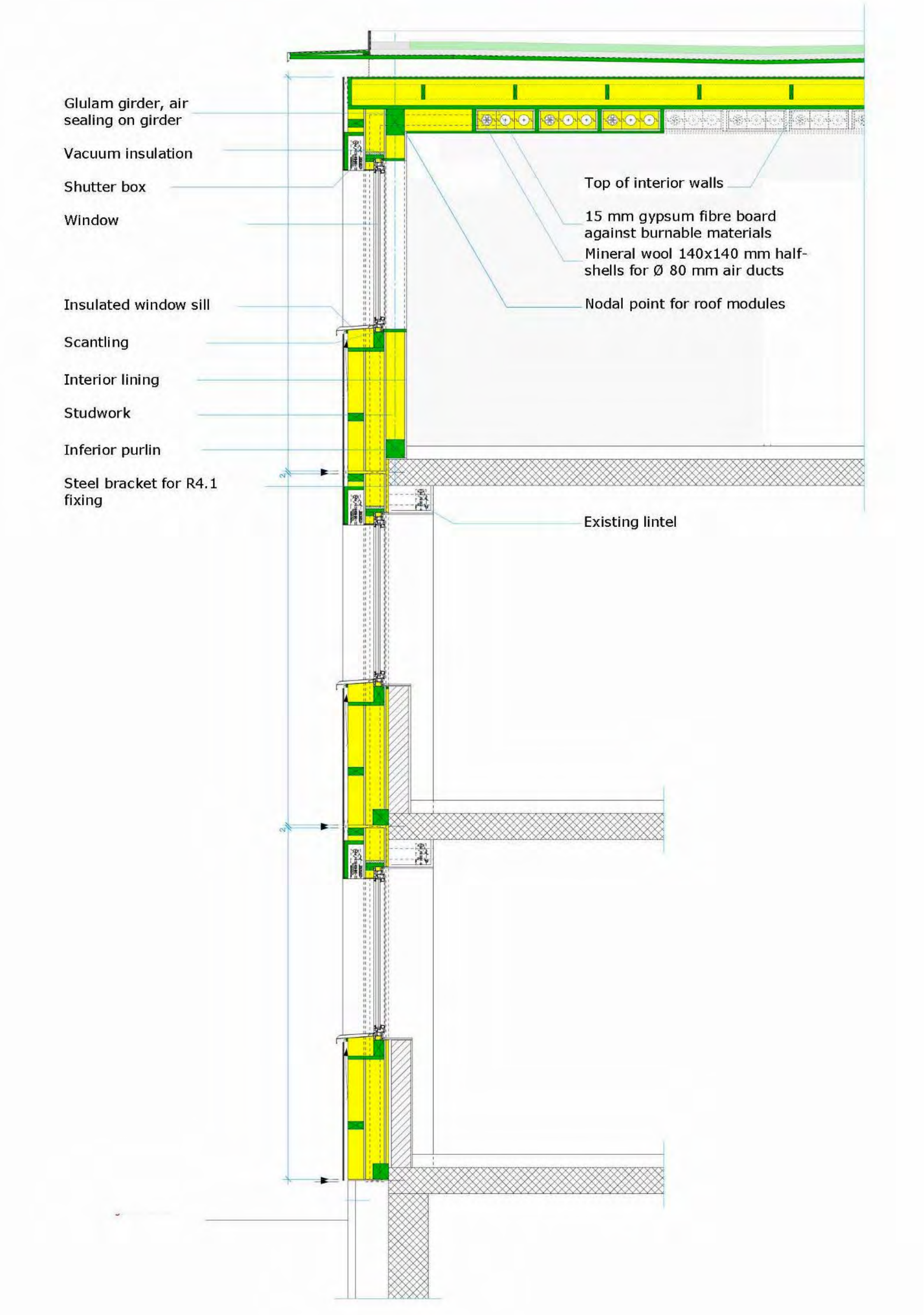


Figure 52: Cross-section of existing two-storey building, façades with F4.1 base module, lightweight vertical extension with slightly altered F4.1 base module and prefabricated flat roof units

3.4. Pitched roof modules

Prefabricated pitched roof units can be installed on existing rafter/purlin constructions or using self-supporting assemblies. Suitable provision must be made for connecting up ventilation ducts on site both at façade-roof junctions and at junctions between roof units.

Starting point for development of wall-roof junction details:
The first step in developing solutions for existing rafter/purlin constructions, new wall-roof assemblies (vertical extensions with pitched roof) or vertical extensions with flat roof (R8 and R9 modules) is always to clarify the structural framework. The nodal points, around which the entire assembly is arranged, are dictated by the position of the wall plates.

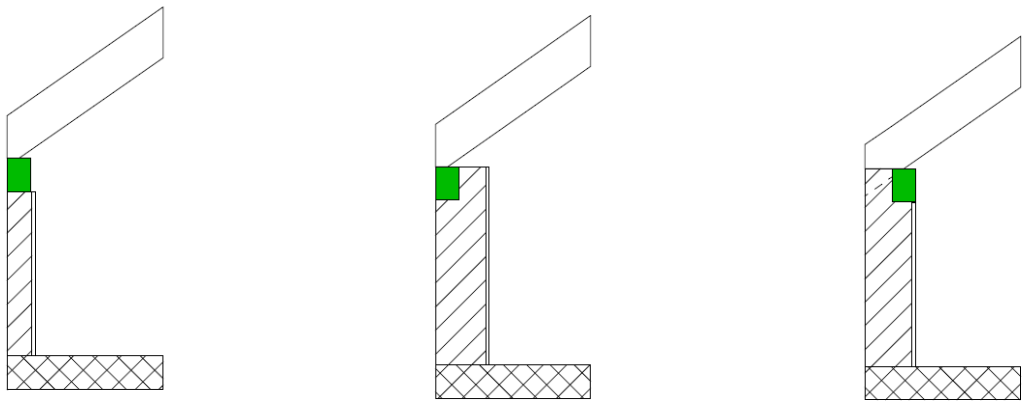
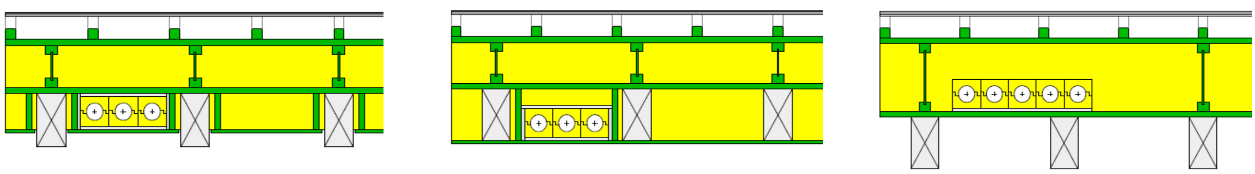


Figure 53: Structural framework: vertical force transmission at wall plate (without shear loads)

Depending on the particular variant, the ventilation ducts of pitched roof units fitted to existing rafters may be located between the rafters, thereby creating a composite layer. The following drawings illustrate the potential implications of incorporating ventilation ducts between the structural members of roofs and the benefits of a two-layer solution. Ventilation ducts installed between rafters can only run parallel to these given that multiple penetrations through rafters would severely impair their structural performance. Moreover, the total height – i.e. ventilation duct diameter plus sectional insulation plus any necessary gypsum fibreboard – must be smaller than the rafter height if part of the existing rafter is to remain exposed. The installation of ventilation ducts in the spaces between rafters also has implications for the positioning of the ducts in the façade units. As the location and spacing of the rafters are already fixed, these parameters must be factored into the design of the F4.1 base module. Otherwise, the ducts from the façade may, at worst, end up in alignment with the rafters.



Variant 1:
Combined rafter and ventilation duct layer.
Partly exposed rafters fulfil structural and visual function. Ventilation ducts can be run parallel to rafters. Number of possible ducts depends on distance between inside rafter faces.

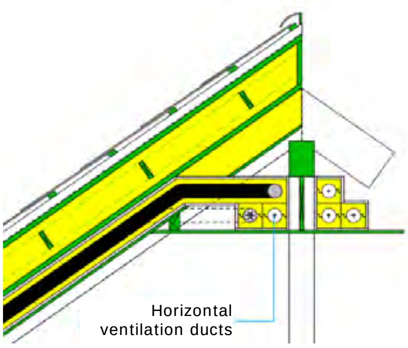
Variant 2:
Combined rafter and ventilation duct layer with underside covered.
Rafters, with lower face fully covered, fulfil structural function only.

Variant 3:
Complete separation of existing rafter layer from ventilation duct layer.
Entire pitched roof units are placed on top of existing rafters. Rafters fulfil structural and full visual function.
Significantly fewer implications for design regarding number of ducts, positioning and design constraints on façade solution.

Figure 54: R1 module variants

Note on heat losses from ventilation ducts:
Should the thermal insulation layer over the ventilation ducts be too thin, heat losses from the ducts to the outside air can be significantly reduced through the integration of VIP panels, without any increase to the total thickness of the roof construction? Yet such cases are likely to be rare. As a general rule, the upper structural layer is sufficiently well insulated to obviate the need for VIP panels in roof constructions.

Continuation of ventilation duct to central ventilation plant:
The 90° change of direction in the ventilation ducts and their collective routing to the central plant can be designed as follows:

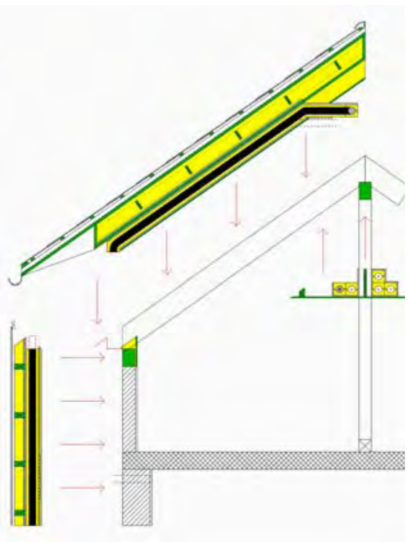


The ventilation ducts are carried out of the ventilation layer in the area of the ridge (not all at same height) and are run parallel to the ridge up to the central plant.

The ventilation ducts running parallel to the ridge must not encroach on the structural members supporting the rafters. One option involves grouping the ducts within a small cross-sectional area below the ridge.

Figure 55: Routing of ventilation ducts parallel to ridge

Procedure for vertical extension or attic refurbishment:



Assembly of façade and pitched roof modules in area of ventilation ducts. Connection of ventilation ducts is same as for vertical extension with flat roof (see figures 46, 47). As the final operation, the ducts running parallel to ridge are installed and covered up.

Figure 56: Assembly of façade and roof modules, for existing purlin/rafter construction

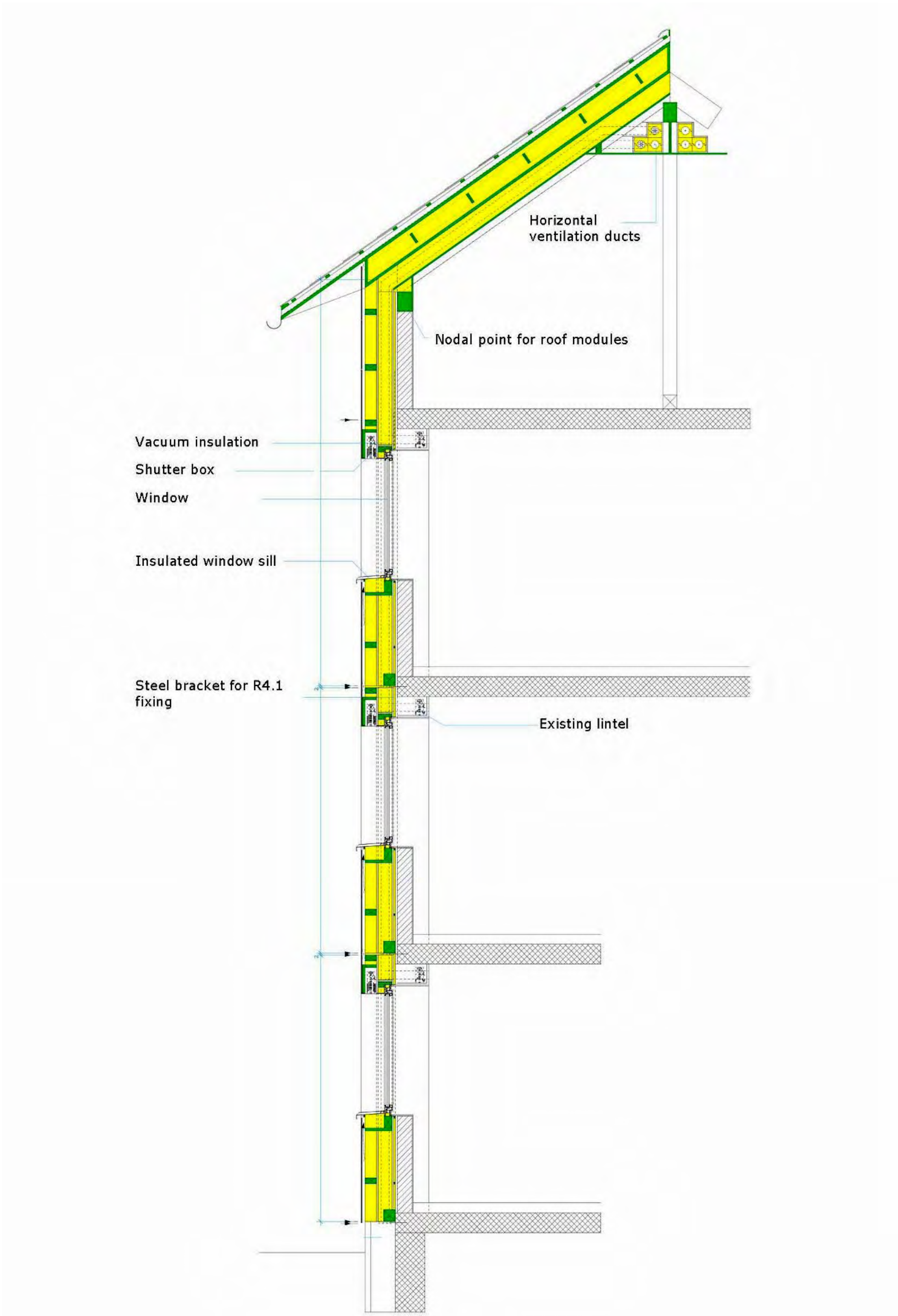


Figure 57: Cross-section of pitched roof module, through plane of windows

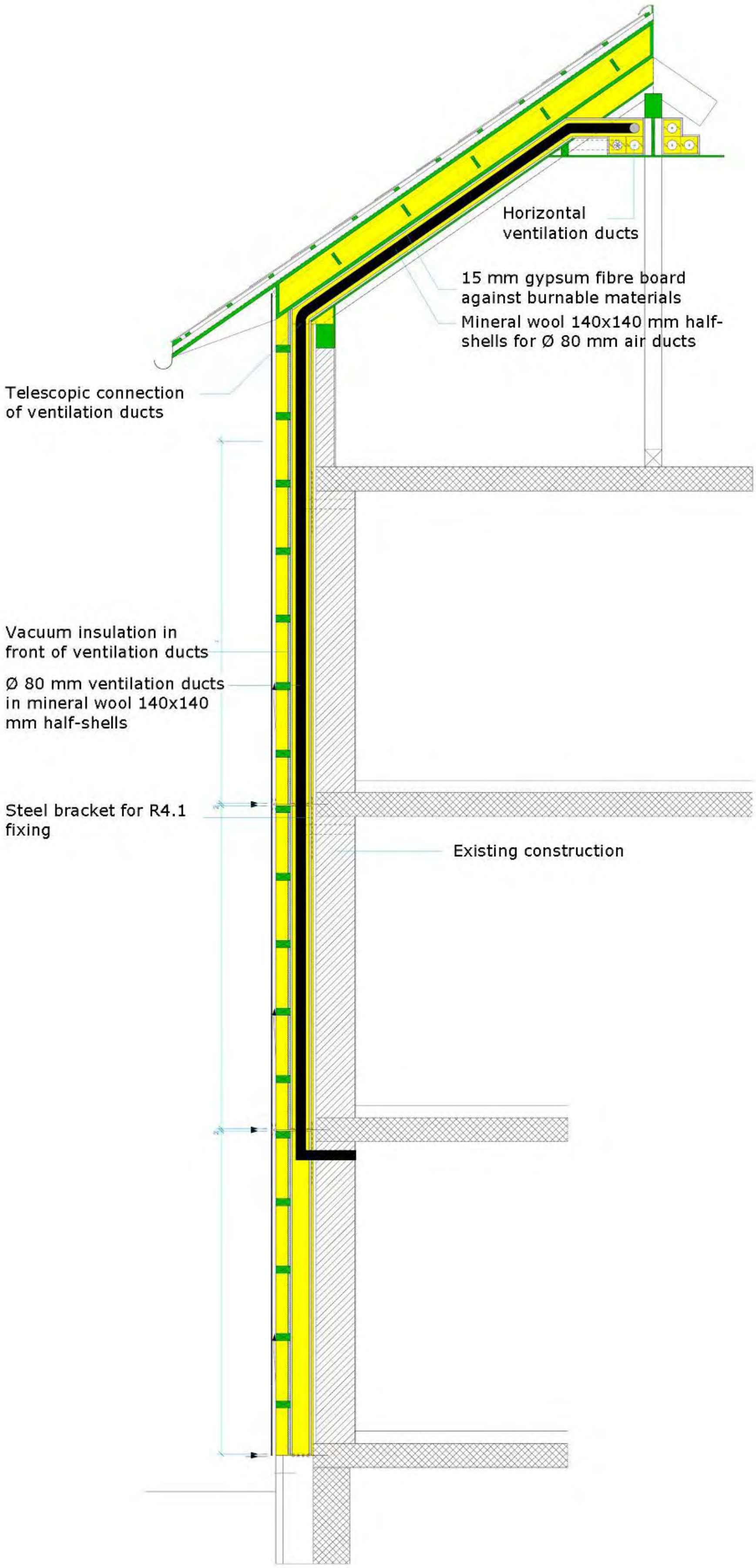


Figure 58: Cross-section of pitched roof module, through area of ventilation ducts

4. Guidance on project implementation

The following details relate to the two main project phases: design and construction. The guidance presented here, however, makes no claim to completeness with regard to the general process of designing and building structures, its scope being limited to the concept proposed in this report. It is intended to complement the existing framework of building-sector standards, codes, regulations etc. governing consultancy, design, detailing, site supervision, construction and facility management, and to provide further advice or support for the relevant project parties. It deliberately eschews any modification of the established organizational structure of the project team members, e.g. clients, architects, specialist designers and contractors. Nor are any changes recommended to their respective remits, competencies, rights and obligations. During all project phases, the team members remain bound by the relevant legal and professional framework, including planning and building codes, Swiss SIA standards together with all other good-practice guidelines and requirements in the construction sector. The architect, for example, thus continues to assume overall project responsibility in line with Swiss standard SIA 102.

The guidance presented here is limited to the building envelope and does not extend to any possible interior refurbishments, external remodelling etc.

4.1. Preliminary clarifications

Given that advanced retrofit schemes involve the outward relocation of the building envelope, the following planning issues require clarification in consultation with the relevant statutory bodies:

- Permissible building set backs, lines etc.
- Changes in massing (e.g. change from pitched to flat roof or vice versa, integration of solar panels/collectors, vertical extensions)
- Impact on plot ratios
- Agreements, easements, concessions and the like vis-à-vis public or private neighbours

Likewise useful is the outline clarification of the following issues:

Relating to the building:

- Permissible loads for existing foundations
- Structural quality of existing masonry with respect to: transmission of extra loads, pull-out behaviour of anchorages (implications for length of metal flats (component no. 6) and possibly for support beam (component no. 8) of F4.1 base module, nature of window lintel/reveal construction in existing masonry)
- Requirements regarding earthquake resistance
- Possible financial subsidies from public authorities for thermal insulation improvements, solar retrofits and the use of other renewable energy sources, including any additional allowances for wholesale building envelope refurbishment instead of isolated improvements
- Situation regarding perimeter French drains (any alterations necessitated by external basement wall insulation)
- Possible installation of ground coil serving ventilation
- Removal of balcony slabs, situation regarding roof overhangs

Relating to on-site operations:

- Logistical framework for deliveries, unloading and interim storage of prefabricated façade and roof modules
- Construction site logistics
- Design of scaffolding (cantilevered platforms that can be dismantled during erection, scaffold anchorages and anchorage removal, particularly for F4.1 module), any operations requiring use of mobile crane
- Measurement checks (clear line of site e.g. for laser)
- Possible use and design of support beam (component no. 8)
- Leakage test reports for ventilation ducts (see section entitled "Responsibility for airtightness")

4.2. Outline scheme

The outline scheme must tailor the choice of façade and roof modules to the client's requirements. Important for client and architect is a co-ordination of the following issues:

1 Definitive space use allocation and building geometries for project
Specifically in relation to additional spaces, e.g. vertical or horizontal extensions, attic and possibly basement conversions.

2 Specifications for thermal building envelope
Relates to all building elements which fully enclose heated and/or cooled spaces on all sides (see Swiss standards SIA 380/1 and SIA 416/1).

3 Selection of F modules, R modules, N modules, works that cannot be covered by modules. Use of renewable energy sources.

The selected module arrangement has implications for the material composition of the building envelope, junctions between the individual façade and roof modules, design measures for U-values and airtightness, building services installations, construction procedures and costs. The selection of modules provides a starting point for the preparation of production information. In terms of energy efficiency, consumption should be cut to a level between the values specified in the Swiss MINERGIE and MINERGIE-P standards. A longer-term view, targeting zero-energy or energy-plus building performance, is likely to be useful for possible future technologies, e.g. use of photovoltaic systems to promote the electrification of mobility.

The following points should also be clarified:

- Window openings
  The low-cost variant for the F4.1 base module is where no alterations to the existing window opening (enlargement of reveals and possible alterations to lintels) are needed. This reduces the volume of builder's works required. (In most cases, removal of the window sill is still necessary prior to installation of the F4.1 base module.) Normally, however, the clear size of the finished opening is slightly smaller. Given that the interior finishing works for the F4.1 base module alone can be completed in less than a day, it is possible to carry out the works while the building is still occupied (i.e. without terminating any leases).
  Nonetheless, from a technical point of view, window enlargements are readily feasible and sometimes welcome, e.g. to improve daylighting or optimize solar gains. As far as the F4.1 base module is concerned, the window size is largely irrelevant. Yet, careful consideration should be given to the associated preliminary works and the impact of such alterations. The same applies for the preservation or removal of existing cast stone surrounds at window reveals.

- Balconies
  Balconies should be regarded as a third basic façade element (alongside the "focal point of detailing" represented by the F4.1 base module and the opaque wall sections). Projecting balconies generally form significant linear thermal bridges in the façade area. The thermal losses resulting from their unaltered retention cannot be reconciled with the primary aim of optimizing details to reduce thermal bridging. The existing balconies must therefore be removed and replaced e.g. by new thermally broken balconies built in front of the façade on their own structural frame. "Enclosure" of the balconies as an extension of the building interior is also conceivable.
  Careful consideration must be given to the shading effects of any new balconies as this may reduce solar heat gains. The same applies for roof overhangs.

Comments on phased construction:
Ideally, any advanced retrofit to a residential building (envelope only) should be carried out without phasing, with the entire envelope upgraded in a single operation. This delivers the best results in terms of quality, total cost and overall construction time. Phased construction is likely to involve compromises. Starting from the ideal situation, the following table gives examples of possible scenarios and describes their main implications. The list is not exhaustive. The aim is simply to outline the possible consequences of a phased construction programme for a better assessment of the possible solutions.

Façade (incl. balconies and external basement wall insulation)	Roof (refurbishment, vertical extension)	Basement ceiling slab (basement ceiling or external basement wall insulation)	Comments
New	New	New	Ideal case, building envelope is fully and uniformly upgraded. Optimizations up to energy-plus standard as possible option to achieve high level of energy security for future.
New	New, in later phase	New or in later phase	Overhangs of many existing roofs are too shallow at both verge and eaves to provide adequate weather protection for new, thicker façade. Ventilation ducts in façades will not come into operation until new roof is installed (where central plant located in roof) All ventilation ducts in façade must be completed.
New	Roof already refurbished	New or in later phase	A properly refurbished roof (good U-values) may pose problems for grouping/routing of ventilation ducts to central plant (where located in roof). Carry ducts along lower face of roof boarding where central plant is located in roof. Alternatively, relocate central plant to other storey (e.g. basement). Extend roof overhangs as these tend to be too shallow (see above).
Windows already replaced, additional façade insulation not yet provided	New	New or in later phase	In many cases, new windows are still hung internally. Their retention creates unfavourable conditions for use of the F4.1 module.
Windows already replaced and façade insulated	New	New or in later phase	Problem of routing ventilation ducts in façades. Ducts housed in internal shafts, provision to be made for collective routing in new roof.

Table 2: Examples of phased constructions

4.3. Involvement of other specialists

On advanced retrofit schemes, early interdisciplinary consultations are absolutely indispensable for efficient design and construction given that the details in the largely prefabricated modules need to be clarified at the outset (bottom-up design approach). Unresolved details may lead to wrongly prefabricated units.

Apart from the architect, the parties to be involved at this early stage include the structural engineer, HVACR engineer, building physicist and contractor. The early involvement of contractors is advisable as they can pinpoint the particular issues they regard as relevant and provide support in the preparation of production information, work specifications and construction programmes. In extreme cases, they can even prevent time being unnecessarily wasted on irrelevant details given the variations in the scope of detailing handled by different contracting companies. The information provided in this report should suffice for the initial treatment of fire protection issues. An inspection of the designs by the fire authority should be arranged prior to the final preparation of production information. It is only necessary to consult the sanitary engineer at this stage on matters relating to the building envelope if the integration of water pipes in the prefabricated modules is essential. The same applies for electrical engineer.

4.3.1. Common background knowledge and basic specifications

An understanding by all project parties of the "focal point of detailing" concept described in Section 2 is an essential part of the common background knowledge needed to construct the prefabricated modules. The provision of information in the form of this document can provide a useful introduction for the first co-ordination meeting while also offering assistance in the later detailing of the selected modules – see Step 3 in "Outline scheme" section: "Selection of F modules, R modules, N modules, works that cannot be covered by modules

Specification of reference sizes

Various reference sizes recur and needed to be fixed. Specification of the ventilation duct diameters yields clear-cut external sizes for the sectional insulation. The use of 15 mm gypsum fibreboard to achieve the required fire rating automatically dictates the respective size of EI30 nbb and EI60 nbb assemblies. As a result, the dimensioning of penetrations in façade, roof and existing walls is partly predetermined.

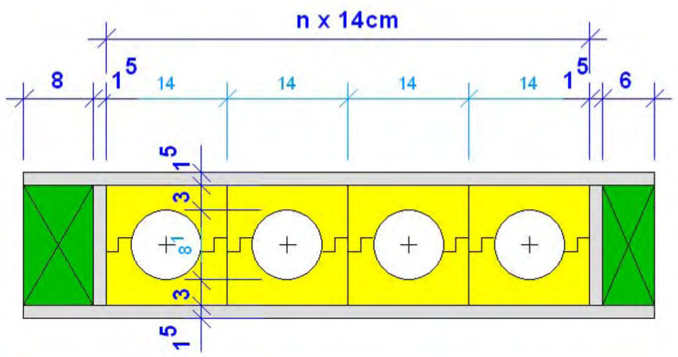


Figure 59: Clear-cut sizes for ventilation area with EI30 nbb rating, here incorporating 80 mm ducts

Reference sizes for F4.1 modules

The starting point for the design and installation of the F4.1 base modules is the external angle between the reveal and the outer face of the existing external wall (see black arrow in drawing below). Due account must be taken of the tolerances along this vertical edge and particularly those applying to the corresponding edges on the storeys above and below. The fact that the ventilation ducts have to be aligned over all storeys automatically entails the exact vertical alignment of other components in the F4.1 base module (e.g. timber uprights in layer 1 – see component no. 5 in exploded drawing). Any significant offsets in the reveal edges between storeys may, if disregarded, result in unopenable windows. Allowance must additionally be made for on-site measurement tolerances.

The gypsum fibreboard fixed to the reveal reduces the existing clear wall opening by at least 2 x 10 mm. The small distance between the gypsum fibreboard and internal face of the window casement when opened to 90° (marked A in diagram below) is a key dimension for setting out the components of the F4.1 base module in the plan drawings. While safety tolerances can be applied, these will unnecessarily reduce the clear opening size if overly generous. The window (with correctly drawn pivot point) is then positioned at a depth such that the internal face of the casement, when closed, lies within the plane of the F4.1 base module. (The absence of a projecting window casement also prevents damage during transportation). The lower lintel face can serve as a similar reference edge for cross-sections. The reference size at the apron wall depends on the situation after removal of the window sill and making good. In most cases, this level needs to be redetermined.

These dimensional specifications automatically define the axes for the ventilation inlet and outlets (example marked B in drawing below). This allows the exact positioning of drill holes from the inside during the interior finishing works. It is also possible to determine the size of the support beam used for temporary placing of the F4.1 base module (see component no. 8 in exploded drawing).

The evenness of the existing façade dictates the thickness of the compressible insulation (see component no. 4 in exploded drawing) as well as the distance between the existing masonry (external face of render) and first gypsum fibreboard (marked C in drawing below). The variations across the entire façade may amount to several centimetres either way. Within the limited area of the F4.1 base modules, however, 3 cm compressible insulation should suffice.

A series of "dimension strings" can thus be identified which regulate the sizes of the F4.1 base module components, the window to be ordered and the F1/F2/F3 opaque façade modules.

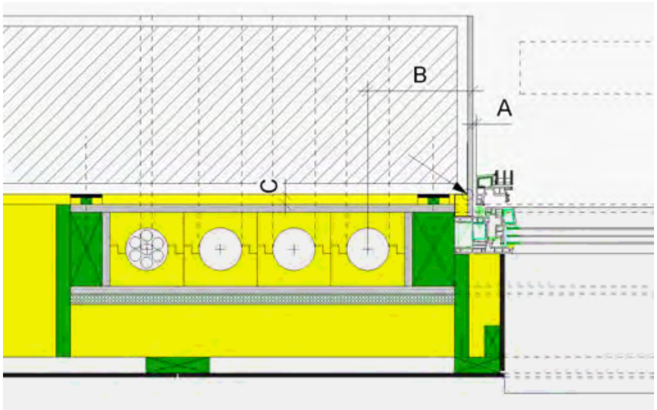


Figure 60: Reference size at external angle of window reveal in existing building

Remedies are available where catering for the "lowest common denominator" leads to excessive reductions in clear opening sizes. If acceptable from an aesthetic point of view, the position of openings within the module can be shifted to accommodate any non-alignment between storeys. The following example is merely intended to show how the system can be adapted in line with dimensional constraints. This only applies, of course, where no enlargement of the existing reveal is needed.

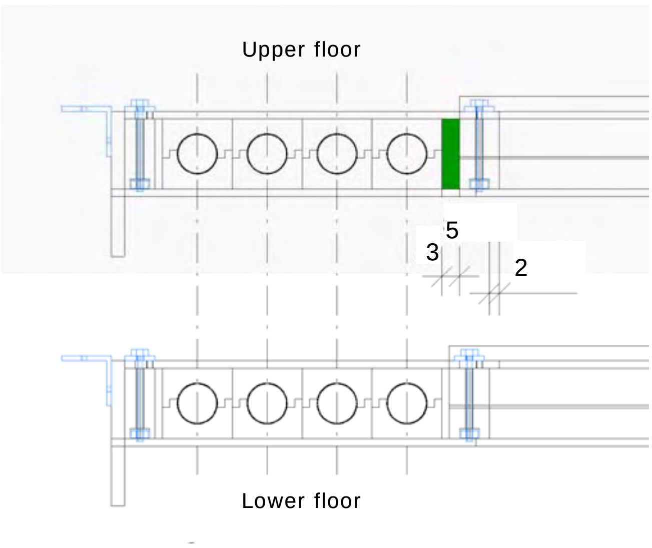


Figure 61: Shifted windows within module F4.1

In the example, the window on the lower floor is 2 cm to the left of that on the upper floor. Extra material is incorporated on the upper floor (here 3.5 cm rock wool, shown in colour) to ensure the alignment of the ventilation duct axes between the two floors.

For offsets greater than 1.5 cm, the gypsum fibreboard can be omitted as 30 mm rock wool plus the insulation section already achieve an EI30 nbb rating.

4.3.2. Issues for clarification by architect and contractor

1) **Ventilation concept**
using sizes from F4.1 system, based on R8 module detail system and ventilation duct arrangement (critical path). If the central ventilation plant is to be located in the roof area, allowance should be made e.g. for adequate widths in front of the plant. Provision for 20 ducts, for example, necessitates a width of n x 14 cm = 20 x 14 cm = 2.8 m. The 15 mm gypsum fibreboard only needs to be incorporated where an EI30 fire rating is specified vis-à-vis the surrounding materials.

2) **Clarification of structural design**
Positions at which roof units can be supported, support widths, spans, positioning of walls for torsional stiffness, earthquake performance (multiple tiebacks or special system for "earthquake-resistant storey (vertical extension) on earthquake-resistant structure (existing building"), incl. outline design of service runs.

3) **Unitization**
of R8 modules, based on structural concept, penetration by ventilation ducts/sectional insulation/gypsum fibreboard, junctions between F-R and R-R modules, possible module sizes for road transportation, on-site handling.

4) **Detail design**
Ventilation ducts incl. cleaning arms and sound insulation, adaptation of units to unitization concept. Product specifications based on details of industry partner products (see tables for various applications).

4.3.3. Issues for clarification by specialist designers

The list below represents the absolute minimum in terms of points to be clarified by each specialist designer and the architect as co-ordinator:

Ventilation engineer:

- Separate supply and extract ventilation to each room or cascade ventilation
- Location of central ventilation plant
- Routing and lengths in façades and roof
- Recirculation (instead of extract) system in kitchen to eliminate the need for an EI60 nbb rating (also more energy-efficient), filter replacement requirements
- Specification of ventilation ducts diameters
  80 mm diameter; the ventilation engineer may also select larger diameters, e.g. 100 mm, if needed. This would have implications for the reference sizes
- Air inlets and outlets at special locations, e.g. in area of apron wall
- Accommodation of utility services apart from ventilation, e.g. electricity, sensors, water, controls for new blinds etc.
- Location of cleaning arms
- Moisture accumulation in horizontal and vertical duct runs
- Other points, e.g. relating to pressure loss, angles/bends, sound insulation to central ventilation plant, telephony etc.

Façade/roof module contractor:

- Design of details centred on critical path of ventilation ducts plus associated penetrations
- Unitization of façades and unitization of roofs
- Façade-façade, façade-roof and roof-roof junctions
- Logistics, building site organization
- Responsibility for airtightness of ventilation ducts in modules
- Procedure up to safe installation of VIP in finished module (acceptance prior to encasement), guaranteed damage-free installation of units delivered from façade manufacturing plant

Building physicist:

- Expert calculation and management of heat losses
- System monitoring to ensure specified standards are met
- Cost optimization
- Sound control
- Solution for heating systems (removal, replacement, location of renewable energy sources)

Structural engineer:

- Loading of existing foundations and consequences
- Loading of existing masonry
- Possible tensile tests for anchorages to existing masonry (binding statements)
- Detailed information e.g. for support beam (see component no. 8 in exploded drawing)
- Earthquake resistance and development of economical solution

Other engineers or specialist consultants*:*

- Electrical installations, service runs, photovoltaic systems, lightning conductors
- Rainwater downpipes
- Blind controls
- etc.

Development partners:

Further information on the products used for the façade and roof modules can be provided by the companies and organizations mentioned on page 12.

5. References

Publications within the IEA ECBCS Annex 50[8]:

[I] Mark Zimmermann: ECBCS Project Summary report “Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings, March 2011

[II] Peter Schwehr, Robert Fischer, Sonja Geier: Retrofit Strategies Design Guide, ISBN 978-3-905594-59-1, March 2011

[III] René L. Kobler, Armin Binz, Gregor Steinke, Karl Höfler, Sonja Geier, Johann Aschauer, Stéphane Cousin, Paul Delouche, François Radelet, Bertrand Ruot, Laurent Reynier, Pierre Gobin, Thierry Duforestel, Gérard Senior, Xavier Boulanger, Pedro Silva, Manuela Almeida: Retrofit Module Design Guide, ISBN 978-3-905594-60-7, March 2011

[IV] Reto Miloni, Nadja Grischott, Mark Zimmermann, Chiel Boonstra, Sonja Geier, Karl Höfler, David Venus: Building Renovation Case Studies, ISBN 978-3-905594-61-4, March 2011

[V] Mark Zimmermann, Hans Bertschinger, Kurt Christen, Walter Ott, Yvonne Kaufmann, Stefan Carl: Retrofit Advisor, Beta-version, March 2011

[VI] Peter Schwehr, Robert Fischer: Building Typology and Morphology of Swiss Multi-Family Homes 1919 – 1990, January 2010

[VII] Bertrand Ruot: French housing stock built between 1949 and 1974, October 2010

[VIII] Bertrand Ruot: Elements of morphology of collective housing buildings constructed in France between 1949 and 1974, October 2010

[IX] Gerhard Zweifel: Retrofit Simulation Report, March 2011

Recommended books on MINERGIE-P and ventilation:

- Huber, Mosbacher: „Wohnungslüftung“; Faktor Verlag; 2006
- Ragonesi, Menti, Tschui, Humm: „Minergie-P“; Faktor Verlag; 2008

Additional literature:

- Bundesamt für Energie, "Vakuum-Isolations-Paneele im Gebäudesektor", 2005
- Bundesamt für Energie, "Ökobilanz eines Vakuum-Isolations-Paneels im (VIP)", 2003
- Bundesamt für Energie, "Neubauen statt sanieren?", 2002

[8] Further information at home pages: www.empa-ren.ch/A50.htm, www.ecbcs.org/annexes/annex50.htm

Part B

Retrofit Module Design Guide

Part B: Large Size Prefabricated Façade Modules

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Table of Content - Part B

1. Introduction

1.1. Definition

In future the key focus must lie on the development of renovation-concepts in order to improve energy-efficiency of our building-stock and on increasing the use of renewable energy sources in their operations. It makes sense to use technologies, which have been proofed successfully within new passive houses and low energy buildings and adapt them for the renovation proceedings.

Objective is to find innovative and feasible concepts for the renovation of typical multi-family houses. Not only aiming on highest possible energy-efficiency but also on users comfort after and during the renovation works. This means to find a way that occupants may stay in their apartments during the renovation proceedings (“inhabited construction site”) and to improve their living environment.

To find such concepts for renovation of typical residential buildings the IEA ECBCS Annex 50 focused on the development of multi-functional roof- and façade modules, which are highly prefabricated. These multi-functional modules get integrated active components - like collectors and PV-plants - and supply lines or distribution infrastructure (plug-in-and-play-modules). Finally the development should lead to system, which makes high-performance renovations feasible and affordable.

1.2. Energy-efficient building renovation

Using prefabricated façade modules it is possible to improve the U-value of the existing exterior walls. The thickness of the insulation or the U-value of the entire system (old exterior wall and new façade module) should be oriented on passive house standard. Further it is necessary to integrated passive house windows into the system. Aim is to get a construction free of thermal bridges. Not only existing thermal bridges should be eliminated. The junction and fixing of the new façade system has to be done without generating thermal weak points.

The integration of solar combs into the façade module leads to even better U-values - and an improved thermal envelope. But within renovation it is very difficult to reach a standard like it is possible in new buildings. Therefore the integration of solar collectors and PV-plants into the prefabricated system contributes to active and nearly CO_2-free energy generation within the envelope.

1.3. Ecological aspects

Due to the chosen material – timber – a high ecological quality is achieved. But it is essential to consider the restrictions which arise by using timber-based constructions. Depending on different standards and building codes the application of timber within the façade is limited to buildings up to 4 levels.

1.4. Acceptance by users

The assembling procedure is done from outdoor due to the prefabrication process shorter than usual. So the disturbing effects on users during the renovation are reduced significantly. It is only the removal of the old windows and the cladding of the window-reveal that has to be done from the inside. This makes the “inhabited construction site” possible.

1.5. Quality of completion

Prefabrication offers beside other advantages a very high quality-standard: starting with a high standard of work-planning the procedure in the production hall is highly predictable and can be controlled easily. Further the entire process is independent from the weather conditions.

2. Approach

2.1. Partners from the industry

The project team consisted of:

- GIWOG - Gemeinnützige Industrie-Wohnungs AG, Oberösterreich (builder)
- gap-solution GmbH, Leonding (contractor)
- Energiesysteme Aschauer / Futus Energietechnik GmbH (energy-engineering)
- Hohensinn Architektur GmbH, Graz (architect)
- Kulmer Holzbau GmbH (carpenter and subcontractor)

The project was funded by:
- Austrian federal Ministry of Transport, Innovation and Technology (Programme “Building of Tomorrow”)
- Federal Government of Styria

Starting point of the project was the idea of the builder GIWOG to carry out a high-performance renovation with prefabricated modules and an innovative energy concept. But the innovation should be visible by a shining architecture – the design was done by the office of the Hohensinn Architektur GmbH. The entire renovation concept – the improvement of the thermal performance, the development of the prefabricated modules and the energy concept was coordinated by the engineering of the office TB Energiesysteme Aschauer and gap-solution GmbH.

After a careful planning the carpenter Kulmer GmbH Holzbau assembled a prototype. A series of discussions concerning statics, building physics and critical details led to the final module, which was proved and checked by all relevant project partners. Not until then the serial production started.

2.2. Scientific partners

The AEE – Institute for Sustainable Technologies (AEE INETC) was involved as consultant on building physics, energy efficiency and on the development of the module.

Additionally a monitoring-procedure and an evaluation of the results are done together with gap-solution. Therefore spot-measurements and questionnaires are carried out.

3. Prefabricated façade modules

3.1. General information

The prefabricated façade modules are mounted on a substructure made of timber, which is mounted on-site onto the façade-surface. The substructure acts as levelling lathing and hosts installations like wiring and pipe-work. Therefore the entire heat dissipation system and all supply-lines are installed in this layer – the intermediate space is filled with insulation material.

The large-scaled façade modules have a length of 12 m and are 3 m high – so it is possible to transport them with a low-loader to the construction-site. The assembling procedure on-site was done by a truck-mounted crane and additional mobile-cranes.

Figure 1: Former building stock (Source: AEE INTEC)

3.2. Basic module und prototype

The visual appearance and design was done by the architect. But the solar comb had to be integrated into the architectural concept – as visual part. The development of the basic module considered an integrated window and a decentralised ventilation device. Further the floor-to-floor height defined the height of the module (about 3 m), because the intermediate floors provide a good fixing-subsurface.

The junction between the single modules was done by tongue-and-groove system. The assembling procedure started at the bottom – the first module rested on a steel-angle bearing. Afterwards all previous modules were on the lower ones.

But it was carefully obeyed, that all junctions, fixings and the entire construction was free of thermal bridges.

To prove the construction system a prototype was assembled – but not until all discussions on statics, buildings physics and critical details were finished the type approval was submitted.

Figure 2 shows the module system exemplary – a work plan as a view on the gable of one of the building blocks. The first module reaches from the line of the floor between cellar and the upper line of the window. The depicted vertically joints are only the edges of the glass-panels, covered by cover strips.

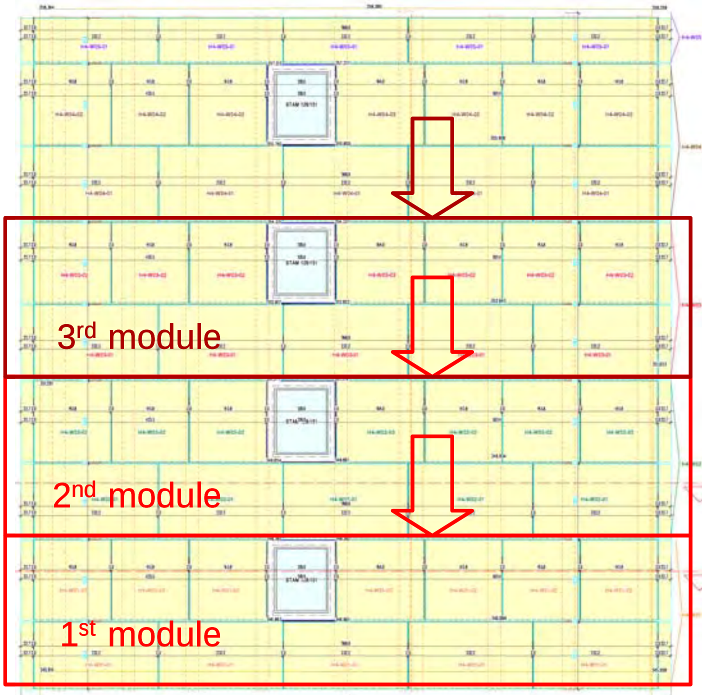


Figure 2: Work plan showing the module system for a gable of a building block (Source: gap-solution GmbH)

Figure 3: Assembling the prototype in the fabrication of carpentry Kulmer Bau (Source: AEE INTEC)

Figure 4 shows the layer composition of the basic module. On the left side the existing wall is depicted – followed by a levelling slat, which the prefabricated module is assembled on. The basic frame is made of timber; in-between a first layer of insulation. The solar comb is mounted on the outside upon a MDF-board[9] followed by a ventilated airspace and covered with a single-pane safety glass. On the back of the timber frame construction and OSB-board completes the prefabricated element.

[9] MDF means Medium Density Fibreboard

Figure 4: Layer composition of the basic façade module (Source: gap-solution GmbH)

3.3. Details of construction

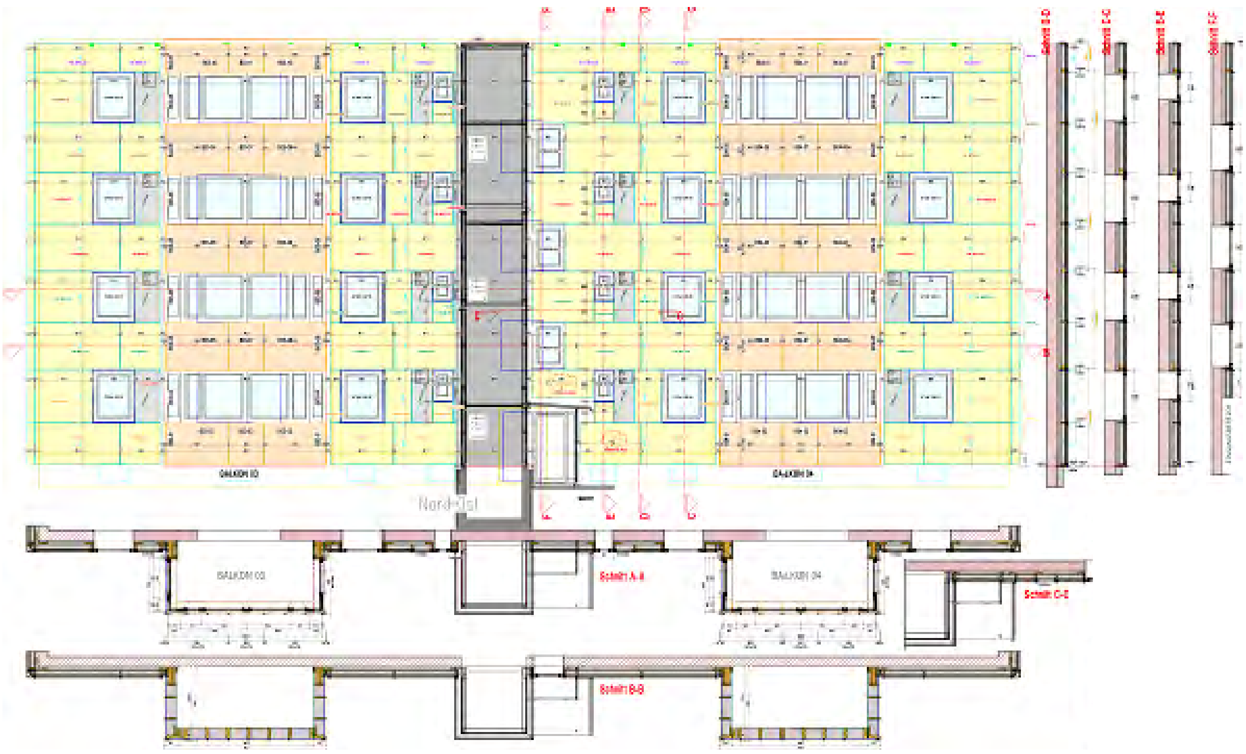


Figure 5: View of the façade (Source: Kulmer Bau)

The layer composition and thickness of insulation enables the basic module to reach passive house standard – finally it has a thickness of about 24 cm. The approval has done according to PHPP 2007 (7th edition of the Passive House Planning Package).

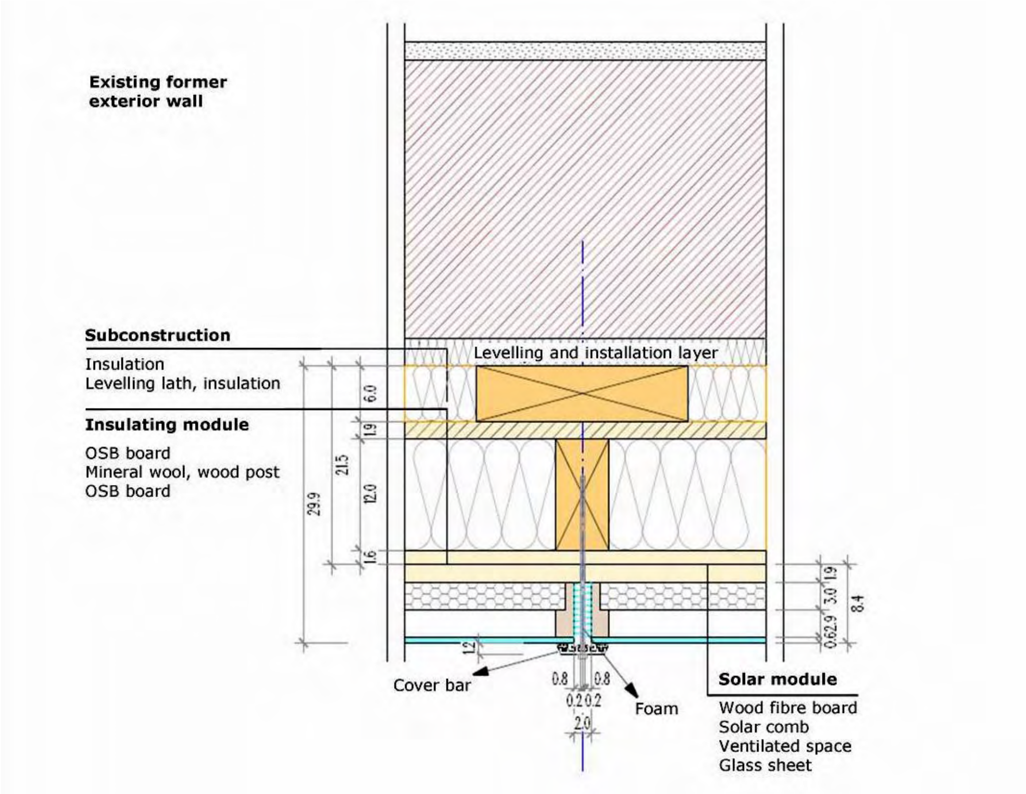


Figure 6: Detail of work plan showing the prefabricated module on the levelling lathing and the existing former exterior wall (Source: gap-solution GmbH)

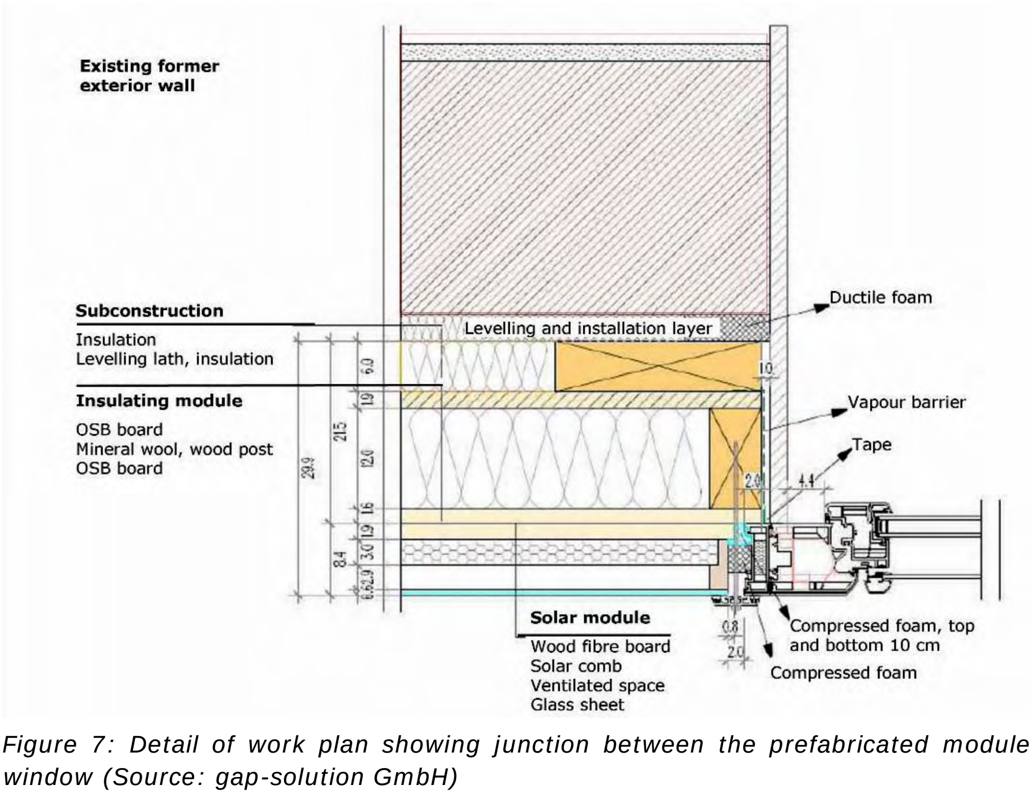


Figure 7: Detail of work plan showing junction between the prefabricated module and the integrated window (Source: gap-solution GmbH)

The basic module comprised a decentralised ventilation device with heat recovery. The ventilation device was covered with an opaque insulation glass panel. The inlet and outlet of the ventilation device was provided within the airspace of the rear ventilation behind the glass panel.

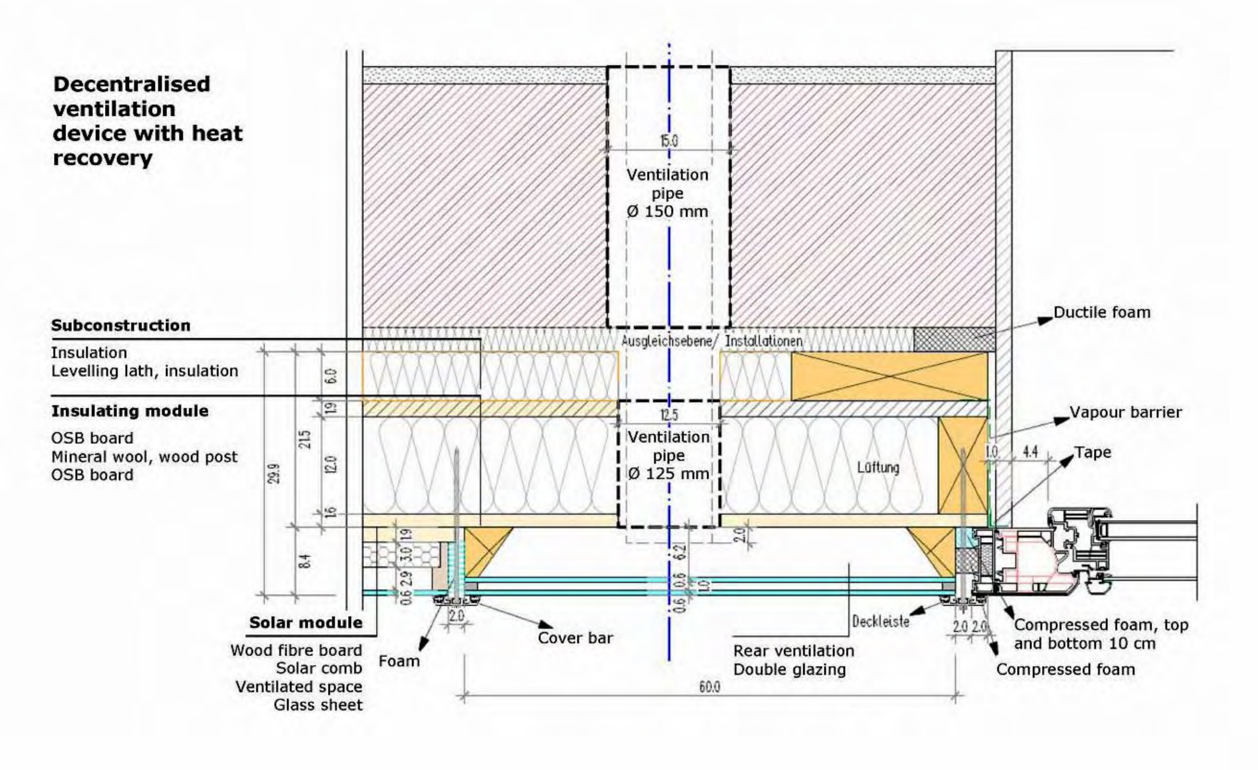


Figure 8: Detailed section through the ventilation duct – on the outside the insulation glass panel covers the rear-ventilated airspace. The ventilation duct penetrates the entire module and the exterior wall. (Source: gap-solution GmbH)

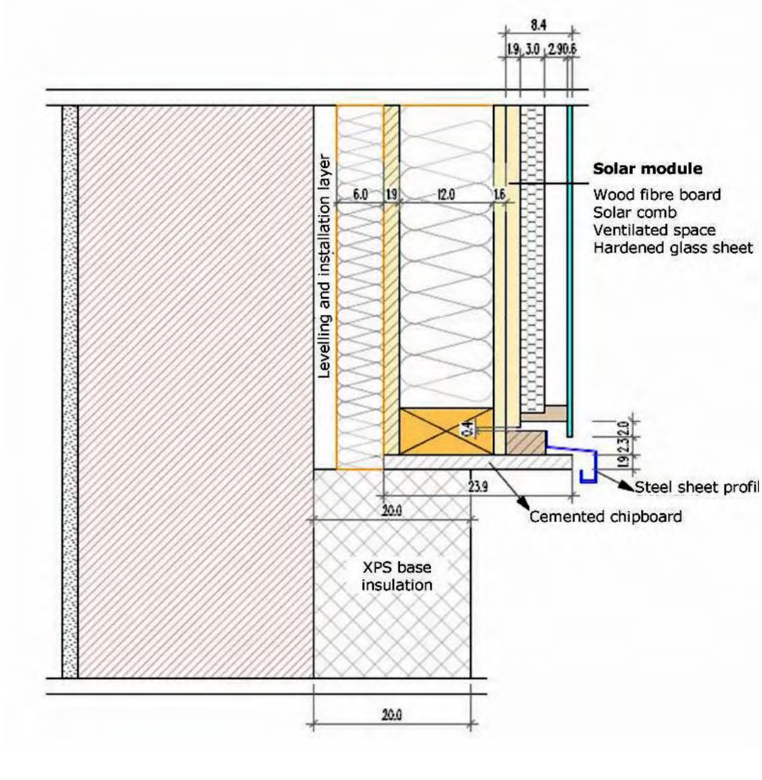


Figure 9: Detailed cross-section showing the bottom of the first module within the plinth. The exterior wall, which is not covered by the module got a XPS-insulation (Source: gap-solution GmbH)

3.4. Joining techniques of the modules

All horizontal joints are designed as a kind of tongue-and-groove junction (Figure 10). This enables the correct module position and a vertical coupling of the modules. But the sealing against driving rain is achieved by horizontally arranged façade plates. The vertically oriented caulks are covered with cover strips and fixed with screws (Figure 11).

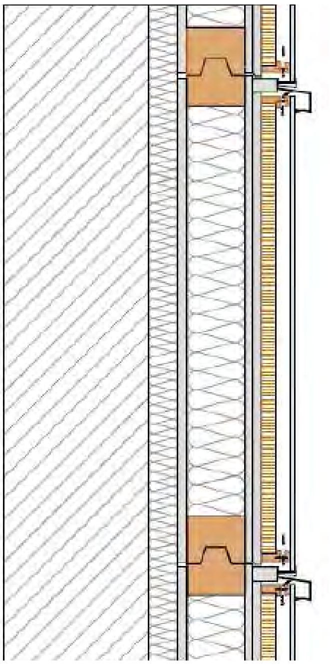


Figure 10: Detailed cross-section showing the tongue-and-groove coupling between the modules (Source: gap-solution GmbH)

Figure 11: The upper picture shows the vertical joints with the cover strips fixed by screws. The picture below shows the horizontally mounted façade plate to ensure the sealing against driving rain (Source: gap-solution GmbH)

3.5. Installation and levelling lathing

The installation and levelling lathing – made of timber laths – provided space for the heat dissipation system, which was installed right on the outside of the exterior wall, and the supply lines for the heating system. The remaining space was filled with insulation panels.

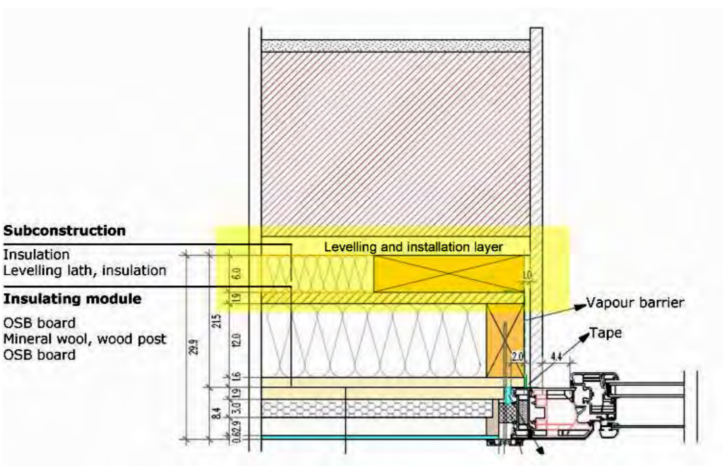


Figure 12: Detailed cross-section showing the levelling lathing (Source: gap-solution GmbH)

Figure 13: Photo during renovation works on the exterior wall with the levelling laths assembled on and in-between the insulation panels with inserted heating pipes.

3.6. Junctions

All junctions within window-reveals, building angles and attics are completed and closed after the assembling procedure of the prefabricated modules was finished.

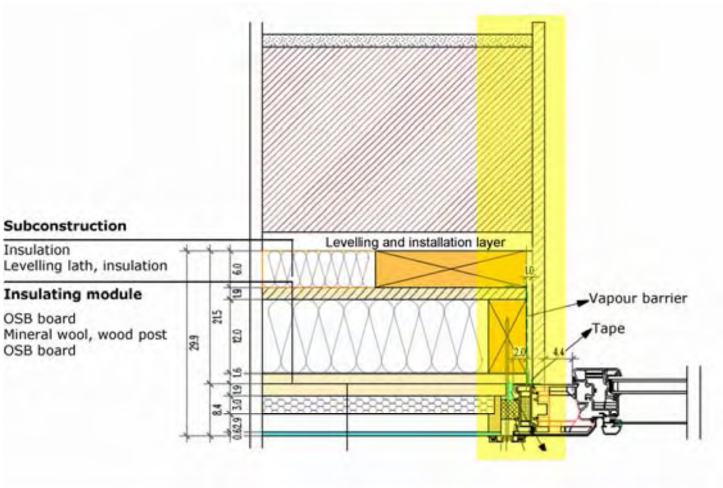


Figure 14: Detailed cross-section showing the cladding of the window-reveal. At the junction between new window and the former exterior wall the vapour-barrier had to be closed carefully (Source: gap-solution GmbH)

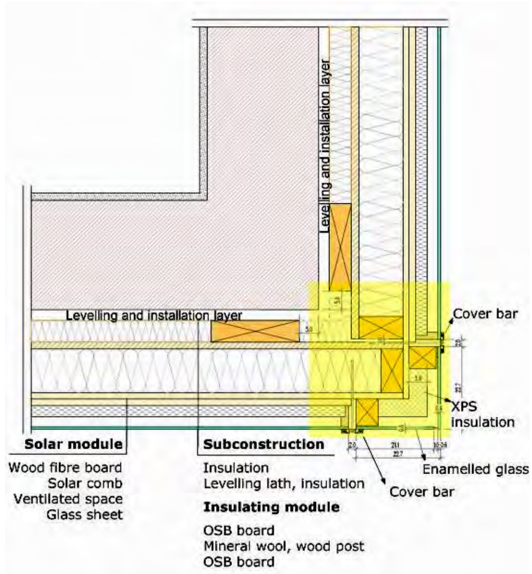


Figure 15: Detailed cross-section showing a building's angle. The vapour-barrier had to be sealed between the two modules (Source: gap-solution GmbH)

3.7. Assembling during fabrication and transport on-site

Figure 16: Assembling procedure in the fabrication of the carpentry Kulmer Bau (Source: gap-solution GmbH)

The dimensions of the module allow a transport by low-loader to the building-site were it is installed by means of mobile cranes and assembling operators on the prepared levelling slat on the outside of the existing exterior wall. The mounting procedure starts with the lowest module – resting on steel angle brackets which are mounted on the plinth - the further modules are assembled above and connected together horizontally with tongue and groove joints.

Figure 17: Transport on-site and assembling procedure (Source: gap-solution GmbH)

3.8. Assembling procedure of the façade module

The prefabricated façade modules are assembled in the fabrication hall according to the detailed work planning. Afterwards they are transported with a low-loader to the building-site and lifted by a truck-mounted crane to their correct position at the façade. Assembling operators on mobile cranes are positioned on each side to help during the installation.

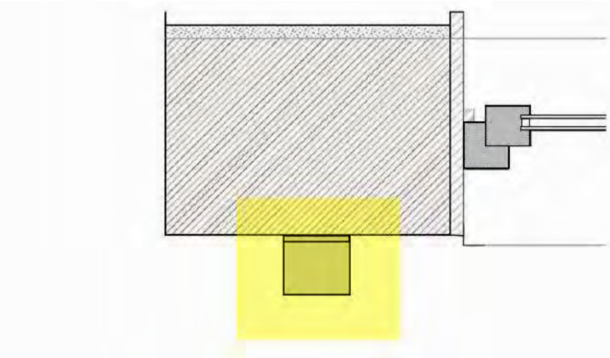
The installation on-site is based on three steps:

Step 1: Installation of steel-angle bearings at the plinth of the existing building, which will take over the vertical loads of the modules

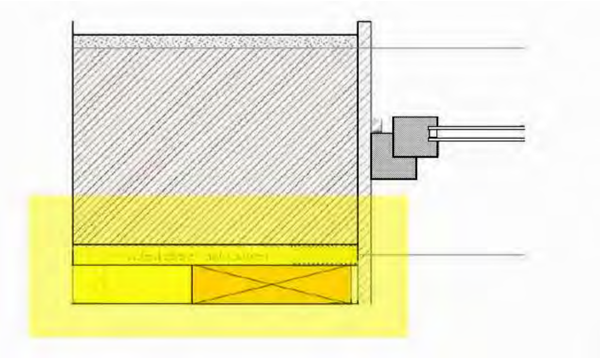
Step 2: Installation of the substructure made of timber laths. The substructure acts as levelling plane, hosts the heat dissipation system and the supply lines. The remaining space in-between is filled with insulation panels.

Step 3: Assembling the large-scaled façade modules by truck-mounted crane onto the prepared subsurface. Tow additional assembling operators, which are positioned on each side help during the adjustment and fixing.

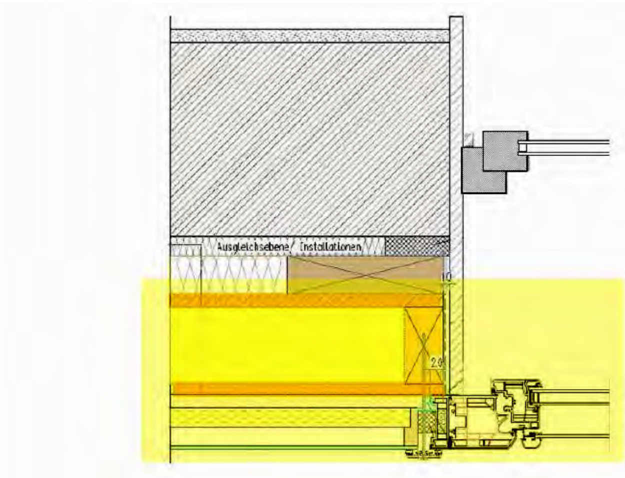
Step 4: Removing of the old windows from inside, closing vapour barriers and cladding of the window-reveal. Further all remaining adaptations (closing and sealing of all other vapour-barriers at angles and junctions).



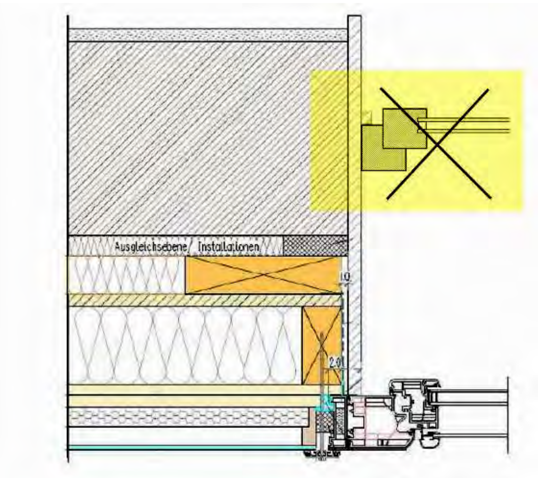
Step 1: Mounting the steel-angle bearing



Step 2: Mounting levelling laths



Step 3: Assembling façade module



Step 4: Removal of old window inside

Figure 18: Assembling procedure of the façade modules in detail (Source of detailed drawings: gap-solution GmbH)

Figure 19: Window details

3.9. Building physics and energy-concept

The entire building envelope was covered with the prefabricated façade modules. The thermal performance of the module is achieved by a innovative concept, which was developed by gap-solution. Core of the development is the solar comb – a special comb made of cellulose. The solar comb is on the side of the module which is oriented to the sun and is covered by a glass panel. This rear ventilated air space protects the solar comb from weather and mechanical damages. To generate an attractive appearance the surface is painted in different colours. The light from the low sun in winter is falling through the glass panel and warms the solar comb. So the temperature on the outside of the system is increased. The temperature difference between warm inside and cold outside in winter decreases and heat losses are minimized. During summer the structure of the solar combs shadows itself due to the high sun.

Key components of the energy-concept are:

- Large-scaled façade modules with solar combs (gap-Solution)
- Passive house windows with integrated blinds (mounted in intermediate space between insulation gals panels)
- Single room ventilation devices with heat recovery
- Integration of former balconies within the new thermal envelope.

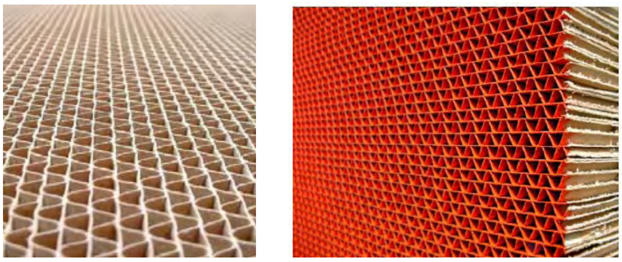


Figure 20: Solar comb in detail (the right picture shows a comb with painted surface (Source: gap-solution GmbH)

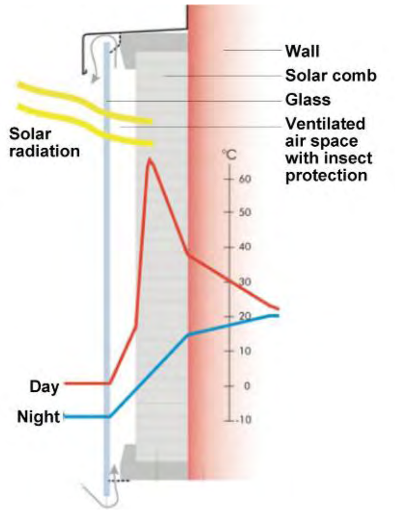


Figure 21: How the façade system with the integrated solar comb works. The picture shows the temperature curve during day and night. (Source: gap-solution GmbH)

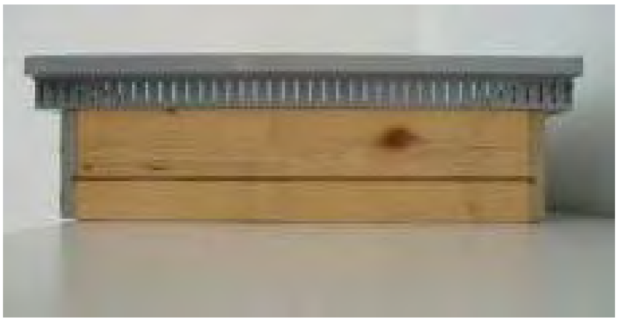


Figure 22: The prototype of the façade module. The timber frame and the ventilation slots can be seen. (Source: gap-solution GmbH)

3.10. Heat distribution and dissipation system

The heat dissipation system follows the principle of thermal activation of building components. The heat dissipation system is installed on the outside of the existing exterior wall. As mentioned before these XPS insulation boards are installed within the levelling laths. These XPS-boards are equipped with inserted heating pipes. So the wall-areas below all windows are warmed from the outside.

Figure 23: Two views on the exterior walls during installation works. The heat dissipation (XPS-boards with inserted heating pipes) is assembled in the wall-areas below the windows (Source: AEE INTEC)

Figure 24: Heat dissipation system installed on the outside of the exterior wall (Source: AEE INTEC)

3.11. Integration of façade collectors

South-oriented façade got integrated façade-collectors (instead of the solar combs) – to contribute to the active energy generation. Due to the orientation of the buildings blocks these collectors were installed on the south façade of the long building row.

Figure 25: Assembling procedure of the façade modules with integrated collectors (Source: AEE INTEC)

4. Monitoring und evaluation

Within the research project a comprehensive monitoring is applied. So it is possible to evaluate the energy related key figures of the system and façade concept.

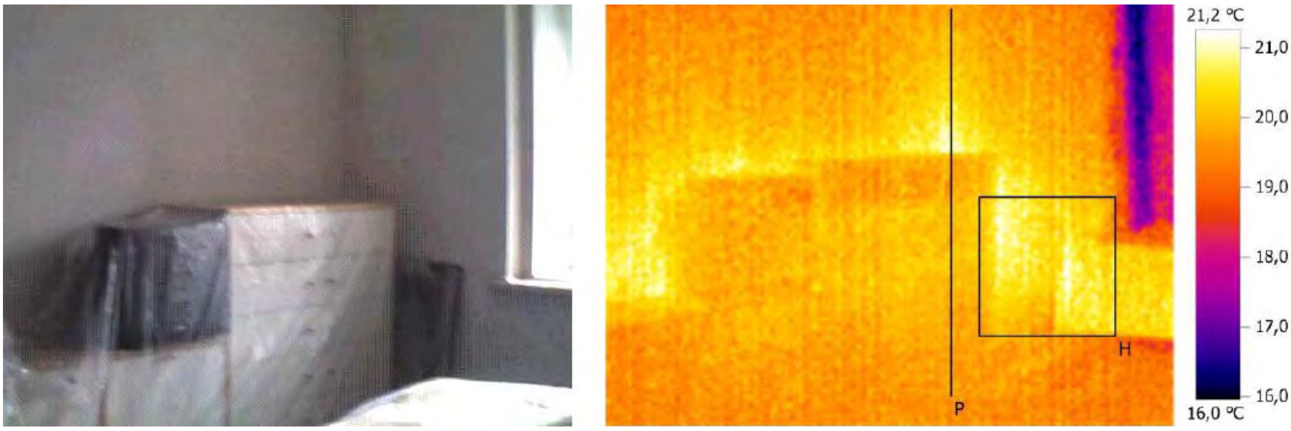


Figure 26: Inside views of apartment. The left picture shows the realistic photography, the right one the thermo-graphical analysis (Source: GIWOG)

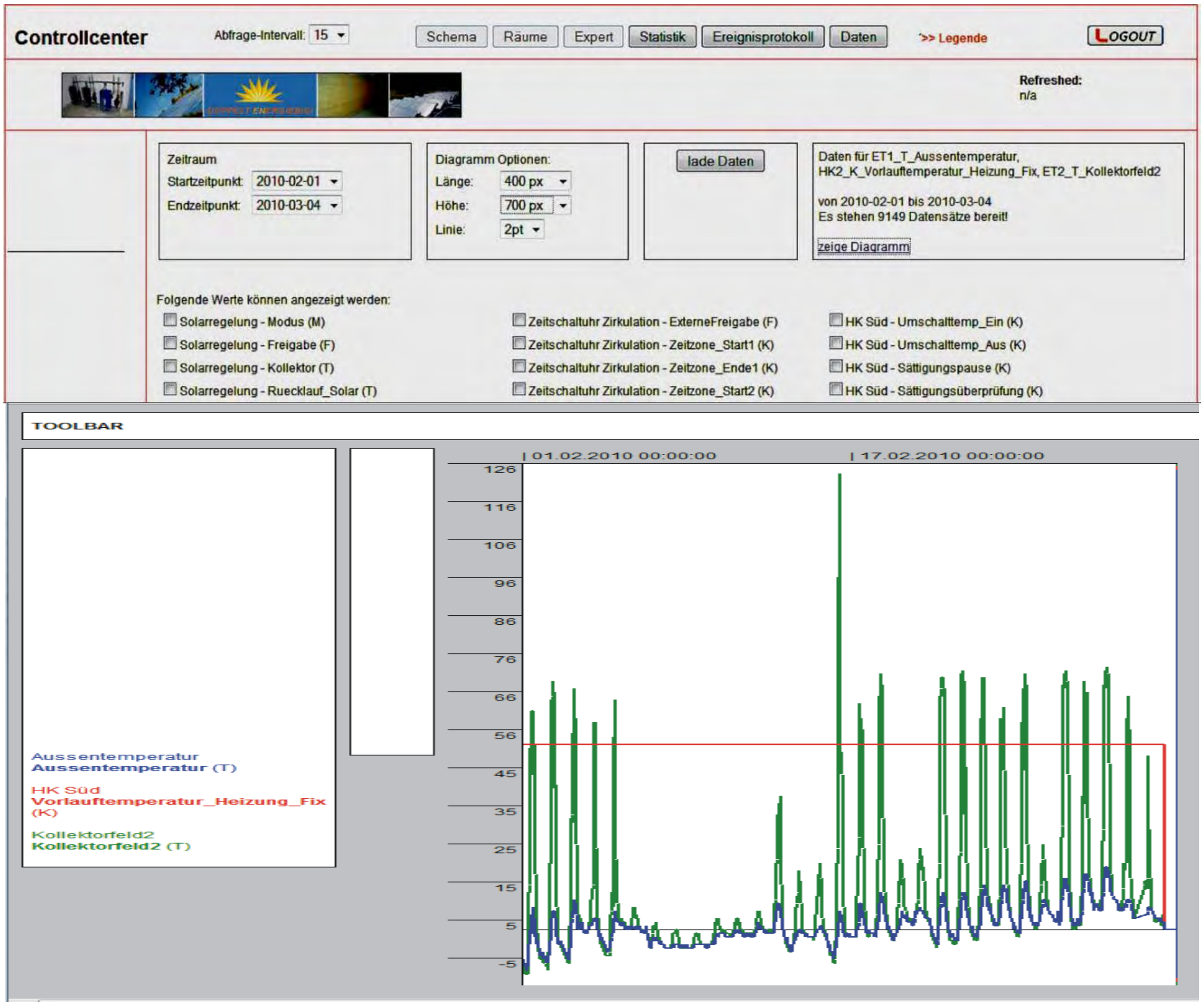


Figure 27: Online data measurement by data control system, available via web (Source: FUTUS Energietechnik GmbH)

5. References

Additional publications within the IEA ECBCS Annex 50[10]:

[I] Mark Zimmermann: ECBCS Project Summary report "Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings, March 2011

[II] Peter Schwehr, Robert Fischer, Sonja Geier: Retrofit Strategies Design Guide, ISBN 978-3-905594-59-1, March 2011

[III] René L. Kobler, Armin Binz, Gregor Steinke, Karl Höfler, Sonja Geier, Johann Aschauer, Stéphane Cousin, Paul Delouche, François Radelet, Bertrand Ruot, Laurent Reynier, Pierre Gobin, Thierry Duforestel, Gérard Senior, Xavier Boulanger, Pedro Silva, Manuela Almeida: Retrofit Module Design Guide, ISBN 978-3-905594-60-7, March 2011

[IV] Reto Miloni, Nadja Grischott, Mark Zimmermann, Chiel Boonstra, Sonja Geier, Karl Höfler, David Venus: Building Renovation Case Studies, ISBN 978-3-905594-61-4, March 2011

[V] Mark Zimmermann, Hans Bertschinger, Kurt Christen, Walter Ott, Yvonne Kaufmann, Stefan Carl: Retrofit Advisor, Beta-version, March 2011

[VI] Peter Schwehr, Robert Fischer: Building Typology and Morphology of Swiss Multi-Family Homes 1919 – 1990, January 2010

[VII] Bertrand Ruot: French housing stock built between 1949 and 1974, October 2010

[VIII] Bertrand Ruot: Elements of morphology of collective housing buildings constructed in France between 1949 and 1974, October 2010

[IX] Gerhard Zweifel: Retrofit Simulation Report, March 2011

References related to Retrofit Module Design Guide Part B:

[1] Willensdorfer A. (2009): "Passivhausstandard und –komfort in der Altbausanierung. Mehr-geschossiger Wohnbau in Graz/ Liebenau." International Symposium in High-Quality Thermal Retrofitting of Large-Volume Buildings – Ökosan´09.Weiz. 145

[2] Willensdorfer A. (2010): "Wohnbausanierungen auf Passivhausstandard – Erfahrungsbericht". Symposium Mehr als nur Sanieren. Salzburg

[3] Geier, S. (2010) "Retrofitted Buildings Go Solar-Active!". EuroSun2010. Graz

[4] www.gap-solution.at/

[5] http://www.futus.eu/

[10] Further information at home pages: www.empa-ren.ch/A50.htm, www.ecbcs.org/annexes/annex50.htm

Part C

Retrofit Module Design Guide

Part C: Large Size Prefabricated Steel Frame Retrofit Modules

Authors:

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François Radelet E3 Performances/Arcelor Mittal; Bertrand Ruot, Laurent Reynier, CSTB;
Pierre Gobin, VINCI Constructions; Thierry Duforestel, EDF; Gérard Senior, AETIC;
Xavier Boulanger, ALDES, France

Paris, March 2011

The participation in IEA ACBCS Annex 50 was funded by ADEME, Agence de l'environnement et de la maîtrise de l'énergie via the RECOLCI project initiated in the framework of the French PREBAT 2007 programme

Partner involvement

Project partners were involved in consortium

- EDF: French leader in energy supply
- Saint-Gobain Isover: worldwide leader for thermal and acoustic insulation solutions
- Aldes: French leader of ventilation systems in residential buildings
- Arcelor Research Liège: RD center for development of solutions for steel construction of Arcelor Mittal, worldwide leader in steel production
- Le Centre Scientifique et Technique du Bâtiment (CSTB)
- Architects bureau AETIC: refurbishment and high environmental quality operation specialist
- VINCI Group: world leading construction company

In addition, a "users club" comprising USH, OPAC 71, Grenoble city advisor, SMABTP, was involved during the project to give feedback on its various steps. During façade module conception and development working package, each partner took on a role according to their core competencies and expertise.

Saint-Gobain Isover participated in all discussions concerning the technical choices made, and provided its expertise on alternative solutions existing in France and Europe (other prefabricated renovation solutions…) as well as its knowledge on dealing with specific issues (openings, air and watertightness, thermal bridges…). Isover was involved in designing the model (insulation installation, window fixing, watertightness…) and monitored the project throughout the various stages in producing the model.

Arcelor-Mittal took an active part in designing the modules (choice of profiles, module drawings…). Arcelor-Mittal also carried out studies to measure the façade modules' mechanical resistance and thermal performance using its Liège research centre (AMLD) and the subsidiary of Arcelor-Mittal Construction, Profile du Futur. The latter also took part in making and designing the model, as well as implementing it on site. Profile du Futur also studied implementing the solution on the Autun building (gridding, number and nomenclature of modules).

Vinci provided its expertise regarding implementation methods and real job-site constraints. Vinci conducted preliminary studies on the modules' thermal performance.

A.E.T.I.C (architect's practice) provided contracting insight and knowledge of architectural and design constraints for the solution definition. A.E.T.I.C produced detailed drawings of the solution for all façade specific issues (window edges, inner/outer corners, etc…).

Aldes took charge of the whole feasibility study of ventilation system as well as studying the implementation of the double-flow ventilation solution.

C.S.T.B commented on the technical choices made and the thermal performances obtained and brought expertise on building morphology, and building techniques used during the period 1948 -1975 and developed together with EDF and Aldes a thermal simulation tool.

EDF has brought its expertise in coordinating evaluation, through various criteria, (thermal, acoustic, environment, financial) of the developed façade module and was apart of setting of the thermal simulation tool.

Table of Content

1. Introduction

In the frame of IEA annex 50 Project *Prefabricated Systems for Low Energy Renovation of Residential Buildings*, a French project has been implemented, sponsored and financed by ADEME under the name of *RECOLCI: Réhabilitation Énergétique des immeubles de logements Collectifs par Composants Intégrés*

The target was to set a solution for façade renovation of collective buildings, meeting the following requirement:

- Energy efficient: heating and cooling consumption plus domestic hot water limited to 50 to 60 $kWh_{PE}/(m^2 \cdot y)$
- Keeping noise protection
- Low intrusive solution for the occupants
- Use of a combination of building components to create the prefab solution with reduced cost due to high level of duplication
- Reduced installation costs due to prefab (better safety, ease of installation, low disturbance for occupants)
- Aesthetic, modular solution with high diversity of cladding and exterior finish. The solution has been studied deeply and carefully as a concept solution

The following pages describe the French façade module RECOLCI, its performances, its production mode (off site) and installation.

An economical approach and overall evaluation are done based on a “as if “renovation of Immeuble 53 OPAC Saone et Loire ZAC Saint Pantaléon Autun (71), France

2. Context of development of the solution

French residential building stock accounts 30.6 millions dwellings; 44% are collective buildings Residential sector energy consumption represents 30% of total energy and 25% of greenhouse gas emissions. Collective buildings energy consumption accounts for 40% of total energy consumption of residential buildings.

Old buildings (built before 1974, when first thermal regulation was implemented in France) are 65% of total building stock (20 millions dwellings), 70% of collective buildings as main residences. Energy consumption of “old” collective buildings is high (250 $kWh_{PE}/(m^2 \cdot y)$ for heating). Due to high variety of building types, renovation operations are very often long, complex and expensive.

Thus the RECOLCI project has developed new solution to tackle the renovation issue. The façade module described hereafter is part of global energy efficient renovation of collective buildings built between 1948 and 1975. The collective buildings can be owned by social houses organism or be part of private sector.

Beyond the installation of the façade module and ventilation system (embedded or not in the modules), roofs and floors are also refurbished to ensure energy efficiency of the buildings.

The façade module has been preferably developed for buildings with less than 7 storeys (limit height of high rise buildings (28 m) in France).

Figure 1: Typical French apartment building (Source: Aetic France)

3. Specification of the solution

Based on the project context (see [I]) the aimed solution has been defined in order to meet functional and performance requirements:

- **Offer flexibility**
  The solution needed to be flexible enough to suit a great variety of façades (size modularity) and offer standardized implementation by fixing workshop-prefabricated components.
  The façade system needs to be able to receive all kinds of facing materials.
- **Provide space and ambiance**
  The solution needed to be "free-standing" and allow an extra storey to be added easily on to the top of the building (by elevation). This is clearly the most important part of the RECOLCI solution: the latter has to be mechanically proportioned to facilitate the addition of at least one more storey.

The solution has to limit daylight loss as much as possible and be able to offer at least the same acoustic protection against external noise as before.

Off site prefabrication was the preferred choice to reduce installation time and site implementation costs. The modules can bear the weight of the new window to be installed.

- **Thermal performance of the solution**
  The solution needed to meet high targets in terms of efficient energy in use. The performance has been chosen between 60 and 80 $kWh_{PE}/(m^2 \cdot y)$ in the H1 zone (heating, lighting, ECS and ventilation) post-implementation. This target has been translated in terms of thermal performances to be reached for the walls (based on thermal simulations).

  It has to be noticed that an objective of 50 $kWh_{PE}/(m^2 \cdot y)$ is reachable (see [IX]). The simulations show that the façade solution has to reach a $U_p \leq 0.2$ $W/(m^2 \cdot K)$ at the level of the flat roof ($U_p \leq 0.13$ in the case of non-furbished attic). As for the floor insulation, the solution will have to achieve $U_p \leq 0.22$ $W/(m^2 \cdot K)$.

  Regarding airtightness, the goal was to try and have the best possible air-sealing for openings in order to achieve an overall permeability of ≤ 0.6. The façade solution was also required to enable, wherever possible, the installation of double-flow ventilation with heat exchanger on exhausted air and thermodynamic unit.

4. French RECOLCI façade module description

The solution is a prefabricated façade module including or not the ventilation system in its structure

4.1. Overall description of the solution

In order to meet the most important mechanical constraint related to adding on a building storey, mechanical studies have demonstrated the necessity to use 20 cm metal cross-section profiles from Arcelor-Mittal Construction's StylTech range (cold-laminated profiles with a high C and U type elasticity limits, 2.5 and 1.5 mm thickness).

To ensure the "self-standing" nature of all modules forming the façade, these are stacked vertically one on top of the other so that loads may be vertically lowered from top to bottom (from the roof to the foundations). The modules have a unit height equivalent to 2 storeys. Modules are conveyed and moved on the job-site using suitable lifting equipment.

The modules are fastened to the façade for bracing but the weight of the elements and the roof elevation are transferred through the uprights of the façade module frames. The modules are reinforced by intermediary uprights to ensure mechanical resistance. Before joining the modules onto the façade, a first insulation layer ≥ 10 cm is fixed onto the façade (traditional insulation –fastening technique using plug anchors).

The prefabricated façade modules are then attached to brackets fixed on the façade. Horizontally the spacing between two modules never exceeds 60 cm. If necessary, totally opaque modules (with no window opening) may be fabricated. Between the modules, reinforcement bars (sag bars) and rods are placed to ensure load transfer (see Figure 3). This space between modules will be filled with insulation on site.

The modules are prefabricated and insulation between uprights is installed in the workshop (20 cm thickness between uprights) with a wrapping to protect the insulation from damage during transportation and for possible storage on site. The window edges are insulated with a thickness of 7 cm of insulation and a pre-frame has been pre-mounted so that a new window may be mounted easily on site.

The window is fixed in the pre-frame. The interior covering between the window and the former master frame joined to the existing wall must be done on site by checking there is good air tightness (installation of an air-tightness membrane).

The modules are ready to receive any kind of facing (centre distance between uprights ≤ 60 cm). The implementation of a siding on the vertical uprights of the module is facilitated by the fact that the installation surface is already flat.

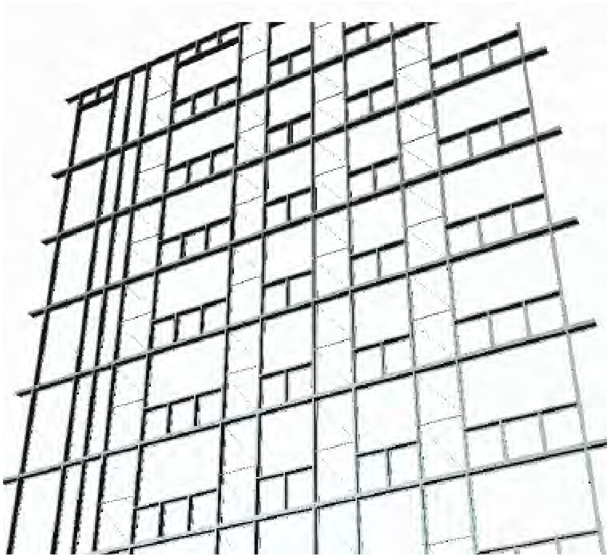


Figure 2: Overall image of the RECOLCI solution applied to the façade of a building

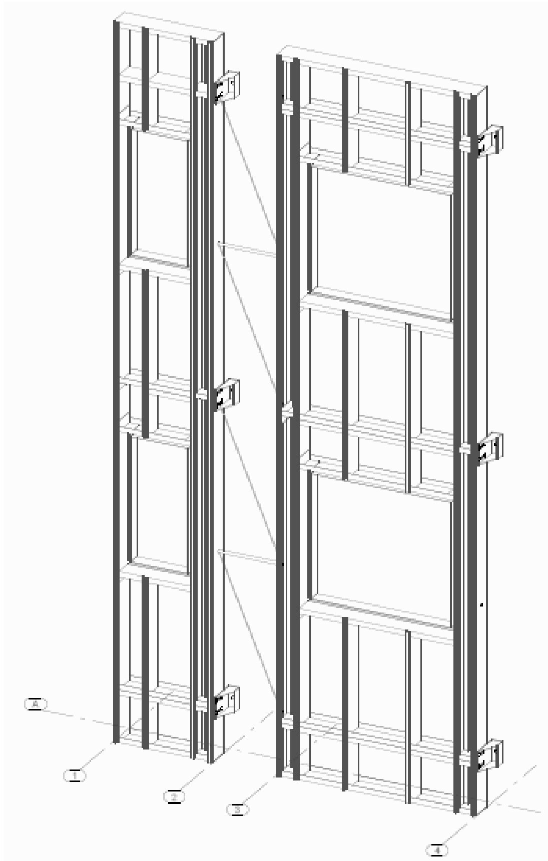


Figure 3: Connected RECOLCI modules: a 2-storey high module (left), 2 modules horizontally connec-ted (with rods and reinforcement bars, or sag bars)(right)

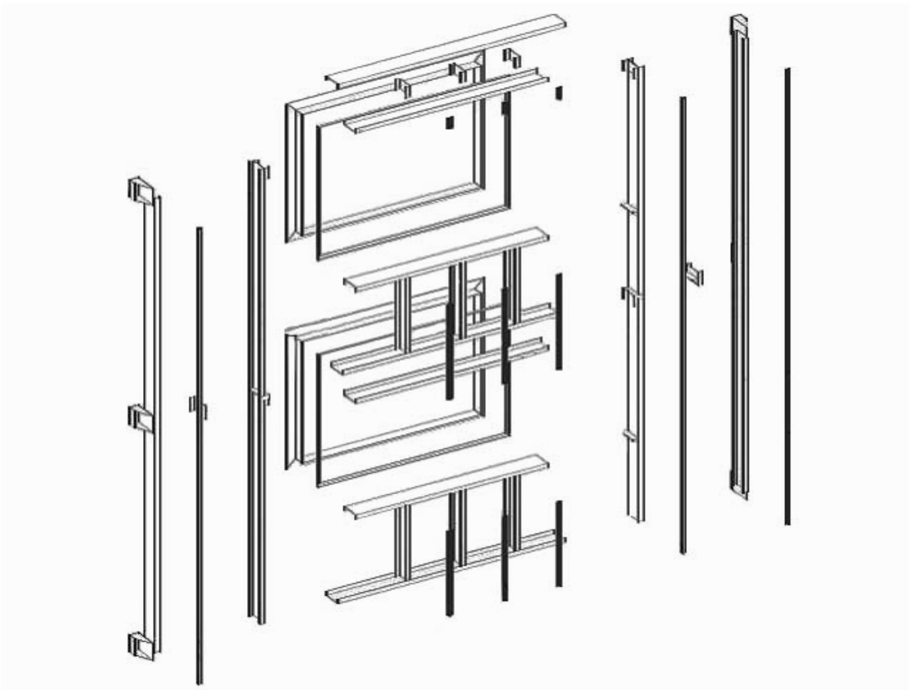


Figure 4: Breakdown of the different StylTech profiles by Arcelor-Mittal Construction (C, U, L and Ω) used to produce RECOLCI façade modules

4.2. Performances

4.2.1. Mechanical properties

The calculations made by Arcelor-Mittal show that the RECOLCI façade module solution can transfer loads of up to 3.3t by the module's main vertical upright (the framework uprights of each module) if the spacing between the joining points (the fixing brackets) does not exceed 2.5 m horizontally; this is the case for the RECOLCI solution.

The transferring loads method should facilitate the addition of a storey made of light metal structure on top of a building. Naturally, intermediary load-bearing points need to be planned sufficient in number in the central part of the building according to its depth (or width) - whereas a narrower building could ultimately transfer loads only by the "façades".

The sections chosen meet the mechanical requirements of load transfer (wind, siding and vertical lowering of loads) and the constraints to installing glass wool.

However, a cross-section profile optimization could be imagined to combine:

- a reduction in thermal bridges
- ease of glass wool installation in the module
- lightening the structure

4.2.2. Dilatations

Metallic façade elements are submitted to temperature variations occasioning dilatations. Fixations elements are designed with oval holes in order to counterbalance these length variations.

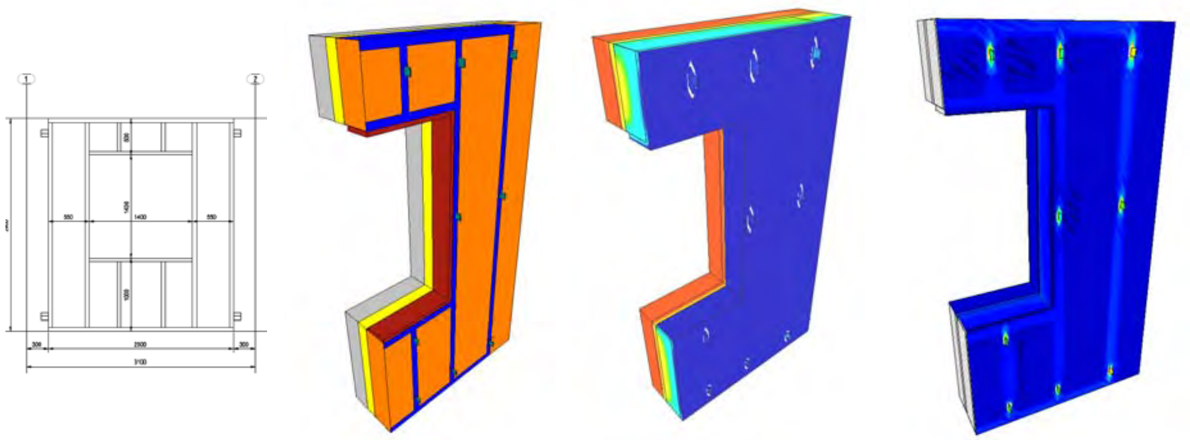
4.2.3. Seismic

Façade module has to meet requirement of seismic rules. This has to be studied case by case.

4.2.4. Thermal performance

Façade module thermal performance has been calculated with Triso numeric modelling software. Note C04367/0/CA37430 on thermal calculations entitled Simulation Thermique RECOLCI produced by Arcelor-Mittal Liege R&D shows that with:

- 10 cm of glass wool insulation against the wall (λ= 32 mW/(m·K))
- 20 cm glass wool insulation between studs (λ= 35 mW/(m·K))
- 50 mm glass wool insulation in the window edges (λ= 32 mW/(m·K))



Module geometry — Module modelling — Isotherm representations — Flows representation

Figure 5: Thermal simulation of façade module

U_P Module façade (with thermal bridges) obtained is:

- 0.22 W/(m²·K) by using composite thermal break fasteners, or brackets (λ = 2 W/(m·K))
- 0.25 W/(m²·K) by using modular steel fasteners, or brackets (λ = 50 W/(m·K))

It can be noted that these U_P values remain relatively high compared with the full thickness of the system which includes 30 cm of insulation in total. This can be explained by the fact that 20 cm cross-section studs are necessary to have sufficient load resistance.

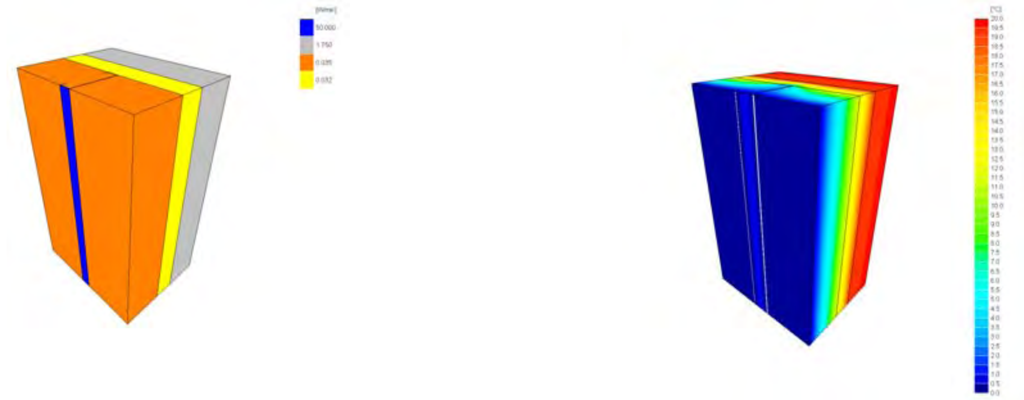


Figure 6: More generally the U_P evaluation for a module (blind part of the wall) with U_P = 0.16 W/(m²·K)

The following linear thermal bridges have been estimated:

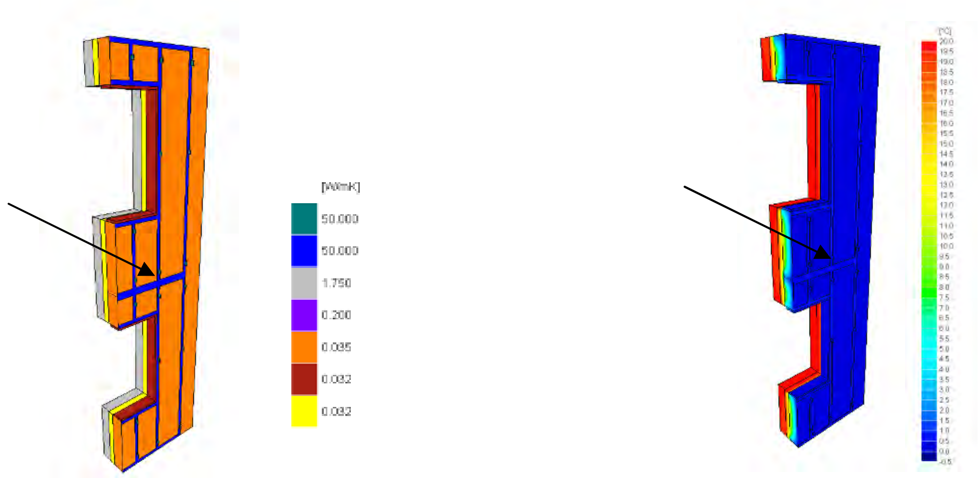


Figure 7: integrated thermal bridges, Ψ liaison module = 0.035 W/(m·K).

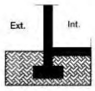
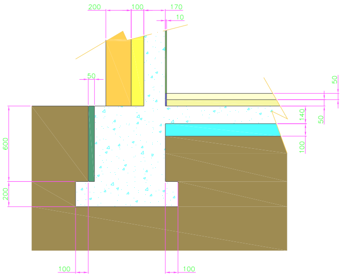
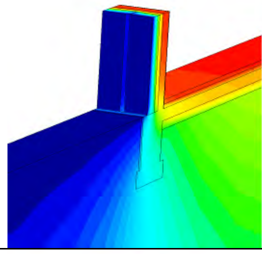
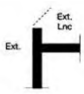
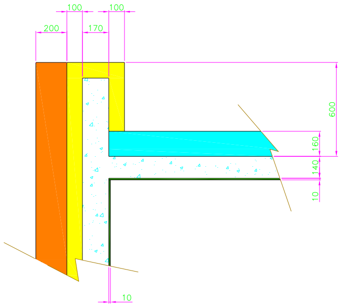
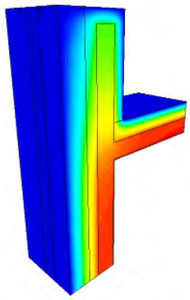
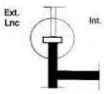
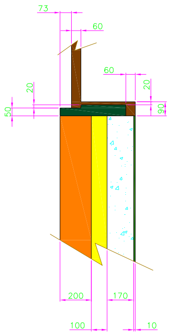
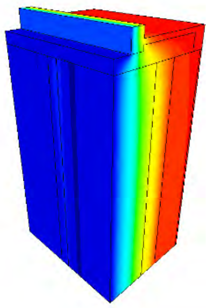
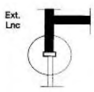
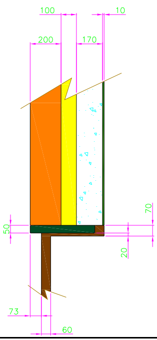
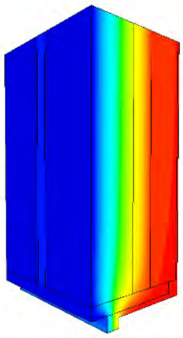
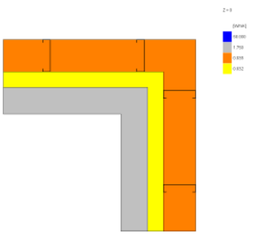
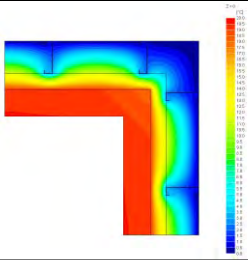
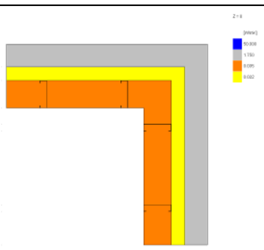
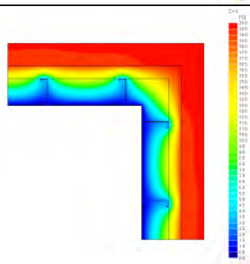
Ground façade liaison				Ψ = 0.42 W/(m·K)
Roof façade liaison				Ψ = 0.26 W/(m·K)
Doors				Ψ = 0.15 W/(m·K)
Lintel				Ψ = 0.13 W/(m·K)
Corner outside				Ψ = 0.09 W/(m·K)
Corner Inside				Ψ = 0.03 W/(m·K)

Figure 8: Connexion thermal bridges

4.2.5. Moisture control

Simulations made using the WUFI software show that the solution creates no problems in terms of moisture control. No accumulation of water has been observed within the structure by using a glass wool insulation (the product's permeability to water vapour enables the drying of the structure). Nevertheless, it is recommended to cover the inner part of metallic studs with anti corrosion /rust paint.

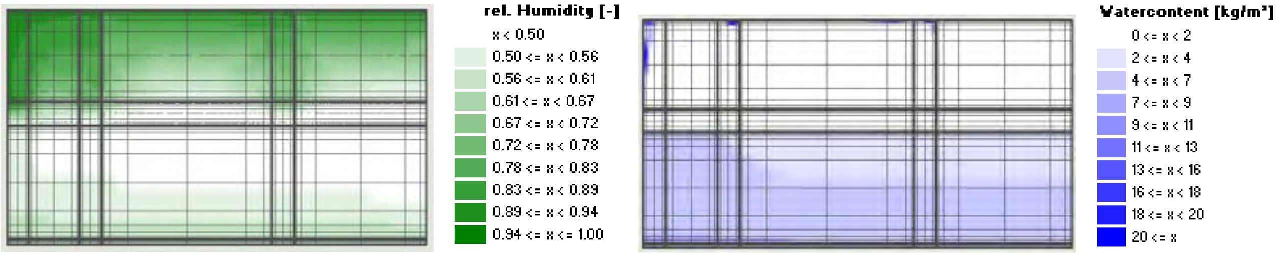


Figure 9: Relative humidity and water content of the RECOLCI structure in the springtime (drying virtually complete)

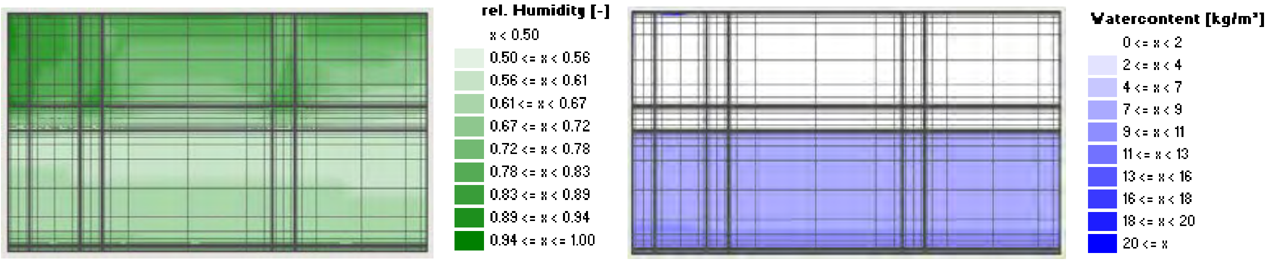


Figure 10: Relative humidity and water content of the RECOLCI structure in the summer (the structure is completely dry, there is no trace of water content, even North facing)

4.3. Steps of offsite fabrication of the façade module

These steps were validated during the assembling of a model under replicated offsite fabrication conditions.

4.3.1. Steps of fabrication of the module made off site

They include:

a) Construction of metallic part of the module
b) Installation of the interior smart vapour retarder membrane to maintain insulation during transportation to site, ease air tightness
c) Installation of insulation
d) Installation of the exterior HPV membrane for wind and rain protection
e) Installation of insulated pre-frame for windows
f) Fixing vertical studs to bear the finishing cladding system

The prefabricated modules then come in the form of rectangular-shaped components covered on both faces by protective membranes. They are ready to be installed on site

A pre-frame has been pre-fixed to be able to receive the master frame of the new window. The position of the pre-frame and the insulation thickness around the window cavity is adjusted according to the configuration of the window (horizontally or vertically).

The prefabricated façade modules have a max. width of 2.7 m to facilitate transportation (transported slantwise).

Through their design, the RECOLCI modules can be adjusted in size to suit each type of façade and the dimensions of its windows (dimensional modularity of the solution). Groups of different-sized modules may be defined for the same façade in order to adapt to the geometry of each façade. Regardless of their sizes, the panels will also be fabricated in the same way (assembling standardisation) without modifying the design.

Figure 11: Assembling of prototype façade module

4.4. Ventilation system

The RECOLCI solution for ventilation involves implementing wherever possible a centralized double-flow ventilation. Study of the morphology of the buildings has shown that this was possible in most cases for the category of buildings targeted by PREBAT (multi-family housing complexes built between 1949 and 1974) by using existing ducts and not having to pass the ducts through the façade. The fan and extraction units are installed on the exterior, on the flat roof. Individual heat exchangers are installed inside the apartments. These units are installed in the bathroom or WC, lodged in a suspended ceiling. Centralized ventilation was chosen rather than individual modules per room to go for the most economical solution. Individual modules per room also present the potential disadvantage of generating additional noise pollution if not correctly insulated acoustically.

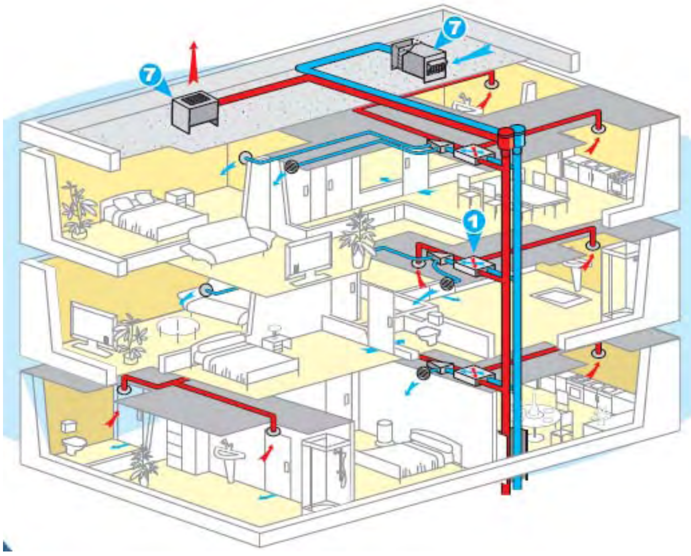
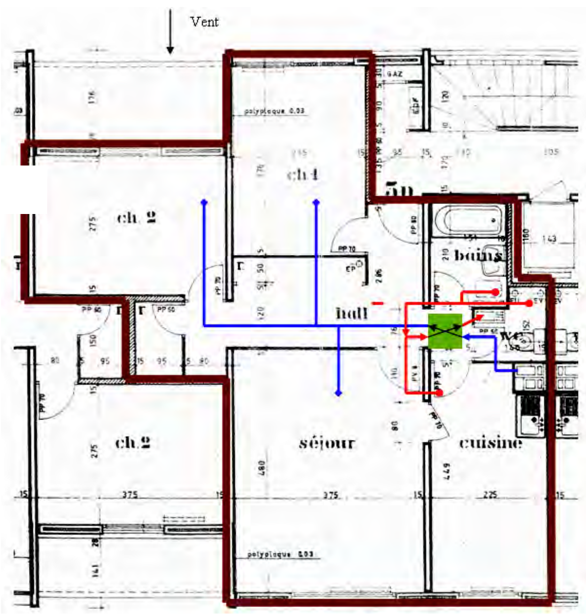


Figure 12: Fan /extraction network, heat exchangers in centralized double-flow ventilation.

Performance data of ventilation system:

- Air flow per apartment is in average 100 m³/h: ventilator fans consume between 0.1 and 0.25 W/(m³·h). Typical fans consume about 250 – 300 W motor power and can cover the needs for up to 30 apartments.
- Individual thermal heat exchanges are placed inside the dwellings in ceilings area.



Legend:

Heat exchanger

Return air — Air inlet

Exhaust air — Fresh air

Figure 13: 1st solution: Existing shunt ducts reuse. This solution is the easiest to be implemented and it warranties also a good internal comfort. But in any case, it also depends on new interior duct accessibility.

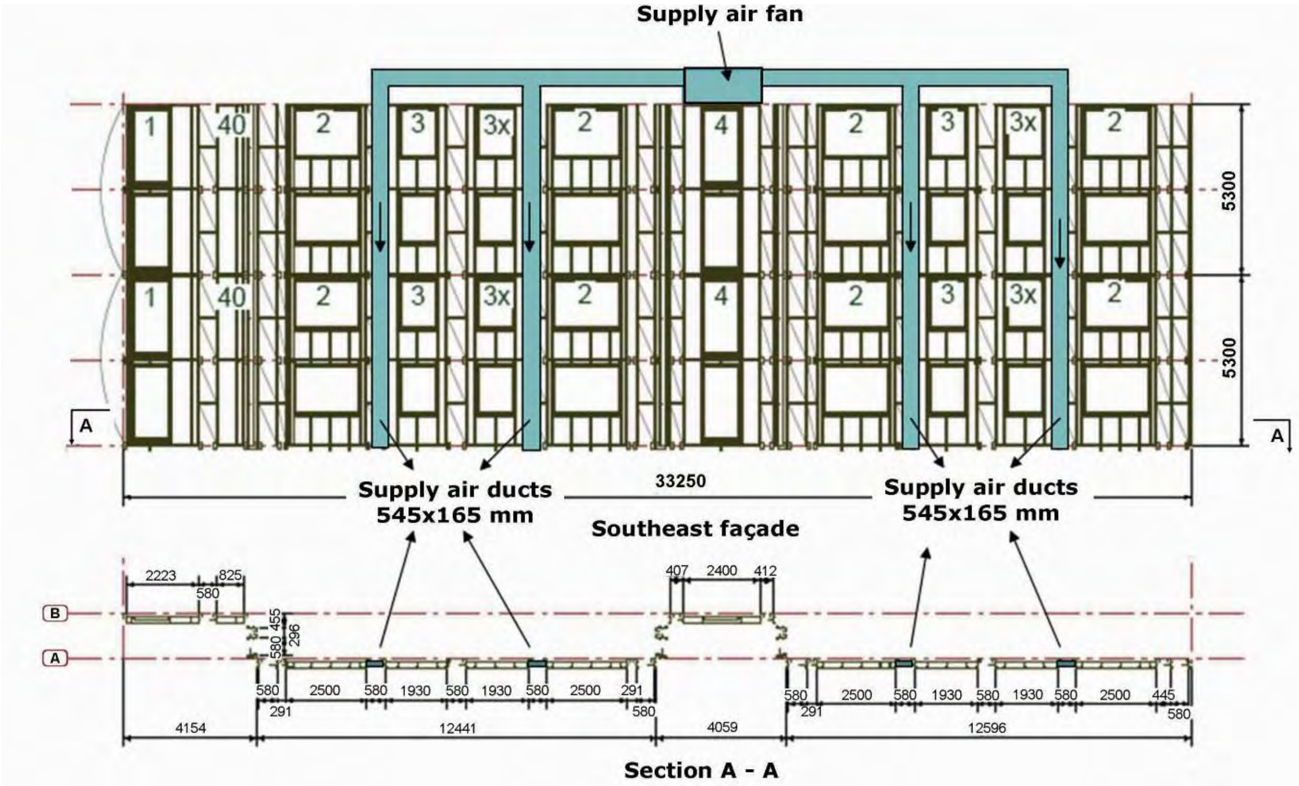


Figure 14: 2nd solution. Façade integration of fresh air ducts at Autun Building 53A, Southeast façade. Ducts can be long. In order to integrate them into the façade modules, ducts should preferably have a rectangular section.

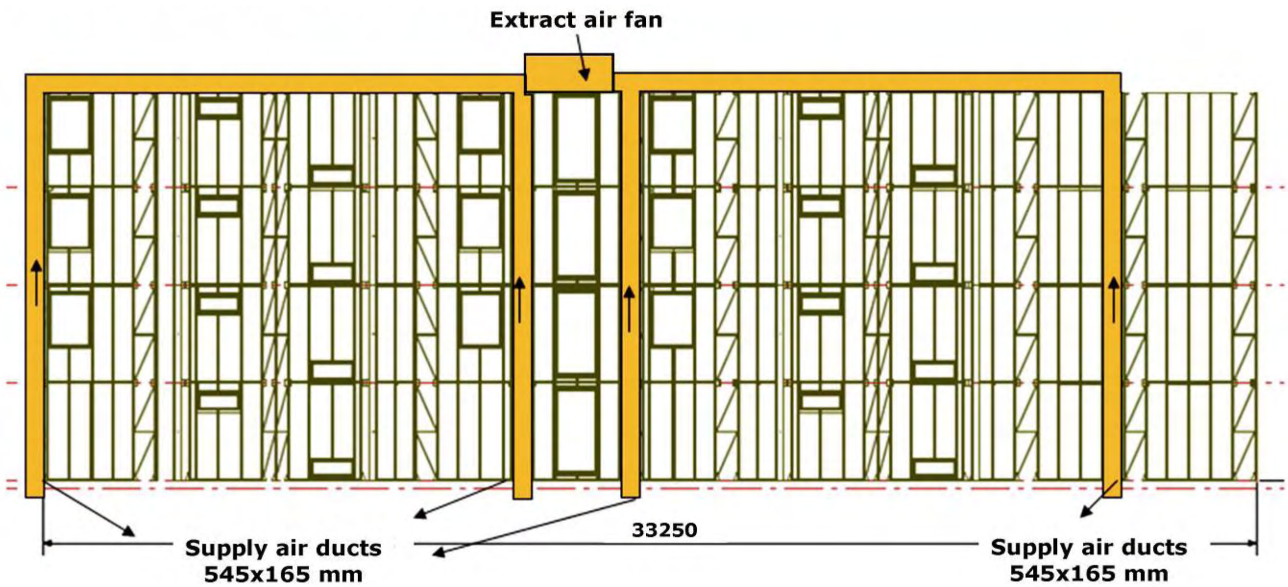


Figure 15: 2nd solution. Façade integration of return air ducts at Autun Building 53A, Northwest façade

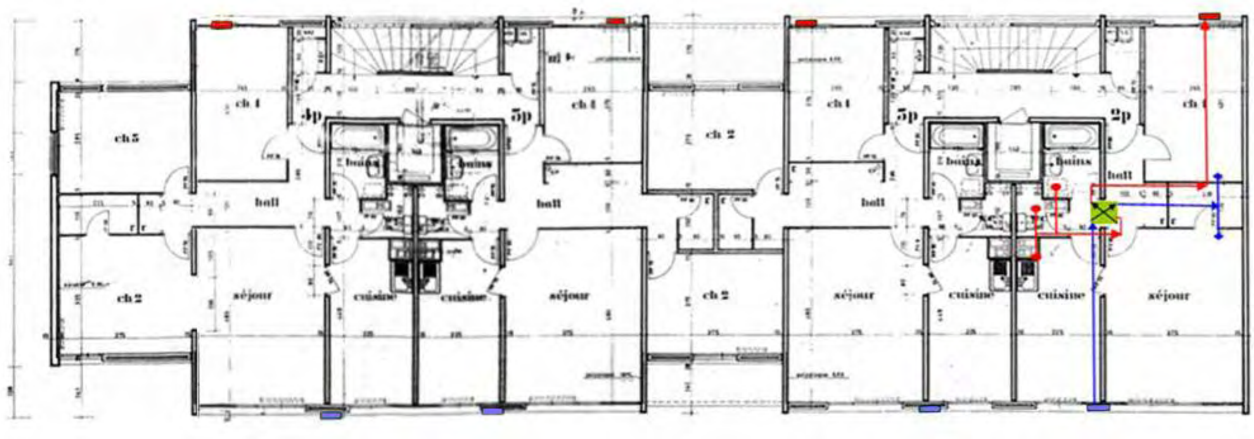


Figure 16: Example of 2-duct system for Autun building 53A, first floor. No part is planned to be prefabricated.

5. Installation on job-site

Component advantages

- Multi-storey module allows quick and easy installation.
- Weight (around 400 kg) is compatible with cranes handling
- By preparing at building foot, it is possible to reduce installation time of windows frames (dormers insertion at reception)

Installation sequence

- Installation is done by vertical band in order to better position the module
- It is necessary to look at the waterproofing and air tightness of modules
- Cladding installation is considered as traditional.

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5.1. Installation of the façade module

Careful gridding of the façade allows to determine the type and dimension of modules to be prefabricated. Preliminary audit and measurement of the existing façade must be carried out. Mechanical resistance of concrete floor slab edges and ground capability to bear additional foundation work must be checked. Accessibility to the job site for the solution is a key criterion of choice.

The modules come with bolted (or welded) lifting hooks on the exterior framework of the module to enable handling operations for loading, unloading and implementation. The installation is performed with scaffolds or cradle and hoists installed on the roof.

5.1.1. Steps of installation

a) Installation of fixing brackets on the wall and basement
b) First layer insulation
c) Installation of windows in the module /ensuring air tightness. Installation of module (anchoring to basement and to the wall. In order to ensure a good load transfer, it is important that the modules are aligned in the vertical dimension.
d) Insulation between two adjacent modules
e) Mounting of cladding

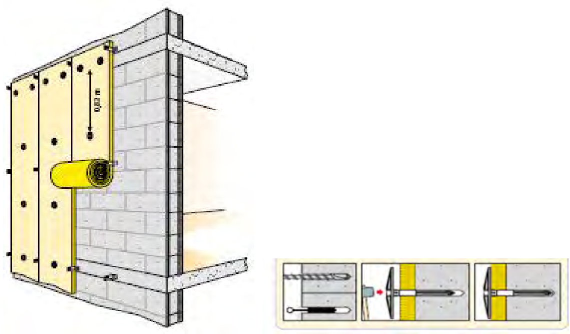

Figure 17: Mounting of brackets

Figure 18: First insulation layer

Figure 19: Mounting of windows

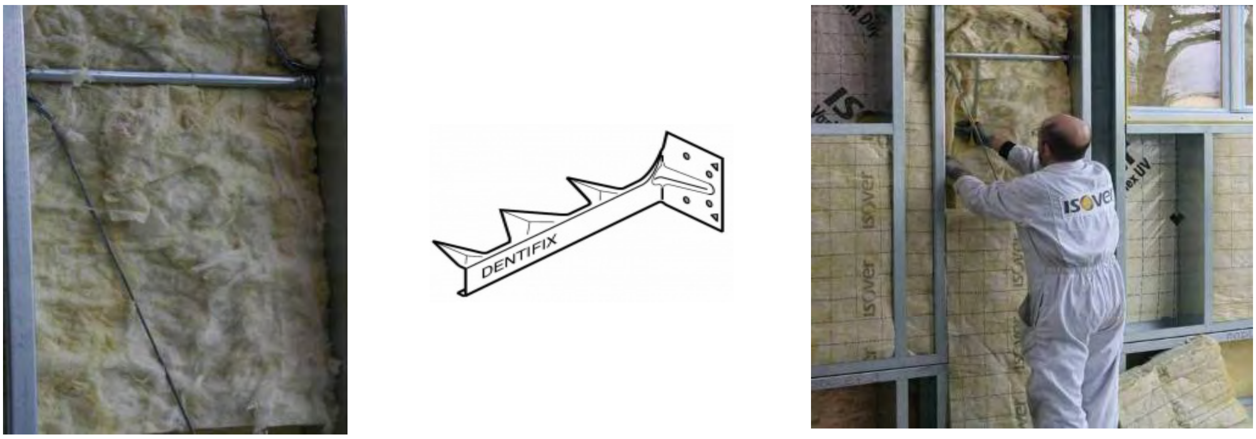

Figure 20: Insulation between two adjacent modules

Figure 21: Mounting of cladding (ATLAS facing by VETISOL)

5.1.2. Construction details

a) Liaison bay module

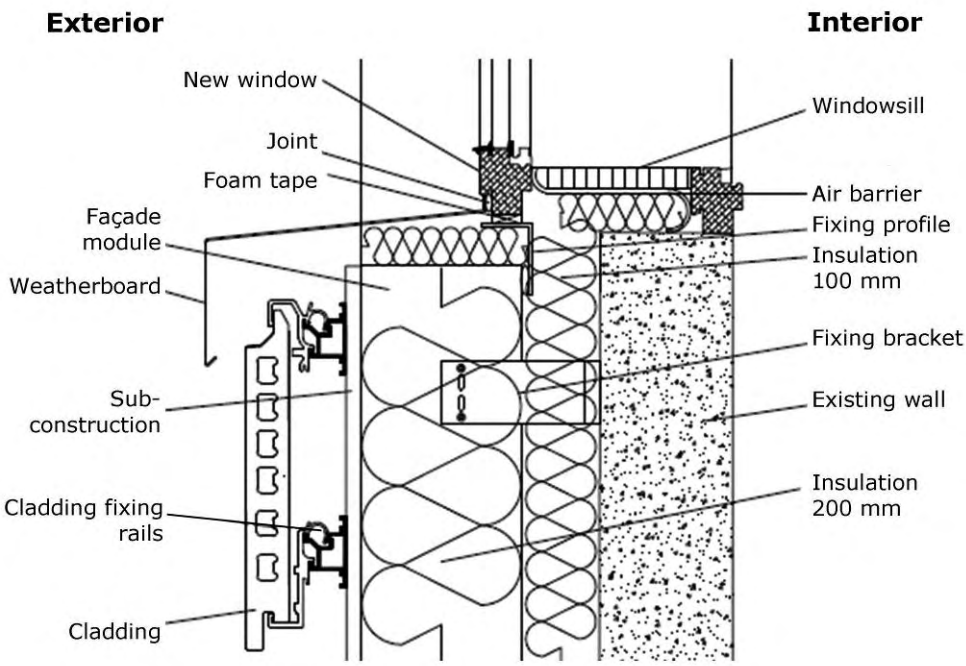

Figure 22: Details on installing the new window at the level of the ledge (water tightness, air tightness, insulation of the window edge, pre-frame, interior and exterior covering)

b) Bay lintel

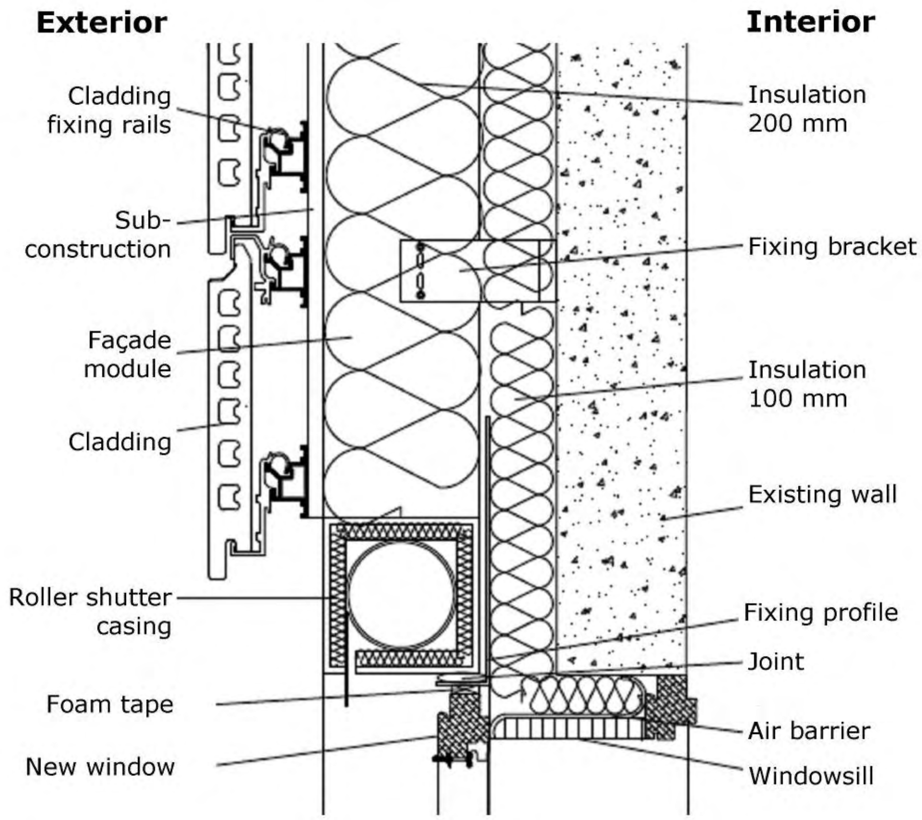

Figure 23: Details on installing a roller shutter encasement in the façade module (water tightness- air tightness, insulation of the window edge, pre-frame, interior and exterior covering)

c) Liaison walls – basement

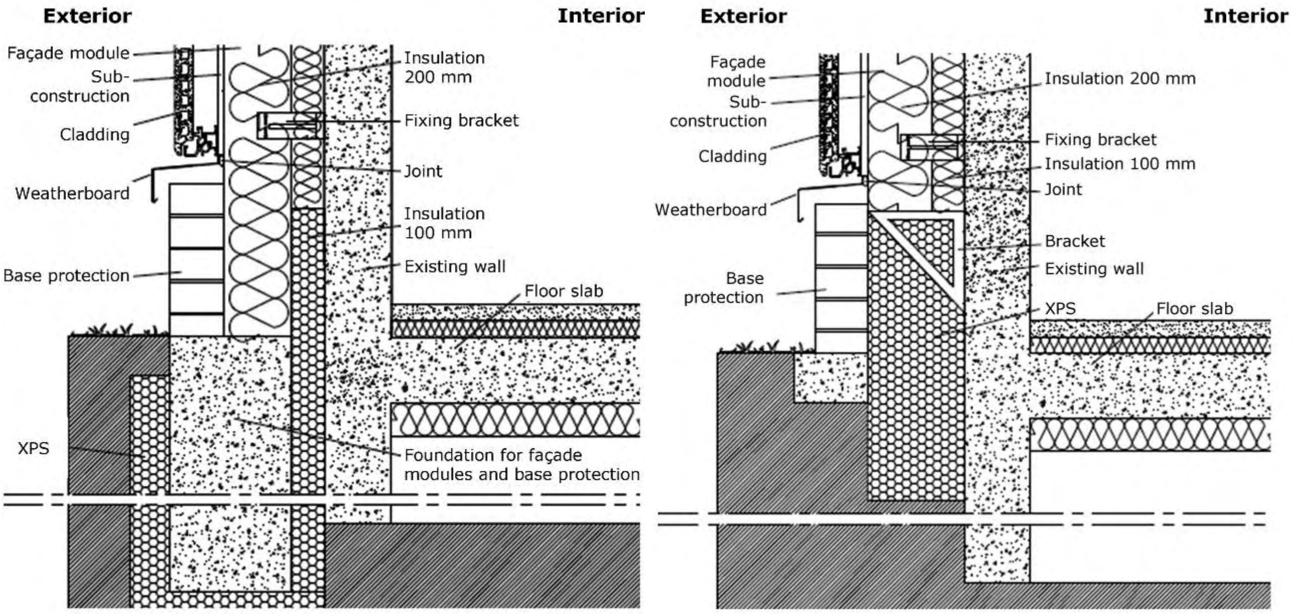

Figure 24: Details on supporting the RECOLCI solution at the foot of the façade (water tightness, ground insulation, ground protection)

d) Inside corner

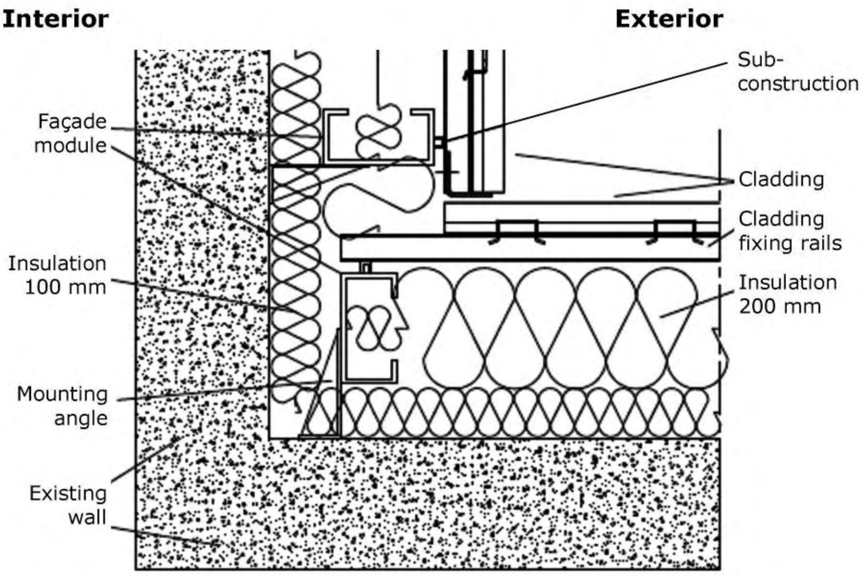

Figure 25: Detail of fixations inside corner

e) Flat roof (without building elevation)

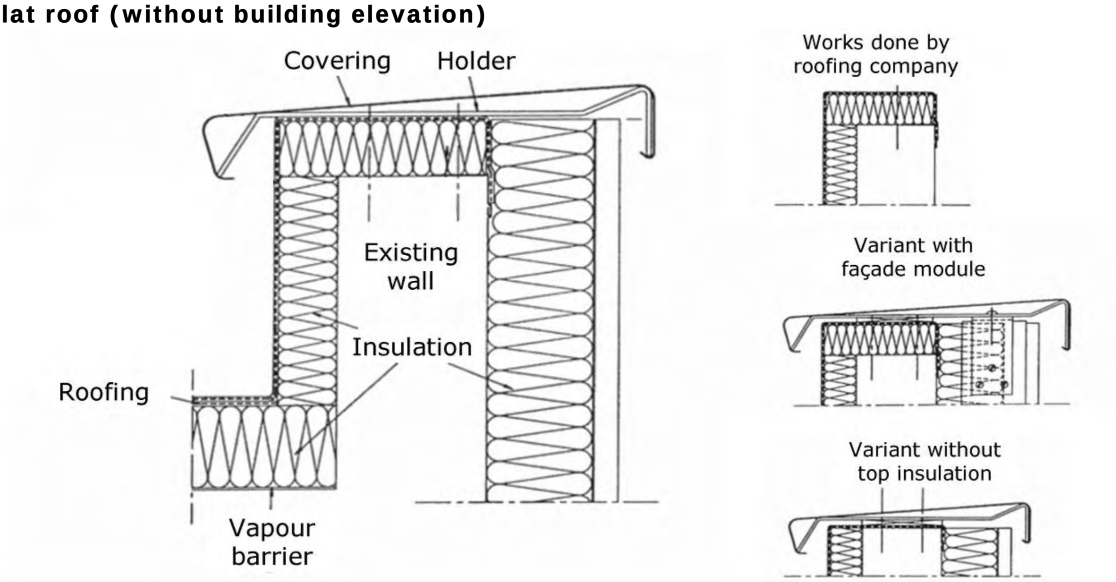

Figure 26: Flat roof details

5.2. Implementation of ventilation system

Figure 27: Installing fan/extraction units on flat roof, installing ventilation ducts, installing heat exchangers

6. Use of module solution

The use of façade module takes into account constraints (technical, regulatory), which can be specific for the French situation.

6.1. Potential applications for façades refurbishment

The French façade module RECOLCI is dimensioned in order to allow construction of an additional storey (1) on top of buildings.

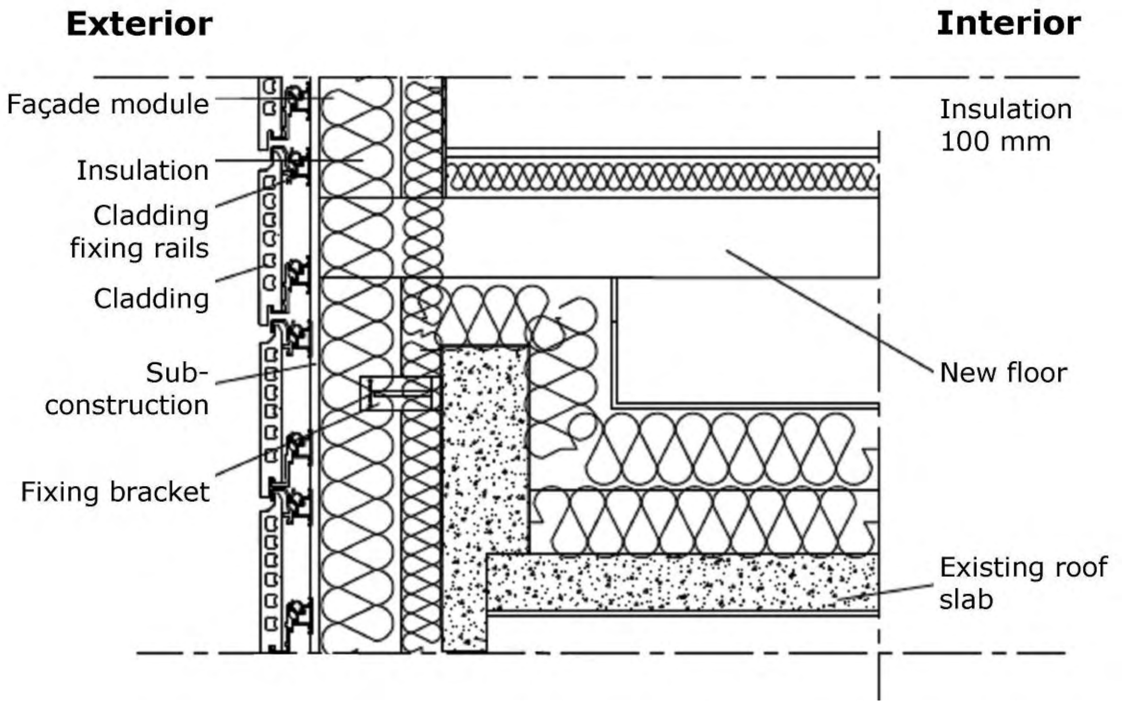

Figure 28: Adding dwellings with building elevation

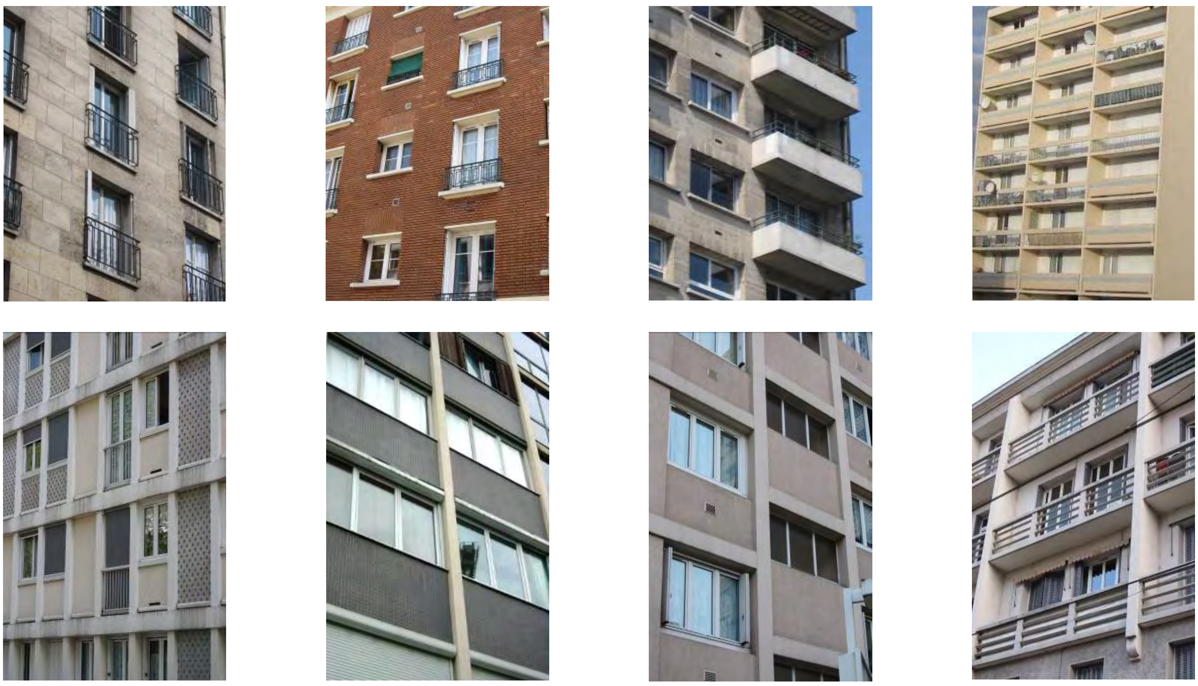

Figure 29: Potential façade applications

Figure 30: Loggias and balconies: integrated in new interior volumes to create new areas. In that case keep and close the balcony with specific balcony module.

6.2. Application to the Autun building (building n°53A)

The concept of French façade module RECOLCI was tested and simulated (gridding, estimated cost) in a real configuration (Autun building OPAC 71)

Figure 31: Test building for RECOLCI façade

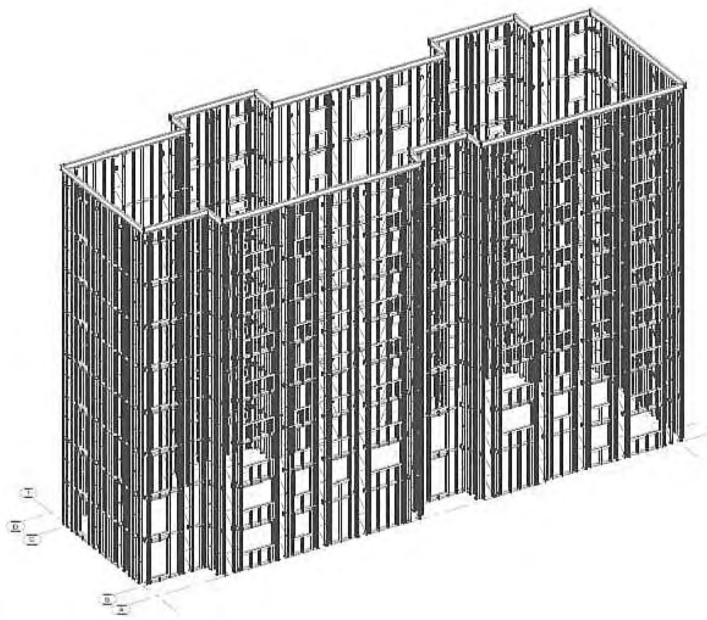

Figure 32: Gridding the Autun façade. Source: gridding from Profil du Futur 'ArcelorMittal

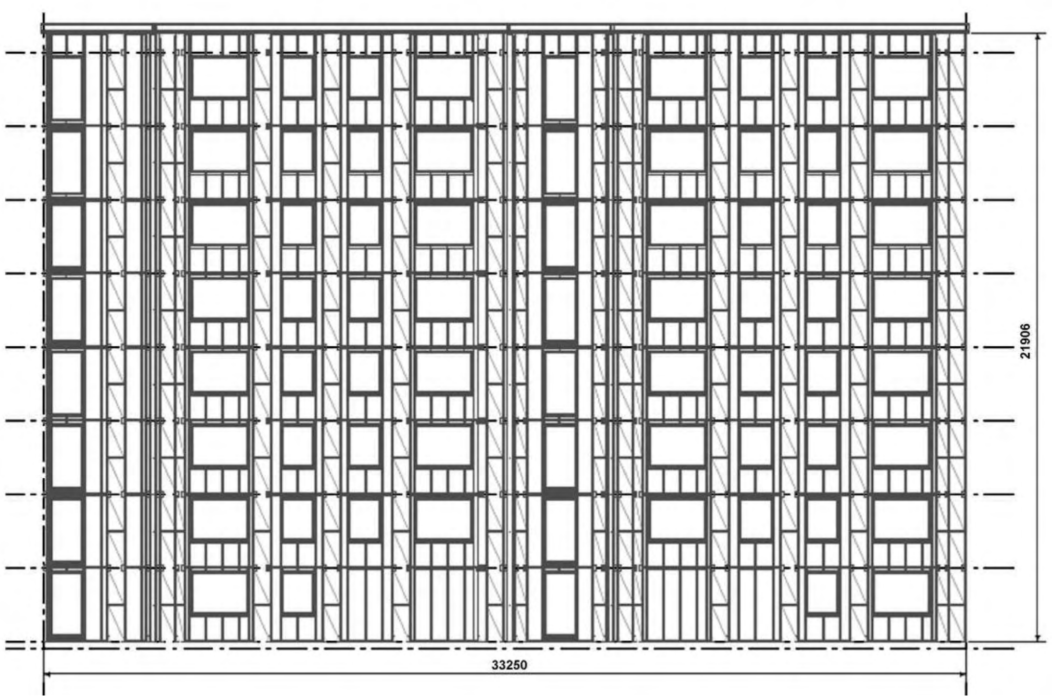

Figure 33: Representation of the "self-standing" structure of the RECOLCI solution on the façade of Autun building n°53A

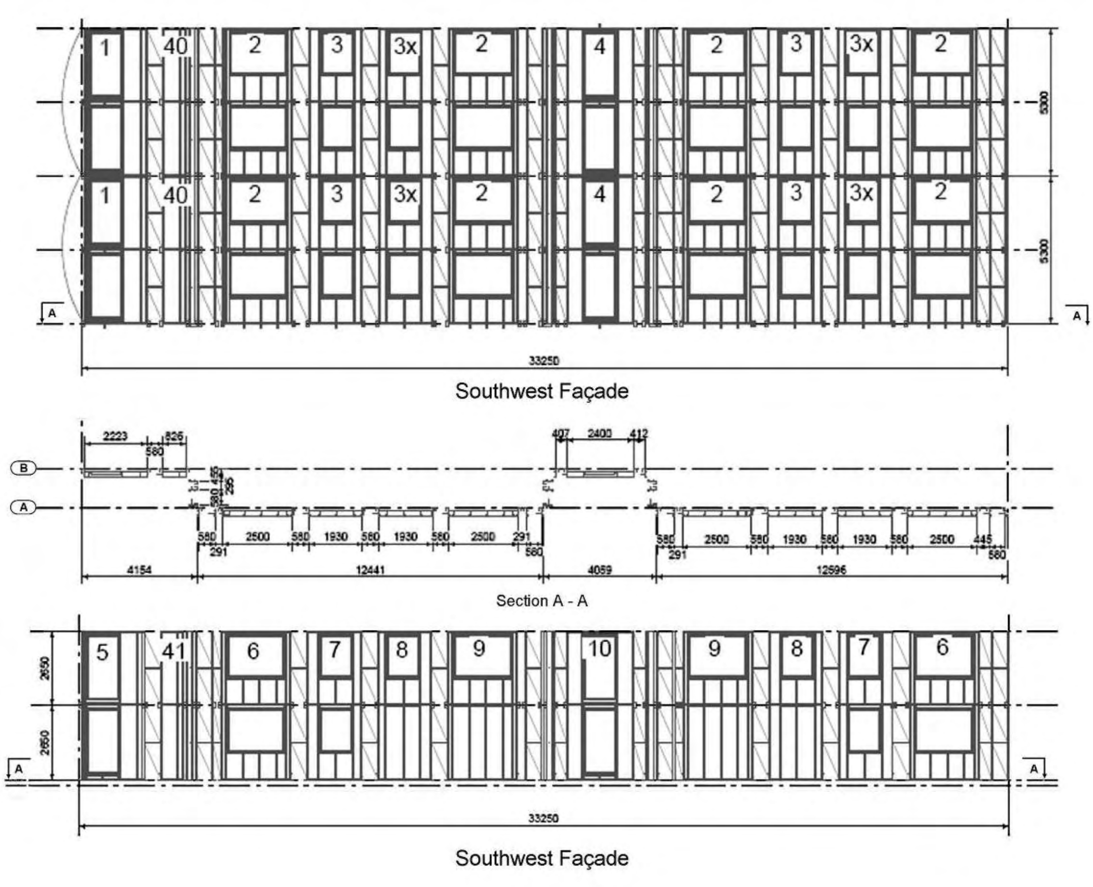

Figure 34: Detailed sketch of the RECOLCI solution modules on the South-West façade of Autun building n°53A. Top: intermediary modules - Bottom: modules at the base of the façade

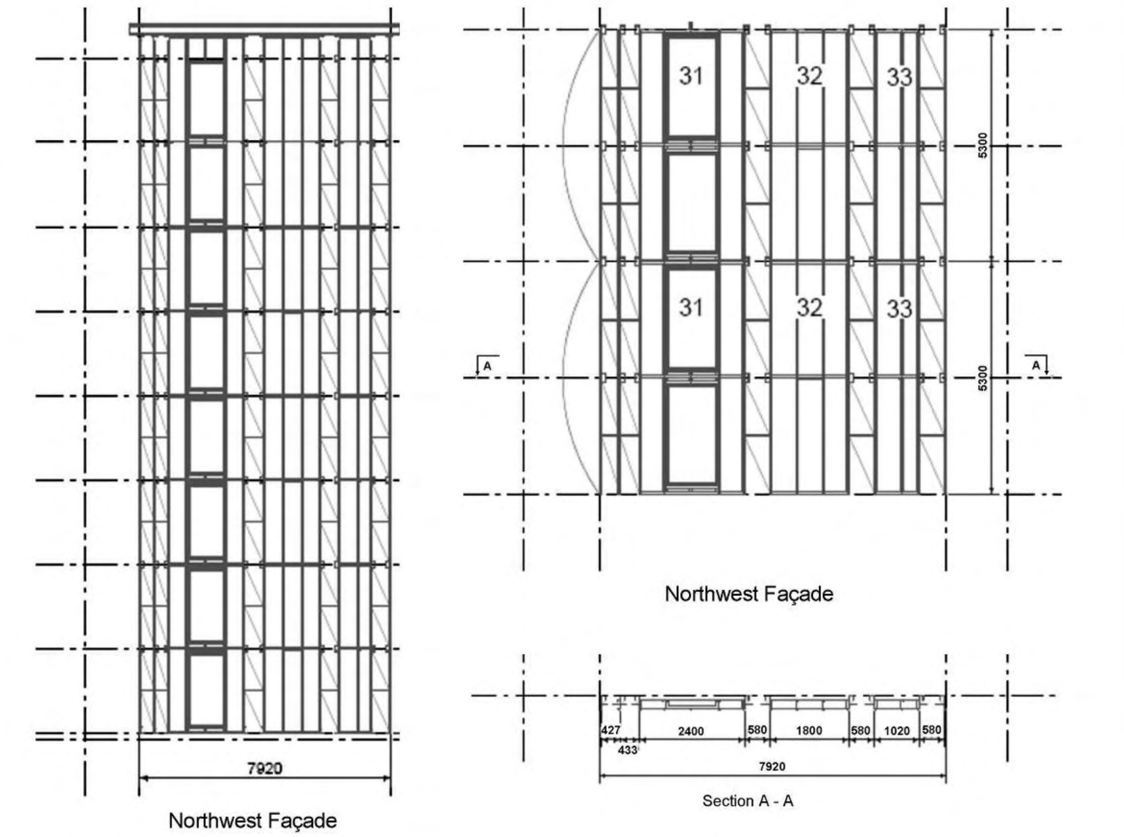

Figure 35: Detailed sketch of the RECOLCI modules on the Northern gable of the Autun building n°53A

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7. Economical approach

7.1. French façade module cost

A cost evaluation has been performed in the frame of the RECOLCI project based on the Autun building 53. It shows RECOLCI solution around 163 €/m² without cladding.

Autun building 53	**Without cladding**		**Cladding**	**With cladding**	
	Autun	RECOLCY		Autun	RECOLCY
Opaque façade	90	127	87	177	214
Transparent façade	258	337		258	337
Total excl. tax	111	54	76	187	230
Total incl. 5,5% VAT	117.10	162.5	80.2	197.3	142.7

Table 1: Cost calculations for the RECOLCI modular façade in €/m²

7.2. Thermal performance

The calculations of the Autun building shows that the façade module solution combined with ventilation double flow, triple glazing and an efficient treatment of roofs and walls allow to reach a level of consumption of 50 kWh/(m²·y).

	Typical values	Improved values
Roof		
- Flat roof	0.15 W/(m²·K)	0.1 W/(m²·K)
Floor slab		
- against crawl space	0.25 W/(m²·K)	0.15 W/(m²·K)
- against ground	0.33 W/(m²·K)	0.15 W/(m²·K)
Windows		
- Double glazed PVC window	1.3 W/(m²·K)	
- Triple glazed renovation window	1.2 W/(m²·K)	0.8 W/(m²·K)

Table 2: Improvements of thermal performance

Type of energy consumption	Simulation of RECOLCY concept	Simulation of improved solution
Heating	24.3	18.5
Hot water	17.2	17.2
Auxiliary energy for heating / hot water	2.3	2.0
Ventilation	12.3	12.3
Total (kWh/(m²·y)	56.1	50.0
U–value building W/(m²·K)	0.50	0.43

Table 3: Simulated energy consumption with improved envelope properties (kWh/(m²·y)), Source: Reynier L., RECOLCI – Tâche 4.4, Modélisation des performances de la solution RECOLCI sur le bâtiment 53 d'Autun, CSTB, Mars 2010, 35 pages

7.3. Profitability of French RECOLCI solution using façade module

Various approaches were conducted with a financial simulation model developed in the frame of RECOLCI project (see conclusion of T4 rapport final project RECOLCI). The major economical interest of RECOLCI solution (Façade module and ventilation system) is the capability to allow increase of renovated building area. The additional surfaces can be sold or rented. In any case, selling of the additional areas is the most profitable operation.

Nevertheless, for building occupants co-owners who benefit directly of energy savings, a high level of rent of additional surfaces (more than 140 €/(m²·y)) shows an interesting period of amortization of investment .

On the contrary, in social housing sector (low level of rent for existing and additional surfaces), it is very difficult to get economic return on the French façade module solution.

8. Conclusions

French module solution which has been developed in France in the frame of RECOLCI project show that performing insulation façade solution (U= 0.22) associated with a double flow centralized ventilation system and proper treatment of the whole building allow to reach a level 50 $kWh_{PE}/(m^2 \cdot y)$ for energy consumption (heating and cooling, ECS, ventilation).

The façade module is a metallic frame integrating windows, insulation and air tightness prefabricated off site and accepting all kind of finishing cladding systems installed on site.

Ventilation ducts can be embedded inside the façade module or installed apart due to availability of existing ducts in many French collective buildings.

The major interest of the façade module is to be self standing and able to support load bearings allowing addition of surfaces (one or two storeys that could be rented or sold) to an existing building to close loggias and balconies.

The modularity of the façade module allows its use in many types of façades of collective buildings (except the historical ones).

It is thus part of the portfolio of solutions to be considered by an owner (private or social sector) when looking at global retrofitting of his building.

9. References

Publications within the IEA ECBCS Annex 50[11]:

[I] Mark Zimmermann: ECBCS Project Summary report "Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings, March 2011

[II] Peter Schwehr, Robert Fischer, Sonja Geier: Retrofit Strategies Design Guide, ISBN 978-3-905594-59-1, March 2011

[III] René L. Kobler, Armin Binz, Gregor Steinke, Karl Höfler, Sonja Geier, Johann Aschauer, Stéphane Cousin, Paul Delouche, François Radelet, Bertrand Ruot, Laurent Reynier, Pierre Gobin, Thierry Duforestel, Gérard Senior, Xavier Boulanger, Pedro Silva, Manuela Almeida: Retrofit Module Design Guide, ISBN 978-3-905594-60-7, March 2011

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[VI] Peter Schwehr, Robert Fischer: Building Typology and Morphology of Swiss Multi-Family Homes 1919 – 1990, January 2010

[VII] Bertrand Ruot: French housing stock built between 1949 and 1974, October 2010

[VIII] Bertrand Ruot: Elements of morphology of collective housing buildings constructed in France between 1949 and 1974, October 2010

[IX] Gerhard Zweifel: Retrofit Simulation Report, March 2011

References related to Retrofit Module Design Guide Part C:

[1] Specification Cahier de charges fonctionnelles et constructives VCF/GBN/5674/09

[2] Reynier L., RECOLCI – Tâche 4.4, Modélisation des performances de la solution RECOLCI sur le bâtiment 53 d'Autun, CSTB, Mars 2010, 35 pages.

[3] Note C04367/0/CA37430 Arcelor-Mittal Liege R&D Evaluation thermique du module de façade

[4] Note WUFI Saint Gobain Isover CRIR

[5] T4.Rapport final evaluation RECOLCI

[6] T15 Recolci: Definition du champ des contraintes et des opportunités Aetic G Senior 27/03/2010

[11] Further information at home pages: www.empa-ren.ch/A50.htm, www.ecbcs.org/annexes/annex50.htm

Part D

Retrofit Module Design Guide

Part D: Prefabricated Metal Panel Retrofit Modules

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Guimarães, March 2011

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Research partners

Funding programmes and project team:

This work has been funded by FEDER Funds through the Operational Programme Competitiveness Factors - COMPETE and by National Funds through FCT – Portuguese Science and Technology Foundation Programme in the frame of the project FCOMP-01-0124-FEDER-007189 - Reabilitação Energética de Edifícios (Thermal Rehabilitation of Buildings).

The company DST S.A. (Domingos da Silva Teixeira, S.A.) in Braga was responsible for the production of the prefabricated rehabilitation module prototypes. However, some of the materials incorporated into the module were provided by some companies who sell building materials. The aluminium composite used in the panel finishing was provided by the company INOR IBERICA, SA and the agglomerated black cork insulation was provided by the Portuguese company SOFALCA, Ltd.

The LFTC (Building Physics and Construction Technology Laboratory) of the Civil Engineering Department of Minho University was responsible for the design and for the thermal characterization of the prefabricated modules and for their optimization in terms of energy performance. Experimental tests of the prototypes were carried out in the test buildings located in the Azurém Campus of the University.

FCT Fundação para a Ciência e a Tecnologia
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1. Introduction

1.1. Goal

Within the scope of IEA ECBCS Annex 50 “Prefab Systems for Low Energy / High Comfort Building Renewal”, a Portuguese Project was set up, funded by FCT – Fundação para a Ciência e Tecnologia (Portuguese Science and Technology Foundation Programme)– entitled “Reabilitação Energética em Edifícios” (Thermal Rehabilitation of Buildings) and with the reference FCOMP-01-0124-FEDER-007189.

The aim of this project is to develop prefabricated retrofit solutions for an efficient rehabilitation regarding energy consumption, solar energy control, thermal comfort, thermal performance and acoustics and lighting behaviour, among others issues.

The developed modules will be applied onto the existent building’s façade. The prefabricated solutions can integrate all the tubes and pipes related to the HVAC, domestic hot water and high quality solar systems, as well as all the necessary domestic cables, allowing their easy assembly.

1.2. Background

The weight of energy consumption in existing buildings in the overall consumption in the building sector is becoming increasingly relevant. This is mainly due to an increasingly better quality of the new buildings envelope, achieved through the widespread use of insulation, the use of more efficient windows and better use of energy conservation techniques, resulting in buildings with significantly less heating and cooling needs, when compared with the existing ones.

According to the Census 2001 [1], there are in Portugal 2 560 911 buildings built before 1990 (year of the publication of the first Portuguese building thermal performance code). These represent 76.6% of the existing buildings [1]. Due to the lack of thermal requirements and thermal concerns at the time of their construction, these buildings appear as highly energy consumers when the purpose is to guarantee minimum comfort conditions.

On the other hand, the degradation state of a vast part of the Portuguese building stock assumes proportions that can be considered alarming. This causes a reduction on the populations quality of life and a deterioration of the built heritage, while collective memory. In the last years, Portugal has invested only 13% of the total budget in the construction sector in rehabilitation of the building stock [2]. In Europe, on average, this investment is of about 40% [3]. In general, the country is not yet sensitive to the buildings rehabilitation necessity or importance, being always the new buildings much more valued.

Therefore, the project FCOMP-01-0124-FEDER-007189 was launched in order to develop solutions that enable effective rehabilitation of existing buildings, increasing the value of retrofit and encouraging this practice.

1.3. Retrofit solutions guidelines

The developed retrofit module aims to:

- Increase multi-family and single-family buildings energy efficiency through the application of insulation materials contributing to the achievement of final energy consumptions lower than 50 kWh/(m²·y).
- Be an integrated solution with the ability of including hot water, ventilation, heating and/or cooling ducts inside the module, allowing not only to hide them but also to assure the ducts insulation;
- Apply materials with high potentiality of reuse/recycle, and incorporate materials with low embodied energy (energy needed for production, transport and application of the material), minimizing the environmental impacts of the modules production;

- Be an effective solution capable of reducing the execution/application time, reducing the inconvenience caused to the occupants and involving lower financial investment, leading to a greater acceptance of this type of solutions by users.
- Comply with the Portuguese building regulations, particularly the thermal performance of buildings regulation [4].

On the other hand there is also the possibility of inserting inlet/return grids for mechanical or natural ventilation.

2. Prefabricated façade module

2.1. General

The system under development is based on traditional discontinuous prefabricated insulating finishing (although with integrated ducts), on optimized levels of insulation and on the use of a mounting system that allows a simple application and withdrawal of the modules, based on two steel U-profiles on each side of the modules, with a system of pins and holes to be fitted into a support structure that is bolted to the existing wall (Figure 1).

The dimensions of each module are of about 1 m x 1 m and its weight is of 12 kg/m². These dimensions were selected in order to ease their transportation and on site application.

The selection of the materials was based on a balance between technical and economical aspects and on the value of the embodied energy. Therefore, the selected materials were the following:

- Agglomerated black cork insulation – selected due to an industrial production without additives, being an 100% recyclable material, with a density of 110 kg/m³, with a thermal conductivity of 0.045 W/(m·K) and also very abundant in Portugal;
- Extruded polystyrene (XPS) – selected due to the technical possibility of moulding or creating cavities to lodge ducts and also due to its competitive price, once it is one of the most applied insulation products in Portugal and also in Europe;
- Aluminium finishing - since it is a 100% recycled product, easy to manipulate with traditional working tools and available in a wide range of colours and textures.

Then, after the study and test of several design alternatives, the final prefabricated module composition (from the outside to the inside) is the following: aluminium composite exterior finishing (6 mm); agglomerated black cork insulation (60 mm); steel U-profiles (1.5 mm); extruded polystyrene insulation (XPS 120 mm) with or without moulded ducts or cavities for ducts and cables; smart vapour retardant.

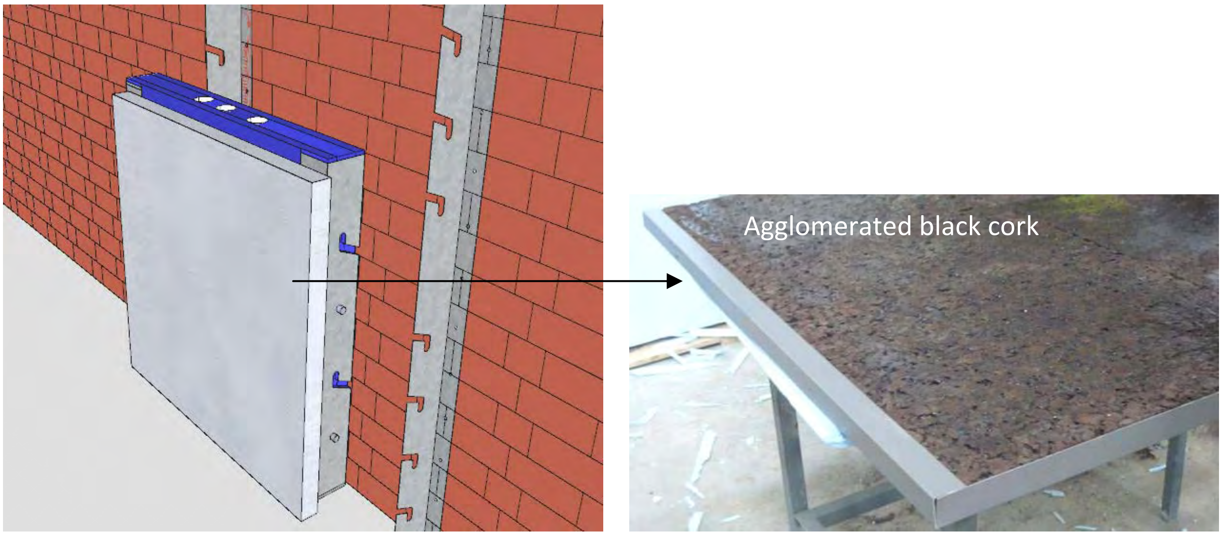


Figure 1: Prefabricated retrofit module

2.2. Views and cross sections

For a more comprehensive overlook of the retrofit module it is presented in Figure 2 the whole module in a 3D view, lateral views and middle section.

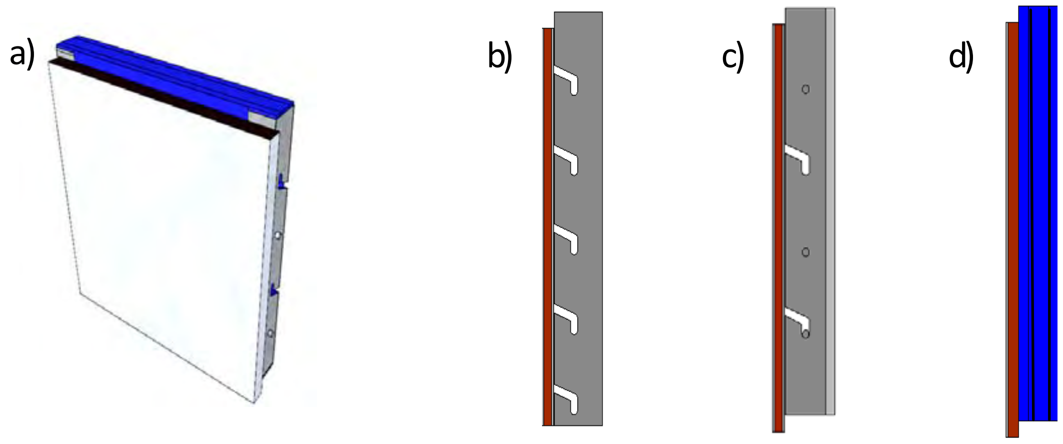


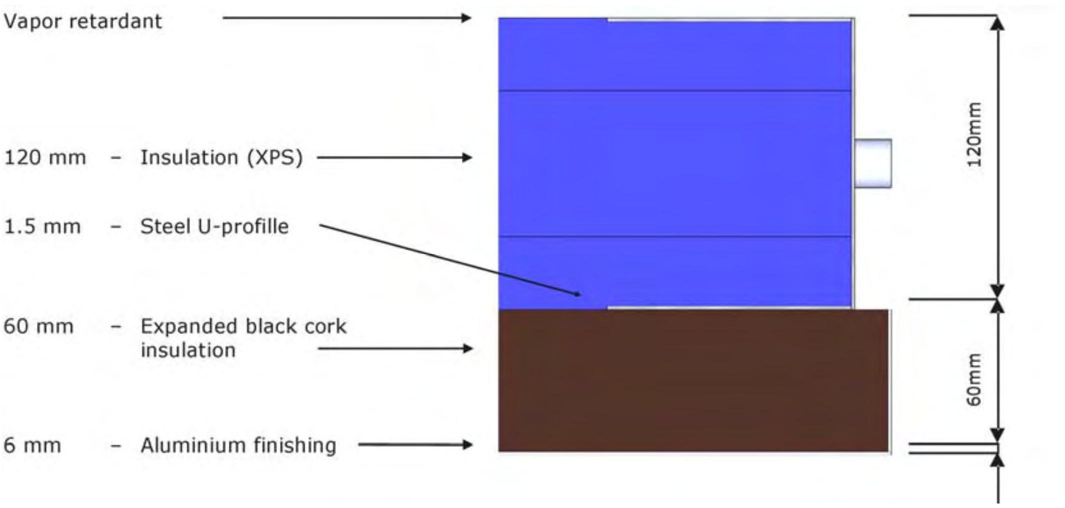
Figure 2: Module 3D view (a); lateral view with support structure (b); lateral view without support structure (c); middle section (d)

2.3. Construction details

The solution will have a total thickness of 18.8 cm and a total weight of, approximately, 12 kg/m². It is expected that with the application of this retrofit system the walls of the outer envelope will increase their thermal resistance by about 4 m²·K/W (taking into account the average value of thermal resistance resulting from the thermal resistance of the standard zone, the thermal resistance of the ducts zone and the thermal resistance of the support structure zone).

Figure 3 shows the module top view and composition.

Prefabricated module (composition):



Module structure (top view):

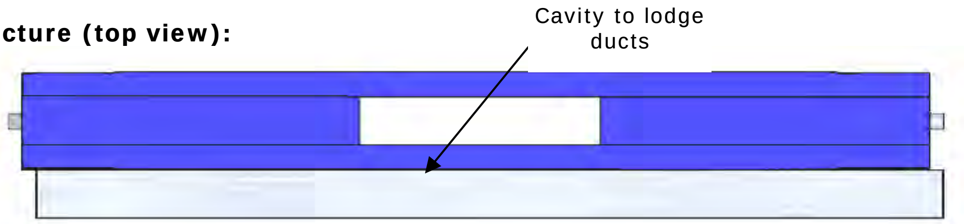


Figure 3: Module top view and module composition

2.4. Connecting technology of the façade elements

This retrofit module was designed to minimize glued and mechanical connections in its assemblage in order to improve the recycling potentialities. Thus, the XPS insulation is only fitted to the steel U-profiles and the aluminium finishing is shaped like a box in order to lodge the cork insulation (Figure 4). However, there is a glued connection between the aluminium finishing and the steel U-profile that can firmly connect these materials and also allow an easy separation of them in case of deconstruction (Figure 4).

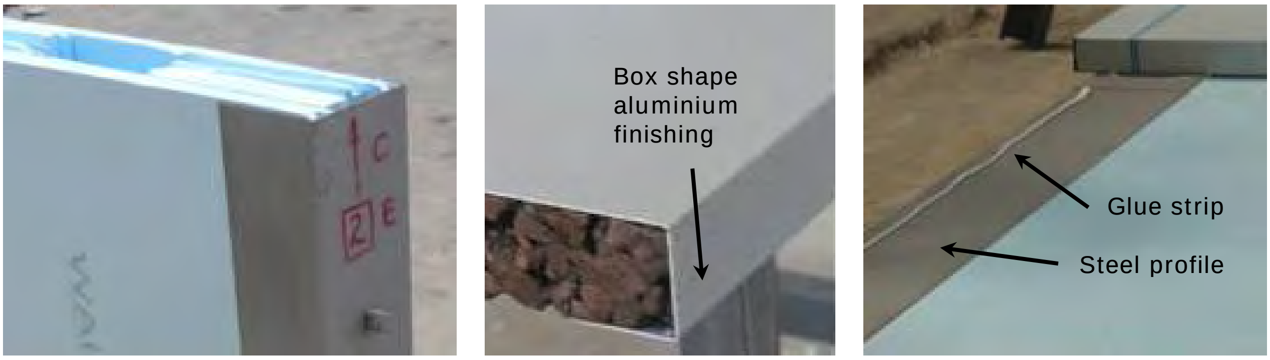


Figure 4: Retrofit Module connections: steel U-profile (left), cork insulation (centre) and aluminium finishing application (right)

With this design, the retrofit module has a high recycling potential, making possible to recycle and reuse the materials individually. This approach leads to a more sustainable solution that is based on the use of low embodied energy materials whenever possible, on the type of connections selected allowing easy deconstruction, on the improvement of the energy efficiency of the buildings and on the recycling ability of the solution in the end of the product life cycle.

2.5. Module types

Four types of modules are available for different needs. Figures 5 and 6 show these four solutions:

- standard module;
- module with a cavity to lodge cables, heating and cooling systems ducts or other installations;
- module with moulded ducts;
- modules to be applied in the buildings corners.

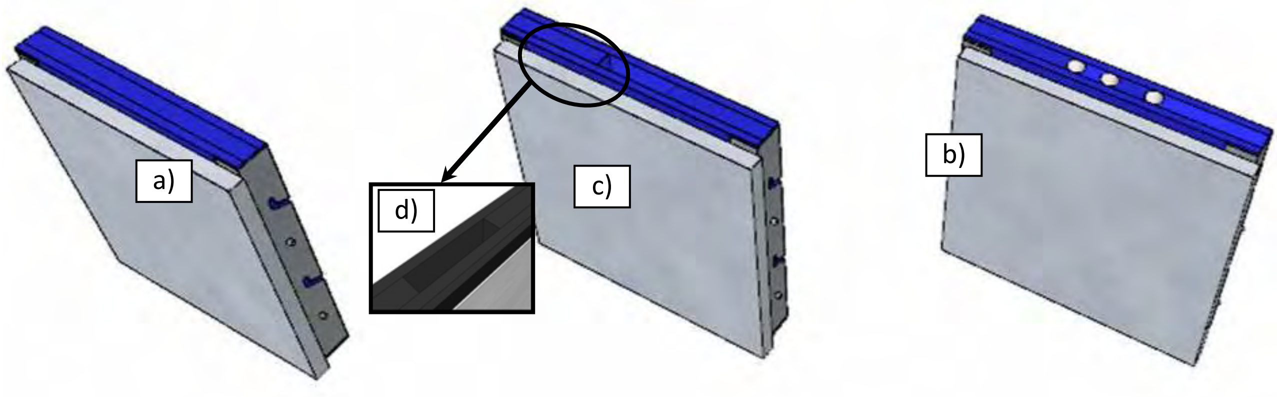


Figure 5: Original design of the prefabricated retrofit module – a) without ducts or cables; b) with moulded ducts; c) with ducts and cables cavities

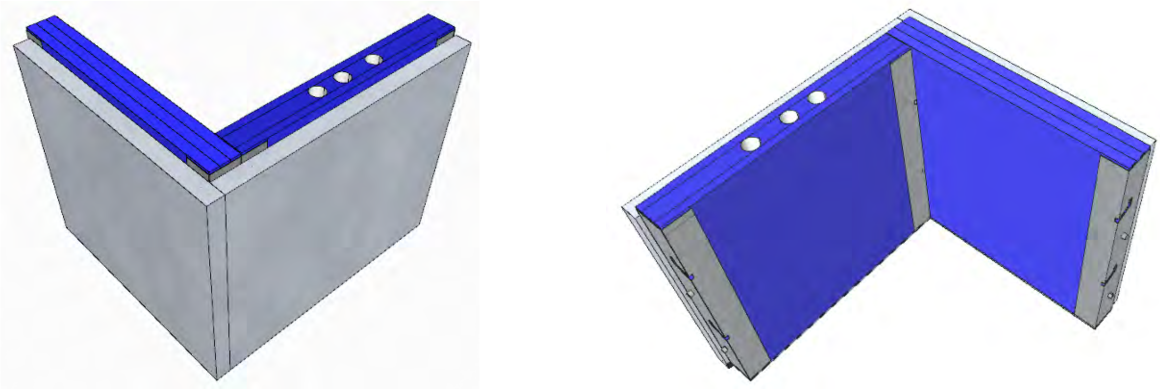


Figure 6: Prefabricated retrofit module – corner modules

2.6. Connections

The connection between the modules is done through a system of pins and holes like shown in Figure 7. This connection system will help the module fitting into the metal support structure and also to connect the modules side by side. The fitting system of the modules, placed on their sides, is a steel U-profile with a thickness of 1.5 mm.

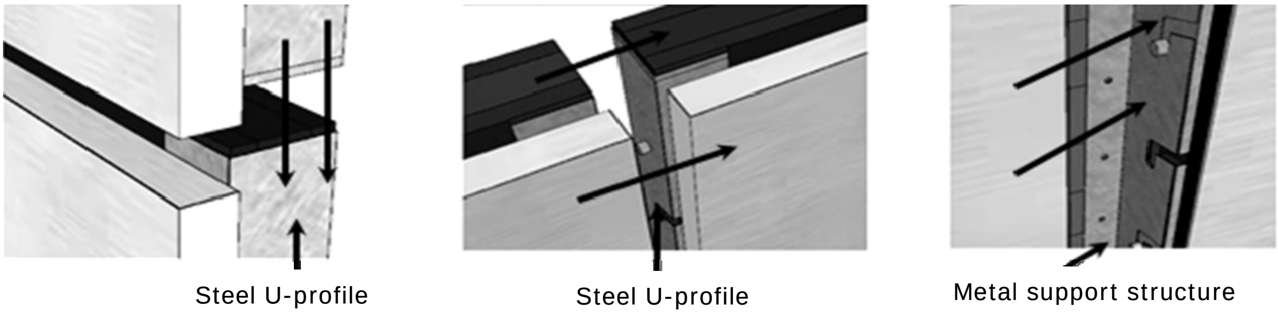


Figure 7: Retrofit module connection system and installation options

The location of the holes and pins differs from the right to the left steel U-profile of the module. This placement allows the pin to be plugged simultaneously into the left slot of the support structure and into the module slot immediately on its right (module already placed), thus ensuring a better distribution of the applied loads.

2.7. Manufacturing of the façade elements

The concept behind the module development is that it should be simple, assure a high quality and with economical viability. Its construction upholds the following steps (Figures 8 and 9):

- Production of the steel U-profiles and support structure;
- Application of the XPS insulation in the steel U-profiles;
- Production of the aluminium finishing with box shape;
- Application of the smart vapour retardant and cork insulation in the aluminium finishing;
- Connection of the aluminium finishing to steel U-profiles.

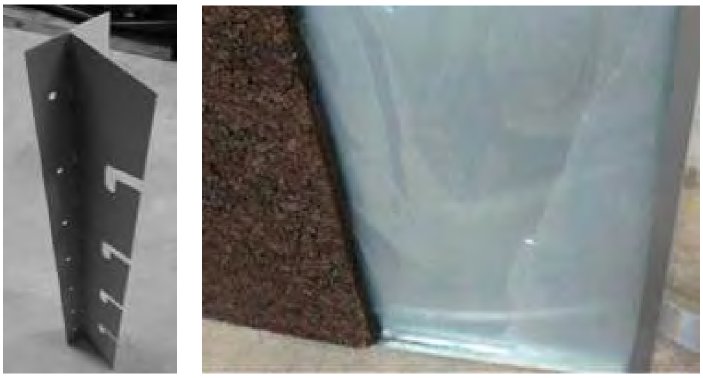


Figure 8: Support structure (left); smart vapour retardant and cork insulation application (right)

Figure 9: Application of the exterior aluminium finishing (left); retrofit module (right)

2.8. Façade module assembly process

The application of the solution to the existing wall is going to uphold two phases as shown in Figure 10:

- 1st phase - install the metallic support structure;
- 2nd phase - fit the module to the support structure using the system of indented pins (module) and gaps (support structure).

Figure 10: Steps needed to apply the retrofit module to the case study building

This mounting procedure allows a faster installation of the retrofit system and an easy replacement and reparation of the modules when needed.

2.9. Module performance

The prefabricated module performance was characterized and tested according to several issues:

- Thermal Bridges;
- Moisture control;
- Thermal transmittance coefficient (U-Value).

2.9.1. Thermal bridges

Important thermal bridges can appear in this type of highly insulated solution, especially in the connection zone. In order to minimize this problem, a mortise, like the one shown in Figure 11, was created. Thus, the connection zone is covered with a 60 mm thick layer of black cork applied in the exterior side.

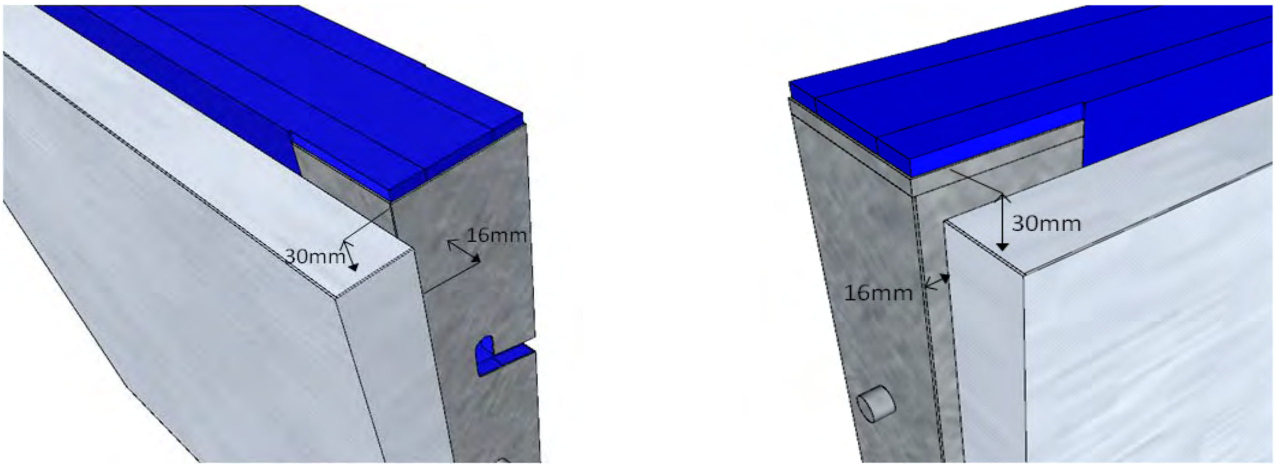


Figure 11: Retrofit module thermal bridges correction

The software THERM – 2D heat transfer model based on the finite element method [5] was used to analyze the thermal bridges in the retrofit module. The most critical sections of the prefabricated module include the connection between the module and the support structure, the steel U-profiles section and the docking area between the modules.

Figure 12 shows the module section (a) and the results obtained with this software tool, regarding the flux magnitude (b), colour infrared diagram of the temperature (c) and isotherm lines (d).

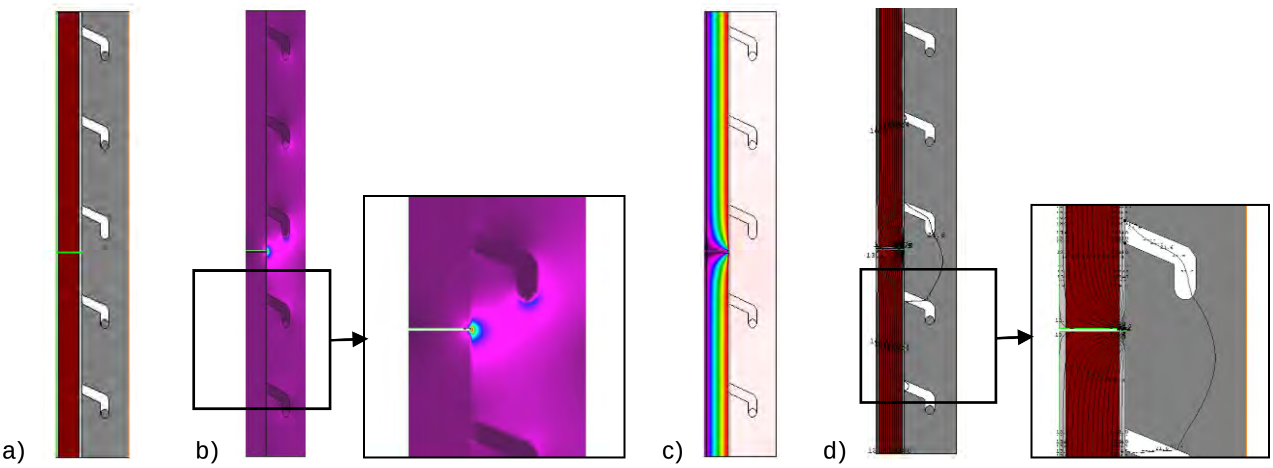


Figure 12: Prefabricated retrofit module docking area section

The colour diagrams show, as expected, that the critical heat flux occurs on the docking area between the modules. However, since the isotherms are parallel towards the end, it indicates that heat transfer is essentially 1D, which is a good performance indicator. It is also possible to observe that the only point where a slightly higher flux magnitude occurs is in the exterior part of the docking area between modules. The calculated U-Value of this section is 0.7 W/(m²·K).

This analysis was carried out for other sections of the module and the following values were obtained:

- middle section (see Figure 13a) – simulated U-Value = 0.21 W/(m²·K)
- cavity section (see Figure 13b) – simulated U-Value = 0.33 W/(m²·K)

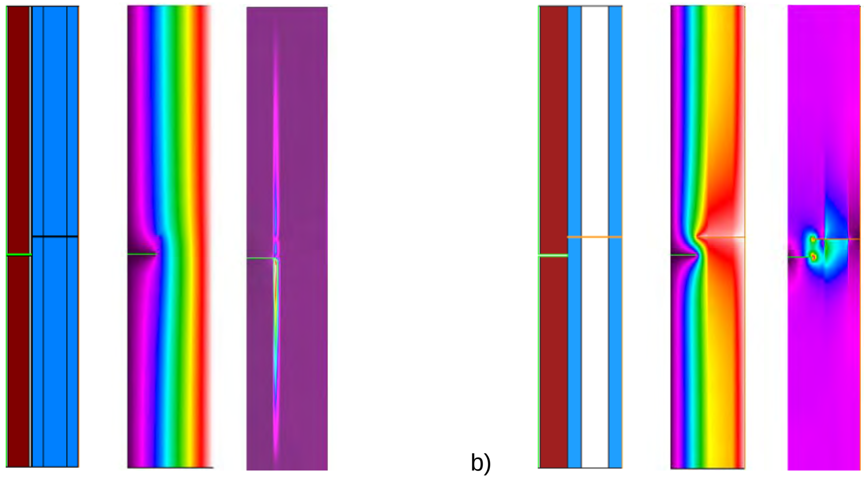


Figure 13: Prefabricated retrofit module standard (a) and cavity (b) sections

Applying the corrective solution shown in Figure 11, and according to predictions obtained with the TERM tool, it is possible to get an 80% reduction in heat flux that occurs in the docking area, thus drastically reducing the thermal bridge in this zone.

2.9.2. Moisture control

To analyse moisture problems in the module, it was used the program WUFI®, acronym for "Wärme- und Feuchtetransport instationär" ("Transient Heat and Moisture Transport"). WUFI® is designed to calculate the simultaneous heat and moisture transfer in a building component [6].

The critical zones for moisture occur between the different material connections and between the module and the existing wall (see Figure 14).

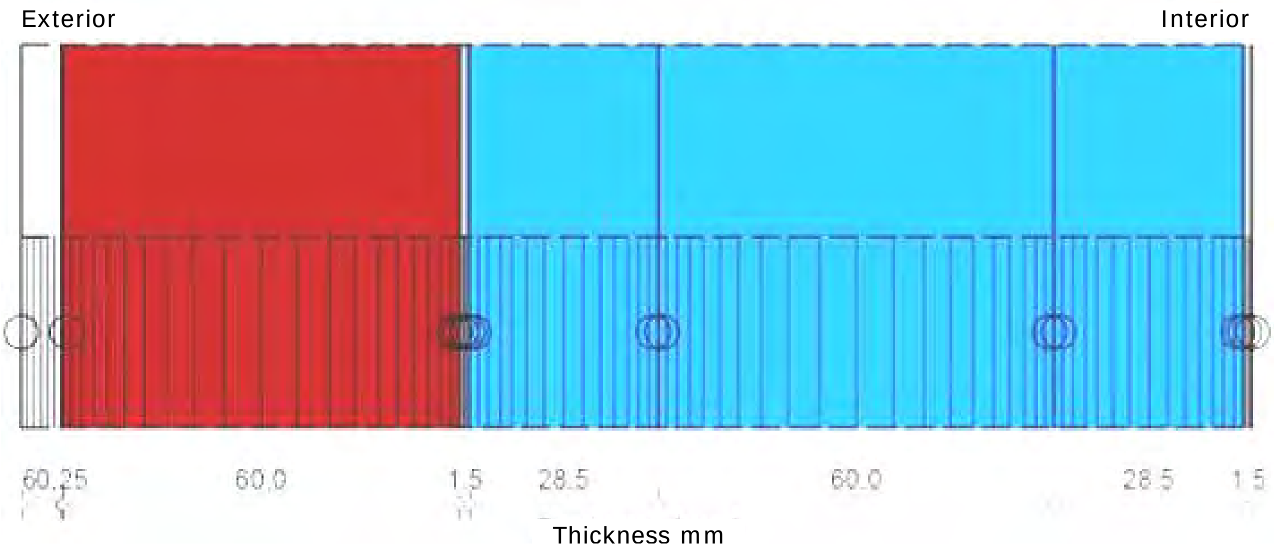


Figure 14: Prefabricated retrofit module - Transversal section

The simulated relative humidity range (20%-90%), combined with the observed temperatures, showed no risk of moisture build-up. In Figure 15 it is presented a whole year simulation results of the temperature inside the module (in red), the relative humidity (in green) and the moisture content (in blue). Therefore, no moisture content was observed inside the prefabricated module.

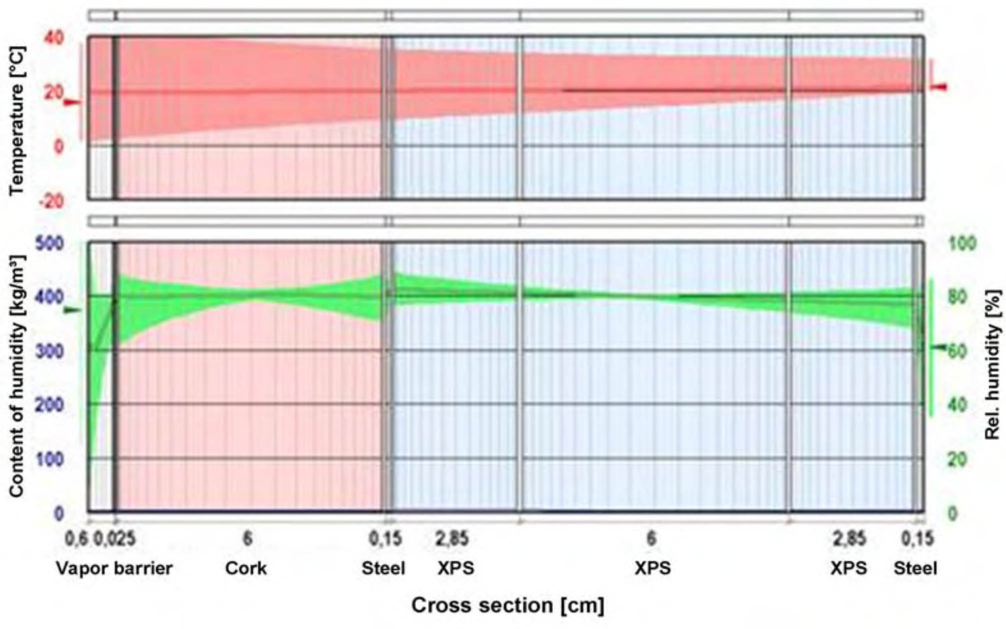


Figure 15: Prefabricated retrofit module - moisture transfer calculation

The amount of vapour passing through the wall can be controlled with the addition of a vapour retarder between the interior finishing and the existing wall, minimizing the chances for interstitial condensation if more extreme climatic conditions occur.

2.9.3. Thermal transmittance coefficient (U-value)

In order to determine the retrofit modules thermal performance, it was necessary to test them in a controlled environment. In this sense, several modules were applied onto a wall separating two controlled rooms in a controlled test building facility and instrumented with several flux meters and thermocouples connected to a monitoring system (see Figure 16).

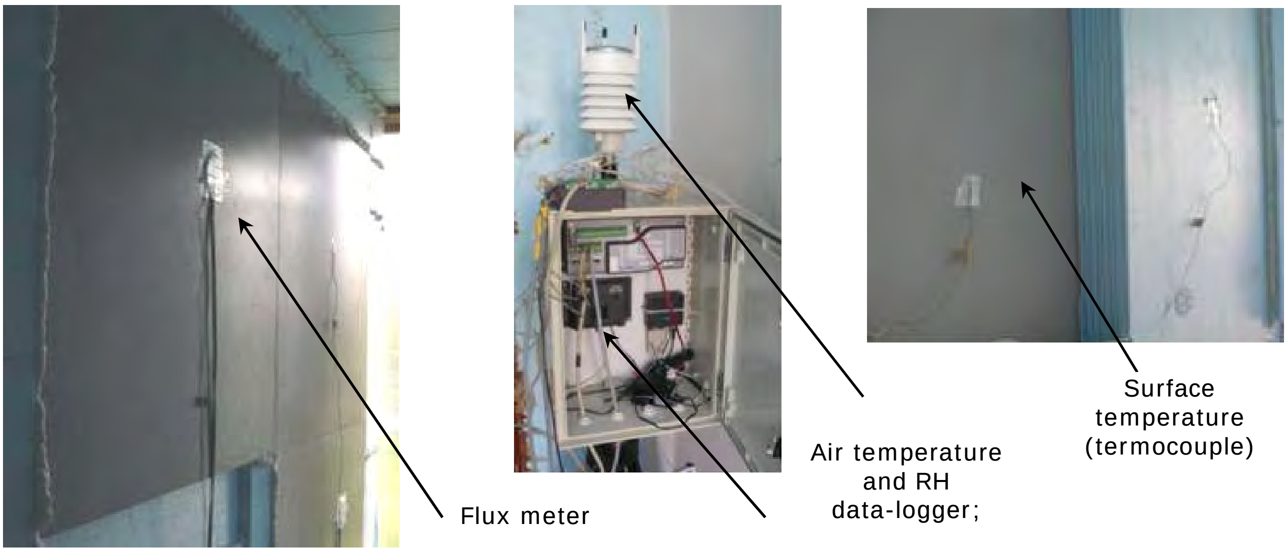


Figure 16: Prototypes with measurement system

The obtained results within the measurement campaign, presented in Figure 17, show that the application of the module to the existing wall reduced significantly the heat flux between the two compartments.

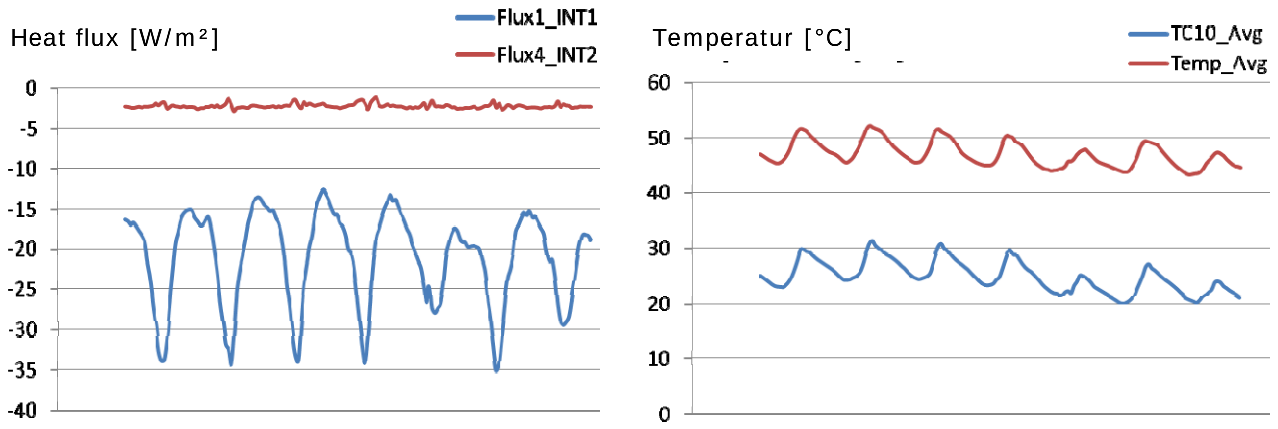


Figure 17: Heat flux in the partition wall without the module (Flux1_INT1) and heat flux in the partition wall with the retrofit module (Flux4_INT2) and air temperature in room 1 (TC10_Avg) and air temperature in room 2 (Temp_Avg).

The infrared images of the module when applied to the partition wall (Figure 18) show a significant surface temperature difference between the retrofit module and the partition wall. There is also an indication that a small thermal bridge is present in the connection between modules, as predicted by the software THERM.

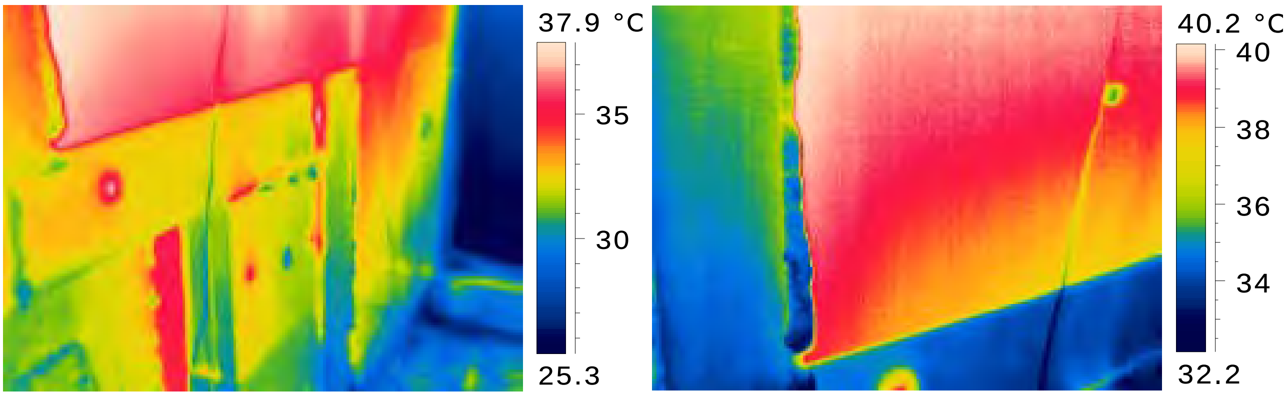


Figure 18: Retrofit modules infrared image.

One of the conclusions of the measurement campaign was that the U-Value in the retrofit module standard zone is 0.19 W/(m²·K). The U-Value in the ducts cavity zone is 0.30 W/(m²·K), which results in an overall retrofit module U-Value of 0.23 W/(m²·K).

3. Module application

To evaluate the energy performance of the retrofit modules integrated in a real building, it was modelled a single-family house from the 80's, located in Braga (north of Portugal) with an area of 55 m², a steel reinforced concrete pillars and beams structure and single pane CMU (Concrete Masonry Unit) exterior walls. The building retrofit was simulated with the dynamic simulation tool eQuest® [7] and modelled with Google SketchUp® (see Figure 19 [8].

Figure 19: Case study with retrofit needs: a) photograph; b) exterior 3D model; c) interior 3D model; d) 3D model cross-section

The overall retrofit strategy of the building consisted not only on the module application onto the external walls, but also on the general improvement of the building envelope, i.e., roof slab insulation (application of 12 cm of XPS), ground slab insulation (application of 8 cm of XPS) and replacement of the existent single glazing and aluminium frame windows (Uwdn = 4.1 W/(m^2·K)) by double glazing and aluminium frame with thermal break windows (Uwdn = 2.5 W/(m^2·K)).

The original building presented a U-value for the exterior walls of 1.9 W/(m^2·K). With the application of the prefabricated retrofit modules it was possible to significantly reduce this U-Value to 0.2 W/(m^2·K) (overall value, including thermal bridges) strongly contributing to a better energy performance of the building. The results obtained with the test building thermal simulations showed a significant reduction of its energy needs as presented in Table 1.

Energy needs kWh / (m^2·y)	**Single family building in Braga**	
	Original situation	With retrofit module
Heating	334.1	18.7
Cooling	0.3	5.3
Domestic hot water	19.4	19.4
Total	353.8	43.4

Table 1: Simulated final energy needs for the case study

The use of the retrofit modules reduced significantly the U-value of the exterior walls and this allowed the reduction of the building energy needs in 69%. With the application of the remaining measures the reduction of the energy needs was of about 89%, helping to achieve the 50 kWh/(m^2·y) goal defined in the project.

It is also possible to observe a slight increase in the cooling needs, since the higher insulation level of the building requires a longer time for the building to cool. This problem is aggravated when many consecutive hot days occurs. However, the cooling needs are not significant when compared with the total needs.

4. Conclusions

The Portuguese retrofit module solution, developed within the frame of the Project - FCOMP-01-0124-FEDER-007189, has a measured overall thermal resistance of 4.35 $m^2 \cdot K/W$ and a U-Value of 0.23 $W/(m^2 \cdot K)$. It presents a small thermal bridge in the docking area section, between modules, and no significant thermal bridges occur in any other sections. The module shows no risk of moisture build-up.

A major advantage of this module is the type of connection to the existing wall that can greatly reduce the installation time. Another advantage is the simplicity of the fabrication method that can guarantee the solution quality.

Just as an example, the application of this solution to a test building resulted in the reduction of the thermal transmission coefficient of the exterior opaque envelope from 1.9 to 0.2 $W/(m^2 \cdot K)$ contributing to a reduction of 69% of the total building needs.

Therefore, this is a solution with good performance indicators, showing a great potential to be used in high quality low energy building retrofit, having in mind that this solution has been developed and optimized for the Portuguese reality.

However, this solution can also be a valid option for other countries' realities using different materials but maintaining the same concept. Table 2 shows some alternative solutions with equivalent thermal performance.

Thickness (mm)	Original retrofit module materials	Alternative retrofit module materials		
6	Aluminium composite finishing	Aluminium composite finishing	Aluminium composite finishing	Aluminium composite finishing
60	Agglomerated black cork insulation	Rock wool insulation	Glass wool insulation	Rock wool insulation
1.5	Steel U-profile	Steel U-profile	Steel U-profile	Steel U-profile
120	Extruded polystyrene insulation	Rock wool insulation	Polyurethane panel insulation	Expanded polystyrene insulation
1	Vapour retardant	Vapour retardant	Vapour retardant	Vapour retardant
U-Value W / ($m^2 \cdot K$)	**0.23**	**0.23**	**0.24**	**0.24**

Table 2: Alternative solutions in terms of materials for the retrofit module

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Research Partners:

AEE - Institute for Sustainable Technologies (AEE-INTEC), Austria

Enviros s.r.o., Czech Republic
Brno University of Technology, Institute of Building Services, Czech Republic

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Lucerne University of Applied Sciences and Arts, Technology and Architecture, Switzerland
University of Applied Sciences Northwestern Switzerland, School of Architecture,
Civil Engineering and Geomatics, Switzerland
Swiss Federal Laboratories for Materials Science and Technology Empa,
Building Science and Technology Laboratory, Switzerland

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