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Energy and thermal improvements for construction in steel

(ETHICS)

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Energy and thermal improvements for construction in steel

(ETHICS)

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FINAL SUMMARY

Introduction

ETHICS is concerned with evaluating, measuring and improving the thermal and energy performance of steel-clad and steel framed buildings. It addresses important building physics and performance issues using laboratory test methods, numerical calculations and by measuring the 'as built' performance of real buildings. Finally, design guidance for commercial, industrial and residential buildings is prepared and a design tool to assist in assessing and optimising whole building performance is established. This tool is checked with whole building measurements and results from standardized calculation tools.

Buildings account for 40% of the EU's energy consumption and offer the largest single opportunity for reducing energy needs. The EU Directive Energy Performance of Buildings (EPBD), which Member States are required to incorporate into national legislation, will ensure that building standards across Europe place a high emphasis on minimising energy consumption. In response to current needs and in anticipation of future legislation there are therefore important market opportunities for the development of new products and systems using steel that will maintain and enhance the position of steel in construction.

This present report provides guidance for the optimum design of steel structures and envelope systems. There is a general lack of data in this area, in particular regarding air-tightness, that is treated within this project. The performance of energy efficient steel buildings and steel products in practice is shown.

Keywords

During the preparation of this project relevant aspects were identified, they are listed below. They predefine the structure of the ETHICS project:

- Air-tightness of buildings,
- Thermal performance of building envelopes (on site measurements and improvements),
- Investigation of innovative techniques for improving thermal comfort,
- Measured robust data on whole building performance,
- Design 'tools' for overall energy assessments (heating, cooling and lighting) focussing on pre-design tools for use early in the design phase,
- Design Guidance for energy and thermal improvements for whole buildings (residential and non-residential).

Tasks and results

The project starts with the investigation of two important aspects of energy efficient building design that have special importance to steel construction: air-tightness (WP1) and the thermal performance of the envelope (WP2).

Air-tightness is an important attribute for improved energy efficiency of building envelopes. Uncontrolled ventilation losses should be minimised and the benefits of a mechanical ventilation systems are greater if buildings are air-tight. Additionally moisture problems can occur if warm wet air can infiltrate into façades.

Various solutions for building envelopes in steel consist of plane prefabricated elements (e.g. roof and wall sandwich panels, cassette profiles, curtain walling) and their joints. They were be tested in laboratory according to EN 12114 (determination of air-leakage 'a-value' [$m^3/(h \cdot m \cdot daPa^{2/3})$]) to verify requirements on a European level. This is the first comprehensive research project at a European level with this objective and involves smog and infrared surveys.

The results show that no general statement regarding the air tightness of sandwich element joints is possible. The joint tightness depends on the particular joint geometry and joint width realized during the installation. At each joint there is a joint width, where the joint meets the requirements of the joint tightness. In particular, the location, size and compression of a sealing strip within the joint lead to strongly different behaviour of joints with regard to the air-tightness. Only the variation of a joint can be compared and valued. Partly, quite small variations of the joints lead to unwanted high air-leakage rates that do not fulfil the requirements.

If the tested elements are installed with the minimum possible gap width, all the longitudinal joints are to be called airtight. In practice, after installation of up to 15 m long elements much larger fluctuations in the element and joint width occur. The variations in joint width can be based on the minimal realizable joint width up to 10 mm. Here is demand for the future, to design more fault-tolerant solutions.

The results concerning liner-tray facades ("cassette walls") are different: The tested joints were very air-tight, significantly better than the requirements.

Beneath testing of single joints the air-tightness performance of whole buildings was investigated using the blower door method. These tests indicate irregular leakages (for instance joints or penetrations that are not sealed carefully). The n_{50}-value is important for the determination of the whole energy performance of a building. The results spread in wide range and typical relevant leakages were identified.

In WP 2 investigations concerning heat transmission were performed, also on an element or product level (numerical and tests in laboratory) any by on-site measurements using infra-red cameras. Linear thermal bridges were quantified for typical solutions in steel construction and simplified calculation method for various steel sandwich panels is presented.

Numerous buildings were investigated with infrared surveys. This broad study improves the understanding of heat losses in real buildings. This study highlights the difficulties of coordination between different contractors, one being responsible for the cladding system, one for the air tightness and one for insulation. This results in a situation whereby no individual party is responsible for the global air tightness and thermal performance of the system. During the course of the thermal imaging survey, it was apparent that uniformity and replication of cladding interfaces across the façade was difficult to maintain during the construction phase.

In parallel with the work done in WP 3, indoor conditions are considered. Differences in local climates influence both their energy demand and comfort qualities.

A comprehensive study gives recommendations, how transparent and lightweight steel and glass architecture could be optimized to reach low energy demand and which is capable of high standards of thermal comfort, that can be designed all over Europe with adaptation to the regional climate. The following issues were addressed with a view in particular to control summertime overheating:

- Optimisation of thermal inertia and ventilation strategies,

- Compilation and design of new strategies based on the combination of massive components (high thermal inertia) with air exchange in the buildings (night-day cycles, circulation ways, etc.),

- Use of innovative materials (PCM – phase change material) to improve thermal inertia with minimal additional mass offer an interesting solution for light-weight steel constructions),

- Multifunctional floor systems as heat exchanger and/or heat storage,

- Improving of façade systems (high efficient solar shading in steel, integration of natural or mechanical ventilation).

These technical solutions that are investigated within WP 3, were varied for different European climates.

WP 4 provides real data on the whole energy performance of steel buildings. A number of state-of-the-art projects were identified and monitored. These monitoring programmes are complex and costly, but indispensable to demonstrate that steel construction can be competitive in terms of both energy thrift and comfort standards.

For selected buildings the energy consumption was assessed in conjunction with thermal comfort (low energy design that leads to poor comfort is clearly unacceptable).

Finally, a valid set of monitored buildings can be presented, nevertheless remarkable problems have to be solved within this field. On one hand, the willingness of the building owners varied during the runtime of the project, whether they accept that the results were published or not. On the other hand, technical failures occurred during the monitored period, thus gathering data for a whole year took more time than expected.

WP 5 addresses standardized methods used to calculate energy performance. The Energy Performance of Buildings Directive (EPBD) required all European countries to implement the new regulations and calculation methods. A review of these regulations is given.

The results of the monitoring (WP 4) were used to verify the results of the calculations according to the standardized methods with regard to local climate and specific use of the buildings.

The required calculations of the energy demand are complex and difficult to apply during the early stages of design when important decisions are made regarding materials and products. In response to this a design tool was developed to support the initial design phase of steel intensive buildings to generate approximated results with significant reduction of work. This tool ECALTO was cross-checked with some calculations based on the (local) standardized calculation methods.

The energy performance and suitability of design approaches vary considerably depending on building type. Hence WP 6 and 7 focus on the two main building categories:

- Residential Buildings (WP 6)

- Non-Residential Buildings (WP 7)

Analysis of these different building types considering the knowledge assembled in the earlier workpackages leads to recommendations concerning energy saving measures.

A further important part of these work packages is the preparation of energy certificates for selected buildings. These certificates give prospective owners or tenants better information regarding the expected running costs of buildings or apartments. With buyers and prospective tenants better informed, builders and developers have greater incentive to incorporate energy-efficient technologies and designs into their buildings.

SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

Objectives of the project

The overall objective of this project is to investigate energy performance of a range of steel buildings and propose solutions for improvement. As part of the study, there will be an investigation leading to potential improvement in selected aspects of particular interest to steel construction, including air-tightness, thermal bridges, and thermal inertia. In addition, there will be a long-term-monitoring of buildings that will ensure a clear and comparable set of data on the energy performance and development of energy saving strategies depending on type of building and its use.

The energy performance of state-of-the-art steel construction will be studied in detail by monitoring energy data and carrying out additional investigations using sophisticated technologies, including infrared survey and analysis, and blower-door-test. All this is expected to help develop detailed understanding of steel buildings used for different purposes, and of their performance within various European climates. The generated data, which does not currently exist for steel-intensive buildings, will be a useful tool in the current initiative for reducing CO_2 emission. Design guidance will be presented to assist in future steel projects requiring high levels of thermal efficiency.

Therefore the project was divided into seven work packages:

WP 1: Air-tightness of buildings

WP 2: Thermal performance of building envelopes in steel

WP 3: Innovative techniques for improved thermal comfort

WP 4: Real building performance data

WP 5: Design ‘tools’ for whole building assessments

WP 6: Design guidance on energy and thermal improvements for residential buildings

WP 7: Design guidance on energy and thermal improvements for non-residential buildings

Comparison of initially planned activities and work accomplished

To reach the objectives stated above, a work plan as given by the programme bar chart (see Table 1) was developed and implemented by the due dates.

The project started with the investigation of two important aspects of energy efficient building design that have special importance to steel construction: air-tightness (WP 1) and the thermal performance of the envelope (WP 2). Various solutions for building envelopes in steel consist of plane prefabricated elements (e.g. roof and wall sandwich panels, cassette profiles, curtain walling) and their joints. They have been tested in laboratory according to EN 12114 (determination of air-leakage 'a-value' [$m^3/(h \cdot m \cdot daPa^{2/3})$]) to verify requirements on a European level. Wide ranging testing has been carried out to develop an appropriate body of knowledge of 'as built' performance that will benchmark existing design approaches and inform future design recommendations.

To ensure and enlarge the use of steel products for façade and roof systems, these constructions have been investigated using laboratory techniques and in-situ measurement of selected buildings throughout Europe. This means use of infrared and other techniques to assess the thermal bridging and to determine the effectiveness of possible improvement strategies. Further laboratory tests and numerical FEM simulations have been used to compare the 'as built' performance of steel cladding systems with calculated U-values.

Compared to the planned activities measurements using heat flux plates have not been carried out due to technical reasons whereas the number of FEM simulations has been increased.

In WP3 it has been demonstrated that transparent and lightweight steel and glass architecture that has low energy demands and which is capable of high standards of thermal comfort can be designed all over Europe. The following issues will be addressed with a view in particular to control summertime overheating:

- Optimisation of thermal inertia and ventilation strategies,
- Compilation and design of new strategies based on the combination of massive components with air exchange in the
- Use of innovative materials (PCM – phase change material) to improve thermal inertia with minimal additional mass offer an interesting solution for light-weight steel constructions),
- Improving of façade systems

Providing clear and comparable information the real whole energy performance of buildings was investigated in WP 4. A number of state-of-the-art projects, where steel buildings are expected to perform well have been identified. Studies of these buildings were carried out as follows:

- Collecting and analysing data on whole building energy use (8 plus 6 level 2 that include level 1)
- Monitoring of energy performance and thermal comfort parameters, at which the following are mandatory: space heating/cooling demand, DHW energy demand, overall electricity, outdoor conditions (external temperature, solar radiation, etc.), internal conditions of selected rooms (temperature, humidity, etc.), at least one year (6 instead of 5 buildings in Finland, Germany, UK, Belgium, Spain),
- Advanced monitoring for one building (CRM4, Belgium) for a monitoring period of two years

WP 5 addressed standardized methods used to calculate energy performance. A review of the national and international regulations was necessary to show specific and beneficial effects for steel construction. The required calculations of the energy demand are complex and difficult to apply during the early stages of design when important decisions are made regarding materials and products. In response to this a design tool (ECALTO) has been be developed to support the initial design phase of steel intensive buildings to generate approximated results with significant reduction of work. The results of the monitoring (WP 4) were used to verify the results of the calculations with ECALTO.

The energy performance and suitability of design approaches vary considerably depending on building type. Hence WPs 6 and 7 focused on the two main building categories:

- Residential Buildings (WP 6)
- Non-Residential Buildings (WP 7)

Recommendations for architects and building owners for energy efficient solutions in steel have been assembled in the form of guidelines.

In conclusion it can be said that all tasks addressed by the proposal have been finished.

Table 1: Programme bar chart ETHICS

WPs	1st year				2nd year				3rd year			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
WP1.1												
WP1.2												
WP1.3												
WP1.4												
WP1.5												
WP1.6												
WP2.1												
WP2.2												
WP2.3												
WP2.4												
WP2.5												
WP3.1												
WP3.2												
WP3.3												
WP3.4												
WP4.1												
WP4.2												
WP4.3												
WP4.4												
WP4.5												

WPs	1st year				2nd year				3rd year			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
WP5.1												
WP5.2												
WP5.3												
WP5.4												
WP6.1												
WP6.2												
WP6.3												
WP6.4												
WP7.1												
WP7.2												
WP7.3												
WP7.4												
WP7.5												
WP7.6												

Description of activities and discussions

1 Air-tightness of buildings

1.1 Introduction

This work package is concerned with the air-tightness testing of building envelopes on-site to determine as-built air-tightness performance values along with air-tightness testing within controlled laboratory conditions to determine the air permeability of junctions and interfaces.

As work package leader Corus/Tata has adopted an approach to identify the pertinent issues concerning building envelope air-tightness. This approach is reliant on identifying issues relating to buildability, whilst considering aggravating factors such as installation methods, ownership of the air tightness barrier/layer and cladding component design and manufacturability.

The causes of high envelope permeability are well documented in numerous technical literatures produced by pan-European partners. Most of which, uphold that lap and end joints are critical when assuring air tightness of built up steel cladding systems. Whilst also highlighting the importance of ensuring adequate seal compression of composite panel cladding systems. Interfaces between dissimilar construction systems and components universally results in increased air leakage rates.

As a manufacturer of both composite and built-up cladding systems, Corus/Tata provides technical literature to the wider steel construction industry to promote air tight construction and reduce heat loss through unwanted air infil- or exfiltration. However, evaluation of envelope performance is not routinely assessed or documented and therefore, the feedback route to determining improvement opportunities is seldom available.

1.2 National and European regulations and requirements regarding air-tightness

The basic methodology for measuring the air-tightness of a whole building is to either pressurise or de-pressurise the entire building with respect to the ambient air pressure. Air egress or ingress can then be measured giving an indication of the permeability of the building fabric.

There are three common ways of expressing this air-tightness:

<u>Air changes per hour</u>

This is generally given by:

$$n_{50} = \frac{Q_{50}}{V} \ [1/\mathrm{h}]$$

Where: Q_{50} is the volume of air pumped to keep the building pressurized or depressurized to 50 Pa $[\mathrm{m}^3/\mathrm{h}]$

V is the conditioned volume of the building

<u>Air Permeability Index</u>

$$\mathrm{API} = \frac{Q_{50}}{S_T} \ [\mathrm{m}^3\mathrm{h}^{-1}\mathrm{m}^{-2}]$$

Where $S_T =$ The total external envelope area *including* the floor $[\mathrm{m}^2]$

Air Leakage Index

$$\text{ALI} = \frac{Q_{50}}{S}\ [\text{m}^3\text{h}^{-1}\text{m}^{-2}]$$

Where $S =$ The total external envelope area *excluding* the floor [m^2]

Comparison of requirements across Europe

Table 2: Comparison of air-tightness requirements across Europe

Country	Max Air Permeability		Pressure difference (Pa)	Comments
UK	10	$m^3h^{-1}m^{-2}$	50	area includes ground floor
Finland	4	ac/h	50	this is the default value
Norway	3	ac/h	50	less than 2 storeys
	1.5	ac/h	50	over 2 storeys
	4	ac/h	50	domestic
France	1.2 (1.7)	$m^3h^{-1}m^{-2}$	4	ALI: offices/apartments. ref. val., default in brackets
	2.5 (3.0)	$m^3h^{-1}m^{-2}$	4	ALI: industrial. ref. val., default in brackets
	0.8 (1.3)	$m^3h^{-1}m^{-2}$	4	ALI: single houses. ref. val., default in brackets
Belgium	3	ac/h	50	housing with mechanical ventilation
Germany	1.5	ac/h	50	mechanical ventilation
	3	ac/h	50	natural ventilation
	0.6	ac/h	50	passivhaus standard
Italy	10	$m^3h^{-1}m^{-2}$	98	schools
Netherlands	0.2	m^3s^{-1}	10	$\leq 500m^3$
	(Building Vol/500)*0.2	m^3s^{-1}	10	$>500m^3$
Sweden	2.88	$m^3h^{-1}m^{-2}$	50	housing. area includes ground floor (quoted as 0.8 l/s/m^2)
	5.76	$m^3h^{-1}m^{-2}$	50	industrial. area includes ground floor (quoted as 1.6 l/s/m^2)
Switzerland	0.75	$m^3h^{-1}m^{-2}$	4	
Spain	27	$m^3h^{-1}m^{-2}$	100	windows and external doors, northerly, coolers areas
	50	$m^3h^{-1}m^{-2}$	100	windows and external doors, southerly, warmer areas

As it can be seen different countries use different metrics when defining levels of airtightness, n_{50}, API and ALI, which makes a comparison difficult, particularly since some countries also quote their requirements at different pressures for example France at 4 Pa compared with the majority at 50 Pa.

Although the above table gives the air-tightness requirements for different countries, not only the units are different but also the status of the requirement varies. Below are some comments explaining the requirements.

UK – The target API value for buildings in the UK is 10 $m^3h^{-1}m^{-2}$ (50 Pa). All new buildings over 500 m^2 floor area must be tested and the actual value used in energy calculations. For buildings that are not tested a default value of 15 $m^3h^{-1}m^{-2}$ must be used.

France – For buildings that have not been tested and are not built to any particular standard, the default ALI used for energy calculations is 3, 1.7 or 1.3 $m^3h^{-1}m^{-2}$ (4 Pa). Where good practice has been employed for building values of 2.5, 1.2 or 0.8 can be used. If testing has been completed the actual value should be used.

Finland – The default value for energy calculation is 4 ac/h (50 Pa) but the value for the reference building is 2ac/h. Although there is no national requirement for testing local authorities are likely to test any building claiming a better value than 4 ac/h.

Spain – There is currently no requirement for air-tightness of whole buildings.

The only airtightness requirement for Spain could be found in "Documento Básico HE – Ahorro de energía, April 2009" on page HE1-9. In chapter 2.3 "air permeability" it says:

The air permeability of windows and external doors, measured at an overpressure of 100 Pa, should be lower than 50 $m^3h^{-1}m^{-2}$ for northern areas and 27 $m^3h^{-1}m^{-2}$ for southern areas.

2.3 Permeabilidad al aire

1 Las carpinterías de los huecos (ventanas y puertas) y lucernarios de los *cerramientos* se caracterizan por su permeabilidad al aire.

2 La permeabilidad de las carpinterías de los huecos y lucernarios de los *cerramientos* que limitan los *espacios habitables* de los edificios con el ambiente exterior se limita en función del clima de la localidad en la que se ubican, según la zonificación climática establecida en el apartado 3.1.1.

3 La permeabilidad al aire de las carpinterías, medida con una sobrepresión de 100 Pa, tendrá unos valores inferiores a los siguientes:

a) para las zonas climáticas A y B: 50 $m^3/h\ m^2$;

b) para las zonas climáticas C, D y E: 27 $m^3/h\ m^2$.

Germany – Some countries have different requirement depending on whether they are naturally or mechanically ventilated. Germany is a good example of this with targets of 3 ac/h (50 Pa) for natural and 1.5 ac/h (50 Pa) for mechanical ventilation.

This paragraph gives information about the basic methodology and a short comparison of air-tightness requirements across Europe. The full report concerning the European regulations and requirements regarding air-tightness is given in **Deliverable WP 1a**. – "Report on national and European regulations and requirements regarding air-tightness".

1.3 Parameters that affect air-tightness

<u>Details Residential buildings</u>

The aim of this work is to collect, following successive campaigns of auscultation, any defects that permit air losses and thus affect air tightness. This affects the energy balance of the building in terms of thermal losses.

Air crossing the envelope layer is mainly due to imperfect construction details as:

- Porosity of the materials,
- Joints and interfaces,
- un-correct cladding joints,
- Connection and fixing systems,
- Envelope penetration, structural penetration and function penetration as vents, chimneys,
- Windows, doors frames,
- Shutter cage,
- Uncorrected setting of insulation material as mineral wool material, rolls, semi rigid panels, sandwich panels, etc,
- Deterioration of building fabric,
- Air infiltration through the building material (mainly for masonry wall systems),
- Un-efficient airtight building arrangements (as acroterium) to be developed,
- Un-correct disposition of equipment material as: Electric plugging, water and heat plumbing, equipment connection etc,
- Variation during time of the quality of building material.
- Un-correct functioning of the ventilation system, walls and roofs.

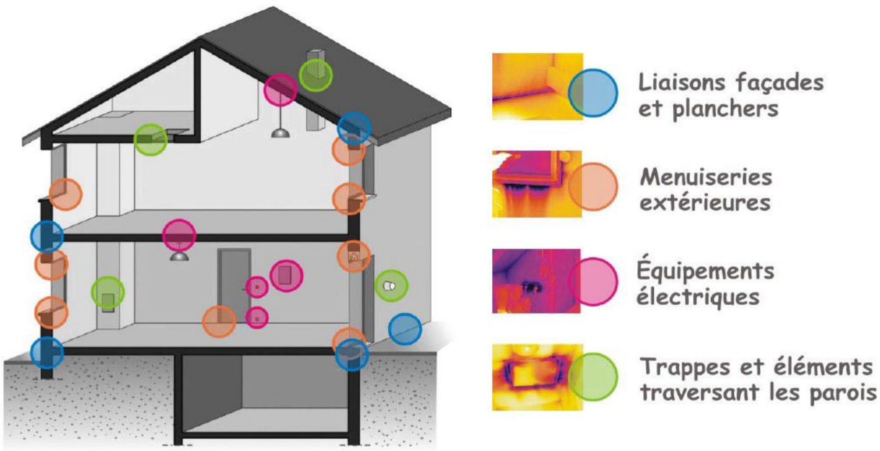
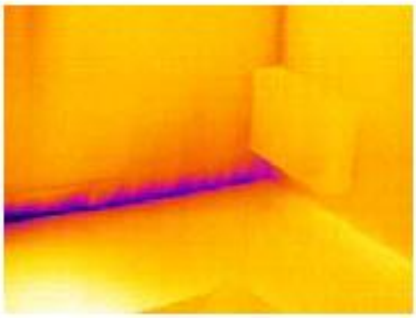


Figure 1: Example of typical air gaps [Cete2006]

Untight details can be made visible by a combined use of a blower door and Infrared-Camera (see Figure 2 – Figure 5, [Cete2006].



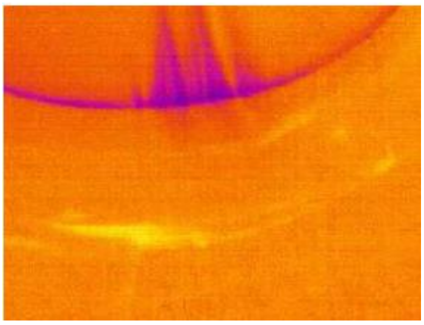


Figure 2: Wall/slabs joints [Cete2006]

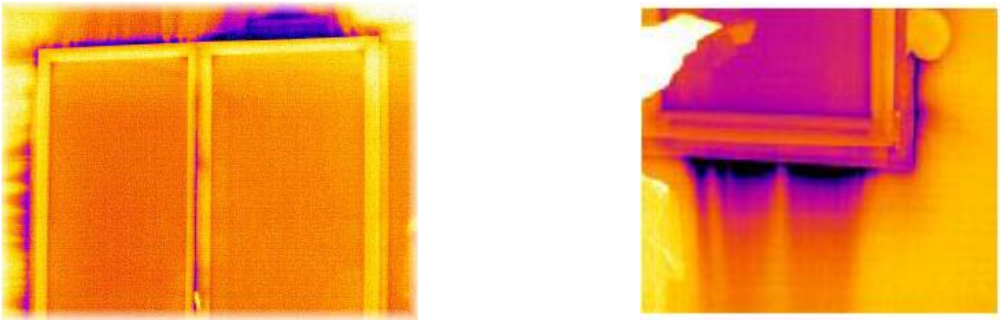


Figure 3: Window frame joint [Cete2006]

Figure 4: Trough wall openings – Attic access [Cete2006]

Figure 5: Plumbing an electric openings [Cete2006]

<u>Details industrial buildings, example Germany</u>

Using the example of an industrial building in lightweight steel construction it is shown how to check whether the air tightness requirements concerning the joints and concerning the whole building are achieved.

In a study of the joints during the construction phase, doubts have arisen as to whether the gaps between the steel sandwich elements in the façade area meet the required properties relating to the air-tightness/impermeability.

The pictures show a view of the industrial building and as-built joint details.

Figure 6: industrial building and as-built joint details

The following measurements were conducted on site:
- Infrared surveys of the jointing of the Steel-Sandwich-Construction
- Location and visualization of leakages using a fog machine
- Pressure differential test (Blower Door) on the whole building

Subsequently experimental examinations to determine the joint tightness of the steel sandwich panels were carried out at the laboratory test stand at the RWTH - Institute for Steel Structures.

The heated volume of the building is V = 3150 m³ and the envelope surface determine from inside the building dimensions to A_E = 1830 m².

The Blower Door investigations show that all requirements regarding the building tightness are achieved.

In contrast, the laboratory measurements (see WP 1.3) of single joints showed, that for specific displacements of the joints, which can be found at the building, the requirements are not fulfilled.

<u>Details industrial buildings, example France</u>

The investigation from CTICM focuses on penetration and interfaces.

The following pictures show some air tightness defects observed in recent industrial constructions.

Drainage openings into roofs

Figure 7: Drainage openings in roofs: Thermal bridge + air tightness gap

Opening in roofs: in this case electric wires to cross the roof – also structural member penetration into the roof

Figure 8: Openings in roof; electrical wiring and small structural supports

Envelope penetrations

Figure 9: Structural penetration in the envelope

Sky dome frame: un-efficient ceiling of the clear polycarbonat and the surrounding steel sub frame

Figure 10: Unefficient skydome joints

Figure 11: Air leaks at joints of skydome elements (not seen on the photo but real)

During a rainy day and depression testing the sky dome has shown water leak into the building due to sky dome deformations under pressure balance. This shows that sky dome joints are not designed regarding excessive pressure (50 Pa) and leaks can occur during heavy winds.

Joints between envelope panels and structural frame – no sealing bands

Figure 12: Un-ceiled joint between structural element and envelope elements

Joints between structural and envelope elements

Figure 13: Joints between structural and envelope elements

Gap between structural frame and the envelope

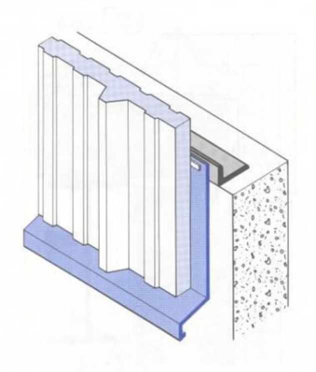


Figure 14: Gap between structural frame and the envelope in this case concrete foundation

Air gap at panel joints

Open joint – Not fully ceiled

Moisture and corrosion at joint showing air penetration and condensation

Figure 15: Two case example of not fully joined panels

Acroterium arrangement

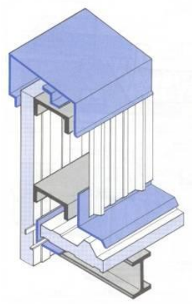


Figure 16: Air gaps in acroterium arrangement

Special

Figure 17: Unused screw punching penetration

Figure 18: Deformed panels

Unfinished situations

Figure 19: Unfinished interface at sky dome arrangement

Figure 20: Missing path of mineral wool

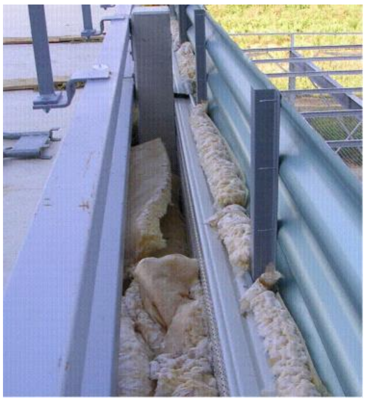


Figure 21: Unfinished situation

1.4 Laboratory air-tightness tests

As part of this project a number of air-tightness test have been undertaken using a dedicated building physics test facility developed at TATA Steel RD&T, further tests were made at RWTH Aachen (see **Deliverable WP 1b**).

The facility of TATA is capable of carrying out non-destructive physical performance tests on building elements in both planar and 3D arrangements to aid in the evaluation and development of new and existing product types in building envelope design.

Air-tightness testing and thermography studies have been conducted on composite panel interfaces commonly found in building envelope design to assess their contribution to whole building performance. The purpose of the air-tightness testing was to achieve two goals:

- To generate in house air-leakage performance data of different interfaces commonly found in composite panel building envelope design.
- To assess the performance of the recently developed facility for undertaking accurate laboratory based air-tightness testing of building elements.

This paragraph gives details of the test method, an excerpt of results of the air tightness tests and recommendations for future improvements. The full report concerning the laboratory tests is given in **Deliverable WP 1b**. – “Measuring of air-tightness in laboratory tests”.

1.4.1 Test set-up

Air tightness tests were conducted using a purpose built building physics test facility. The rig provides a chamber into which building elements can be mounted and tested to assess their air-leakage and thermal performance. The test chamber is made up of three major elements: floor, walls and roof. Figure 22 shows a picture of the building physics test facility with the roof removed.

Figure 22: Picture showing the building physics test facility with the roof removed

Toggle clamps are used to compress a 6 mm sealant tape between the wall panels and provide an air-tight joint. These joints also provide structural integrity to the wall system. The clamps are positioned along the vertical joints at 750 mm centres and at the centre of each panel top and base edges.

The roof is a single piece construction which sits directly over the assembled wall panels. The same sealing method is used for the roof as with the wall panels. The sixteen toggle clamps located at the top of each wall panel is used to compress the sealant strips positioned between the roof and walls.

The building physics test facility was developed to allow a varied range of building elements to be tested in different arrangements. To provide this flexibility, different test apertures can be formed by removing individual wall panels and replacing them with the building element. In the current work, three different construction details were tested. The first two sets of tests were on planar joints; a composite panel side lap joint and end lap joint. The third test was on a typical external corner detail. Details of each of type of construction are given in Deliverable 1.2. – “Measuring of air-tightness in laboratory tests”.

To test the side lap and end lap joints, a centre wall panel was removed and replaced by two smaller wall panels. A timber frame was constructed between these panels to allow the test specimen to be mounted in the aperture. To test the external corner detail, one of the comer posts was removed along with the adjacent end wall panels which connect to the same corner. As with the planar joint tests a timber frame was constructed to provide a suitable aperture to mount the test specimens. The timber frame was sealed against the remaining walls of the rig using the same PVC sealant and toggle clamps used for wall to wall interfaces, as described in the previous section.

The composite panels which make up the test specimens were cut to suit the size of the test aperture. Both arrangements were constructed according to the guidelines provided by the product supplier. All planar tests were undertaken using dry joints, i.e. joints were tested without the use of on-site applied sealant. Acoustic adhesive and sealant was used to seal the outside edges of the composite panel specimens to the timber frame. Figure 23 shows the composite panel specimens for the two types of joint sealed within the timber aperture prior to testing.

Figure 23: Arrangement of composite panel specimens within test aperture for (A) side and end lap joint tests and (B) external corner joint tests

1.4.2 Test procedure

Airtightness test

Tests have been performed in accordance with the standard BS EN 12114:2000 [3]. The procedure described in section 7.2.2 of the standard "Measurement of air permeability of specimen fitted in a non-airtight test rig" was followed in undertaking all air-tightness tests and is described in detail on the following page.

Before the test starts it is necessary to measure the air temperature to an accuracy of ±2 K, the relative humidity to an accuracy of ±10 % and the barometric pressure to an accuracy of ±1 kPa. The atmospheric conditions in the apparatus and around the test specimen must be between the limits stated below:

- 18 ˚C to 22 ˚C air temperature
- 100 to 102 kPa atmospheric pressure
- 25 to 50% relative humidity

These quantities are required to remain constant throughout the duration of the test. Conditions outside these limits can be corrected, to provide an adjusted air flow measurement. It is necessary the test specimen is conditioned at these ambient conditions before the test.

The procedure followed to determine the air flow through a building element using a non air-tight test rig is described below:

1. Three pressure pulses are applied at 10 to 12 % higher than the maximum pressure difference for the test. The duration of increase in pressure shall be greater than 1 second, with each pulse maintained for at least 3 seconds.
2. Air pressure differences shall be applied in several steps up to the maximum pressure difference for the test, as defined by the product specification. Deliverable 1.2. – "Measuring of air-tightness in laboratory tests" shows the pressure – time curve followed for the test.
3. The air flow rate and static pressure difference is measured at each step and recorded. The duration of each step shall be such that the air pressure in the test rig has stabilised before an air flow reading is made.
4. Repeat steps 1-3 with the joints covered by adhesive tape or an air-tight sheet covering the whole sample to determine the residual air-flow rate measurements.

Smoke propagation and thermography

To identify the location of possible air-leakage paths, smoke testing and thermography was undertaken following the completion of the air-tightness tests. Thermography studies were carried out according to the standard BS EN 13187:1999 [4]. Irregularities in the thermal properties of the components constituting the external envelope of a building result in temperature variations over the surfaces of the structure. The surface temperature is also influenced by air flow within and/or through the envelope of the building. The surface temperature distribution can thus be used to detect thermal irregularities due, for example, to insulation defects, moisture content and/or air leakage, in the components constituting the external envelope of the building.

Building thermography is a method of indicating and representing the temperature distribution over a part of the surface of a building envelope. This technique involves providing a temperature difference across the sample in excess of 10 ˚C and pressurising the internal volume. The temperature difference was provided by use of a 1 kW convection heater placed inside the test rig. A pressure difference of 200 Pa was provided by the same method used in air-leakage tests. A thermal imaging camera was then used to locate “hot spots” on the external face of the panel. The location of the hot spots correlates to the position of air-leakage paths as the hot internal air escapes, it warms the external surface of the panel. Thermographs were taken from several different angles to eliminate the detection of possible reflections from other heat sources.

1.4.3 Test results

Side lap joint

The side lap joint tests undertaken on the Trisomet 333 composite panels (test ID SL1-4) were carried out using 4 varying joint compression rates. Test SL1 was completed at full compression i.e. 0.0 mm joint gap. Tests SL2, SL3 and SL4 were undertaken with a joint gap of 1.2 mm, 2.0 mm and 3.0 mm respectively to determine the effect of poor alignment of the composite panel side lap joint on air-leakage performance. The joint gaps were introduced by use of a strip of steel packing material the same thickness as the desired joint gap. The packing was placed in between the two panels upon fixture to the support structure and then removed when the panels were secured before testing. Figure 24 shows a picture of the packing piece used to form a 2.0 mm joint gap between the panels.

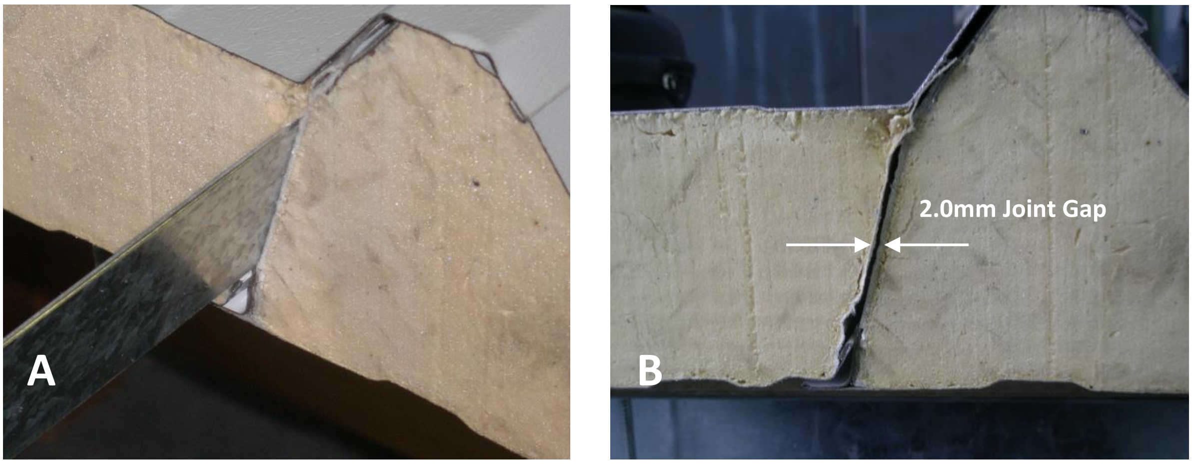


Figure 24: A) Steel packing piece used form 2.0mm joint gap, B) Resulting 2.0mm joint gap formed between the panels after assembly to the support structure

Side lap joint tests using the FischerTHERM composite panels (SL5-7) were undertaken under full joint compression to allow comparisons to be made with previously published data [5] and most importantly, to effect of the factory installed EPDM gaskets on the airtightness performance. Figure 6 shows a picture of the assembled joint which features an EPDM gasket and a compressible open cell PUR strip.

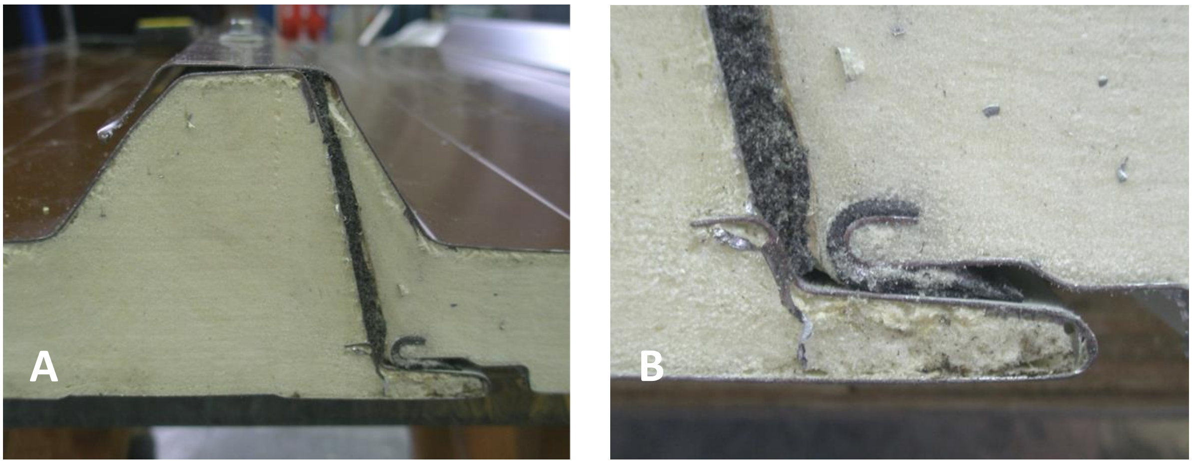


Figure 25: A) The FischerTHERM composite panel side lap joint when assembled, B) Close up picture of the EPDM gasket seal

Air-tightness, smoke propagation and thermography test results

Table 3 provides a summary of the results for all tests undertaken. The leakage rate recorded at pressure differences 50, 100, 200 and 1000 Pa are given, low pressure on corrugated side (external side). The following subsections describe the tests performed and observation made during testing. Results obtained from the external corner detail tests (CD1) were inconclusive and are not presented here. Section 3.2.4 provides an insight into the findings of this test and reasons for the inaccuracies found.

Table 3: Summary of air-leakage rates at pressure differences 50, 100, 200 and 1000Pa

Test ID	Test Description	Air leakage rate (m^3/hr/m)			
		50 Pa	100 Pa	200 Pa	1000 Pa
SL1†	Trisomet 333 - 0.0 mm gap	0.09	0.17	0.34	1.70
SL2†	Trisomet 333 - 1.2 mm gap	0.12	0.24	0.47	2.36
SL3†	Trisomet 333 - 2.0 mm gap	0.15	0.31	0.61	3.07
SL4†	Trisomet 333 - 3.0 mm gap	0.29	0.57	1.15	5.74
SL5	FischerTHERM - 0.0 mm gap	0.02	0.03	0.06	0.32
SL6	FischerTHERM - 0.0 mm gap	0.02	0.03	0.06	0.30
SL7	FischerTHERM - 0.0 mm gap	0.01	0.01	0.02	0.12

† *Average values based on 3 repeat tests.*

(SL1-4) – Trisomet 333 side lap joint

Figure 26 summarises the air-tightness test results for tests SL1 to SL4. The results presented are average results for the three repeat tests undertaken on a Trisomet 333 composite panel side lap joint at 0.0, 1.2, 2.0 and 3.0 mm joint gaps with no on-site applied joint sealant.

The Trisomet composite panel system features a thin compressible factory applied joint seal which sits on one side of the panel joint (see Appendix A). This seal is compressed when the panels are assembled to the support structure. On-site applied butyl mastic is also used along the overlapping trapezoid between the two panels. For this test the on-site seal was not fitted to test the performance of the panel in absence of this second seal.

As expected, the results show a tendency for leakage rates to increase with increasing pressure difference. They also show how leakage rates increase with increasing joint gaps. When the joint is closed, i.e. 0.0 mm joint gap, the factory applied joint seal is fully compressed and offers the best performance against air leakage. Small incremental increases in the joint gap compromised the performance of the factory applied seal and air leakage rates increased by approximately 40 % at 1.2 mm and 80 % at 2.0 mm.

Above 2.0 mm the factory applied seal offered no protection as the surface of the seal was completely out of contact from the adjacent composite panel. As a result air-leakage rates escalated rapidly. Testing the side lap arrangement with a 3.0 mm joint gap showed that air-leakage rates increased by as much as 3.5 times that of a fully compressed joint.

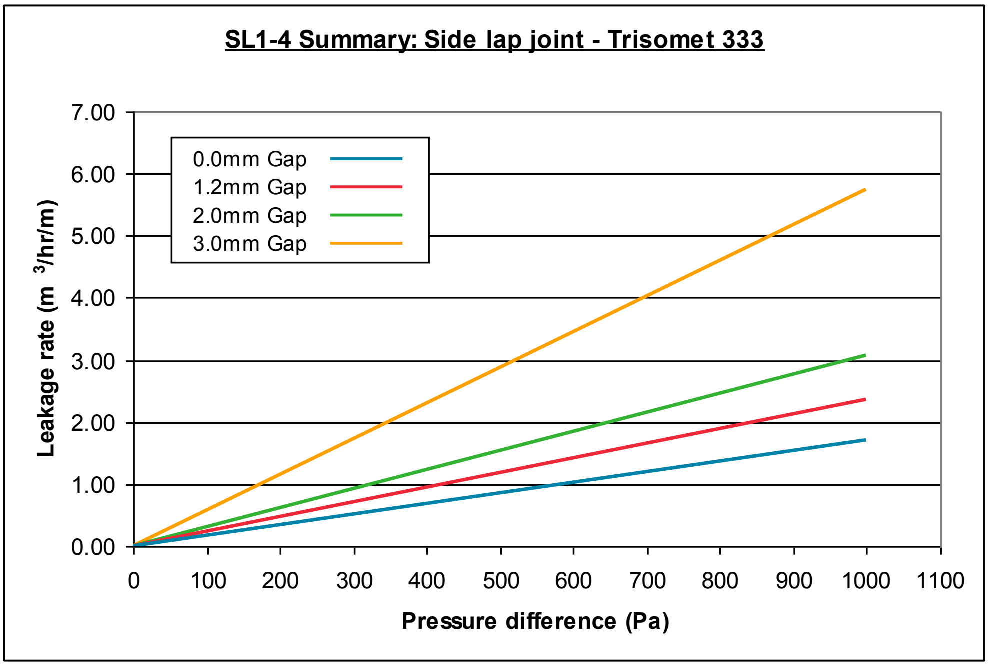


Figure 26: Summary of test results for side lap joint tests SL1 to SL4 – Trisomet 333 composite panel at 0.0 mm, 1.2 mm, 2.0 mm and 3.0 mm joint gaps

Smoke testing was used in an attempt to observe the location of possible leakage paths through the joint. The colour of the external steel skin of the composite panel, however, made it difficult to distinguish the grey smoke against the plain, light coloured background. The relatively high leakage rates recorded for this test also made it difficult to determine the location of a leakage path using this technique, as the smoke blowing through the joint was at too high velocity to observe the smoke visually.

Thermography was used in conjunction to help determine the location of possible leakage paths. Figure 27 shows a thermograph image taken using the thermal imaging camera of the Trisomet 333 side lap joint with a 3.0 mm joint gap. The internal and external temperatures of the test rig were recorded at 21 ˚C and 35 ˚C respectively, providing a temperature difference across the sample of 14 ˚C. The inside of the test rig was held at an elevated pressure to encourage air movement through the joint. A pressure difference of 200 Pa was sustained throughout the thermography trials. The joint of the panel can be clearly seen from the thermograph. Air-leakage through this interface was concentrated around the top portion of the side lap joint, centred around the top stitching screw, as indicated by the high surface temperatures recorded at this point and the elevated surface temperatures on the adjacent composite panel left of the joint.

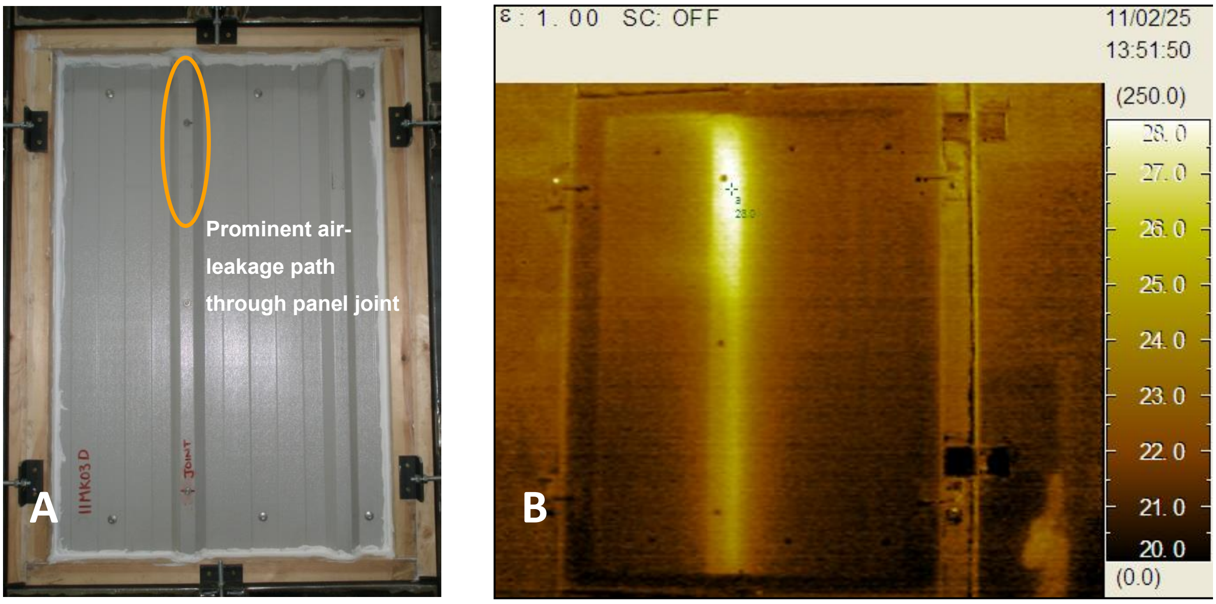


Figure 27: A) Visual image identifying the location of the prominent air leakage path, B) Thermograph taken of the side lap joint test (SL4) at a positive pressure difference of 200 Pa and an internal / external temperature difference of 14 ˚C

(SL5-7) – Fischer profil side lap joint

Figure 9 shows the averaged air-tightness test results for side lap joint test SL5 to SL7. The results presented are average results for the three repeat tests undertaken on a FischerTHERM composite panel side lap joint at full joint compression with no on-site applied joint sealant. A second trend line is also presented showing the results published by Fischer Profil for the same joint test completed in 2005 [5]. The data used to generate this trend line is based on the leakage rates given for pressure differences 50, 100, 200 and 300 Pa.

The FischerTHERM composite panel features a 7 mm open cell PUR compressible foam seal and a serrated EPDM gasket located on the inside edge of the composite panel side lap joint (see Appendix A). The construction of this panel does not require an on-site applied joint seal to be fitted. When the panels are assembled and fixed to the support structure the foam seal and gasket become compressed. The design of the gasket provides an improved joint seal as an internal pressure builds due to the fins of the serrations becoming further compressed against the adjacent panel.

The air leakage results were on average 25 % higher when compared against the published Fischer Profil results. Due to the superior air-tightness of the Fischer Profil composite panel it was difficult to obtain accurate air-leakage rates using the current set-up. The accuracy of the air flow meter used to determine the net flow through the sample was not capable of measuring below 0.01 m/s, which for the lower end pressures was too coarse to determine an accurate air-flow measurement. Readings taken at higher pressure differences (+600 Pa) compared better against previous test results.

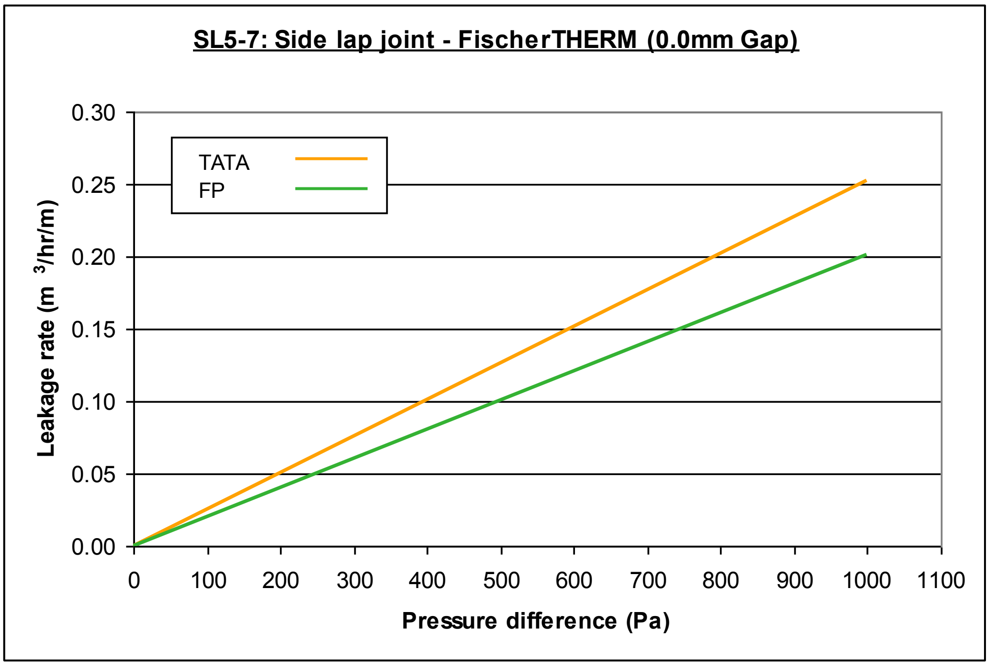


Figure 28: Averaged test results for side lap joint tests SL5 to SL7 – FischerTHERM composite panel at full joint compression compared with previous test results published by Fischer Profil

Smoke testing revealed leakage through this joint along the full length but only at high pressures. The darker colour of the panel and the lower leakage rates allowed the smoke to be seen much more easily. Figure 10 shows a picture of the smoke propagating through the test specimen at a pressure difference of 600 Pa.

Figure 29: Leakage through the side lap joint test of the FischerTHERM composite panel at an internal pressure difference of 600 Pa, confirmed using smoke testing

1.5 Measurement of the air-tightness of whole buildings by blower door tests

Various blower door tests were made within this project. For some of these a detailed documentation is given in **Deliverable WP 1c** – "Measured air-tightness of steel buildings". For some other projects the main results of the blower door tests (n_{50}-value) were presented in WP 4.

1.6 Summary and improvements (Deliverable WP1d)

Air tight material

In many buildings it is common to install a vapour barrier like a membrane of polyethylene on the warm side of the wall. The polyethylene can also be placed where it can serve as air barrier, provided that continuity and structural strength required by the system are performed.

If the airtightness layer has a low permeability to water vapour and is located on the cold side of the wall, the risk of condensation on the surface of the air barrier is increased. In such cases, the location of the air tightness system compared to the heat shield is essential.

Envelope systems

- Materials that compose the building envelope must be sufficiently airtight;
- It must have a continuous surface around the building envelope;
- It must be strong enough to resist the pressure of air without excessive deflections and be designed to transfer loads to the building structure;
- It must be durable enough to get adequate performance in the environment to be put into service.

Steel panels

By nature, steel panels are air tight and present a barrier to air if not altered by corrosion or fixing devises. Nevertheless the weak point of steel panels remains the connection of two panels, longitudinal and transversal connection that are not air tight. Sealing material, compressible rubber (or other) bands and/or plastic tapes partly resolve this problem. Setting of the material shall be carefully proceed at construction time to avoid any poor performances. The remaining question is the maintenance and time related properties of the material. Submitted to heavy temperature change, plastic tapes tent to alter and disconnect (de-glue) from the supporting material. The quality of the construction joint, clean smooth surfaces will facilitate the setting of air tight joints.

Built-up systems

In built-up systems the air tightness is provided by the complete complex, internal steel skin, insulation material, external skin made of steel sheetings in the case of steel clad system (walls and roof) or the bituminous layer in case of "support d'étanchéité" roof. Usually air tight screen can be placed on the inner site of the complex. This is not often the case in industrial buildings.

Along longitudinal joints, every layer of material shall be carefully placed, avoiding any gaps, voids and punchings. Sealing tapes can be used on overlapping joints, not often the case, and compressible rubber bands placed at the joint between steel sheetings are preferred. Usually these joints are placed on the inner skin of the complex.

Practically a slightly ventilated cavity is also formed in the overlapping joint, at the far external overlapping, to avoid any transfer of water and condensation into the envelope complex. The external steel skin of the complex, works as watertight element while the inner skin/Liner will perform the airtight barrier.

Along transversal joints at end lap, when reaching flashing light gauge elements, compressible foam blocks should be set in every valley of the steel sheeting avoiding any large air gap. These blocks are tailored at the sheeting shape. Glued foam blocks are better but are more difficult to set in place.

Sealing tapes can be used in non seen (secret) areas. Sealing tapes should carefully be chosen, maintenance is difficult and variations in properties can change during time, i.e.; gluing performances. Metallic sealing tapes are sensitive to corrosion.

Change in sheeting form at specific joints (sheeting, lashings, ridges, eaves, etc. will create complex overlapping that are not correctly covered by sealing tapes.

Composite panels

In a composite panels system the air tightness is provided along longitudinal joints by the interlocking profile of the joined panels including rubber bands if any. The two joint panels are set in place with compression and locking, compriming the rubber band. Any defect in compriming the band will give air leaks and not completed locking will create longitudinal voids that will produce longitudinal air leaks. Along transversal joints at end lap, by partial overlapping and compressed rubber seals, or by specific light gauge element dedicated to the steel composite panel used (closed system).

Connecting devices

However, the air tight material may not depend on its own characteristic to perform the required air tightness. It shall be supported and connected to another material, or by the structure, providing strength and rigidity to the appropriate part of the system. In the case of an "exclusive – only providing air barrier" air tightness system (i.e. manufactured and sold as unique air tight device by a particular company), the connection characteristics, supports and devices, must be identified and included in the evaluation of the system.

The air tightness system must resist all pressures from the wind and transfer them to the building structure without damage, and the same is true for all its components.

Air tight screen

In the case of unique systems, it is usually the developer to demonstrate how the air thigh system can bridge joints, will seal penetrations and will be linked to other building elements like windows, doors, walls and roof, in way to deeply reduce - even suppress - air leakage.

Ideally, the rate of maximum air permeability of the system as a whole (including materials and seals) should be specified. Only rates of air permeability for materials are available data, which is far from facilitating the evaluation of systems. The subsequent development of the evaluation of air tight roofing system should be extended in that way.

Air barrier layer

Some system can suggest the use of air barrier layer that overlay all joint and connections of the envelope. This material, usually a soft plastic screen should be carefully set in place improving physical joint at any structural penetration and tighting (gluing) any un-continuity of the sheets on overlays. The positioning of sheet is also important, at the warm site of the envelope, acting also as a vapour barrier, or at the cold site of the envelope, behind rain screen. In that case, inner part of the wall shall be ventilated (controlled ventilation) to avoid condensation, and external part behind the rain screen shall also be ventilated (natural ventilation) to dry any water infiltration.

Durability tests and requirements

In addition to developing criteria for air permeability and structural strength, the sustainability of an air tightness system depends on its compatibility with adjacent materials and environmental loads to which it is subjected during its service life.

Account of issues such as exposure to ultraviolet (UV) under construction and deterioration due to aging shall be overviewed.

Among the climatic factors that may influence the sustainability including temperature, humidity, solar radiation, electrochemical factors and biological agents, it will be possible to extend the service life of a whole if we can make the repairs at a cost effective manner, which usually depends on the accessibility of the air tightness system. However, the majority of air tightness systems are not directly accessible.

There is no universal protocol on sustainability that can be applied to all materials or all possible combinations of materials.

Other requirements

Other requirement shall be specified on air tight systems, for example, the maximum moisture rate inside an acceptable suitable product. It also shows details of the system as components and accessories, the tolerances on installation and any other characteristic that will make the system installed efficient for its use.

To ensure that the air tightness behaves well over time, a program of monitoring and testing can ensure sustainability. Control may be exercised indirectly, through visual observation to identify any symptoms related to air leakage (e.g., efflorescence or stains), or directly, through the use of instrumental measuring. The differences in air pressure, temperature and humidity of cavities are set in relation to external and internal conditions. When you suspect an increase in air leakage in an area of the wall, it may be necessary to conduct tests for air tightness.

An operations manual will help to follow up the building for the appropriate methods of maintenance and repair. The manual should identify the constituent materials of the air barrier, their location and mode of connection to ensure the continuity of the building envelope. It should also describe the requirements and variation limits expected for the service held by the air barrier. A change in service conditions such as increasing the pressure or humidity levels may indicate excessive air leakage. In such cases it will consider the air permeability before starting repair work.

2 Thermal performance of building envelopes in steel

2.1 Introduction

The work in WP 2 is primarily concerned with minimising heat loss through the building envelope in steel as minimising heat loss through the building envelope is an important step in the process leading to good energy performance of buildings. In particular the issue of thermal bridges has been addressed. Indeed with a higher level of insulation, the relative importance of thermal bridges increases in the energy balance. Paying attention to construction detailing and site based practices has therefore become increasingly important in steel-cladding systems in order to achieve appropriate standards of overall energy efficiency.

2.2 Identifying "cold bridging" issues of steel-cladding systems

The aim of WP 2.1 is to identify the common practice of steel-cladding systems in Europe and to explore solutions to minimize local heat losses.

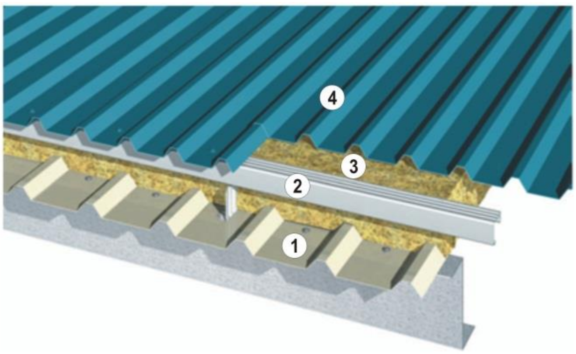
Library of steel cladding systems

An extensive library of steel cladding systems has been edited by the partners which can be consulted in the Ethics mid-term report. The library is classified as follows:

1. **Industrial building:**
    - Built-up systems
    - Composite panels
2. **Residential building:**
    - Light steel framing
    - Residential composite panels
3. **Commercial building**
    - Curtain wall
    - Cassette

For each system, typical solutions to reduce heat losses have been detailed.

An illustrative example of one of the steel systems presented in the mid-term report together with the solution to reduce heat loss is described hereunder. It concerns a steel cladding system for industrial buildings: a double skin roofing solution with bar and brackets spacer system.



Description

1 (trapezoidal) metal liner sheet supported by Z-rafters

2 bar and brackets spacer system

3 Insulation (mineral wool) 120 to 250 mm thick (pinched by the spacer)

4 external profiled metal weathering sheet of 0.75 mm thick

Figure 30: Bar and brackets spacer system

Characteristics

System width: 1000 mm (depending on profile)

Maximum system length: 22 m (depending on profile and transport).

Weight [kg/m²] = 20 (for 170 mm of insulation)

Thermal performance

Spacer system pitch: 1.8 m

120 to 170 mm thick of mineral wool

U_p [W/m².K] = 0.35 to 0.25

Mechanical performance

Span capability: Up to 4 m depending on profile selection and load conditions.

Fastening system

Stainless steel self drilling screws with sealing washers.

Alternatives

Perforated tray to achieve a sound absorption coefficient α=0.9

Solutions to minimize heat loss

An infrared survey was carried out on a twin skin roof without spacer system. Thermographic measurements revealed the presence of thermal bridges in the roof system:

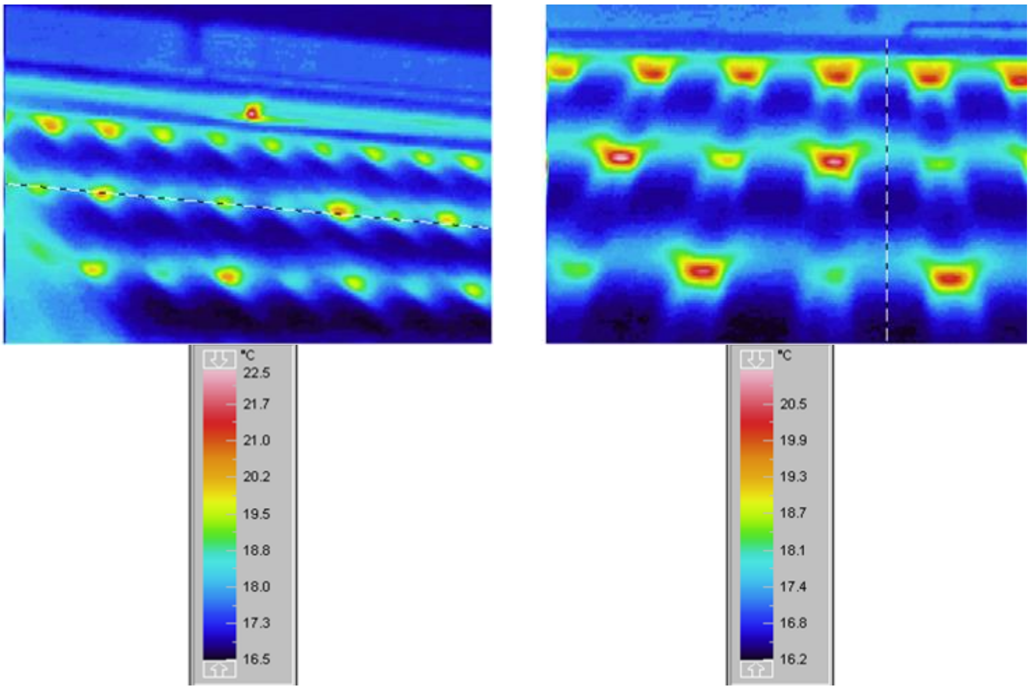


Figure 31: Exterior view on test roof

- The steel joint between the structural roof components creates a linear thermal bridge in the roof system, even though an insulation layer (thermal break) is present in between the joint and the corrugated steel roofing plates. The exterior surface temperature near the joint was 18 °C, approximately 2 K higher than the surface temperature in the insulated roof section.
- The metal fasteners (screws) which penetrate the thermal break to tie the roofing plates to the structural components create important point thermal bridges in the roof system. This becomes evident in Figure 32 which shows the difference in surface temperature between the screws and the rest of the roof surface. The surface temperature of the screws was 20.5 °C, which is 2 to 3 K higher than the surface temperature near a joint without screw.

Thermal breaks are highly recommended between roof decking and the structure to reduce thermal conduction. The figures below show isotherm in a numerical modelization of the twin skin roof:

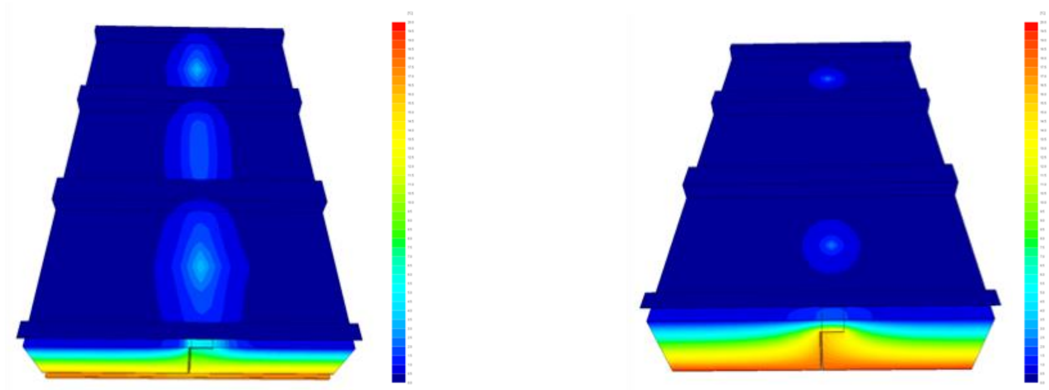


Figure 32: Isotherm within the system without thermal break (left) and with thermal break (right)

A linear thermal bridge appears on the flanges of the structural tray. These are significantly reduced by the implementation of thermal break closed cell polyethylene strips.

Other types of thermal breaks can be used:

- Individual "snap-on" EPS thermal blocks
- Layer of rigid insulation

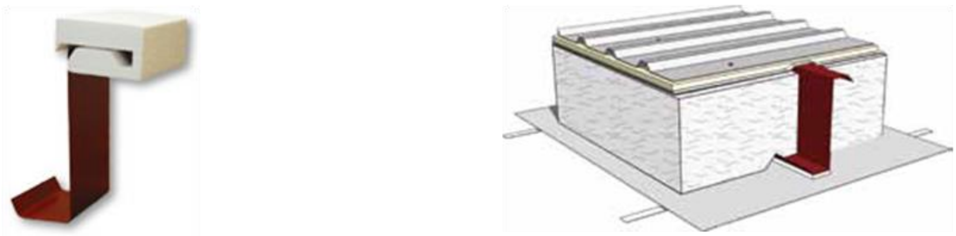


Figure 33: Thermal breaks on Z-girts

In order to understand the impact that different U-values and Ψ-values have on different building geometries a parametric study has been carried out. The study examined the effect of reducing U-values, Ψ-values and the effect this has on α-values for both composite and built-up cladding systems for a range of industrial shed geometries and considered the:

- Contribution of Ψ-values of each interface (e.g. eaves, valley gutter or ridge) towards the overall thermal loss of different building geometries.
- Effect on α -values by reducing U-values for future scenarios of the building envelope specification.

In total 40 parametric studies were carried out and this report outlines the methodology and boundary conditions of the parametric studies.

This report shows that the drip sill (interface between cladding and floor) is the highest source of linear heat loss. The second source of linear heat loss is window/door head jamb when side windows are considered. This is replaced by valley gutter interface for those building with “No side windows”. For all cases, the ridge interface represents the least source of heat loss. This then prioritises which interfaces should be considered when designing for thermal bridging in the future.

Composite Panel

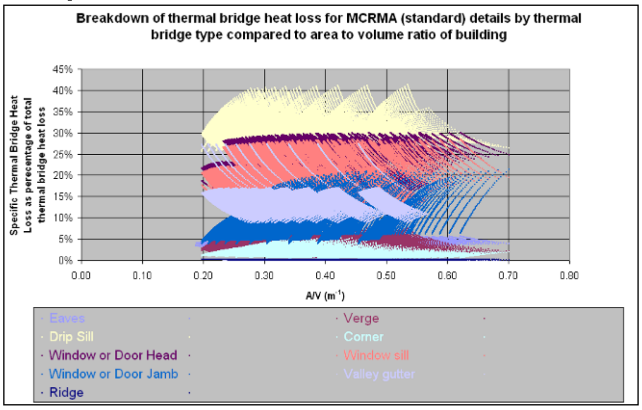


Figure 34: With side window

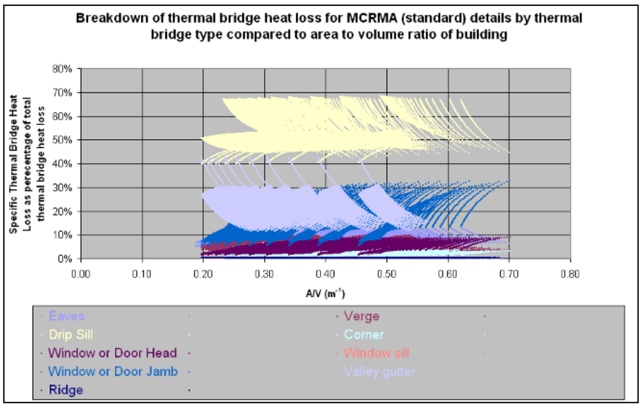


Figure 35: No side window

The report also showed that as the planar heat losses reduce due to improved U-values the effects of the thermal bridges become more apparent and the α value increases.

Composite Panel

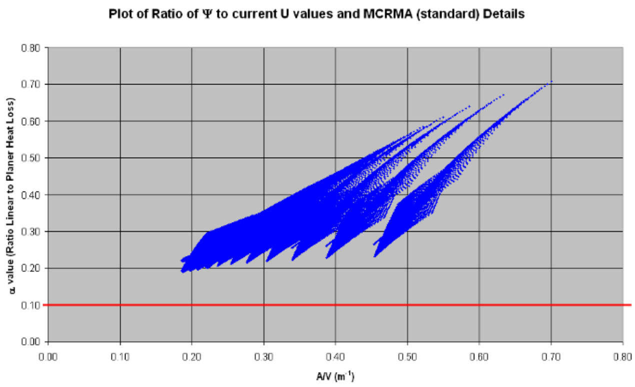


Figure 36: With side window

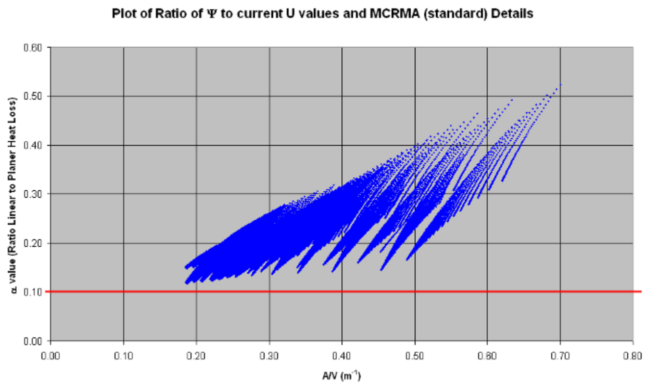


Figure 37: No side window

Thermal bridge cannot be totally prevented but the effects can be reduced by careful design and well executed details during construction. The best case interface details from the various existing published sources demonstrate that it is feasible to reduce linear heat loss with improved U-values. Efforts must be focused on improving site based practices.

The detailed results of the parametric study on the effect of thermal bridges are available in **Deliverable WP 2a** – Report on measured date of heat transfer properties of building envelope systems in steel.

2.3 Laboratory tests on thermal bridging

Measurement of thermal properties using guarded hot box - TATA

A guarded hot box was constructed and commissioned by Tata RD&T in 2009 to measure the thermal properties of building insulation materials. The hot box contains 63 thermocouples, measuring air, wall, specimen surface temperatures and guard space temperatures. These are then used to calculate U-values and thermal conductances (Λ). The U-values are calculated using environmental temperatures and the thermal conductances from surface to surface temperatures. The thermal conductances do not include the effects of air boundary layers. As part of the Ethics project, a programme of work was devised to assess the accuracy of the box and also to determine operating limits of current configuration. Therefore, six materials with published U- and Λ-values between 0.24 W/(m²K) to 14.3 W/(m²K) were tested using the hot box and hot plate. The results obtained from the tests are collected in Table 4 and plotted in Figure 38 below.

Table 4: Results obtained from guarded hot box, hot plate and published sources

	Thickness	Published Value		Test Results			Error
				Hot Box		Hot Plate	
	D (mm)	U (W/m^2K)	Λ (W/m^2K)	U-value (W/m^2K)	Λ – value (W/m^2K)	Λ – value (W/m^2K)	%
Montana composite (A)	100	0.24		0.23	0.24	-	4.2
Trisomet composite (B)	80	0.25		0.36	0.41	-	44.0
Polyfoam floorboard	75		0.39	0.33	0.38	0.38	2.6
Polyfoam floorboard	25		1.16	1.08	1.32	1.29	13.8
MDF	30		3.0	2.01	3.38	3.35	12.7
Gyproc wall board	12.5		14.3	4.03	9.05	10.81	36.7

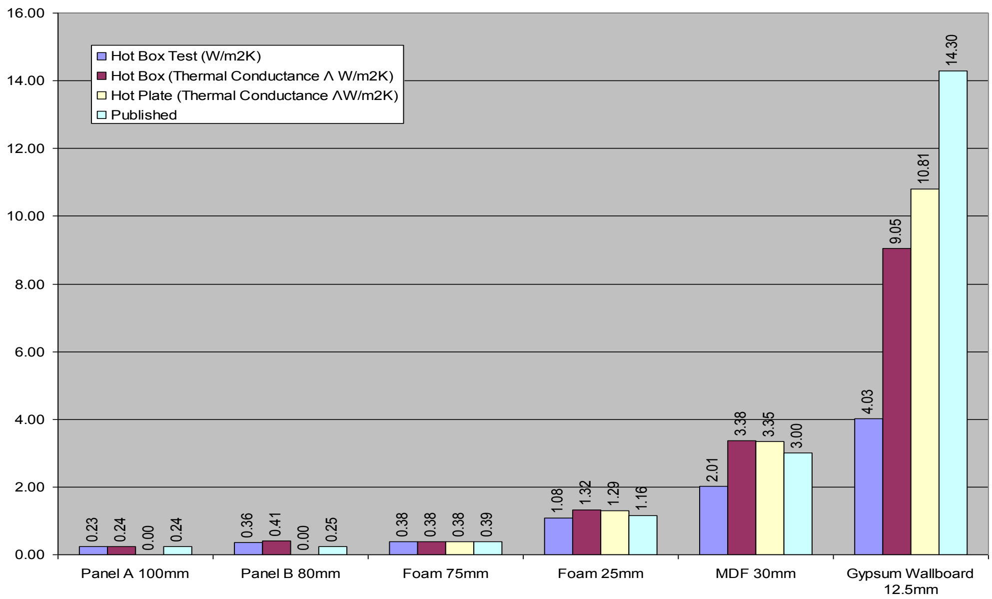


Figure 38: Results obtained from guarded hot box, hot plate and published sources

The results showed that the guarded hot box gives reliable results for materials with U-values within the operating range of the hot box testing (0.5 W/m²K to 5.0 W/m²K). They also revealed that reliable results may be obtained for values below 0.5 W/m²K for flat specimens, but not for U values significantly above 5.0 W/m²K. The largest inaccuracies are found when operating outside the normal operating range between 0.5 W/m²K to 5.0 W/m²K as suggested by BS 874:Part3. The reason for this may be attributed to high flanking losses from the hot box.

Measurement of thermal properties of the "Thermo cassette" in a hot box - RWTH

The investigations done in WP 2.1 showed that in particular the «build-up or cassette" wall system has strong need for thermal improvements. The "build-up" or "cassette" wall system is a relevant product for the steel sector and there are specific reasons for the use of these solutions (e.g. fire safety).

A solution that was developed and tested by RWTH is the "Thermo Cassette", that combines the design of the liner trays with the idea or "Thermo studs". For the first investigations some prototypes were manufactured costly in the pattern shop.

These handmade elements were tested in the hot-box by using an infrared camera (Infratec Varioscan). Figure 39 shows the elements in the hot-box, the visual appearance of both elements is the same.

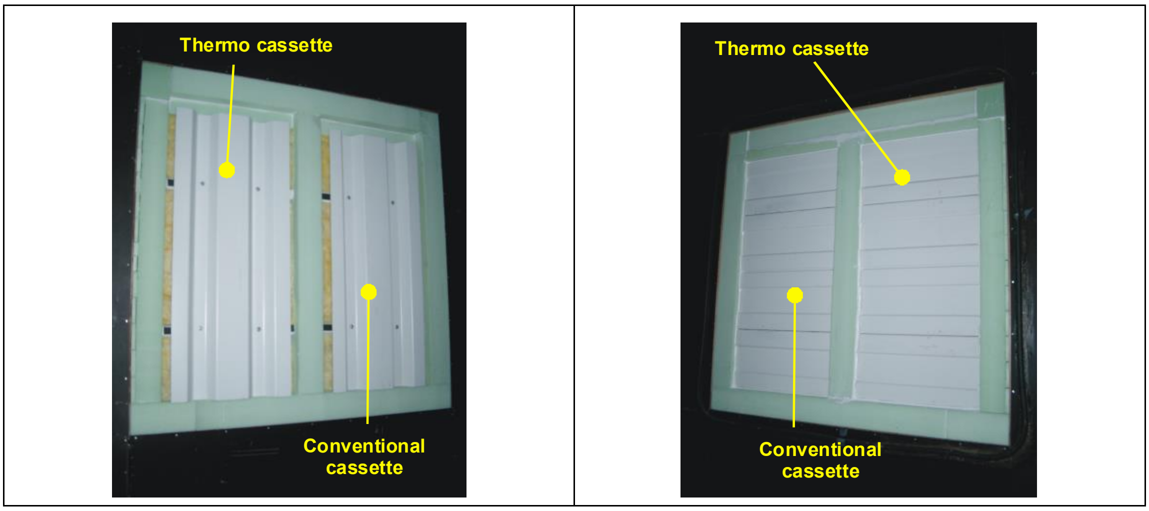


Figure 39: Cassette wall systems in hot-box (left: view "cold" side, right: view "hot" side

The effect of the "Thermo cassette" becomes visible by using the IR-camera (Figure 11). There is a significant effect of the slotted web; the temperatures on the inner side are about 2.5 K higher for the thermo-cassette at the joints.

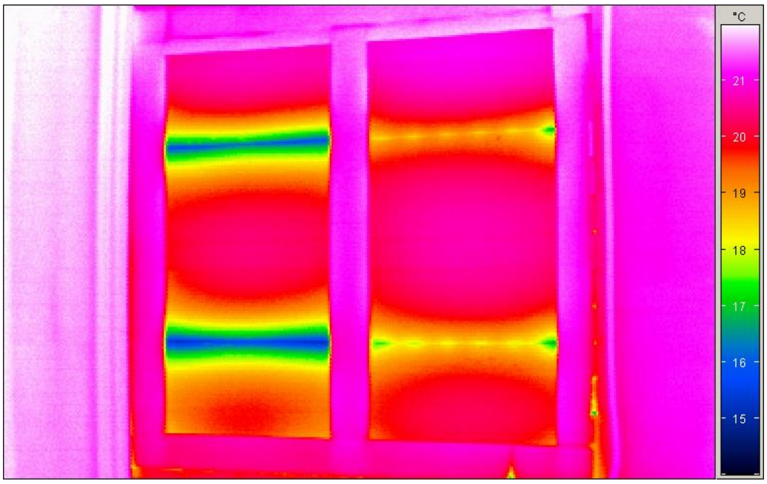


Figure 40: IR-survey (left: conventional cassette, right: thermo-cassette), view from the "hot" side

In parallel to testing the "Thermo Cassette", FE-simulations were performed to quantify the benefit of the Thermo-cassette for the U-value (see WP 2.4).

2.4 Case studies of existing buildings using infrared surveys

The partners involved in this work package have performed infrared surveys in buildings that are used for commercial, office and residential purposes. The aim of the surveys was to provide a qualitative appreciation of the thermal properties of the building envelope. The different buildings and their location are listed in the table below.

Resp. Partner	**Location**	**Building type**	
Corus	United Kingdom	Commercial building	
CRM	Belgium/Liège	Office building	
ArcelorMittal	Belgium/Flémalle	Office building	
ArcelorMittal	Belgium/Liège	Office building/ Experimental house	
ArcelorMittal	France/	Residential houses Villavenir	
ArcelorMittal	Belgium	Residential houses Jolibois	

The detailed results of work package 2.2 are available in **Deliverable WP 2a** – Report on measured data of heat transfer properties of building envelope systems in steel.

<u>Summary of key findings of the thermal imaging surveys</u>

Main weak points detected

<u>Building interfaces and composite panel joint interface</u>

The building interfaces such as composite panel to curtain wall, composite panels to built-up architectural feature, soffit, corners, side laps joints and window (head, jamb and sill) often give rise to thermal and air tightness performance reductions.

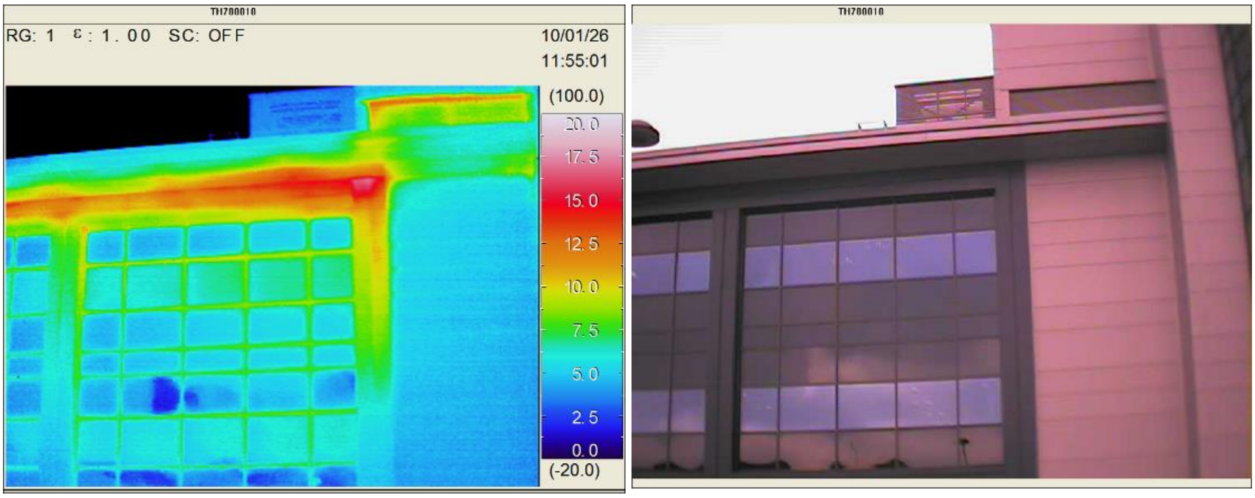


Figure 41: Thermal image showing an intense accumulation of internal hot air at the corner of the built-up architectural feature, as indicated by the red contours. Measurements show a temperature difference of +10 ºC between the built-up feature and the adjacent composite panels

Generally, thermal images of composite steel cladding system show uniform temperature ranges across most parts. However, complex interfaces around the curve envelope and junctions highlight the potential for air tightness and thermal performance defects mostly due to installation anomalies. As can be seen in the figure hereunder, planer interfaces between curved or formed composite panels are prone to misalignment; as a result an air tight joint is not always achieved.

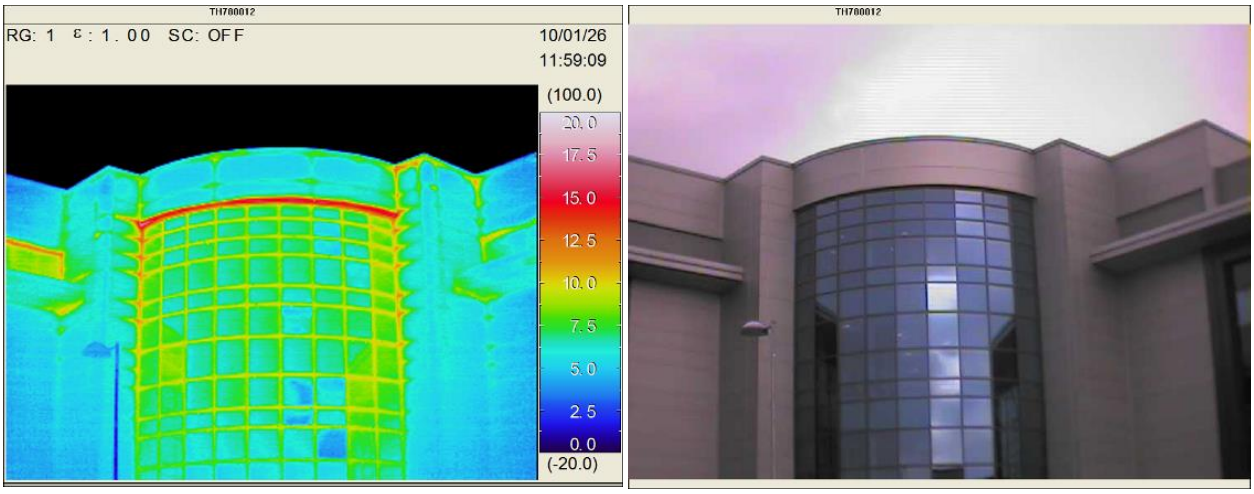


Figure 42: Heat rising from the built-up system which divides the windows causing a stack/chimney effect, contributing to the accumulation at the top of built-up feature

Windows and doors

Windows and doors also are weak points in the thermal insulation. Air-tightness flaws have been detected around doors and windows and especially around the entrance doors.

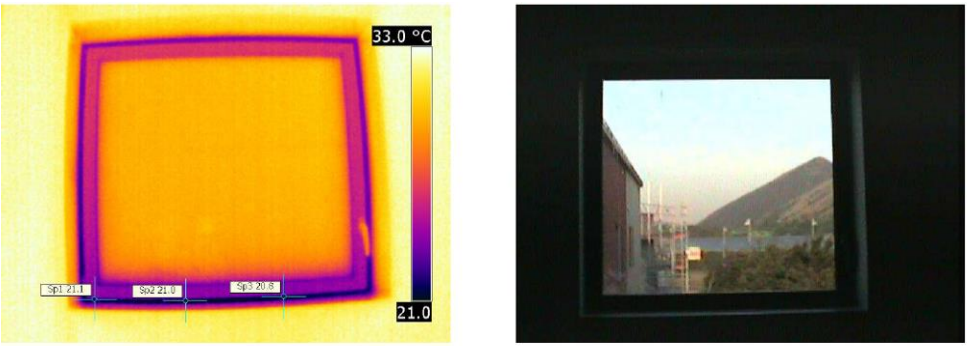


Figure 43: Thermogram of a window and corresponding picture

The images also revealed warm air infiltration behind the head jamb of the curtain wall. This indicates lack of seal, discontinuity of air barrier and inadequate or missing insulation.

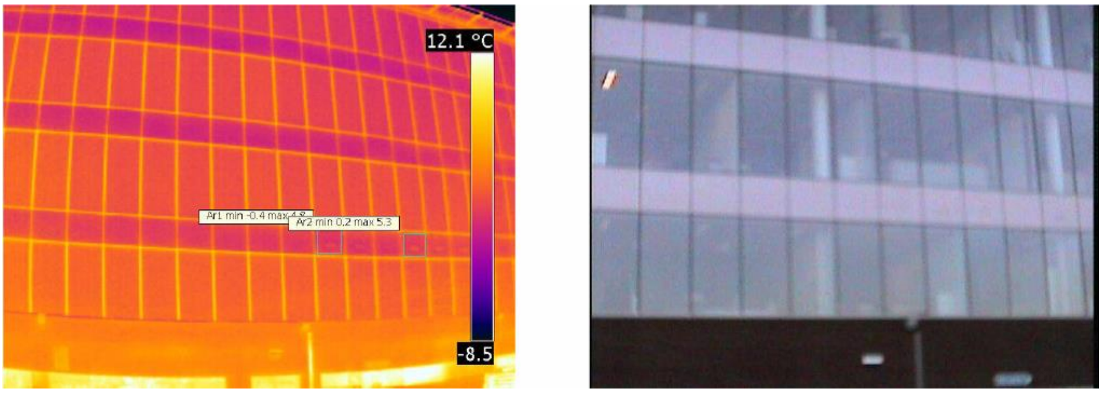


Figure 44: Thermogram of a steel curtain wall

Columns and beams

Thermal bridging due to the presence of columns and beams can significantly affect the thermal performance of the building envelope as shown in the drawing below:

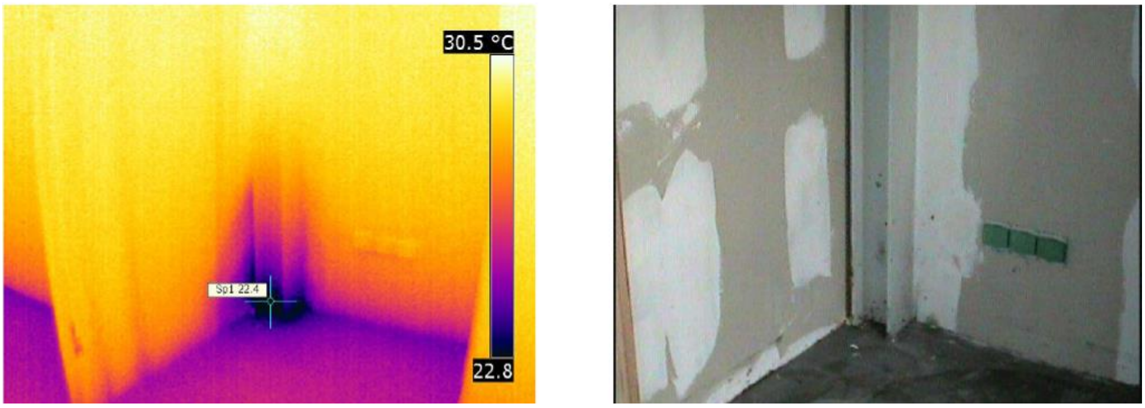


Figure 45: Thermogram and corresponding picture

Light steel framing

Two of the infrared surveys concerned light gauge steel framed buildings. Whilst for the first, the office building/experimental house, the facades prove an overall good thermal behavior because the external insulation layer avoids the thermal bridging effects through the bearing studs, for the second, the residential house Villavenir, thermal bridges within the external walls are erected by the light gauge steel profiles. This is due to the fact that the plasterboards are attached directly on the Light Steel profiles with self drilling screws.

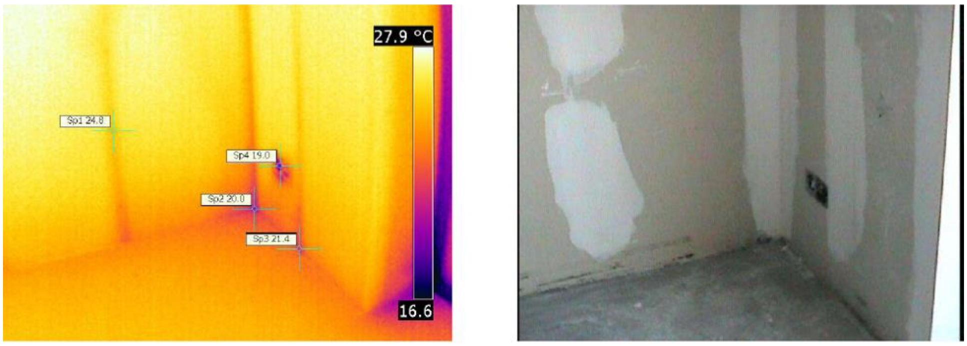


Figure 46: Thermogram 11 and corresponding picture

Implementation of insulation or air tightness systems

Different studies also highlight the difficulties of coordination between different contractors, one being responsible for the cladding system, one for the air tightness and one for insulation. This results in a situation whereby no individual party is responsible for the global air tightness and thermal performance of the system.

During the course of the thermal imaging survey, it was apparent that uniformity and replication of cladding interfaces across the façade was difficult to maintain during the construction phase. An example of this is demonstrated by virtue of two thermal images of an identical planar joint shown in the following figures.

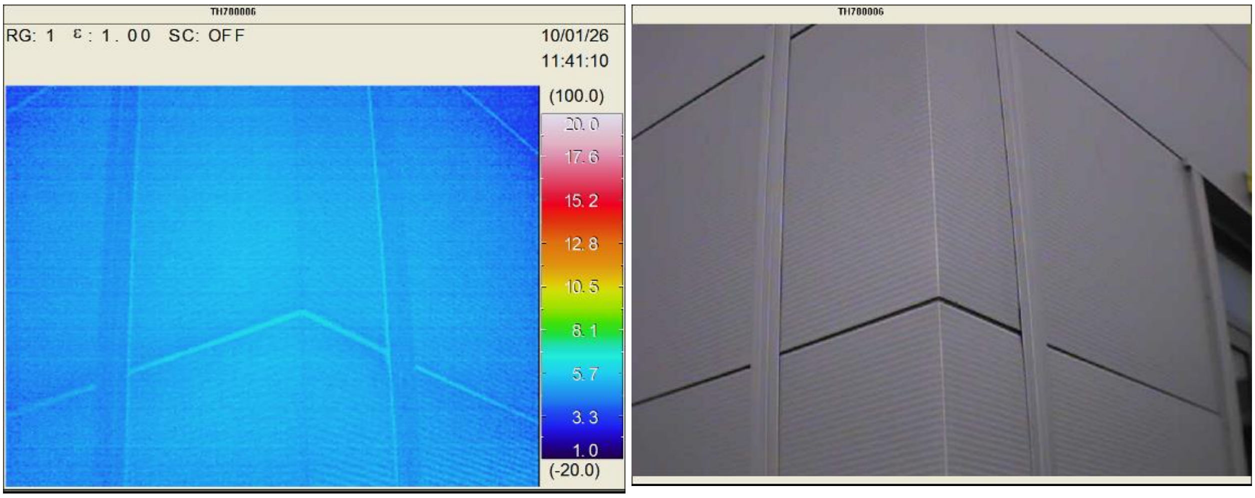


Figure 47: A planar composite panel corner junction performing as intended

This figure shows a covered planer joint between two composite panels, constructed and performing as designed and intended (U-value of approx 0.25 W/(m²K)). Conversely, the following figure, shows the same covered planer joint with reduced performance characteristics. Comparison of thermal and visual images of the joint cover strip indicates that insulation has been omitted or installed incorrectly.

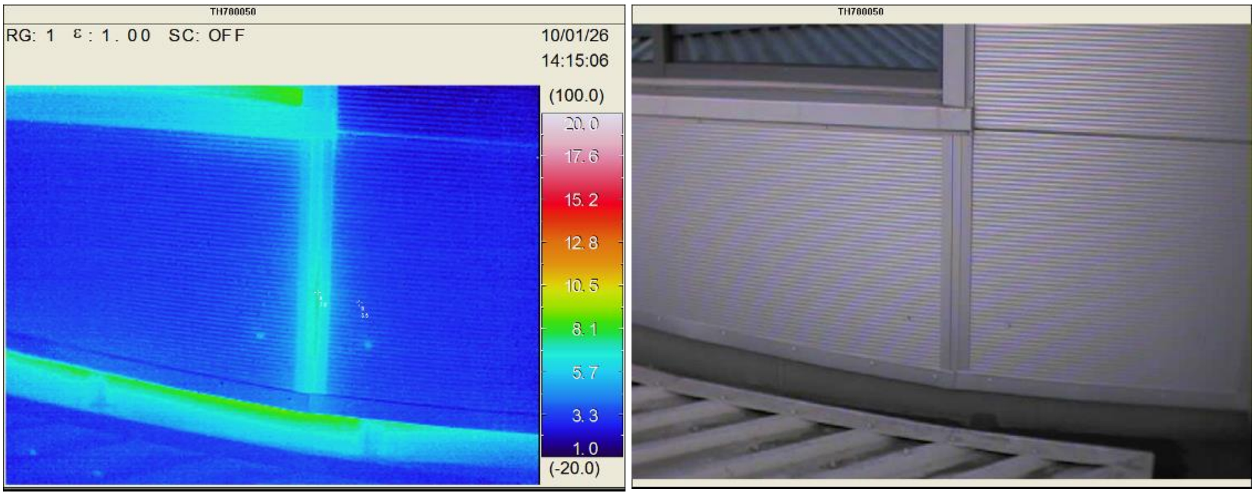


Figure 48: The same planar joint showing thermal losses along the length of the joint, indicating missing or incorrectly installed insulation

Propositions of improvements to reduce thermal bridging

<u>Composite panel joint interfaces</u>

The correct installation of insulation within the joint of composite panels is key to achieving a good thermal performance:

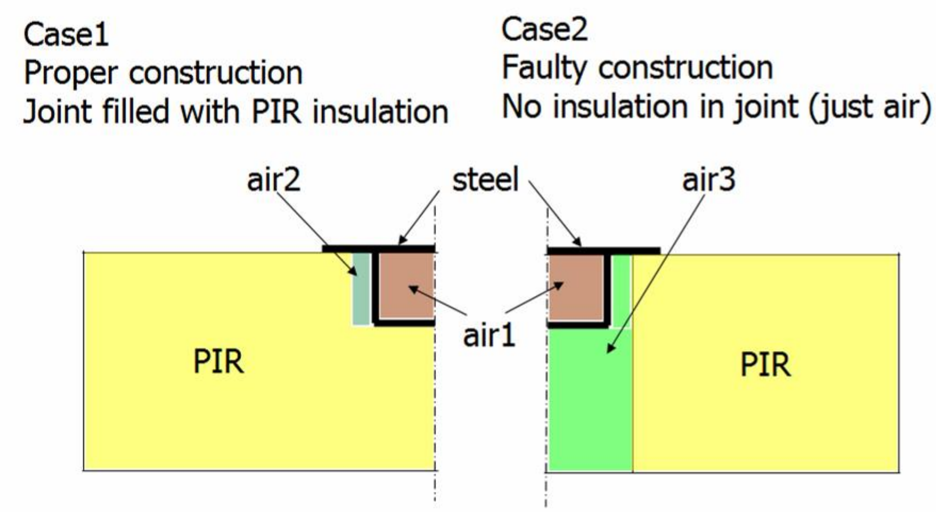


Figure 49: Correct installation of insulation within the joint and compared to missing insulation

The avoidance of multiple systems and construction types also helps reducing thermal bridging or air tightness flaws.

<u>Windows and doors</u>

By implementing air-tight materials around the window frames, the air-tightness of the envelope can be strongly improved.

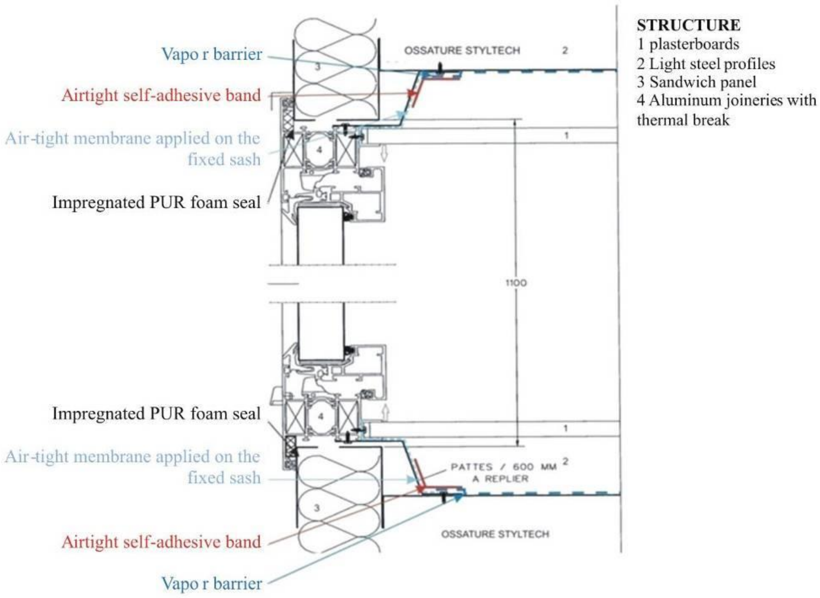


Figure 50: Vertical cut within a window displaying a good practice to improve the air-tightness of the joineries

<u>Columns and beams</u>

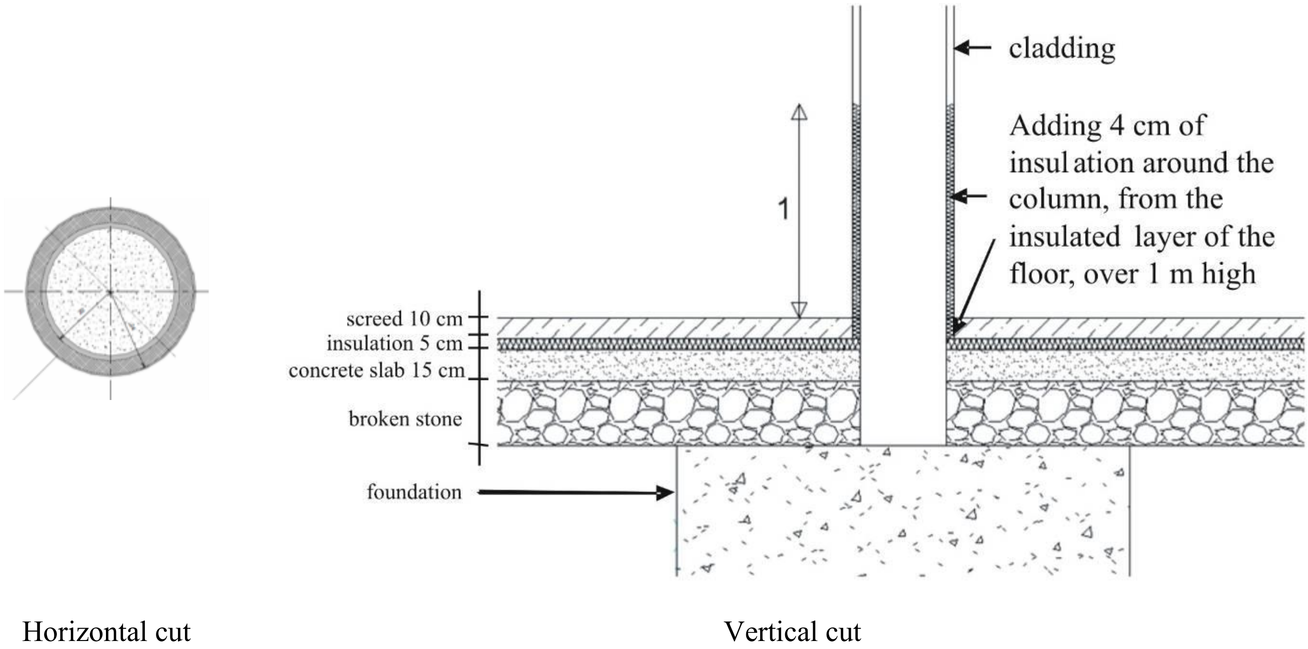


Figure 51: Implementation of thermal break in column/slab interface

<u>Light steel framing</u>

An efficient solution to reduce the thermal bridging due to the light gauge steel profile consists of the implementation of a secondary frame (see the Figure 52). This allows adding an extra layer of air between the plasterboards and the studs.

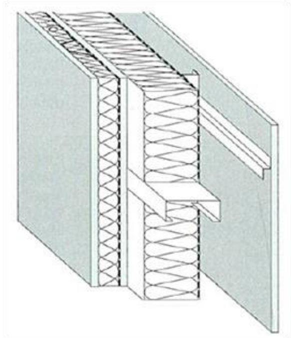
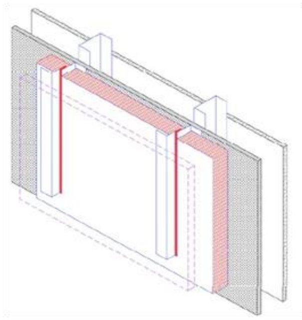


Figure 52: Implementation of a secondary frame

To obtain extremely high insulation level, thermal bridge breakage sections can be installed, within the external secondary frame (Figure 53, left) or inside the steel stud itself (Figure 53, right).



Thermally broken Z-girts

Web Perforated Steel Stud

Figure 53: Thermal break in light steel wall

<u>Implementation of insulation or air tightness systems</u>

During design and construction stage, correct location and installation of thermal insulation and air tightness layer are critical to achieve intended design performance. The key to this are but not limited to the following:

– Appointment of dedicated contractor/trade for overall management of construction activities to ensure continuity of thermal insulation and air barrier layer
– Avoidance of multiple systems and construction types
– Eliminate discrete cavities within the cladding system to reduce the likelihood of exfiltrated air collecting behind cladding elements.
– Inclusion of air tightness as a design parameter with a target air tightness value

It is imperative that adequate efforts are made to ensure proper sealing of the following interfaces to achieve the desired level of air tightness and thermal performance:

- Eaves
- Ridge
- Corner
- Cladding to cladding
- Service penetration
- Window/door head
- Window/door jamb
- Window sill
- Gutter/valley gutter
- Dwarf wall

Pre-manufactured cladding elements tend to show better results than built-up cladding systems.

2.5 Comparison and validation of numerical and experimental results – Simplified calculation methods for U-values of steel cladding systems (Deliverable WP2b)

Comparison and validation of numerical and experimental results

Thermo Cassette - RWTH

In parallel to testing the "Thermo Cassette", the solution that was developed by RWTH in the hot box (see WP 2.2), FE-simulations were performed to quantify the benefit of the "Thermo Cassette" for the U-value:

Table 5: Heat transfer coefficient of double sheet wall with liner trays

	Conventional cassette, d = 130 mm	Thermo Cassette d = 130 mm, 5 rows of slots	Relative improvement
	U-value [W/(m²·K)]		[%]
Without insulating strip	0,79	0,45	43,3
With 3 mm insulation strip	0,65	0,43	34,2

Joints for composite panel systems - Tata

This study is a follow up of the thermography survey of the modern office building in South Wales, UK (see WP 2.3) cladded with micro-ribbed composite panel. The outcome of the survey highlighted the need to investigate the effect of side lap joint thermal bridge (Ψ-value) and its contribution to overall thermal transmittance (U-value) of micro-ribbed composite panel. Both simplified hand and FE calculations for U-value and Ψ-value were undertaken.

The hand calculation showed that the Ψ-value is a function of panel thickness. This fact is largely not expressed in most panel suppliers' literature. A single value ranging from 0.001 to 0.17 W/mK is normally given without any consideration for panel thickness, which is very misleading.

The results of both hand calculation and Finite Element calculation showed a small percentage difference between the two analyses. The study revealed a massive heat loss from un-insulated joint compared to insulated joint and a huge percentage increase in effective u-values of panel with missing or no insulation in the joint. This finding corroborates with the outcome of the thermography survey, which showed massive heat loss from some of the joints as a result of missing insulation.

Table 6: Total Heat Flow (W) for 1K temperature difference applied to 100mm wide models

Panel Thickness	'Hand' Calculation	Condition 1 model	Condition 2 model	Insulated Joint	Empty Joint
(mm)	(W)	(W)	(W)	(W)	(W)
70	3.52E-5	3.71E-5	3.87E-5	3.78E-5	7.93E-5
90	2.67E-5	2.80E-5	2.89E-5	2.84E-5	6.20E-5

The effective U-values of panel, considering the effect of Ψ− values of fully insulated and no insulated joints on a given panel width of up to 12.0 m are plotted in the figure below. As can be seen from the plot, the effect of thermal bridge on the overall U-values for both panel thicknesses (70 and 90mm) are indistinguishable. The graph shows a huge percentage increase in effective U-values of panel with no insulation in the joint. It can also be deduced that, the impact of no insulation in the joint on U-values reduces as the panel width increases.

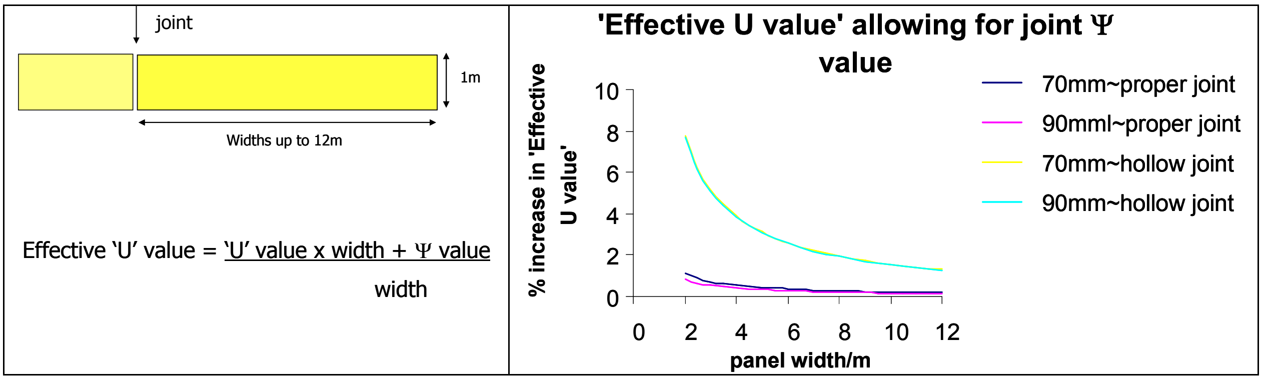


Figure 54: Thermal break in light steel wall

<u>*Simplified calculation methods for U-values of steel cladding systems*</u>

The aim of this study is to propose a simplified calculation method for the evaluation of thermal transmittance coefficient (U-value) of a given steel wall.

Simplified calculations can be used in the preliminary design stage. However, for regulatory calculations or final design, more accurate calculations should be done.

In the calculation of a wall's U-value, the greatest challenge is to know the part of repeating thermal bridges (ΔU). Generally, the calculation of heat transfer through a thermal bridge requires the use of methods with numerical resolution like finite element or finite difference method. The European Standard EN ISO 10211 describes the calculus method for 2D and 3D thermal bridges and superficial temperatures. Figure 55 shows an example of a numerical calculation of thermal bridge.

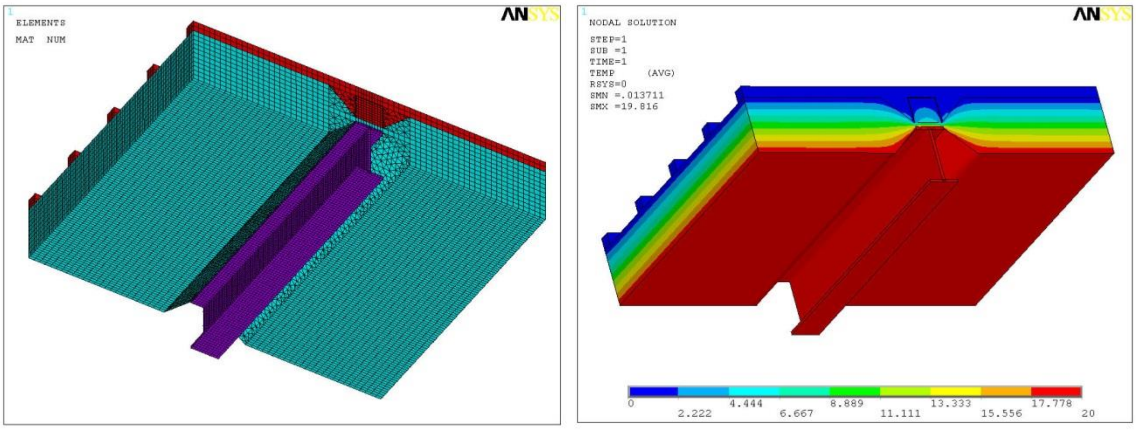


Figure 55: Example of FE calculation of 2D thermal bridge

Infrared surveys are often used to find the location of thermal bridges in a building envelope. However, it is difficult to deduce a Ψ-value from a thermal image. Below an estimate of Ψ from the temperature difference observed on a thermal image:

0 à 2 °C	$\Psi < 0.1$ W/(mK)
2 à 4 °C	$0.1 < \Psi < 0.5$ W/(mK)
> 4 °C	$\Psi > 0.5$ W/(mK)

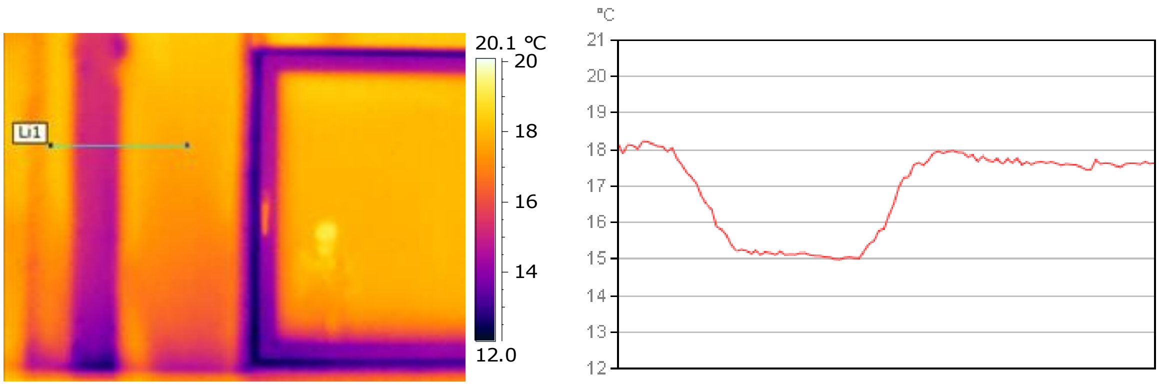
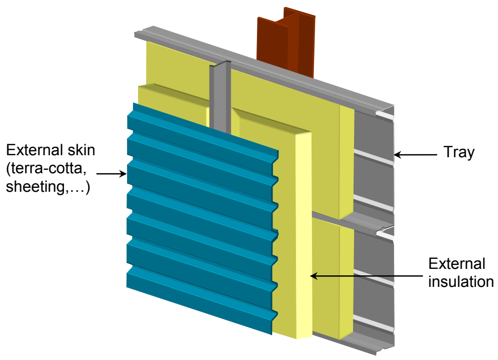
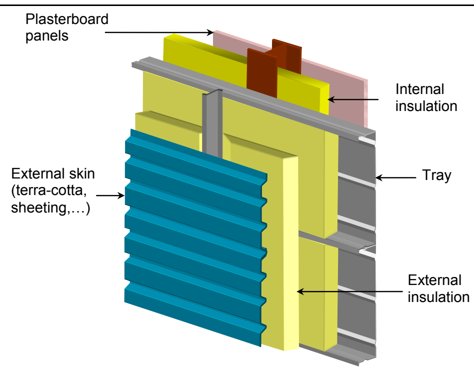
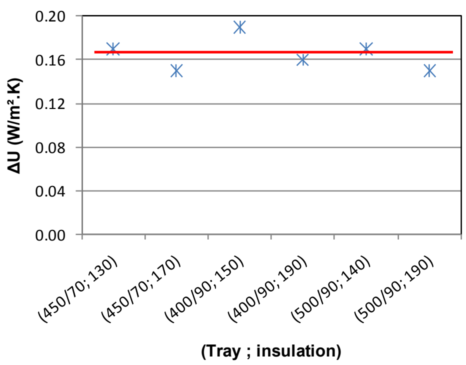
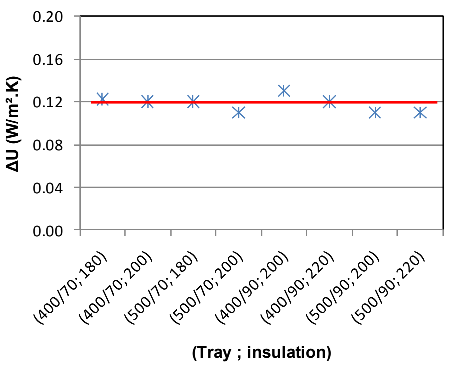
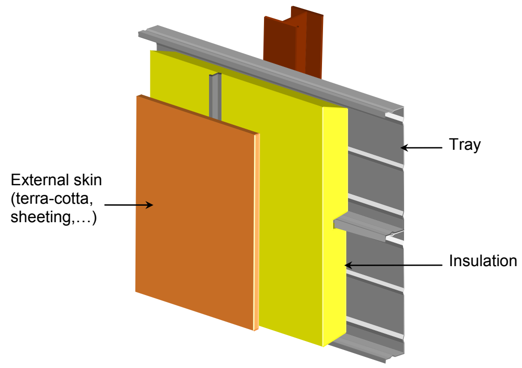
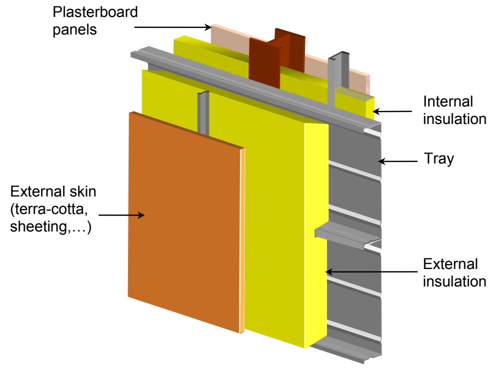
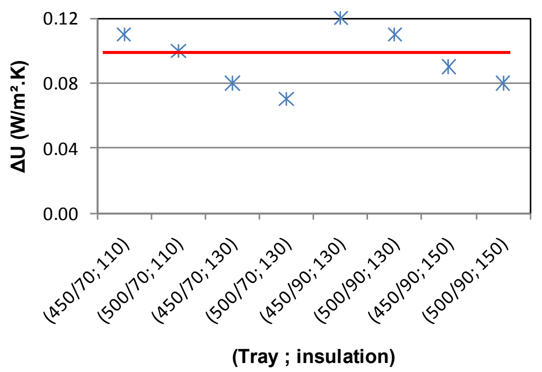
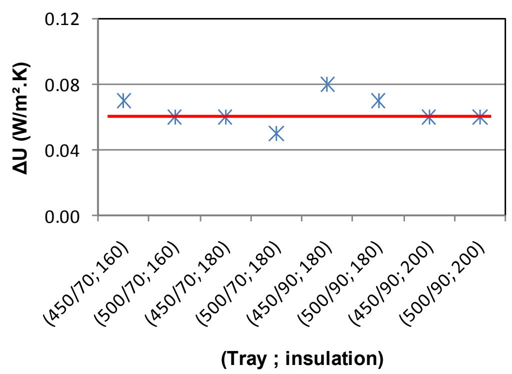


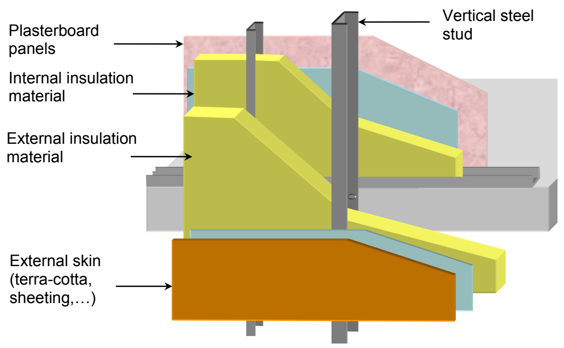
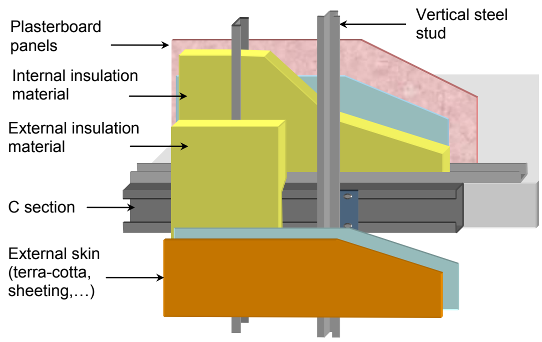
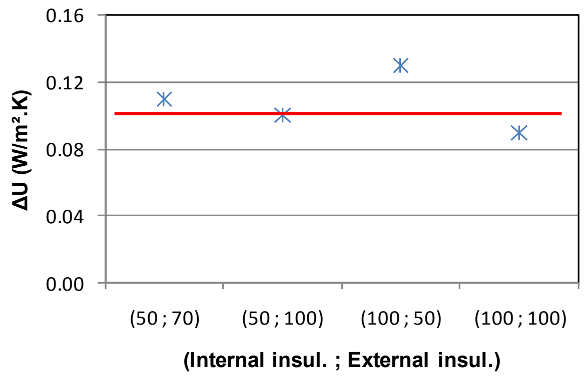
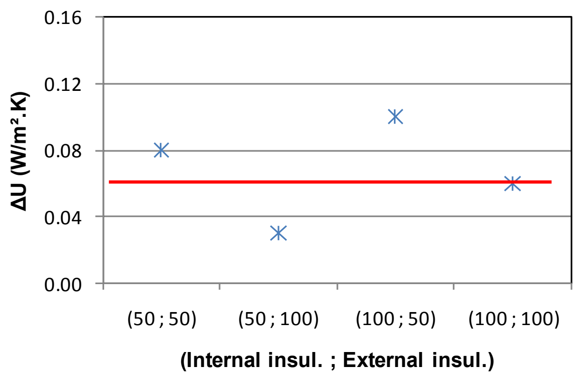
Figure 56: Example of IR survey – Thermal bridge due to a steel beam

In France, the thermal regulation gives values of ΔU for some wall configurations. These values can be used in the absence of a more detailed calculation (numerical). However, these values are generally disadvantageous.

Below we give values of ΔU for some examples of steel walls. These values result from numerical simulations carried out by CTICM and from the new thermal regulation RT 2012.

Double skin cladding with two layers of insulation	Double skin cladding with two layers of insulation and additional internal insulation
	
	
$\Delta U = 0.17$ W/(m²K)	$\Delta U = 0.12$ W/(m²K)

Double skin cladding with a single layer of insulation	Double skin cladding with a single layer of insulation and additional insulation
	
	
$\Delta U = 0.10$ W/(m²K)	$\Delta U = 0.06$ W/(m²K)

Metal frame fixed to floors – Direct fixation	Metal frame fixed to floors – Fixation with C sections
	
	
$\Delta U = 0.10$ W/(m²K)	$\Delta U = 0.06$ W/(m²K)

2.6 Report on simplified calculation methods for U-Values of steel cladding systems

As part of that project a new simplified calculation method for U-Values of steel cladding systems has been developed. The results have been implemented in new European regulations. An extract of these regulations is given in **Deliverable WP 2c**.

2.7 Comparing thermal performance of lightweight steel envelopes and heavyweight construction (Deliverable WP 2d)

The aim of this study is to compare an equivalent building made of concrete facade and the same building with facade made of steel elements that should be able to maximise the use of steel in combination with other materials. This comparison is done only in terms of thermal performances and under some conditions and hypothesis.

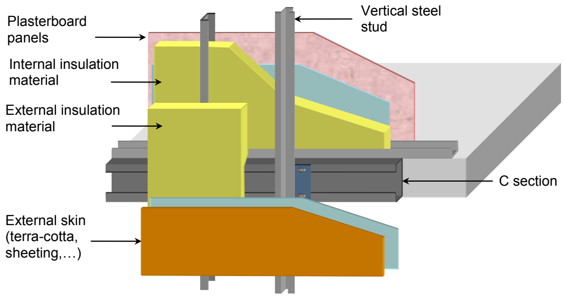
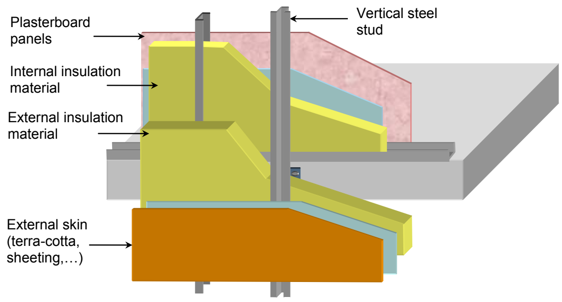
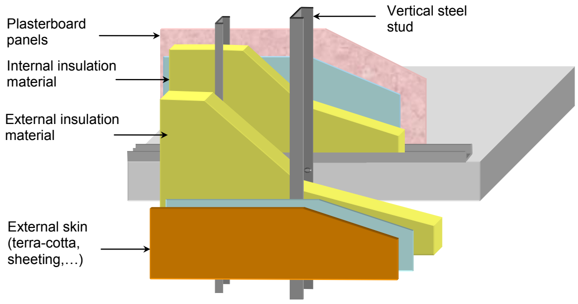
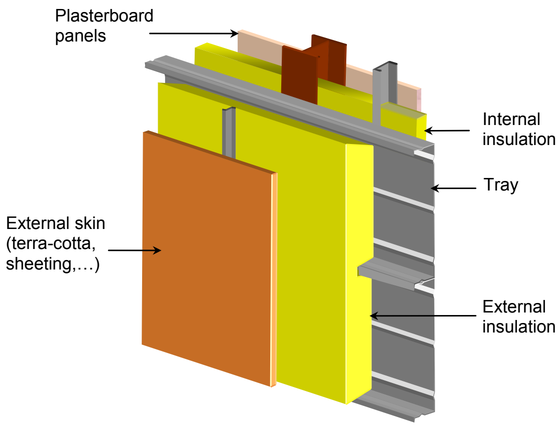
The building chosen for thermal evaluation is the "Jeanne de Champagne" building. This 6 levels residential building is composed of 14 apartments.

Figure 57: Jeanne de Champagne building: area 2370 m². Location: department 51

The building was built in 2002 under the French thermal regulation RT 2000. However, in this study, we selected more efficient walls, representative of current practice in France.

One of the main goals of this analysis is to show that steel-based construction can achieve good performances with probably a lower cost.

For the comparison we have made 5 proposals based on the same building. These proposals differ only in façade composition. All other walls and systems are identical. These proposals are:

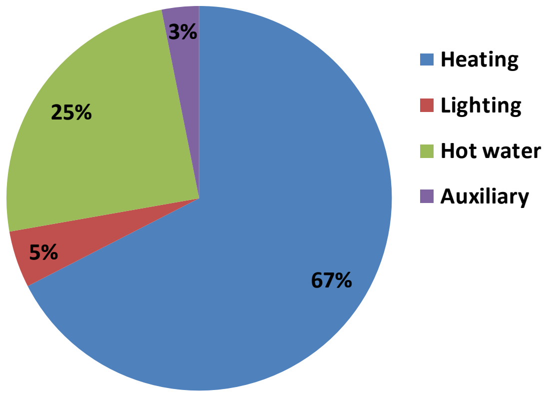
System 1	Concrete classical building		
System 2	Metal frame fixed to floors	Alternative 1: Fixation with C section	
System 3	Metal frame fixed to floors	Alternative 2: Fixation with brackets	
System 4	Metal frame fixed to floors	Alternative 3: Direct fixation	
System 5	Double skin cladding with trays and additional insulation		

It should be noted that the difference between the concrete proposal and steel ones differ only in the façade thermal performances (U-value), the junction thermal bridges (especially at the intermediate floors) and the thermal inertia (more important in the case of concrete building).

After the calculation method and the hypothesis have been defined (see detailed report), the following thermal performances have been calculated for the different systems.

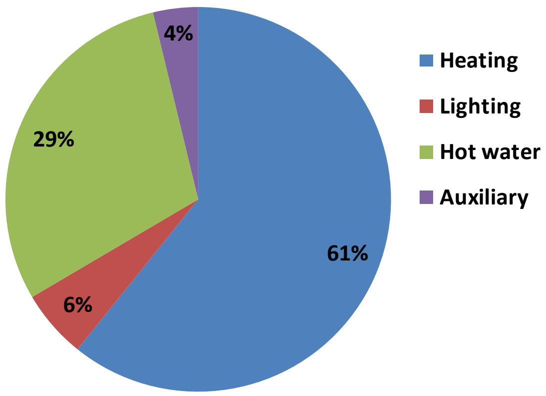
1. Thermal performances of the building with a concrete façade.

Ubât	0.84 W/m².K
Cep	116 kWhep/m².an
Tic	27.3 °C



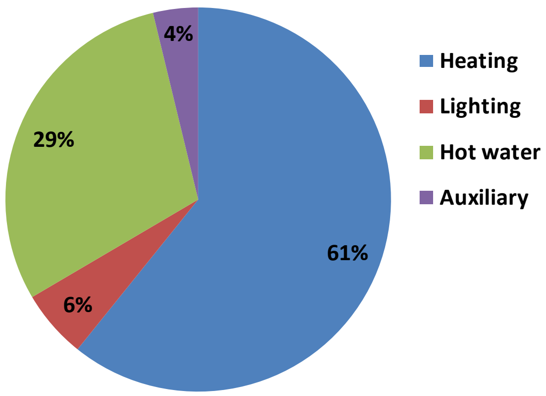
2. Thermal performances of the building with a steel façade (metal frame fixed to floors - fixation with C section).

Ubât	0.70 W/m².K
Cep	96 kWhep/m².an
Tic	29.1 °C



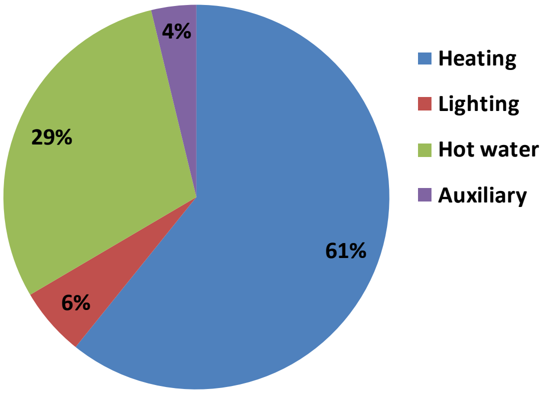
3. Thermal performances of the building with a steel façade (metal frame fixed to floors - fixation with brackets).

Ubât	0.66 W/m².K
Cep	91 kWhep/m².an
Tic	29.1 °C



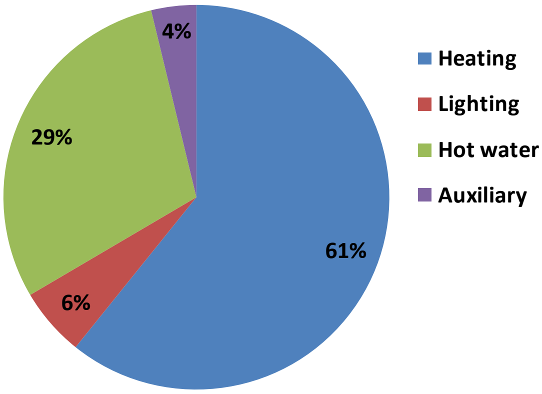
4. Thermal performances of the building with a steel façade (metal frame fixed to floors – direct fixation).

Ubât	0.69 W/m².K
Cep	95 kWhep/m².an
Tic	29.1 °C



5. Thermal performances of the building with a steel façade (double skin cladding with trays and additional insulation).

Ubât	0.64 W/m².K
Cep	87 kWhep/m².an
Tic	29.1 °C



Conclusion

In this study we evaluated the thermal performance of a residential building with different façade systems.

With the chosen assumptions, especially the need to maintain the same living space, the results show that the steel facade systems have better energy performance. However, the comfort temperature is higher than the concrete solution due to a smaller thermal inertia for steel solutions.

System	**Ubât** (W/m².K)	**Cep** (kWhep/m².an)	**Tic** (°C)	**Thickness** (mm)
Concrete classical building	0.84	116	27.3	327.5
Metal frame fixed to floors – Fixation with C section	0.70	96	29.1	264.5
Metal frame fixed to floors – Fixation with brackets	0.66	91	29.1	264.5
Metal frame fixed to floors – Direct fixation	0.69	95	29.1	264.5
Double skin cladding with trays	0.64	87	29.1	294.5

3 Innovative techniques for improved thermal comfort

3.1 Introduction

In the past, light-weight steel construction was not considered as particularly comfortable during the summer. Overheating is a problem of growing importance, the energy demand for cooling must be taken into account for the calculation of the energy performance. The EPBD explanatory statement pointed out, that “Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques (…)”. On the other hand, slender beams and columns increase the use of daylight and innovative steel products can be used as solar shading devices.

Thus it has to be pointed out, in what extent thermal inertia is beneficial for thermal comfort and energy efficiency. This has to be investigated based on a systemized approach, covering ventilation, shading, location etc.

An interesting option in particular for very light-weight buildings is the integration of so called Phase-Change-Material (PCM), the offers the opportunity add remarkable thermal inertia with very few additional mass.

A further relevant field of action for the steel sector within this area is the solar shading. Identification and presentation of available products and the determination of solar shading quantities is needed to enlarge the market share of these products.

3.2 The benchmark building concept

It is not possible to select a specific building configuration that is representative for the whole of Europe. Several approaches have been considered to find an appropriate configuration for benchmarking the various innovative techniques proposed in this project to improve thermal comfort.

To have a broader view of the overall building performance, a reference building comprising various reference zones has been defined. It is clear that there should be at least three reference zones for each façade so they account for all the possible combinations between orientations and exposed external walls. It is also important to account for heat transfer trough both the basement and the top part of the building (roof area). Therefore, the building defined must have at least 3 floors above ground and 9 reference zones for each façade. A cubic shape has been selected for being a broadly used shape (Figure 58).

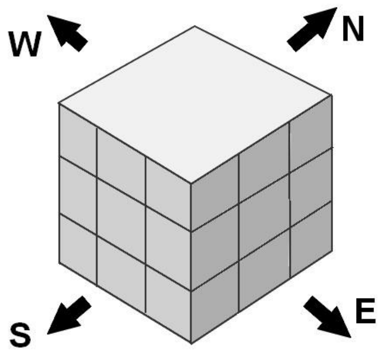


Figure 58 : Generic benchmark building, principle

The building is orientated to the main cardinal points and all the simulations are carried out following that lay out. It was decided to keep always the geometry and orientation of the benchmark building unaltered, to only allow exchangeability on the facades, roof and the flooring systems.

This benchmark building is used for the optimisation of thermal inertia and ventilation strategies (chapter 3.3) and the investigations concerning integrated façade design (chapter 3.5).

3.3 Optimisation of thermal inertia and ventilation strategies

Combined with thermal inertia, there are a number of passive strategies that influence the thermal performance of any steel intensive building. It is interesting to assess and quantify the effect of those strategies before focusing on thermal inertia and how they interact. By doing so, we will be able to get a more precise idea about the affection of thermal inertia over the whole building energy consumption.

The benchmark building characteristics previously defined have been used to produce a number of models that will be used to assess how the following aspects affect the energy demand of a steel intensive building:

- Façade thermal transmittance:
- Roof thermal transmittance
- Window characteristics

These aspects strongly affect the energy consumption of a building. However, they are focused on elements that comprise the building envelope, which is claimed to have a limited affection over the building thermal mass. The goal of analysing these aspects independently is to control their affection before the thermal inertial specific study is conducted.

A broad number of scenarios have been simulated and various alternatives and characteristics have been modified throughout the analysis in order to identify their influence over the study. These are as follows:

- Usage: focus on commercial and residential buildings
- Set point temperature and internal gains
- Weather conditions: Bilbao, Berlin, Helsinki and Madrid
- Relative window areas
- Air infiltration
- Lighting conditions

A comprehensive report is given as **Deliverable WP 3a** - Report on optimised strategies to combine thermal inertia and ventilation to prevent overheating in lightweight steel buildings. The main results are summarized below.

3.3.1 Window characteristics, façade and roof thermal transmittance

The effect of the façade thermal inertia over the building energy consumption is very much limited. A 5 cm air cavity has been considered and variable polyurethane (PU) thicknesses (3, 6, 8 and 14 cm) have been selected for the different solution studied.

The effect of the roof thermal inertia over the building energy consumption is very much limited. Variable extruded polystyrene (XEPS) thicknesses (8, 12, 16 and 20 cm) have been selected as insulation for the different solution studied.

Two relative window areas have been selected. The difference between commercial and residential buildings has also been made relevant with the type of windows used. Due to the considered usages, the internal conditions vary and therefore the requirements for the glazing solar factors.

The following conclusions are drawn after analyzing the results from the models:

- Reducing the thermal transmittance of the façade (increasing its insulating properties) produces a clear reduction on the heating demand. The amount of heat lost through the building envelope throughout the winter time gets limited when the thermal transmittance reduces down to a certain point.
- The opposite pattern is found in the cooling mode. The cooling demand slightly increases as the thermal transmittance reduces. This might be due to the fact that increasing the insulting properties of the building envelope increases the difficulty to transfer the internal gains to the exterior, needing a higher cooling demand to keep constant internal temperatures. This effect is very much climate dependant.
- The heating demand reduction is higher than the cooling demand and therefore, reducing the thermal transmittance seems to be a positive strategy to achieve increased thermal efficiency. This strategy however should compare also heating and cooling economical and environmental cost to provide an integral answer to the optimal building envelope U-value.
- The reduction in the opening area in the southern, eater and western facades produces for the same insulating thicknesses an increment in the heating demand. This is due to a reduction of the solar gains associated to the openings in heating modes.
- In case of refrigeration mode, the evolution is the opposite. The cooling demand gets reduced due lower solar gains through the windows.
- Reducing the thermal transmittance of the roof produces the same effect as in the case of reducing the thermal transmittance of the facades. However, the variations in the demand are less important than in the case of reducing the roof U-Value due to the fact that the roof has a lower surface than the facades.
- In conclusion, the heating demand gets slightly reduced and the cooling demand increases when the roof insulation increases.
- The same patterns as in the case of modifying the façade thermal transmittance is found for the roof when the percentage of openings is reduced. There is however a larger change in the calculated demands. This shows how important the façade characteristics are, in comparison to the reduced effect of the roof due to its limited area.
- The heating demand grows when the window solar factor increases. The lower the solar factor, the lower the solar gains and the larger the heating demand.
- For the same reason, the cooling demands decrease when the window solar factor increases.
- The selection of the most appropriate windows needs to take into consideration both, the heating and the cooling demand. Not only the energy demand but the environmental and economical cost should be considered when selecting the windows.
- Future works should consider the assessment of various solutions with identical solar factor and variable thermal transmittances. It is expected that the predominant affection of the windows over the building energy demand are the solar gains produced by the openings rather than the heat transfer due to convection and conduction through them.

3.3.2 Thermal inertia and ventilation

The conclusions drawn for northern Europe, after conducting the simulations are as follows:

- In general terms an increased thermal mass generates a slight cooling demand reduction for residential use.
- In general terms an increased thermal mass does not generate a significant cooling demand reduction for commercial use.
- For northern Europe, an increased thermal mass does not generate important benefits in terms of cooling demand reduction. This is especially true for commercial use.
- Night ventilation rates up to 4 ac/h generates important cooling demand reductions. Further increased night cooling rates generates smaller reductions on cooling demand.

Further conclusions for southern Europe:

- Increased thermal mass generates a moderate cooling demand reduction for residential use
- In general terms an increased thermal mass does not generate a significant cooling demand reduction for commercial use. The most probable cause would be an insufficient air flow (night cooling) to completely eliminate the energy stored in the thermal mass of the floor slabs.
- In order to evaluate the potential of thermal mass and night cooling ventilation optimization strategies, solar shading strategies shall also be considered.

As final conclusion, we can affirm that it is necessary to perform a global optimization of all the effects studied, in order to achieve the best energy total demand (best balance between heating and cooling demand). So it will be necessary to optimize:

- For heating demand: Glazing area, thermal and optical properties of glazing (U, etc) and thermal mass of floor slabs.
- Cooling demand: Night cooling strategies (air flows and schedules), thermal and optical properties of glazing (U, etc) and shading strategies
- Furthermore, especially for commercial use, a very important factor to take into account must be the illumination demand and comfort issues, as well as its influence on heating and cooling demands.

3.3.3 CFD analysis

Night-time ventilation cooling has a significant potential in reducing the cooling energy in office buildings. In northern and central Europe mechanical cooling can even totally avoided by utilizing the thermal mass. When the night-time outdoor air temperature is low enough, natural or mechanical ventilation is used to cool the exposed thermal mass of a building in order to provide a heat sink during the following day. The performance of night cooling was studied by using thermal building simulation tool IDA ICE and partly CFD-code Comsol Multiphysics (CFD: Computational fluid dynamics).

The following conclusions are drawn after analyzing the results from the models:

- The cooling energy needed in the simulated office building is only about 20 % of total electricity. Therefore the potential for energy saving by night cooling is not very big. Anyway the electrical energy for HVAC (refrigeration cooling, fans and pumps) can be reduced about 10 % by exposing the massive floor and massive ceiling to cold night air. Increase of thermal mass by making the external walls of concrete has only a minor effect. On the other hand, the suspended ceiling has a clearly negative impact by making the room thermally light. Increase of air flow rates during night reduces the cooling energy but care must be taken that the increased fan energy does not eat the cooling energy benefit. This can be assured by sizing the air flow ductwork for increased air flow rate. Other possibilities are to use natural or hybrid ventilation which needs much less electric energy.

- The energy saving by night cooling may be higher by fine-tuning the present control system. For example the minimum room temperature might be lower than in the present study (22 °C). In northern and central Europe the investment on mechanical cooling can even be totally avoided by night cooling.
- A larger surface area for the thermal mass elements may be more helpful than increasing the absolute amount of mass. Thus, thin thermal mass elements spread around the space on the floors, ceilings and walls are more likely to be useful and more suitably placed for both radiation as well as receiving direct solar gain
- The night cooling also lowers the operative temperature because the room surfaces are colder during daytime. This makes it possible to use about half degrees higher room air temperature for the same thermal comfort.
- The accurate simulation of night cooling is not an easy task. Dynamic building thermal simulations can be done but to be accurate, the room flow and temperature pattern should be taken into account. This was demonstrated in the present study by making CFD-simulations for an office room. The convection heat transfer depends considerably on the air supply principle and design.

3.4 Phase Change Materials (PCM)

A phase change material (PCM) is a material which is capable of storing and releasing large amounts of energy by the change of state from either melting or solidifying at a certain temperature. The energy is in the form of heat generated which can be absorbed or released when the material changes state i.e. solid-solid, solid-liquid, solid-gas and liquid-gas phase changes.

PCM is also referred to as latent heat stores and the effect of latent heat brings about two advantages:

- ability to store relatively large quantities of heat in a range of small temperature changes
- and thus achieve high storage densities

The most interesting application of PCM in buildings is referred to the potential of reducing the energy consumption by reducing its cooling demand, as PCMs changes phase at a constant temperature over some period of time, therefore it is possible to smooth out temperature fluctuations and minimize temperature peak. Most PCMs used in the industry mainly feature phase changes from solid to liquids and they tend to be capable of reversing the change multiple times.

The main information about PCM's properties, manufacturers, and types of products is contained in Deliverable 3b - Report on innovative use and test results of Phase-Change Materials. As a brief summary the following table represents their main characteristics:

Table 7 : Main characteristics in PCMs for building applications

Type of PCM	*Usual melting point temperatures for in construction applic.*	*Main advantages*	*Main disadvantages*
Organic PCMs: Paraffin waxes mainly made up of alkanes' (about 75%) & Fatty acids can originate from meat by-products and vegetable/plant extracts	For paraffin waxes between 19 and 44 °C	- Compatible with various materials and suitable for absorption into various building materials - high heat of fusion - Recyclable - Easier to contain than inorganic salt hydrates	- Flammable - Generates harmful fumes combustion - Volumetric latent heat storage capacity is low, - Tend to be more toxic than inorganic - Requires encapsulation for liquid phase
Inorganic: PCMs: Hydrated salts; Glaubler's salt (sodium sulphate decahydrate) and K-18	Between 19 and 36 °C	- Not flammable - High latent heat values - Inexpensive - Higher thermal conductivity compared to organic	- Corrosive - Unstable (more stable than paraffin, but less stable than fatty acids) - Absorb moisture easily (reducing their effectiveness) - Requires encapsulation in order to contain the liquid phase

Paraffin and salt hydrates are identified as the most promising/ common types of PCM to be applied into the building fabric. The methods of incorporating PCM effectively into the building components of a wall panel, floor panel and roof panel are very important. As an example, the following figures represent the application of PCMs macro-encapsulated into wall panels and applied into a composite floor deck whereas it can be located in different ways (embedded in concrete, lined in through of steel deck and underside of steel deck)

An extensive numerical study mainly dealing with the application of PCM in steel sandwich panels is given in **Deliverable WP 3b**, additionally measured results of a small test building are presented. The main results are:

A deeper study considering the dynamic effect of PCMs shows that the incorporation of PCM in a composite panel both increases the surface heat flux across the internal surface and reduces the surface temperature over a 24 hour cycle. A layer of PCM close to the internal surface has an approximately 7 times increase in surface heat flux than that of the same amount of PCM distributed uniformly in the foam. This is due to the insulating nature of the foam and the PCM further away from the internal surface take longer to become effective.

The internal surface temperature reduces slightly due to the uniformly distributed PCM but significant reduction in surface temperature is observed with the PCM layer close to the surface. The external surface temperature sees a large change in percentage terms due to the inclusion of the PCM but in real terms this temperature change is small. This is due to the fact that the PCM is not allowing heat pass through the panel.

The practical tests also show that the heat gain is lower during a day following a hot night. This can be explained by the fact that the PCM is not chilled enough during the night and then it is not able to store as much as heat the following day.

PCM is a solution for the management of energy in building giving rather good results as it has being demonstrated in the previous numerical and experimental analysis. However, there are some issues to overcome and where R+D can contribute significantly in order to get more efficient solutions.

The quality and testing specifications and the implementation regulations for awarding and using the quality mark for Phase Change Materials are identified by the german institute for quality assurance and certification. PCM must survive a defined number of cycles without damage. More than 10000 cycles are required to attain the highest category A [1].

Some products that exceed this number of cycles are presented at the website of PCM Energy P. Ltd [2]. A pilot plant in Hamburg use PCS which are composed of a carrier liquid, microencapsulated in the PCM as a dispersed suspension. For the used fluid a stability of more than 100000 cycles could be demonstrated in the laboratory [3].

Sources:

[1] Güte- und Prüfbestimmungen für Phase Change Materials

http://www.pcm-ral.de/uploads/media/RAL_GZ_896_Phase_Change_Material_2010_01.pdf

[2] PCM Energy P. Ltd

http://www.pcmenergy.com/products.htm

[3] Projektinfo 16/2012 BINE Informationsdienst
http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2012/Projekt_16-2012/ProjektInfo_1612_internetx.pdf

3.5 Solar Shading Elements in steel

The main steel intensive solar shading systems are:

- Continuous steel plates
- Perforated steel plates
- Expanded steel plates
- Stainless steel meshes

Figure 59: Stainless steel meshes used as solar shading systems

These have been studied following two approaches:

- effect of solar shading systems on energy demand
- geometrical study of shading affection

A comprehensive report is given in **Deliverable WP 3c** – Report on integrated façade design for the use of daylight and to prevent overheating for different European climates.

The conclusions drawn for northern Europe, after conducting the simulations are as follows:

– Due to the reduced availability of solar radiation installing static shading elements generates a moderate heating demand rise. This is in part because the shading elements have only been placed in east and west orientations (Generally speaking, installing shading elements in north orientation makes no sense. The same way, installing static shading elements in south orientation is not an adequate criteria).
– The installation of static shading elements has a significant impact in terms of cooling demand reduction. In fact, the impact on cooling demand is clearly higher than that on heating demand. The best total demand result takes place when using the S1 shading element (40 % open area).
– The impact of using static shading elements on lighting demand is moderate. Besides, as the value of this demand is clearly below those of heating and cooling, its impact on the total energy demand is not determining.
– In heating regime, the use of a slab solution with increased thermal mass generates a moderate heating demand reduction. However, in cooling regime, this strategy leads to a moderate cooling demand rise unless shading elements are used in combination with night cooling. So, in order to get the benefits from an increased thermal mass solution, it is necessary to simultaneously make use of shading and night cooling strategies.
– When considering façade designs with moderate glazed surfaces, heating is the dominant regime, and therefore increased thermal mass slab solutions reduce the total energy demand (even when shading and night cooling strategies are not considered).
– When considering façade designs with high glazing area percentages, heating is still the dominant regime but the weight of the cooling regime rises considerably. As a consequence, slabs with increased thermal mass do not work properly in terms of cooling demand reduction, even if shading strategies are applied (furthermore the total demand reduction will be negligible). This approach could only be successful if coupled with night cooling strategies.
– So as a general conclusion, it can be stated that the most opaque shading elements, generate the minimum total energy demand. Furthermore, if we consider that total energy demand rises with increased glazing area percentages, it could be stated that for northern Europe solar gain strategies do not generate decisive improvements in the thermal behavior of the building. The increment of solar gains associated to the use of heavily glazed facades, can’t compensate the increment of energy loss by convection over glazed surfaces. But simultaneously, can generate important cooling demand increments that make necessary using shading elements and night cooling during cooling season, in order to avoid the cooling demand rise.
– The described trends are even more pronounced, with lower solar irradiation availability, (lower solar gain) and lower average exterior air temperatures during the heating season (bigger losses by convection). This can be seen, if we compare the figures from Helsinki and Berlin.

Further conclusions for southern Europe:

- Cooling is the dominant regime, due to the high internal gains and to the high available solar gains (even for moderate percentages of glazed surfaces). The use of static shading elements smooths this behavior. However for facade designs with high percentages of glazed surfaces, in order to equilibrate heating and cooling demands, the installation of shading elements in all the orientations of the building (even in south orientation) is necessary
- That way for façade designs with moderate percentages of glazed surfaces (30%), the best total energy demand will be achieved by installing shading elements in east and west facades. But for higher percentages of glazed surfaces (50%), it will be necessary to extent the use to the shading elements to the south façade. This clearly indicates that solar gains associated to such high percentages of glazed surfaces are excessive and make no sense (the reduction achieved in heating and lighting demand is no longer enough to compensate the dramatic cooling demand rise).
- In general terms, the use of static shading elements generates a significant increase in heating and lighting demands. But as the prevailing working regime is cooling, the cooling demand reductions achieved with shading elements can easily compensate the heating and lighting demand rises.
- Evidently, for façade designs with high percentages of glazed surfaces, the available diffuse solar radiation is enough to avoid a significant lighting demand rise when shading elements are installed (even installing shading elements in south orientation).
- In heating regime, the solution with increased thermal mass works better than the base solution and the use of shading elements have no decisive impact in the heating demand (moderate heating demand rise). The high available solar radiation is enough to activate and to make use of the extra thermal mass of the slabs (even for solutions with moderate percentages of glazed surfaces).
- In cooling regime the use of solutions with increased thermal mass could be counterproductive. The capacity of heat storage of the building is increased but if no energy rejection mechanism is included, cooling demand will rise significantly. The installation of shading elements can smooth this behavior, but will not make worthwhile using high thermal mass slabs. This displays that in order to achieve an optimized total energy demand (make use of the potential of the thermal mass), it will be absolutely necessary to simultaneously apply shading and night cooling strategies.

General conclusions that can be applied to southern and northern Europe.

- The percentages of glazed surfaces in east and west orientations (secondary orientations) should in general be kept moderate.
- Static steel shading elements installed in east and west orientations have a significant potential to improve the energy efficiency and comfort conditions of buildings
- The use of static shading elements on south orientation has to be studied for each case, and should not be generally applied, but it has anyway a significant potential for energy efficiency improvement. For example, in uses with high internal gain (offices, commercial, etc) and high solar radiation availability using this kind of shading elements will simultaneously allow making use of day lighting (to a certain extent) and generate a cooling demand reduction.

All the performed set of simulations have been useful to evaluate the isolated effect on the energy demand of all the analyzed parameters (glazed surface percentages, thermal mass, night cooling, shading elements) and to identify some design criteria necessary to achieve good building designs from an energy efficiency point of view, for different climatic conditions:

- The percentages of glazed surfaces must be optimized for each orientation.
- The shading strategies must be optimized for each orientation
- For the north of Europe the potential of solar gain strategies is limited so the optimum percentages of glazed surfaces will be relatively low. Therefore, design issues related with thermal mass and night cooling could be less relevant
- For the south of Europe the potential of solar gain strategies is high so it is crucial to adequately solve in an integrated way all the design issues related with thermal mass, night cooling and shading.

In any case, the most important conclusion obtained from all the performed analysis is that in order to carry out the integrated design of the optimized façade it will be necessary to identify the best compromise solution for all the design aspects that affect the energy performance (% of glazed surface, glaze thermal and optical properties, thermal inertia, night cooling, shading elements).

4 Real building performance data

4.1 Overview

The objective of WP 4 is a detailed investigation of the energy performance and the thermal com-fort of steel buildings. The goal is to provide positive examples of energy efficient steel buildings and also to identify areas for further improvements.

The following list summarizes the specific buildings for study, testing and development of monitoring programs.

Table 8 : The selected buildings for the different monitoring programs

Climatic Zone	Location/ resp. Partner	Use/ occupancy	Level of investigation
North Europe	Finland/ VTT	Non-residential building	1
	Finland/ VTT	Residential building A	1
	Finland/ VTT	Residential building B	1
	Finland/ VTT	Residential building C	1
	Finland/ VTT	Residential building D	1
	Finland/ VTT	Office and factory building	2
South Europe	Spain/ Tecnalia	LKS Office building building	2
	Spain/ Tecnalia	School	1
Central Europe	UK, Ascot/ SCI	Residential buildings	2
	UK/ Tata	Office building	2
	Germany/ RWTH	Modular Research Building	2
	Germany/ RWTH	Industrial building (Laboratory hall RWTH)	1
	Belgium / CRM Liège	Office building	3
	Belgium/ Arcelor Liège	Experimental house	1
	Belgium/ Arcelor Liège	Residential building, Villavenir	2

In the early phase of the project the monitoring concept were discussed and a template for the way of reporting was developed. The consumption of energy for heating purposes should be normalized according the “degree-day method”. This method was used for most of the buildings (Belgium, France, Finland, Germany, residential buildings UK). Nevertheless, for some projects the measured data were collected before the ETHICS project started, for some other buildings the measurement equipment was fixed, thus the data base is not fully in line for the different projects. A summary of the monitored energy data is given in table 9 at the end of chap. 4.4

Some of these projects were used to investigate the details (airtightness in WP 1, thermal performance in WP 2, thermal comfort in WP 3).

4.2 Whole building energy use of 8 steel buildings to give an indication Europe wide

WP 4.2 aims at collect and analyse energy data consumption according the level 1 of monitoring. This level of monitoring includes monthly and annual energy use of the building.

Deliverable WP 4a will be consulted for the results of this WP.

4.3 Monitoring and energy performance of 6 steel buildings (FI, DE, UK, BE, ES)

WP 4.3 is the level 2 monitoring. This level of monitoring should include monthly and annual energy use of the building. Additionally, level 2 includes hourly measurements including at least: space heating/cooling demand, DHW energy demand (for residential buildings only), overall electricity, outdoor conditions (external temperature and solar radiation), internal conditions (temperature and hygrometry).

Deliverable WP 4b will be consulted for the results of this WP.

4.4 Detailed monitoring of CRM4-building (BE)

WP 4.4 is the level 3 of monitoring. This monitoring includes monthly and annual energy use of the building. Additionally, level 3 includes hourly measurements including at least: space heating/cooling demand, overall electricity, outdoor conditions (external temperature, solar radiation, wind speed), internal conditions (temperature and hygrometry). This is a long term monitoring for a period of more than 2 years.

Deliverable 4c will be consulted for the results of this WP.

The following table gives an overview of the energy performance data of all the monitored buildings within the project (heating demand considering normalization according degree-day method if available):

Table 9 : Summary of monitoring results

Climatic Zone	Location/ resp. Partner	Use/ name	Level of investi-gation	Energy consumption [kWh/m²] heating / electr.
North Europe	Finland/ VTT	Office and factory building Innosteelfactory	2	75 / 158
	Finland/ VTT	Residential building A	1	155 / -
	Finland/ VTT	Residential building B	1	110 / -
	Finland/ VTT	Residential building C	1	180 / -
	Finland/ VTT	Residential building D	1	115 / -
South Europe	Spain/ Tecnalia	LKS Office building	2	153 / 103
	Spain/ Tecnalia	School	1	143 / 48
Central Europe	UK/ SCI	Residential buildings Birchway	2	42.7 / -
	UK/ Tata	Office building Wales	2	90.4 / 26
	Germany/ RWTH	Modular Research Building	2	91 / -
	Germany/ RWTH	Industrial building (Laboratory hall RWTH)	1	179 / -
	Belgium / CRM Liège	Office building CRM4	3	87 / 107
	Belgium/ Arcelor Liège	Experimental house	1	151 / 34.8
	France/ Arcelor Liège	Residential building Villavenir	2	243 / -
	Belgium/ Arcelor Lux.	Office building CAAL	1	Unexpected results

4.5 Thermal comfort in light weight steel buildings (Deliverable WP 4d)

<u>*Summary*</u>

The thermal comfort was both calculated and measured. Both the measured and calculated studies showed that the light weight steel buildings are performing well. In key aspects in thermal comfort in summer time is to avoid excess solar gains indoors by using shadings. In addition the ventilation/air conditioning systems air velocities should be low enough in the working/living areas. In winter time the key aspects are the heating system and ventilation air velocities. In measurements in indoor air temperatures were according to set point and the operative temperature was according to guidelines. In

simulations both light weight and heavy weight office building were compared in respect of thermal comfort by using a detailed human body model in dynamic simulations. The results indicated that the clothing level seems to have the greatest influence on thermal sensation and comfort and the thermal mass of the structures was playing only a minor role. The studied structures were not extreme massive and heavy structures but the typical structures used in office buildings. All cases have a relatively low predicted percentage of dissatisfied (PPD) with the right clothing for the season.

Assessment of thermal comfort

Thermal comfort has been defined by Hensen as ‘‘a state in which there are no driving impulses to correct the environment by the behaviour’’ [Hensen]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE defined it as ‘‘the condition of the mind in which satisfaction is expressed with the thermal environment’’ [ANSI/ASHRAE]. As such, it will be influenced by personal differences in mood, culture and other individual, organizational and social factors. Based on the above definitions, comfort is not a state condition, but rather a state of mind. The definition of thermal comfort leaves open as to what is meant by condition of mind or satisfaction, but it correctly emphasizes that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors [Lin].

Two widely used standards - ANSI/ASHRAE Standard 55-1992 (Thermal Environmental Conditions for Human Occupancy) [ASHRAE] and ISO 7730 (Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort) - present a necessary method (originally presented by [Fanger] in 1972) for evaluation of moderate thermal environment. When using this method, human's thermal sensation is related to the thermal balance of a body as a whole. This balance is influenced by occupant's physical activity and clothing, as well as the environmental parameters: air temperature, mean radiant temperature, air velocity, and air humidity [ISO 7730]. The method is derived for steady-state conditions and - due to treating a human body as whole - is does not allow estimations in any spatially non-uniform conditions.

Currently there are new methods to predict human thermal sensation and comfort under transient and non-uniform boundary conditions. The transient and non-uniform thermal environment as well as our body including our clothing are affecting to our thermal sensation and thus our comfort. Since neither the physiology nor the thermal comfort are not uniform to the whole human body, a detailed model is needed in order to estimate realistic thermal sensation. The model used here for estimating thermal sensation and comfort is based on [Hui]. Basically, the model calculates local human body part’s thermal sensations and local thermal comfort, and based on that information also the overall thermal comfort can be estimated.

For the estimation of thermal sensation and comfort, a human body model interacting with thermal environment is needed. The body model used here is based on Smith’s model (Smith 1991). In this model the human body is divided to 15 parts, and each body part has bone, muscle, fat and skin layers as well as blood circulation. The blood circulation and body core temperature is controlled by a human body control model which acts rather close as the real body “control systems”. For example, when human body core temperature rises above its neutral value, vasodilation occurs and cardial output increases dramatically. Nearly 100 % of this increase goes to the skin tissue. For this development, a state of maximum vasodilation is achieved when core temperature reaches 37.2 °C. At this state, the total skin blood flow rate may be as much as seven times its basal value. This increase in cardiac output is distributed to the individual body parts according to surface area [Smith 1991].

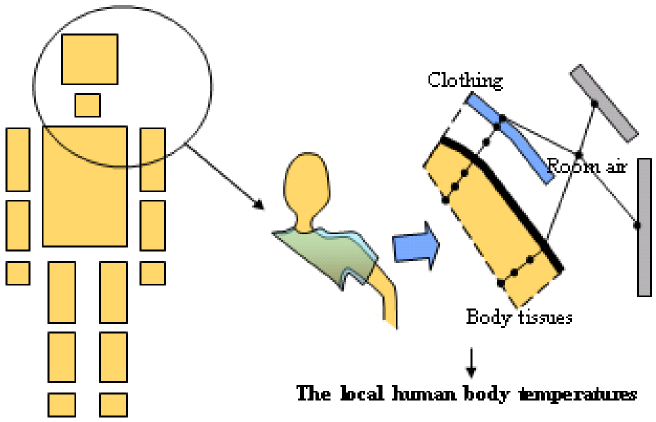


Figure 60: The human model is divided to 15 parts.

The model used in this study is based on Hui's study which includes results from 109 human subject tests that were performed under non-uniform and transients conditions in the UC Berkeley Controlled Environmental Chamber. In those experiments, local body surfaces of the subjects were independently heated or cooled while the rest of the body was exposed to a warm, neutral or cool environment. Skin temperatures, core temperature, thermal sensation and comfort responses were collected at one- to three-minute intervals [Hui]. The Figure above shows the flow chart how the overall thermal comfort is calculated.

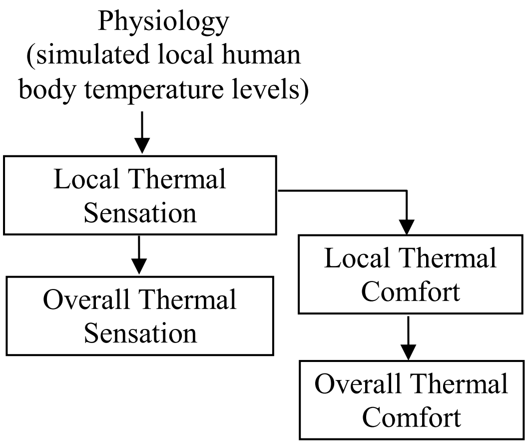


Figure 61: The Overall thermal comfort calculation flow chart

The local sensation model is a function of skin and core temperature and their rates of change. The model has a sub-model to each body part, and together they capture the asymmetry of thermal conditions. Local comfort is predicted from local sensations and average of all body's local sensations, and the overall sensation model integrates the local sensations. The whole body comfort model integrates the local comfort values. Overall thermal sensation is modelled as a weighted average from the local sensations:

For some body parts (e.g., chest and back) the weight is higher than for other parts. The weight is higher either due to body part size or sensitivity. Some body parts are not behaving similarly if the local sensation is higher or lower compared to average thermal sensation. One body part may be more important to determine cold than warm sensation. As the weight is a function between the difference of local and geometrical average of all sensations it assigns larger weights when the local thermal sensation is opposite to rest of the body's thermal sensation.

Sensation can have values from -4 to 4. Value 4 corresponds very hot, 3 hot, 2 warm, 1 slightly warm and 0 neutral. Local comfort is a function of local sensation and overall sensation and overall thermal sensation is a function of local thermal comfort. Comfort can have values from -4 to 4 and value 4 corresponds to very comfortable, 2 comfortable and 0 neutral.

<u>*Measured buildings for thermal comfort*</u>

Office building Vitoria, Spain

The building was located in Vitoria Spain, the building area was 5795,39 m^2. The building had isolated concrete foundations and concrete cut-off walls. The structure was hot rolled steel sections (IPE 240 and HEB240) and structural tubes, the floor was composite slab and the building had inverted roof system. The building had curtain walling.

Figure 62: Office building Vitoria

External temperature and relative humidity has been monitored in the building surroundings by sen-sors located with that intention. Complementary information (solar radiation, precipitation, wind direction, wind average velocity, wind maximum velocity, wind direction and velocity deviations) have been gathered by local weather stations situated 10 km away from the building in a landscape with similar characteristics.

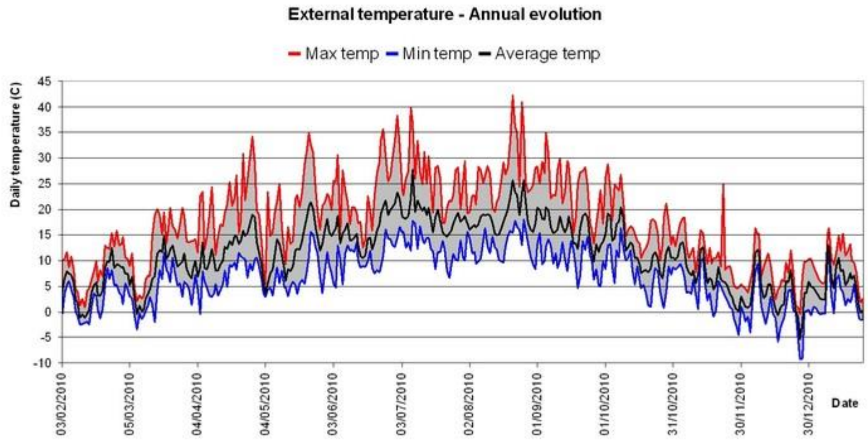


Figure 63: External temperature

Each of the floors is divided in a number of independent office rooms that are privately rented by different enterprises. Thermal comfort parameters have been monitored in one of those offices in the first floor. The selected office area is 569,2 m² and the sensor location has been defined to identify characteristic comfort patterns. The annual evolution of indoor temperatures over a whole year are in acceptable levels showing good comfort.

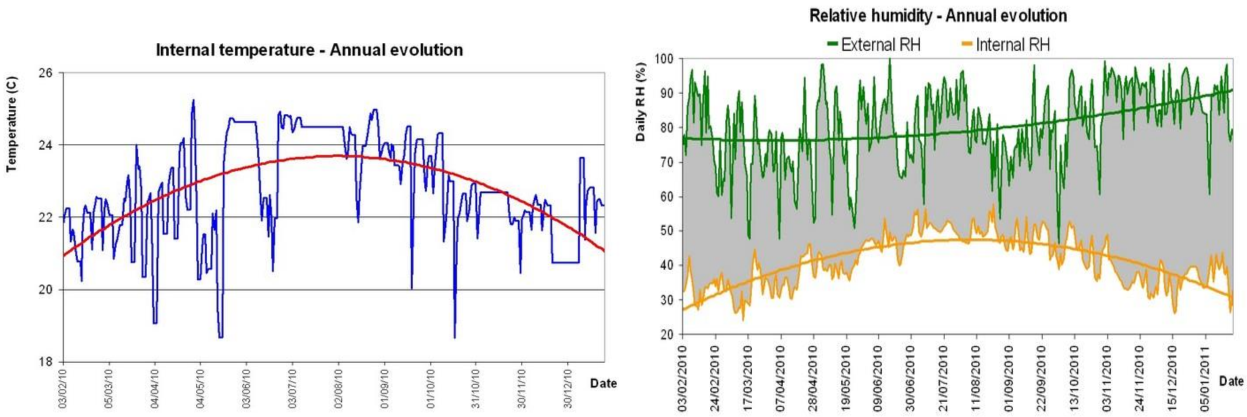


Figure 64: Office building Vitoria, internal temperature left, internal and external humidity (right)

The office building was both measured and simulated. The simulated results are analysed in different deliverable detailed. The simulated results gave similar trends but due to different actual climatic condition and internal loads, the simulated temperatures were somewhat different (not shown in picture). Even though the exterior conditions are rather high in temperature the indoor conditions were comfortable as from results in figure below can be seen. The monitored points are shown in floor plan in Figure above.

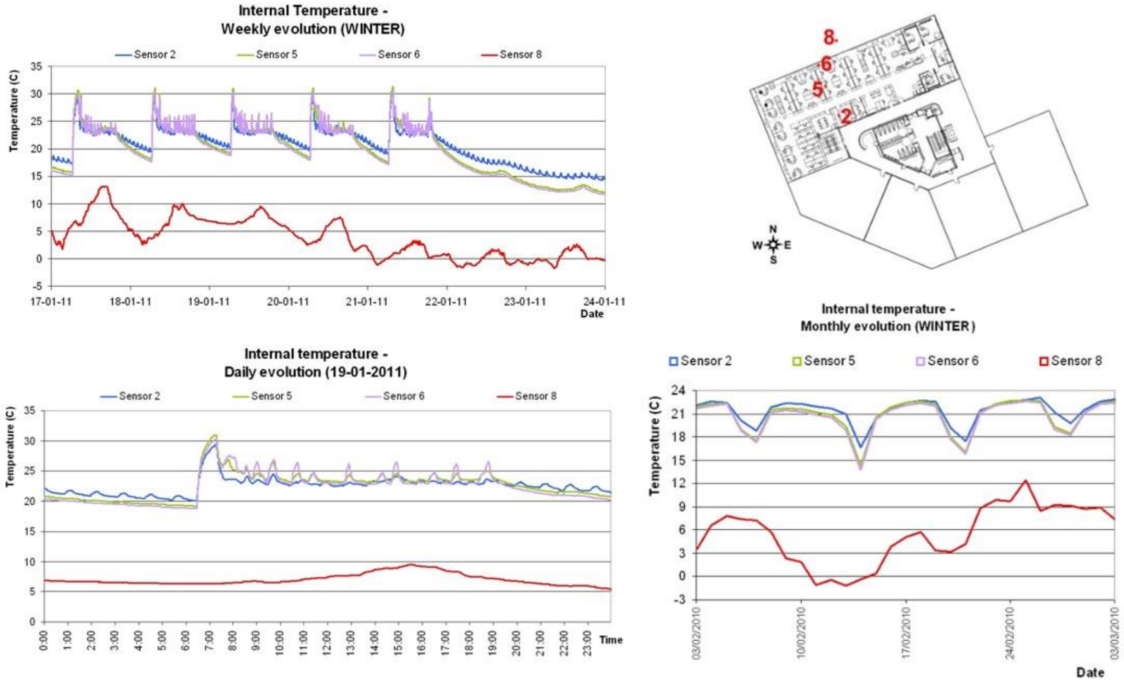


Figure 65: Office building Vitoria, indoor temperatures and monitoring point in the floor plan

Modular school Sant Boi, Spain

Figure 66: Modular school Sant Boi

Yearly climatic conditions have been gathered by local weather stations situated nearby the build-ing. Building internal temperature and humidity conditions have been recorded for a short period of time (one week) to evaluate set point temperatures and comfort conditions. The room and common area temperatures were acceptable during the measurement period. In small periods of time the temperatures indoors were slightly high.

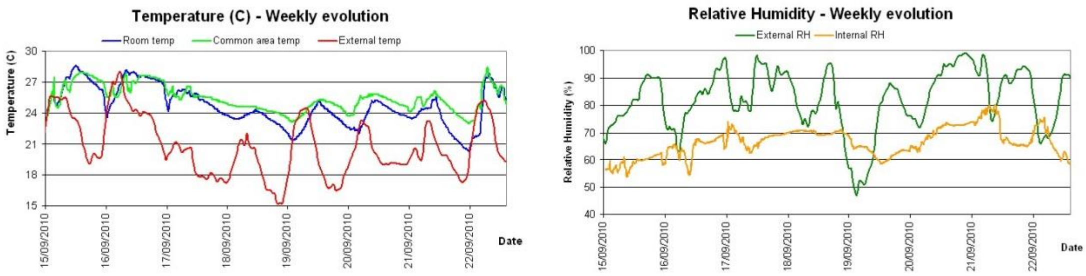


Figure 67: Modular school Sant Boi, temperature and humidity

Ruukki Office Hämeenlinna, Finland

The measured building was located in Hämeenlinna, Finland (about 100 km north from Helsinki). The measurement period was 2009-2010, and the measurements are still ongoing. The building is connected to district heating network. The gross floor area of the building is 4190 m² of which the industry hall corresponds 3946 m².

The thermal comfort measurement were done in the office part of the building had two storeys and the steel house was built in 2005. Building was built according to Finnish building code corresponding U-values being for windows 1.4 W/m²K, roof 0.16 W/m²K, floor 0.24 W/m²K and walls 0.24 W/m²K. Air tightness of the building was measured and the building was rather air tight being 1.3 ach (n_{50}).

The temperature and air velocity measurements were done both in one office room (10 m^2) and in the lobby (72 m²). The measurements started 01.12.2009 and are still ongoing. Continuous measurement were done for indoor temperature and relative humidity in heights of 0.1 m, 1.1 m and 1.7 m from the floor surface. In addition operative temperature and surface temperatures for window and wall was measured. Draught (air velocity measurements) were done in two months intervals.

Figure 68: Measured office and lobby

<u>Measurements of thermal environment in the office room and in the lobby</u>

When the whole measurement period is considered the air temperatures are rather stable especially during winter time both in the lobby and in the office room. The winter was really cold. Due to the placement of the office desk the lowest temperature measurement point was affected the radiator and the office desk thus the lowest temperature was measured in the height of 1.1 m. However, the differences in temperature were small.

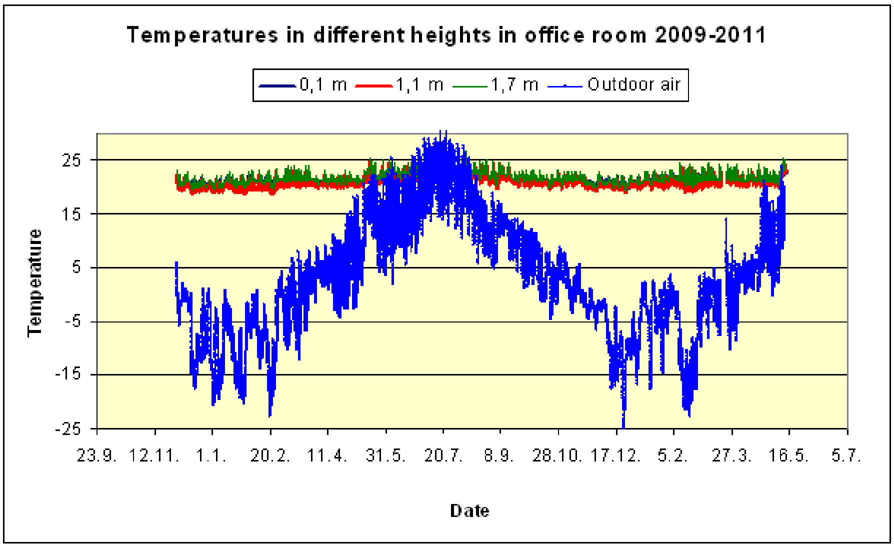


Figure 69: Measured air temperatures in the office room

Compared to the office temperature it can be clearly seen, that the big windows are affecting on the temperatures especially during spring and summer months. Due to high solar gains the temperature is close 30 °C during peaks. The lowest air temperature during winter period was measured in the 1.1 m height. All air temperatures were in 2 ºC range.

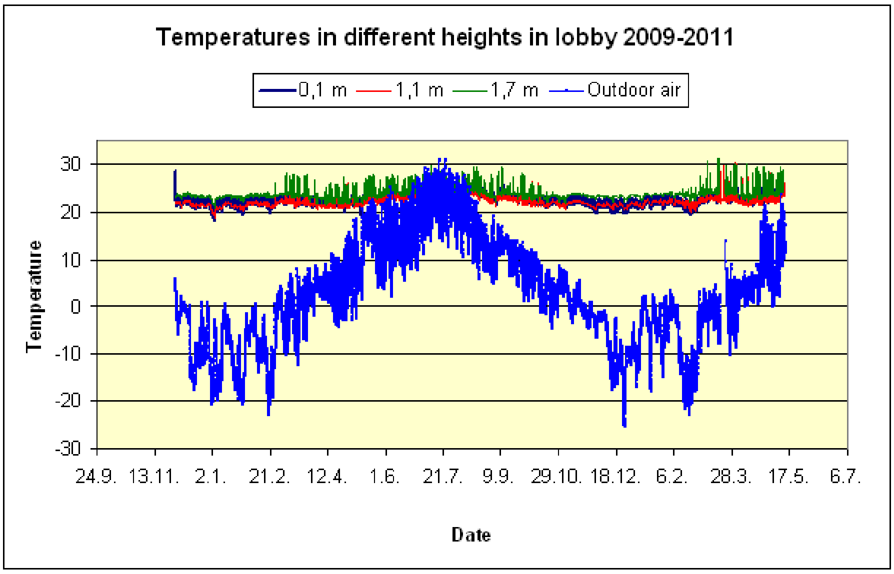


Figure 70: Measured surface and operative temperatures in the lobby

The surface temperatures in the exterior wall and window were obviously lower than air temperature, however, the operative temperature remained in comfort limits, Figure 71.

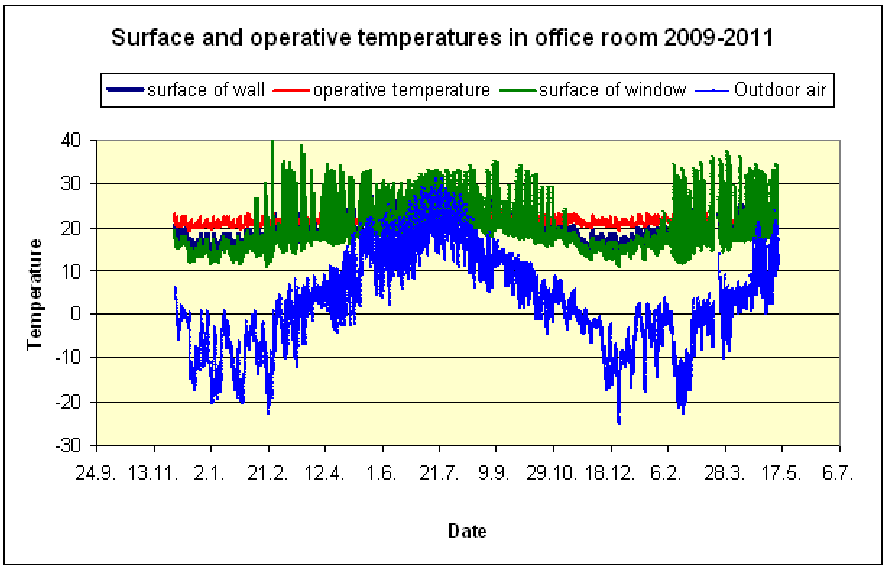


Figure 71: Measured surface and operative temperatures in the office room

In the lobby the lowest air temperature during winter period was measured in the 1.1 m height. All air temperatures were in 2 ºC range.

The window surface temperature in the lobby was low compared to other temperatures in the lobby. However, the temperature was typical to window used in the lobby. Operative temperature was higher in the lobby compared to the office room.

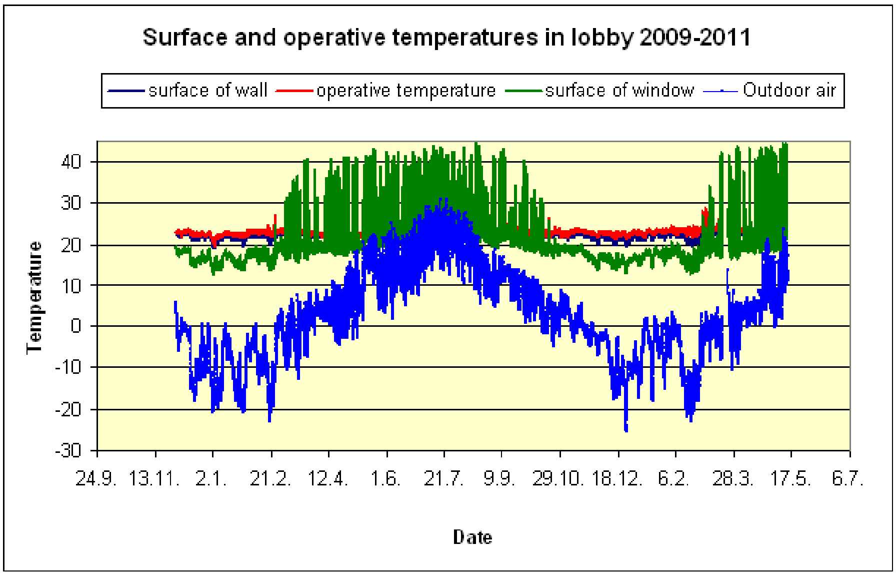


Figure 72: Measured surface and operative temperatures in the lobby

Supply air temperature measurement from the cooling beams during summer period

Supply air temperatures from the cooling beams were measured both in the office room and in the lobby in order to understand better the thermal environment in the studied rooms. The supply air temperature from the cooling beam was rather high in some periods. However, the room temperature never exceeded 25 ºC.

Air velocity measurements

Air velocity was measured in two months intervals and the results were given in 3 min average values. The results were compared to Finnish classifications of indoor air in which S1 corresponds individual indoor climate values (best score) and S3 acceptable indoor air values (close to building code values). The velocity was low according to criteria, the values were nearly always according to S1 (best score) values. The only exception was in January 2010 in the lobby at 0.6 m height. How-ever, also that measurement was according to building code levels.

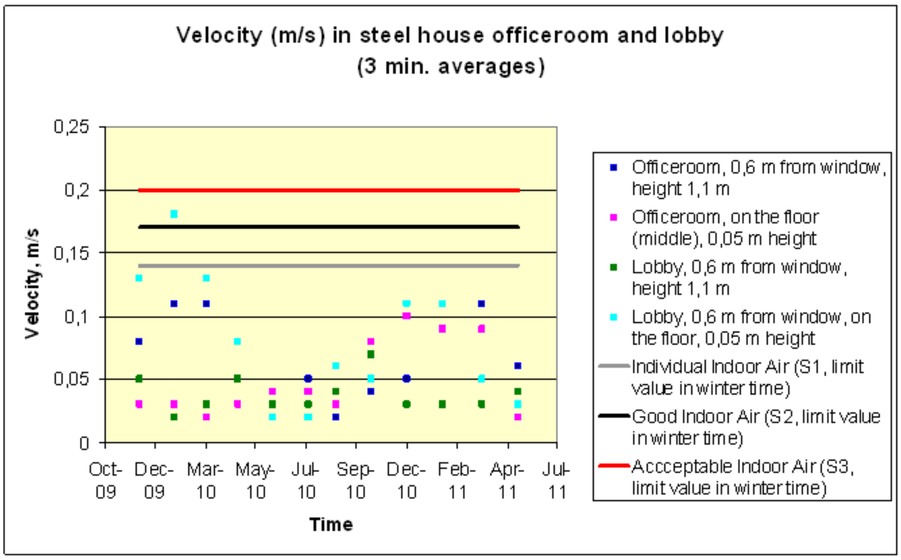


Figure 73: Measured surface and operative temperatures in the lobby

Operative temperatures

During winter period the temperature both in the lobby and office room was within the criteria for S1 (best score) except in a few occasions. However, those exceptions were short in time and the temperature was never too low. However, in the spring time the operative temperature was rather high. In the spring time the heat gains from the sun are reasonable high and also the daily changes in the outdoor temperature are high causing too high temperature indoors. However, operative temperature was never over 25 ºC. Due to rather big windows (high heat gains) in the lobby the late summer months (August) caused high operative temperatures.

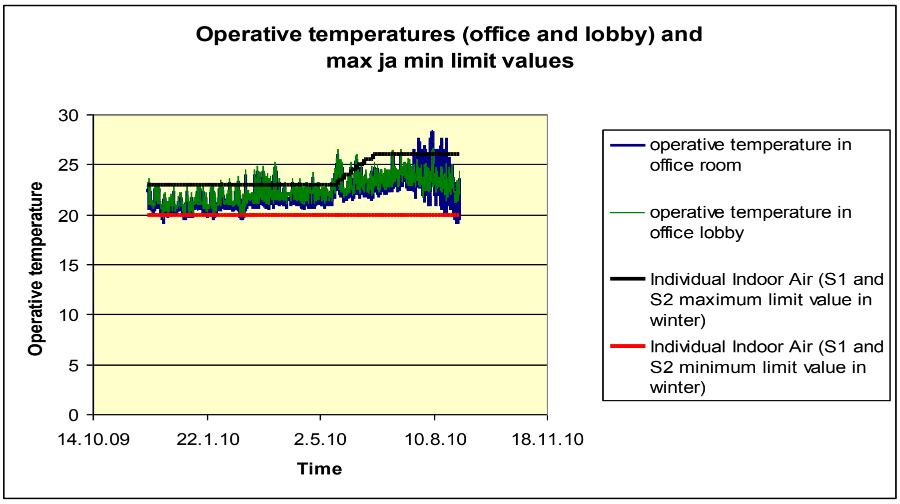


Figure 74: Measured operative temperatures in the office room and lobby.

Human thermal comfort simulations with different thermal mass of office structures

Fanger's Predicted Mean Vote (PMV) model [Fanger] was developed in the 1970's based on laboratory and climate chamber studies to estimate human thermal comfort in buildings. Fanger's PMV model combines four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level) into an index that can be used to predict the average thermal sensation of a large group of people. PPD (Predicted Percentage of Dissatisfied) is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment. Fanger's method is a good starting point for estimation of thermal comfort and it has been widely used in calculation of indoor environment conditions. However, it is applicable only to steady-state, uniform thermal environments. It can not take into account time-dependant phenomena or local examination of different body parts.

To estimate thermal comfort in realistic transient conditions, there is a need for a more accurate human thermal comfort calculation method. Zhang [Zhang 2003] has developed a new thermal comfort model to predict local and overall thermal sensation and comfort in non-uniform transient thermal environments. Figure 75 presents the thermal comfort and thermal sensation scales used by Zhang. For thermal sensation, the index value equal to zero indicates thermal neutrality. Positive index values indicate various degree of "hot" sensation (and negative values of this index indicate "cold" sensation). For example, thermal sensation index value of +4.0 corresponds "very hot" and 1.0 indicates "slightly hot" sensations. The scale of thermal comfort index varies between -4.0 (corresponding "very uncomfortable") and +4.0 (indicating "very comfortable"). In other words, the higher the thermal comfort index value is, the better judgement for thermal comfort is obtained.

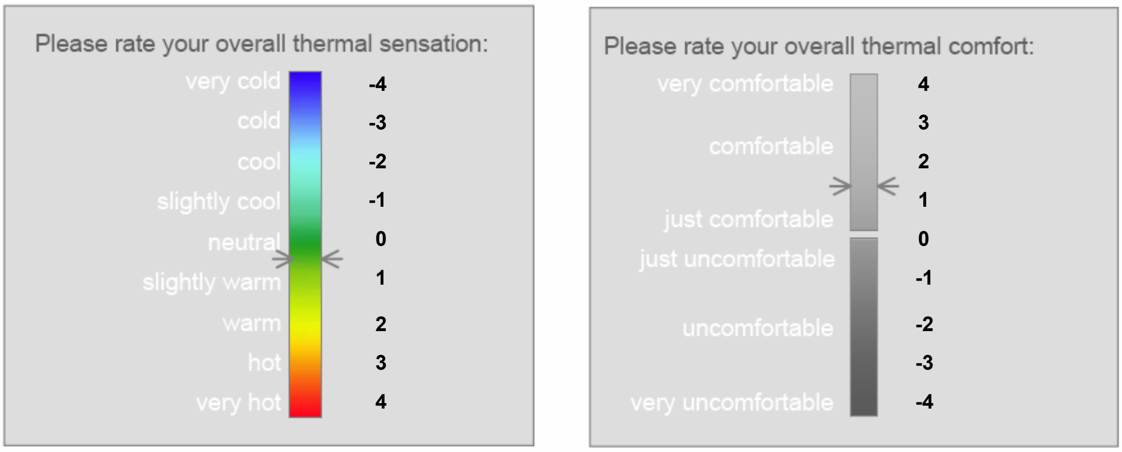


Figure 75:Thermal sensation and thermal comfort scales

[Zhang] represents the local thermal sensation by a logistic function of local skin temperature. Thermally neutral set point temperatures for each body part have been calculated in a thermoneutral environment. When the local skin temperature differs from the local skin temperature set point, the sensation reaches the sensation scale limits between +4.0 (very hot) and -4.0 (very cold). The overall thermal sensation is a weighted average of local thermal sensations. The local thermal comfort is a function of both local and overall thermal sensation.

The Zhang model has been implemented in a new Human Thermal Model, HTM, for predicting thermal behaviour of the human body under both steady-state and more realistic dynamic indoor environment boundary conditions [Holopainen]. HTM is based on true anatomy and physiology of the human body, and it estimates human body tissue and skin temperature levels, used for determination of thermal sensation and comfort. HTM divides the human body into sixteen different body parts each being further sub-divided typically in four realistic tissue layers (bone, muscle, fat, and skin) by concentric cylinders. The functional tissue layers are also connected to adjacent body parts by a blood circulation system, which has been used for physiological thermoregulation of the whole body. The passive and control system of HTM and the validation of HTM tissue temperature calculation is presented in [Holopainen].

HTM is a module of a non-commercial VTT House building simulation tool [Tuomaala 2002], which is used for modelling the thermal interactions between the human body and the surrounding space including convective, radiative, and evaporative heat transfer by means of the finite difference heat balance method. The integration of a human thermal model and a simulation environment enables the quantitative analysis of the significance of both external (structure insulation level, heating/cooling system) and internal (clothing, metaboly) boundary conditions on thermal sensation and comfort.

Thermally neutral set point temperatures for each body part have been simulated with HTM in a thermoneutral environment. HTM calculates the Predicted Percentage of Dissatisfied (PPD) based on the overall thermal sensation calculated with Zhang method. The PMV of Eq. 1 is substituted with the overall thermal sensation. In following thermal comfort simulations HTM is placed in a measured Ruukki office room. The simulation time is one year, the simulated cases are presented in Table 10.

Table 10 : Office room simulation cases

Metaboly: light work		Clothing		Metaboly: at rest (awake)		Clothing	
		Light	Heavy			Light	Heavy
Office building structures	Light	x	x	Office building structures	Light	x	
	Heavy	x	x		Heavy		

The thermal insulation of light clothing alternative is 1.16 clo including briefs, t-shirt, shorts, calf-length athletic socks and soft-soled athletic shoes. The thermal insulation of heavy clothing alternative is 1.45 clo including briefs, t-shirt, long-sleeve turtleneck sweater, jeans, calf-length athletic socks and soft-soled athletic shoes. The metaboly level at rest is 1.0 MET and in light work 1.2 MET.

The simulated mean skin temperatures during the simulated year are presented in Figure 76, thermal sensation in Figure 77, predicted percentage of dissatisfied in Figure 78 and thermal comfort in Figure 79. The average results are presented in Table 11, average results during heating season in Table 12 and average results outside heating season in Table 13. The heating season is defined as the time between October 1 and March 31.

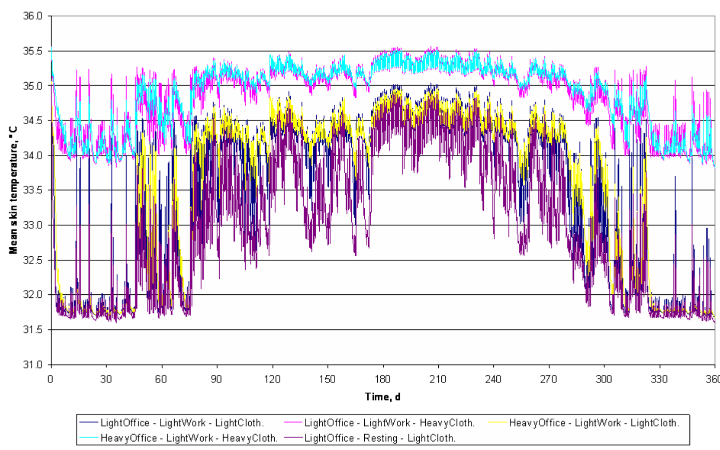


Figure 76: Mean skin temperatures in office room simulation cases

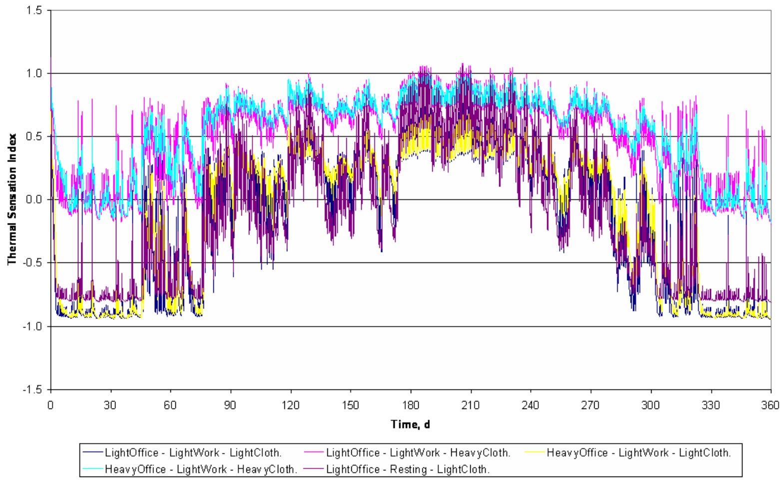


Figure 77: Thermal sensation index in office room simulation cases

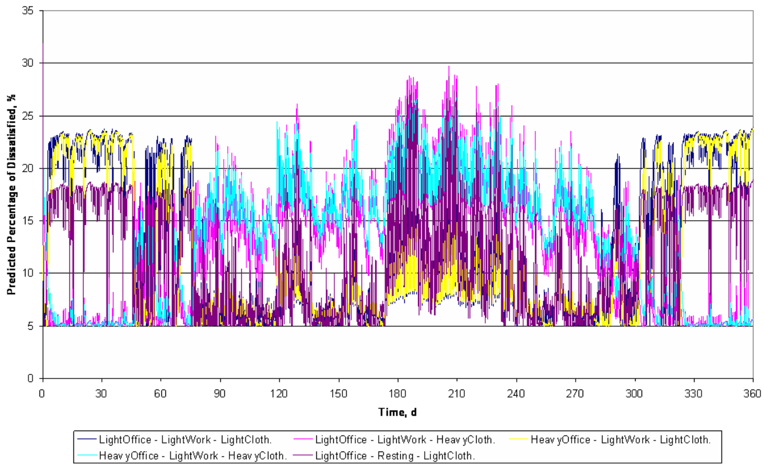


Figure 78: Predicted percentage of dissatisfied in office room simulation cases

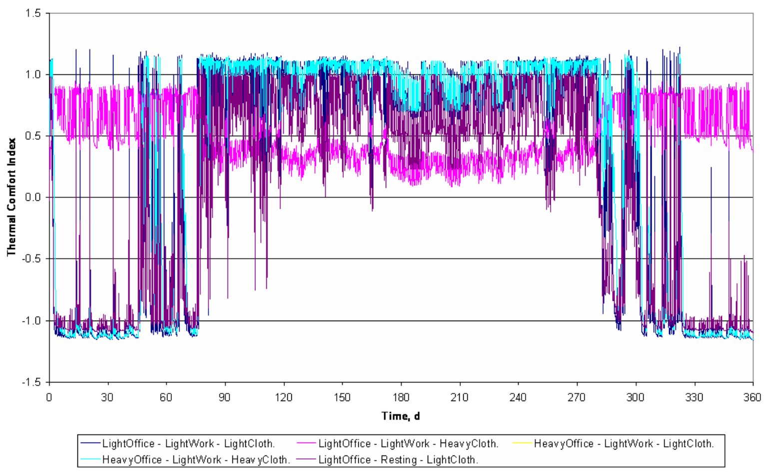


Figure 79: Thermal comfort index in office room simulation cases

Table 11 : Average results during the whole simulation time

	LightOffice Resting LightClothing	LightOffice LightWork LightClothing	HeavyOffice LightWork LightClothing	LightOffice LightWork HeavyClothing	HeavyOffice LightWork HeavyClothing
Mean skin temperature, °C	33.0	33.4	33.5	34.8	34.9
Thermal Sensation Index	-0.1	-0.2	-0.1	+0.5	+0.5
PPD, %	12	12	12	13	13
Thermal Comfort Index	+0.0	+0.2	+0.3	+0.5	+0.5

Table 12 : Average results during the heating season

	LightOffice Resting LightClothing	LightOffice LightWork LightClothing	HeavyOffice LightWork LightClothing	LightOffice LightWork HeavyClothing	HeavyOffice LightWork HeavyClothing
Mean skin temperature, °C	32.2	32.5	32.6	34.5	34.5
Thermal Sensation Index	-0.6	-0.6	-0.6	+0.3	+0.3
PPD, %	13	16	16	8	8
Thermal Comfort Index	-0.6	-0.5	-0.5	+0.6	+0.6

Table 13 : Average results outside the heating season

	LightOffice Resting LightClothing	LightOffice LightWork LightClothing	HeavyOffice LightWork LightClothing	LightOffice LightWork HeavyClothing	HeavyOffice LightWork HeavyClothing
Mean skin temperature, °C	33.8	34.4	34.5	35.2	35.2
Thermal Sensation Index	+0.3	+0.3	+0.3	+0.8	+0.8
PPD, %	10	8	8	18	18
Thermal Comfort Index	+0.6	+0.9	+1.0	+0.3	+0.3

According to the simulations the clothing level seems to have the greatest influence on mean skin temperature. Increasing the thermal resistance of clothing from 1.16 clo to 1.45 clo increases the mean skin temperature between 1.4…2.0 °C and thermal sensation index between 0.5 … 0.9 units.

All cases have a relatively low predicted percentage of dissatisfied (PPD) with the right clothing for the season: PPD is (predictably) lower with lighter clothing outside the heating season (8 % vs. 18 %). During the heating season the PPD is lower with the heavier clothing alternative (8 % vs. 16 %).

The heavier building structure mass has a low effect on the effect on average mean skin temperature: maximum +0.1°C. The effect of metaboly increase from rest (1.0 MET) to light work (1.2 MET) is between +0.3…+0.6°C on average mean skin temperature.

5 Design ‘tools’ for whole building assessments

5.1 Report on national and international tools and regulations

SCI has prepared an overview on national regulations for the whole building assessment, divided into four categories:

- U-Values
- Air-tightness
- Thermal bridges
- Energy use / CO2

The full report concerning the national regulations is given in **Deliverable WP 5a**.

5.2 Preparation of pre-design tool with defined inputs and outputs

The Directive on the Energy Performance of Buildings (EPBD) requested the national authorities to implement calculation methods and regulations containing whole energy performance including heating, cooling, ventilation and lighting. These calculation methods are very complex: new EN standards of about 4000 pages in total have to be considered. These calculations are time-consuming and error-prone.

Therefore there is need for a simplified tool for calculations in the early (and mostly crucial) design phase of buildings in steel. This is of particular interest for prefabricated steel construction, because these buildings are distributed Europe wide and therefore used in different countries with various regulations and climates.

This pre-dimensioning tool should consider the relevant parts that are affected by the steel components: Mainly the quality of the building envelope and the impact of the structure. Details of technical equipment (HVAC) are also very important for the energy efficiency, but widely independent from the steel components. Therefore a simplified method to consider this aspect should be used.

Beneath the technical properties of the building the aspects of the use and the meteorological conditions are important to determine the energy efficiency, but that are "parameters", that act as boundary conditions.

Table 14 illustrates the concept for the calculation tool.

Table 14 : Overview input data for calculation tool

Subjects		**Relevance for steel products / steel construction**
1. Shell / structure / shape	1.1 Transmission (H_T) regular area thermal bridges ground plate …	 very high very high Medium
	1.2 Airtightness (-> impact on H_V)	high
	1.3 Solar gains	medium
	1.4 Daylight	medium
2. Building services	2.1 Boiler	low
	2.2 Distribution	low
	2.3 Heat transfer (e.g. Radiator)	low to high, depending on concepts
	2.4 Chiller	low
	2.5 Hot Water	low
	2.6 Ventilation	low
	2.7 Lighting	low
3. Use	3.1 Time	Strong impact on energy calculation, but not directly related to steel
	3.2 Set Temperature	
	3.3 Heat gains	
	3.4 Ventilation rate	
4. Weather / Climate	4.1 Temperature	Strong impact on energy calculation, but not directly related to steel
	4.2 Solar radiation	
	4.3 Wind	

not so relevant for steel products, except thermo-active steel or composite panels

Parameter for calculation

Transmission losses Q_T / H_T

The calculation of thermal transmission losses Q_T is based on the transmission heat transfer coefficient H_T. The determination of H_T is well-defined (see EN 13790) based on physics, national specifics are marginal.

If H_T is calculated (what can be laburious for complex buildings) , the thermal transmission losses Q_T can be estimated by multiplying by time and by mean temperature difference (see Figure 80). If all data for the building envelope are available, the calculation is straight-line and save.

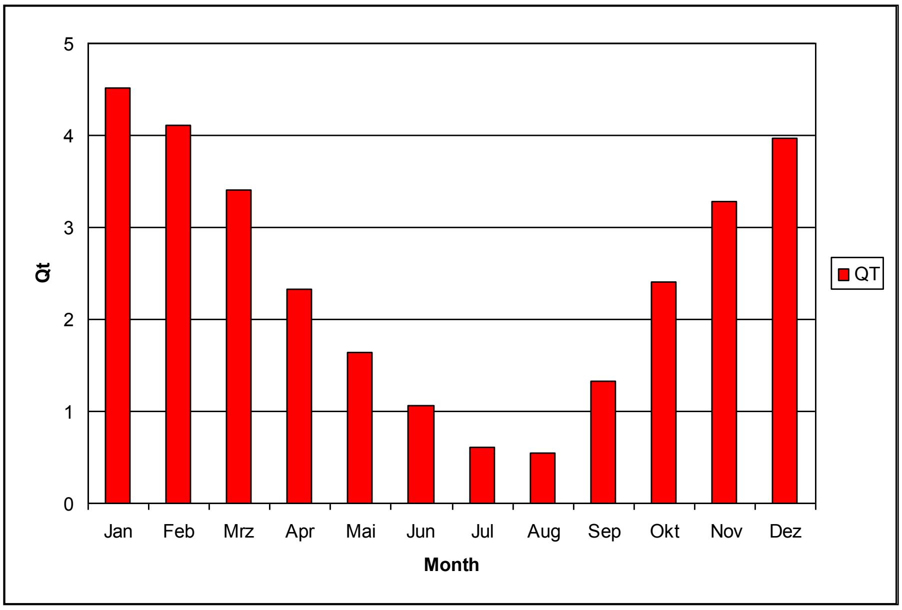


Figure 80: Example Transmission heat losses (monthly values)

Ventilation losses Q_V / H_V

In principle, the calculation of the ventilation losses is similar to the transmission losses, but the serious problem is, that the calculation of the ventilation rate is frequently uncertain, see Figure 81 (exception: air-tight building with mechanical ventilation).

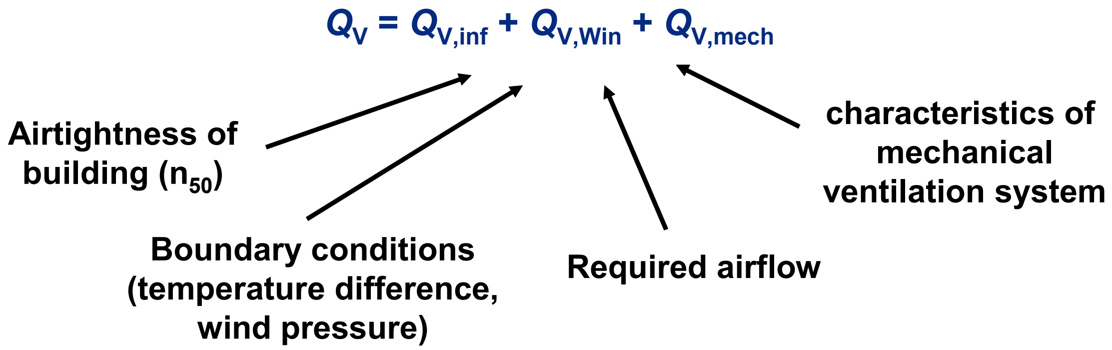


Figure 81: Various impacts on ventilation losses

The German standard DIN V 18599 presents a method for the calculation of the airchange-rate, that considers the different contributions infiltration due to limited air-tightness, natural ventilation and mechanical ventilation. Relevant in the frame of this project is, that the effect of air-tightness is taken into account, nevertheless the uncertainty in this field remains high.

Climate and use

Climate and use should be supplied in a flexible manner.

Outline calculation tool

RWTH develops an Excel-Tool with the following features:

- Monthly balance method
- Free input of weather data (e.g. Meteonorm)
- Calculation of transmission losses: EN 13790
- Solar gains: DIN 4108-6
- Ventilation losses: EN 13790 / DIN 18599-2
- Heating system: only „ep“ and energy source

The following paragraph illustrates the tool. Four input sheets and two calculation and output sheets are defined:

Sheet I. Basic Information

- Location
- „overall dimensions“

Energy calculation tool			
Monthly balance method			
Project:		*Testhalle*	
I. Basic information			
1	Location	**Berlin (Meteo)**	
2	Gross volume [m³]	V_e =	*1600.00*
3	Effective area [m²]	A_N =	*200.00*
4	A/V_e - ratio	A/V_e =	**0.55**

Figure 82: Screenshot Sheet I

Sheet II. Building Envelope

- Input data transmission
  - U-values, areas, thermal bridges
- Input data solar gains
  - g-Values, orientation, shading
- Input data air-tightness

Energy calculation tool							
Monthly balance method							
Project:		*Testhalle*					
II. Envelope							
II.1 Transmission heat loss [W/K]							
II.1.1 Opaque elements							
II.1.1a Opaque elements, with solar gains							
	Building element	Index	Heat transition coefficient U_i [W/(m²K)]	Area A_i [m²]	Temperature correction factor $F_{x,i}$ a) [-]	Orientation - Slope	Absorption value j) α_i [-]
5		AW 1	*0.50*	*140.00*	*1.0*	*south - 90°*	*0.50*
6		AW 2	*0.50*	*140.00*	*1.0*	*north - 90°*	*0.50*
7		AW 3	*0.50*	*70.00*	*1.0*	*east/west - 90*	*0.50*
8		AW 4	*0.50*	*70.00*	*1.0*	*east/west - 90*	*0.50*
9		AW 5			*1.0*		*0.50*
10	Exterior wall	AW 6			*1.0*		*0.50*
11		AW 7			*1.0*		*0.50*

Figure 83: Screenshot Sheet II (excerpt)

Sheet III. Climate and Use

- Exposition concerning wind
- Operation time, set point temperature
- Ventilation rate
- Heat storage capacity

Energy calculation tool					
Monthly balance method					
Project:		***Testhalle***			#
III. Use and climate					
III.1 Climate					
66	Location	Berlin (Meteo)			5
67	wind shield coefficient		e_{wind}	**0.07**	
68	wind shield coefficient		f_{wind}	**15.00**	
III.2 Use					
111	operation time	hours per day	t_d	**8.00**	2
112		days per year	d_{op}	**250**	
	Set point temperature	heating, during operation time	T_{op} [°C]	**19**	
	Night cut off	reduction set point temperature	ΔT	**0**	
	Ventilation rate	during operation time, not for air conditioning purposes	n_{op} [h^{-1}]	**1**	
113	Internal gain	$Q_{i,M} = 0{,}024 * q_{i,M} * A_N * t_M$	$Q_{i,M}$ =	**monthly value**	
III.3 Heat storage capacity [Wh/K]					
114		light pattern construction k) C [illegible] = 12 * V	C [illegible] =	**19200.00**	

Figure 84: Screenshot Sheet III (excerpt)

Sheet IV. Heating system

Energy calculation tool				
Monthly balance method				
Project:		***Testhalle***		
IV. Primary energy efficient value				
140	Heating System			
141	Energy efficiency value n)		e_P =	

Figure 85: Screenshot Sheet IV (excerpt)

Two calculation and output sheets:

Sheet V. Calculation H_T, H_V, Solar gains

- Transmission heat transfer coefficient H_T
- Ventilation heat transfer coefficient H_V
- Solar gains

Energy calculation tool							
Monthly balance method							
Project:		***Testhalle***					
V. Envelope (H_T and H_V)							
V.1 Transmission heat loss H_T							
V.1.1 Opaque elements							
	Building element	Index	Heat transition coefficient U_i [W/(m²K)]	Area A_i [m²]	Temperature correction factor $F_{x,i}$ a) [-]	Orientation - Slope	Absorption value j) α_i [-]
1	Exterior wall	AW 1	*0.50*	*140.00*	*1.00*	*south - 90°*	0.50
2		AW 2	*0.50*	*140.00*	1.0	*north - 90°*	0.50
3		AW 3	*0.50*	*70.00*	1.0	*east/west - 90*	0.50
4		AW 4	*0.50*	*70.00*	1.0	*east/west - 90*	0.50
5		AW 5			1.0		0.50
6		AW 6			1.0		0.50
7		AW 7			1.0		0.50

Figure 86: Screenshot Sheet V (excerpt)

Sheet VI. Calculation Energy

- Net energy use heating
- Primary energy use

Energy calculation tool			
Monthly balance method			
Project:		***Testhalle***	
VI.1 Annual building net energy use [kWh/a]			
120	Mean value of outdoor temperature [°C]	of the location: **Berlin (Meteo)**	$\Theta_{e,M}$ =
121	Heat loss	without night cut-off $Q_{l,M} = 0{,}024 * (H_T + H_V) * (\Theta_i - \Theta_{e,M}) * t_M$ l)	$Q_{l,M}$ =
122		decrease of heat loss by 7 h night cut-off acc. to DIN V 4108-6:2003-06 annex C	$\Delta Q_{l,M}$ =
123	ratio of heat gains and heat losses	$\gamma_M = (Q_{s,t,M} + Q_{i,M}) / (Q_{l,M} - Q_{s,op,M})$	γ_M =
124	Utilisation factor heat gains	$\eta_M = (1 - \gamma_M^{a}) / (1 - \gamma_M^{a+1})$	η_M =

Figure 87: Screenshot Sheet VI (excerpt)

The Excel-Tool “ECALTO” is given as **Deliverable WP 5b**.

5.3 Report on validation of design tool using measured data and numerical results

Representatively for seven buildings which were calculated with "ECALTO" two of them are presented in the Final Report:

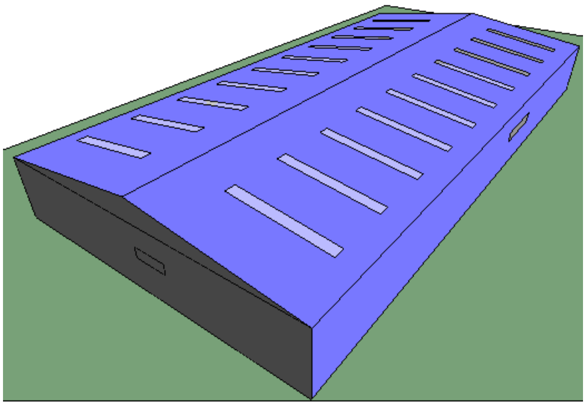
- Warehouse, United Kingdom
- Modular Research Building, Germany

The detailed results for all seven buildings are available in **Deliverable WP 5c** – Report on validation of design tool using measured data and numerical results.

Warehouse, United Kingdom

Building specification

The building is a portal framed steel building cladded with steel composite panels. Figure 88 collates the size of the building, buildings locations, orientation and operation and occupancy profile considered for the thermal simulations.



- Size: 30 x 60 x 6m high (eaves)
- Orientation: North/South
- NCM Operation and Occupancy profile:
  - Warehouse
    - Naturally ventilated
    - 7am – 8pm for 7 days
  - Heating
    - 0 – 7 am: 12°C
    - 7am – 18 pm: 20°C
    - 18 pm – 24 pm: 12°C
- Location: London

Figure 88: Model of medium-size industrial shed used in the thermal simulation

Table 15 presents the key parameters for the thermal analysis. Table 16 collates the assumed parameters for occupancy, equipment, ventilation and lighting. These parameters are default values in the SBEM tool and are typical values for industrial sheds in the UK.

Table 15 : Recipe for Thermal Analyses

No	Parameters		Values
1	Airtightness $m^3/(h.m^2)$@50 Pa		5
2	U-value (W/m^2K)	Cavity wall	0.25
		Wall panel	0.25
		Internal wall	1.7
		Roof	0.20
		Ground floor	0.20
		Window	1.50
		Rooflight	1.80
		Solar shading (effective g-value)	0.50
		Entrance door	1.50
		Vehicle access door	1.30
3	Rooflights (%)		12
4	Psi values (W/mK)	Gutter (Valley)	Default method in NCM to add 10% to U value for each element
		Drip (wall ground fl.)	
		Roof –wall (Eaves + Verges)	
		Wall – corner wall	
		Wall – floor not grd.	
		Lintel (window/door)	
		Sill below window	
		Jamb (window/door)	

Table 16 : NCM Default Parameters for Warehouse Building

Zone	Area	Occupancy		Equipment	Ventilation	Lighting		HVAC
	m^2	m^2/pers.	W/m^2	W/m^2	$l/s.m^2$	lux	W/m^2	
Office	30	10.51	6.95	11.92	0.95	400	15.0	Radiator
Common room	30	10.51	6.95	11.92	0.95	400	15.0	Radiator
Shed	1800	20.0	3.60	5.0	0.50	300	11.25	Air heating
Toilet	30	9.64	7.26	4.73	1.25	200	10.4	Radiator

Results and discussion

The results from both SBEM and ECALTO tools are plotted in Figure 89 below. As can be seen from these results, the monthly predicted heating demands from both tools are similar for January (2.6 %), February (1.2 %) and December (9.1 %). A large variations can be noted for March (36.2 %); March (20.1 %) and November (19.8 %). Overall, the predicted total energy demand over a year period from both tools is 4.9 %. These percentage differences may be largely associated with the set of London weather data deployed for each tool and to some extent the simplified assumptions used for ECALTO.

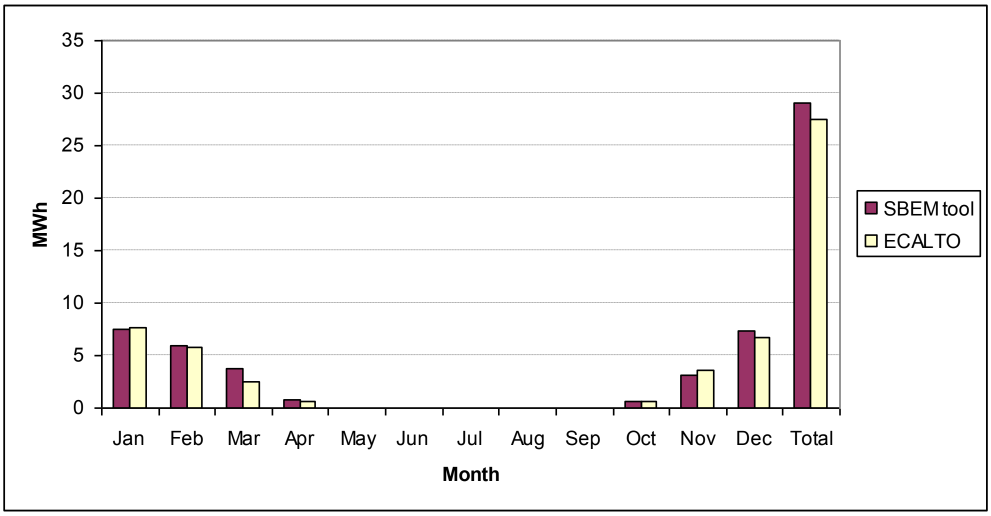


Figure 89: Predicted Heating Energy Demand

The results from both SBEM and ECALTO tools showed that the monthly predicted heating demands from both tools are similar with the exception of March (36.2 %); April (20.1 %) and November (19.8 %). The predicted total energy demand over a year period from both tools is 4.9 %. These percentage differences may be largely associated with the set of London weather data deployed for each tool and to some extent the simplified assumptions used for ECALTO. Considering, the ease and low data input required for ECALTO tool, this result is acceptable and the tool is very useful for estimating building energy demand at pre-design stage.

Modular Research Building, Germany

The Modular Research Building (Figure 90) was erected on the site of RWTH Aachen University for research and demonstration purposes in the field of light weight steel construction using steel sandwich elements. It has a useable floor space of 102 m² on two levels, the volume amounts 332 m³

Figure 90: Modular Research Building

The heating system of the Modular Research Building is based on a condensing boiler. A cooling system is not provided. The Modular Research Building is a classic one-zone-model. The usage profile is a single office.

The various input parameters are given in Table 17 and Table 18. First, the general building data is summarised in Table 17. Table 18 gives an overview of the used components. The table contains information on the individual surfaces, their orientation and the heat transfer coefficients.

Table 17 : General building data, Modular Research Building

Modular Research Building	
Heated building volume	V_e = 378,41 m³
A/V_e	A/V_e = 0,83
Useful Area	A_N = 142,53 m²
Floor height	H = 2,40 m
Construction	Lightweight steel construction
Thermal bridges	General U_{WB} = 0,1 W/(m²K)
Usage profile	Single office acc. to Tab.4 DIN V 18599-10
Heating system	Condensing boiler

Table 18 : Building components, Modular Research Building

Modular Research Building		**Component area [m²]**				**U-value [W/(m²K)]**
Component	**Abbreviation**	**north**	**east**	**south**	**west**	
Window	AF01	5,71	2,05	10,79	6,96	1,40
Door	AT01	0,00	2,73	0,00	0,00	1,40
Exterior wall	AW01	43,89	44,82	38,81	42,64	0,256
Roof	DA01	58,22 (horizontal)				0,245
Floor	FB01	58,22 (horizontal)				0,171

The results for the net energy demand obtained from “ECALTO” and from the commercially available computer program "Solar Computer" are compared. Figure 91 shows the course of one year of the net energy demand for heating of the building.

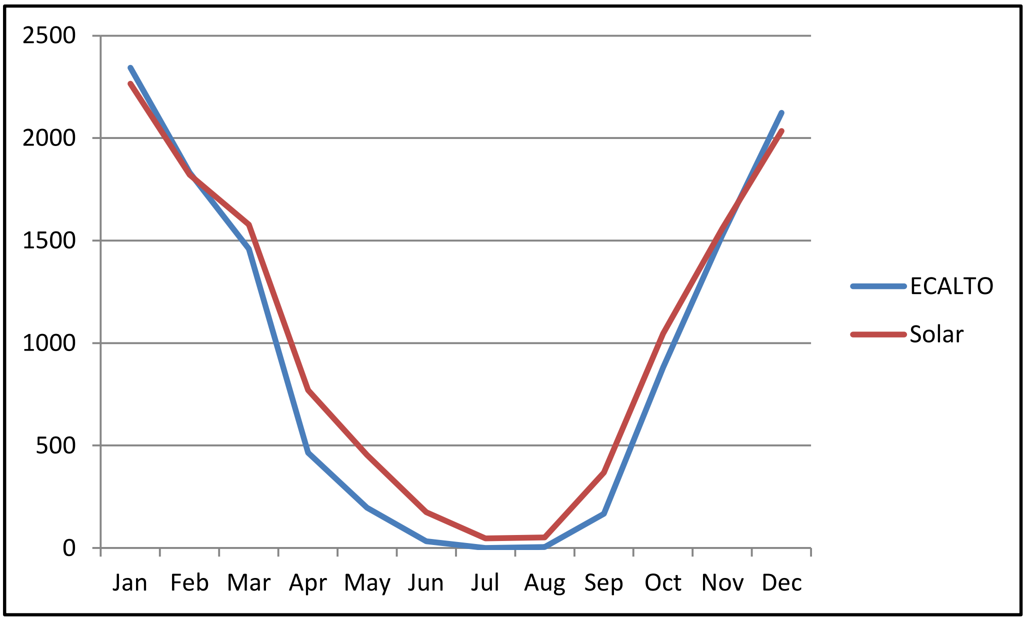


Figure 91: Course of one year net energy demand, Modular Research Building [kWh]

It is evident that the calculation method of "ECALTO" delivers slightly higher values compared to “Solar Computer” in the winter months. During the summer months results of "ECALTO" show a lower energy demand compared to "Solar Computer". Figure 92 shows the comparison of the sum of net energy demand for heating.

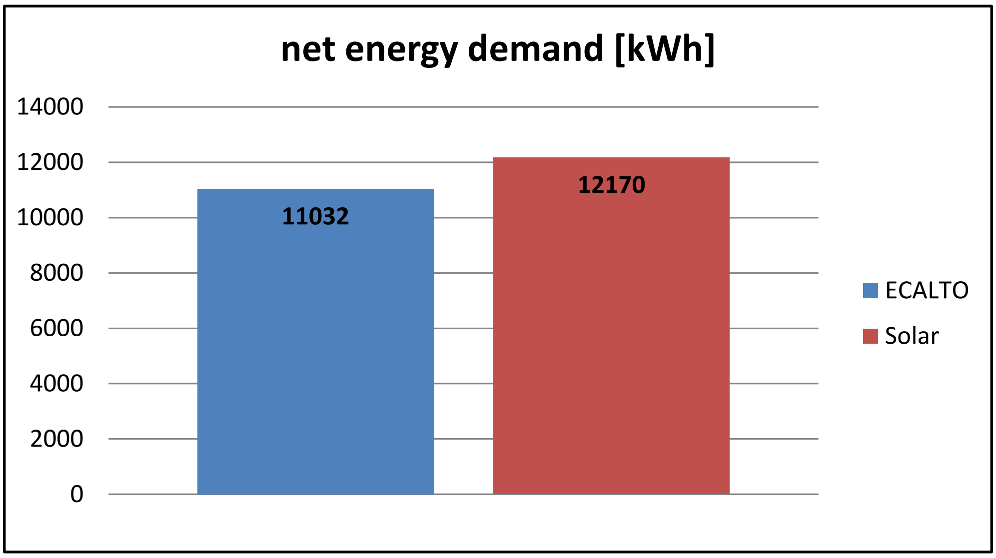


Figure 92: Comparison net energy demand for heating, Modular Research Building [kWh]

The difference for the final energy demand between the two calculation methods is 1138 kWh. This corresponds to a deviation of about 9% based on the results of "Solar Computer" which results from the differences in the calculation of the heat sinks and heat sources.

The target of a maximum deviation of 20% with only about 20% of input effort is observed in the case of the Modular Research Building. With less than 10% variation in all results examined, the accuracy is even significantly better than required.

6 Design guidance on energy and thermal improvements for residential buildings

6.1 Introduction

The housing and residential building sector represents approximately 27 % of the total energy use in the EU, and new building in this sector has been identified as one of the main ways of achieving improvements in the energy use of the built environment. The Energy Performance in Buildings Directive has been enacted in all EU states in the form of national Regulations, and many states are moving toward the concept of low or zero energy construction by 2020.

The use of light steel and modular construction is increasing in housing and residential buildings. In this application, the benefits of this lightweight system are, speed of construction, improved quality of the construction system, and reliable thermal performance of the building envelope. Light steel and modular construction may be used in combination with a skeletal steel framework in a 'mixed' steel construction technology. The important thermal performance characteristics are:

- Thermal insulation.
- Minimising thermal bridging.
- Air tightness.
- Control of condensation.

Thermal insulation is characterised by the thermal transmission or U value of the building envelope. U values significantly lower (or better) than current regulations are obtained using light steel framing. In many countries, U values less than 0.2 W/m²K for external walls and 0.15 W/m²K for roofs are specified. This requires use of steel technologies with proven thermal performance and minimal thermal bridging through any steel elements in the building envelope.

Loss of heat by air infiltration through the building envelope can be responsible for over 30 % of the total heating requirement in a modern thermally insulated building. Therefore, it is equally important to improve air-tightness as to improve thermal insulation. This often requires the use of air-tight membranes or sheathing systems. However, as the air-tightness of buildings increases, it is necessary to maintain fresh air quality and to eliminate the risk of condensation by use of controlled ventilation systems with heat recovery.

Typical examples of cladding systems that achieve target U-values are illustrated. Comparisons with 2 D thermal analyses illustrate the effect of thermal bridging through the C sections embedded in the wall. In this respect, perforated or slotted or thermally broken light steel sections are beneficial.

6.2 Energy efficiency strategies to improve whole energy performance

In WP 4 various residential buildings were investigated in detail by measurement and by standardized calculations. These investigations are a valid data base for parametric studies to work out suitable energy efficiency strategies for improving the whole energy performance.

The following buildings were taken into account:

Table 19 : Projects used for develop energy efficiency strategies, potentially savings

Country	Project	Energy demand starting point kWh/m²a	Energy demand after optimization kWh/m²a
UK	Birchway Eco-Community	64	14
Fin	Housing project Ylöjärvi, House C	250	215
	Housing project Ylöjärvi, House D	175	138
F	Villa Venir	61	32

In Table 19 is also shown the energy demand "as built" and the theoretical results as "best case" of the optimization process. Details of this optimization including intermediate steps are presented in **Deliverable WP 6a** - Influence of various energy reduction measures on whole building performance of residential buildings.

It is clear from the investigations that there is plenty of potential to improve the whole building energy performance for steel construction. The investigations have focussed mainly on the fabric efficiency as this is the area that is relevant to steel construction technologies.

It is of course important to consider the heating and ventilation systems and ensure that they are appropriately designed for the dwelling and they are efficient. It is important to ensure that the building is designed in such a way as to facilitate the incorporation of renewable energy generation technologies. However, this report will consider the primary focus of steel building technologies to be ensuring that the building envelope is energy efficient, leading to a low energy demand.

The efficiency, from a thermal point of view, of the building envelope can be broken down into three areas:

1. U-values - Creating an insulating enveloped
2. Thermal bridging – minimising breaks or penetrations in the insulating envelope
3. Air-tightness – minimising heat loss through uncontrolled ventilation

It has been shown that improving all these areas will lead to improved performance over current typical construction. However it is important to consider the baseline from which one is starting.

For example in the UK it has been shown that there is great scope for increasing energy performance by improving air-tightness. This is demonstrated that by reducing the air-permeability from 10 to 3 $m^3h^{-1}m^{-2}$ you can reduce heating demand by 20 % and by reducing it even further to 1 $m^3h^{-1}m^{-2}$, which is technical feasible although challenging, you can increase this figure to 28 %.

However in the Finnish example, there is less opportunity to gain large increases in performance by reducing air-tightness as the typical performance is already very good.

The same is true when you consider windows, in Finland a frame and glass U-value of 1.1 $Wm^{-2}K^{-1}$ is typical and leaves little room for improvement whereas in the UK the typical value is around 1.8 $Wm^{-2}K^{-1}$ and in France is it perhaps 1.8 to 2.1 $Wm^{-2}K^{-1}$.

This follows through many of the performance factors considered and reflects the cold climate in Finland and the historical push by Finnish Government to improve standards throughout the country to give lower heating bills and improved thermal comfort.

In terms of design it is important to consider the various elements highlighted above and do some preliminary parametric analysis to identify where the best gains can be made in terms of thermal performance with the most cost-effective technology improvements.

For example it may be that minimal change is required to the construction technology to achieve a more air-tight building but considerable change and supervision of the work-force may be needed which will bring its own costs. Conversely adding more insulation should only require the extra-over costs of the material itself until such a time as the thickness of the wall means that the construction technology has to change.

6.3 Energy improvement measures for residential buildings in steel

In general, the energy demand of residential building is determined by the interaction of numerous single aspects, in Chapter 6.2 the most relevant were considered.

One key element is the reduction of the U-Value of the external walls, therefore cost-effective cladding systems are required. There are various strategies by which high levels of thermal insulation may be achieved in the building envelope. Two options, that are relevant for residential, were presented in detail:

1. Warm frame construction
2. Perforated steel sections

These systems are shown in **Deliverable WP 6b -** Recommendations for suitable energy improvements measures for residential buildings in steel.

Beneath the improving of the U-value of the external walls the following aspects were touched in **Deliverable WP 6b**:

- Thermal bridging at steel edge beams and columns
- Effect of thermal inertia
- Ventilation and air-tightness
- Cooling energy demand
- Air tightness

The relevance of the particular measures is depending on the characteristics of each building, e.g. shape, location and use. Thus, in this section the measures are pointed out and explained, but an individual concept for each building project is essential.

6.4 Energy certification for residential buildings in steel

Legislative background

The requirement for Energy Labeling in the EU is a consequence of passing EU Directive 2002/91/EC. This has been named the Energy Performance of Buildings Directive (EPBD).

It sets out a number of Articles which the EU countries must adhere to in the arena of building energy performance including:

- Article 3: National Calculation Methodology
- Article 4: Setting energy/CO_2 standards for performance of new and existing buildings
- Article 5: Encouraging greater use of low and zero carbon (LZC) technologies
- Article 7(1) and (2): Energy Performance Certificates (EPCs) to be generated when buildings are constructed, sold or rented
- Article 7(3): Requirement to display EPCs in public buildings
- Article 10: Qualified and accredited assessors/inspectors

Article 3 then relates to each country developing a calculation methodology whereby energy use and/or CO_2 emissions from a building can be calculated and/or measured. This is then generally used as the tool to check compliance with Article 4 which sets the National standards for buildings, usually via Building Regulations.

Article 7 is concerned with the requirement to generate EPCs when new buildings are constructed or buildings are sold or rented. Finally Article 10 sets out the requirement for each country to put in place a system to ensure that the assessors who generate the EPCs are suitable qualified.

Differences between countries

Although all EU countries are required to implement the EPBD, they are generally free to do so in their own way; this has led to significant differences across the EU. For example most countries have developed a calculation methodology for estimating the predicted energy use for a building based on EN ISO 13790. This is a quasi-steady state energy balance calculation and most countries have chosen to apply this on a monthly timescale.

In general the country will then use this methodology to test a new building and relate its performance against benchmarks in order to satisfy Article 4. In order to pass a country's Thermal Building Regulations the building must satisfy these criteria.

Asset or Operation Rating

There is particular flexibility in the enactment of Article 7. Firstly it is possible to stipulate EPCs based on calculated or measured data or both. In the first circumstance the energy performance of the building is calculated as discussed above and in the second circumstance actual measured energy consumption is used to benchmark the building. These are called Asset and Operational ratings respectively.

What is measured?

Another point of flexibility is the units of measurement for the metric. There are three main options:

- Energy demand (kWh per year, often per m^2 of floor area)
- Primary Energy demand (kWh per year, often per m^2 of floor area)
- Carbon dioxide (CO_2) emissions ($kgCO_2$ per year, often per m^2 of floor area)

These can then also be split into two categories, energy/CO_2 used for heating and energy/CO_2 for all uses.

It is most common to use energy demand as the main metric although notable the UK uses CO_2 as its primary metric.

Performance standards

Finally each country is free to set their own performance targets so even if two countries choose the same unit of measurement they do not have to choose the same performance targets. Many countries have established performance levels, which are banded into 7 or 8 categories, labelled G for the worst performance to A or A+ for the best performance. An example is shown in Figure 93 below.

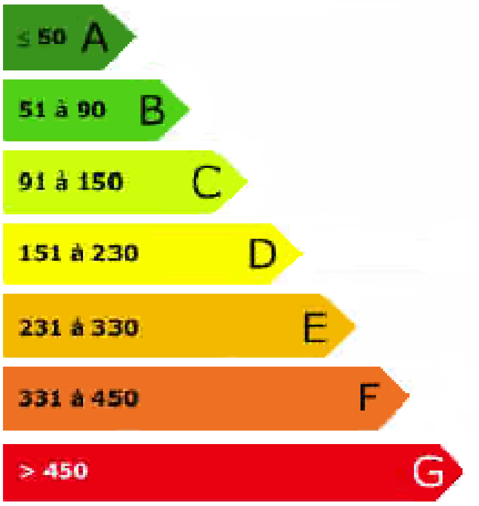


Figure 93: The banding for the French EPC rating, units are $kWhm^{-2}a^{-1}$ of primary energy

Other countries like Germany do not have categories, only a continuous spectrum of colours.

In **Deliverable WP 6c -** Energy certificates for selected buildings in steel several examples for different European countries are presented.

6.5 Guidance for architects and engineers on energy efficient solutions in steel

The guidance for architects and engineers on energy efficient solutions in steel for residential buildings is the whole WP 6 including the deliverables. Nevertheless, an additional document (**Deliverable WP 6d**) was produced, that extract of the more practical information plus an introduction into the use of steel in the residential sector.

7 *Design guidance on energy and thermal improvements for non-residential buildings*

7.1 Introduction

This report is the summary of WP 7 task: **"Design guidance on energy and thermal improvements for non-residential buildings"**. **WP 7 has broadly been divided into 6 sub tasks related to:**

- **WP 7.1** Evaluate the influence of air-tightness and thermal performance of modern steel cladding systems on the overall energy use
- **WP 7.2** Carry out parametric study of whole building performance for typical industrial buildings for different climates including requirements for heating and cooling
- **WP 7.3** Identify innovative cladding systems with improved performance characteristics
- **WP 7.4** Identify energy efficient solutions for steel intensive commercial buildings with optimized façade and floor systems
- **WP 7.5** Application of Energy Certification on non-residential
- **WP 7.6** Prepare guidance for architects on energy efficient solutions in steel

All these activities have produced four deliverables:

a) Report on the influence of various energy reduction measures on whole building performance regarding energy demand for heating, cooling and lighting.
b) Report on recommendations for suitable energy and thermal improvement measures for non-residential buildings in steel.
c) Energy certificates for selected commercial and industrial buildings in steel.
d) Guidance for Architects and Engineers on Energy Efficient Solutions in Steel for Commercial and Industrial buildings.

The work in WP 7 is primarily concerned with producing guidance for designers, owners and architects about the energy efficiency of building systems made of steel elements. This work focuses on non-residential buildings: including office, commercial and industrial buildings. The information gained in previous WP of the project have been summarized to highlight major design issues on the energy efficiency of non-residential buildings. The office occupancy ratio is different than other types of buildings and the volume/external envelope surface ratio is also quite different.

The main issues are summarized as

- Improving the thermal behaviour of the building envelope (façade walls and roof);
- Minimising thermal bridging by preparing best practice in cladding joints and fixings;
- Improving air tightness of the building envelope;
- Achieving efficient air circulation (ventilation) air acclimatization.

Other points to be addressed in the commercial building sector are the best use of day time and night time energy consumption of the building including the effect of the of thermal inertia of the building.

7.2 Influence of various energy reduction measures on whole building performance regarding energy demand for heating, cooling and lighting.

RWTH

In WP 1 and WP2, RWTH has made detailed investigations regarding air-tightness and heat transfer parameters for a reference building. The characteristics were quantified and solutions for improvements were presented. This report evaluates the impact of these details on the whole building performance for non-residential buildings.

Concept of the Parametric Study and Reference Building: The relevance of details (thermal bridges and air-tightness) on the whole building performance is strongly dependent on the dimensions and form of the building. Therefore a basic model of a typical industrial building is taken as shown in Figure 94.

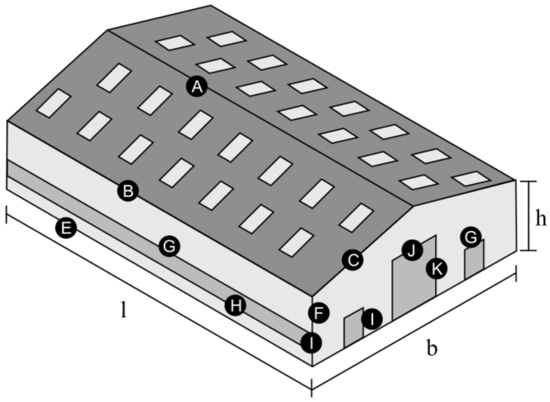


Figure 94: Basic Model for parametric study

The variations in dimensions that were considered are as follow:

- Width: 10 m $\leq$ b $\leq$ 50 m, reference: = 30 m
- Length: 20 m $\leq$ l $\leq$ 100 m, reference: = 45 m
- Height: 5 m $\leq$ h $\leq$ 25 m, reference: = 8 m

The dimensions of the building components (windows, roof lights, doors) are also varied in proportion to the variations of the main dimensions. The details, marked with "A" to "K", are considered in different qualities for air-tightness and thermal bridging effect (Ψ-value).

Parameters investigated are:

- Thermal bridges and Ψ-values: For the relevant details (junctions between works, windows, doors), two standard values are used for normal building and improved one in way to scope on the field of performances.
- Air-tightness: The air-tightness of the whole building envelope is quantified by an air change-rate (n in h^{-1}), at a given pressure difference (typically 50 Pa).
- Quality levels of air leakage: At the joints between works of the building/ and additionally the junctions of the panels in the regular area. Concerning the (openable) joints of doors and windows the air-tightness characteristics were taken from the requirements, for the panels in the regular area and other connections the air leakage coefficients were varied according the results achieved in WP 1 in three different classes (L1, L2, L3 from best to low air tightness).

– As an example, Figure 95 shows the effect on the air-tightness of the whole building (n_{50}-value). For tight and very tight junction (L1, L2) the n_{50}-value is far below the requirements. Also for moderately air-tight junctions (L3, a = 1 m³/(hm) at 10 Pa) for buildings with medium compactness (A/V below 0.4 to 0.5), a n_{50}-value below 1.5 h^{-1} can be achieved.

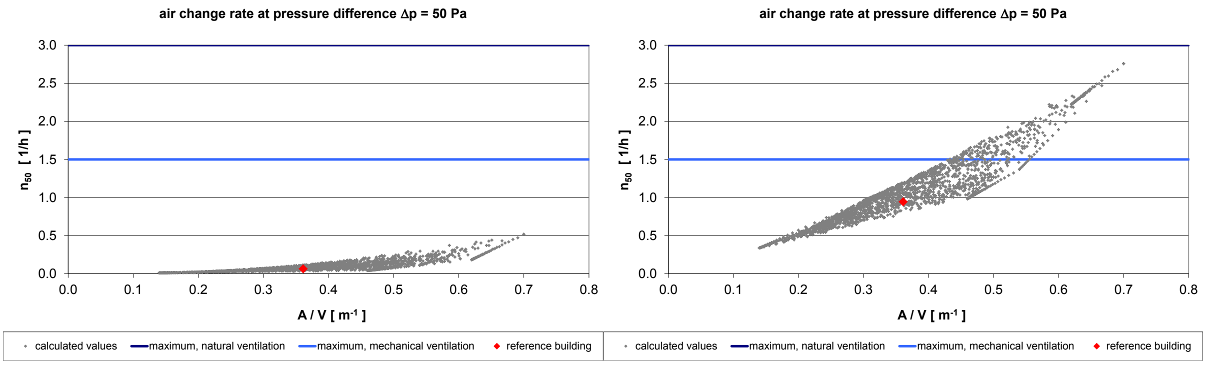


Figure 95: Air-tightness, junctions according class L1 high quality airtight building and class L3 low quality airtight building

Thermal bridges: For the relevant details standard values and improvements concerning the Ψ-values were determined.

Energy performance: These results were then fed into calculations of the energy performance, in which these calculations were carried out for the reference building. A parametric study was made for different locations (Berlin, London, Madrid), different user profiles and different characteristics regarding air-tightness and thermal bridging (Figure 96 shows the results for Berlin).

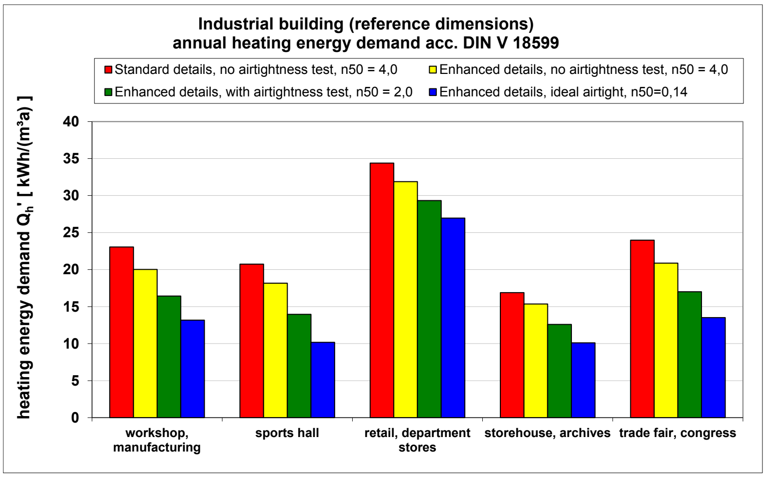


Figure 96: Heating energy demand, Berlin, Germany

This investigation quantifies the effect of air-tightness and thermal bridges on the heating energy demand. Optimizing the details has a significant effect for light-weight steel buildings. The absolute amount depends on the location and the building use, but the energy demand within one data set (one specific use for one specific location) shows the same trend for all these variations.

The energy demand for lighting is dependent on glazing and shading, and cooling is also dependent on building use, orientation etc.

Tecnalia

The work done in WP 3 by LABEIN has focussed on a benchmark of several configuration of buildings including a real experimental building to investigate the best methods for achieving energy savings. Several approaches have been considered to find an appropriate configuration for benchmarking the various innovative techniques proposed in the ETHICS project to improve thermal comfort.

The reference zone is defined as a representative section of a building. A reference zone is not necessarily a room within a building and it is defined by parameters as follows: façade to floor area, façade to volume and proportion of windows. The building structure can be fitted with different types of envelope systems, roof, floor slabs and other elements. The Energy Plus software was used to simulate the behaviour of the building with its various components. The parameters involved in the study were:

Two identical reference zones (materials, construction systems, geometries, proportion of window building usage, services, climates…) show different energy demands depending on orientation and location with regard to the building lay-out.

Orientation is an important parameter that affects solar radiation, wind, etc. The location with regards to the building lay-out takes account of rooms in the corner of a building (where two external walls and two orientations meet). The main building characteristics considered in the simulations are as follows:

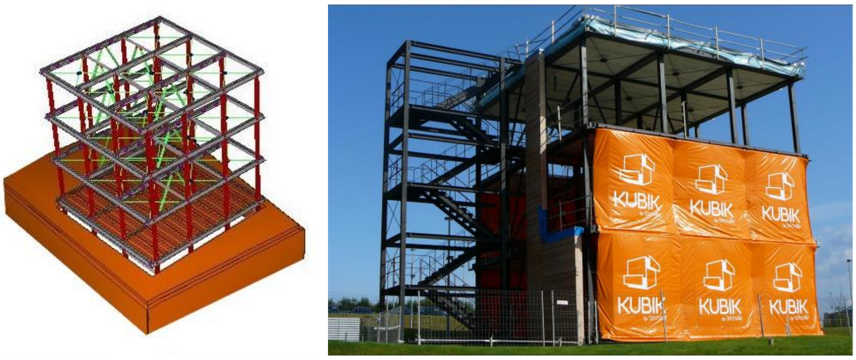


Figure 97: Model and complete steel structure of the reference building

Geometry	System
- Basement and foundations	- Reference facade
- Steel structure	- Roof
- Reference floor slab	- Internal partitions
	- Heating and ventilating – systems (HVAC)

The benchmark characteristics previously defined were used to produce building models that are used to assess how the façade and roof thermal transmittance, window characteristics etc. affect the energy demand of a steel intensive building. The independent analysis of these aspects controls their effect before the specific study of thermal inertia was carried out. A variety of configurations were simulated and the conclusions obtained in this section are presented in other sections of the report.

CRM

In WP 1, the CRM4 building was simulated with the tool "PEB 2.5.2" of the regional government (Région Wallonne of Belgium). This software provides two models: the simple energy models (only U values and the surface of elements are required) and the geometrical model (complete details can be drawn). The simple energy model has been used and the precise details of the envelope, and thermal bridges (at the panel junctions) were not modelled.

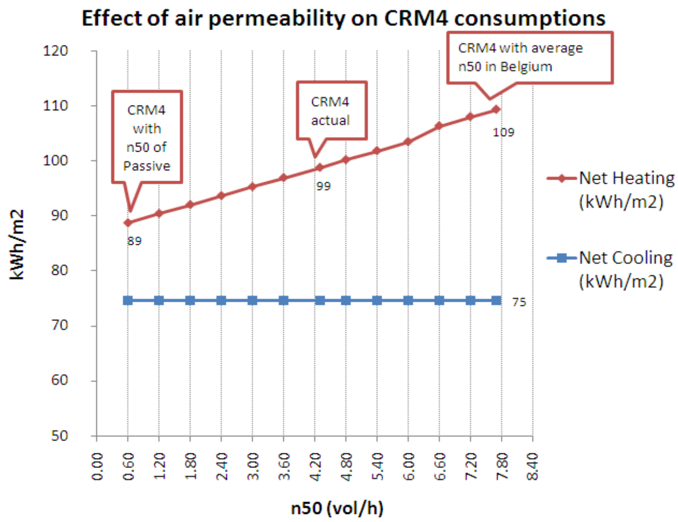


Figure 98: Air tightness effect

Two parameters were considered: air tightness and thermal insulation. Thirteen values of air tightness were simulated for the CRM4 building. The effect seems rather linear (Figure 98). An n_{50} of 0.6 vol/h (at the level of passive buildings) would reduce the heating net consumption by 10 %. An n_{50} of 7.7 vol/h (the average for buildings in Belgium) would lead to an increase of 10 %.

Five types of insulation level were simulated for the CRM4 building (as shown in Table 20):

Table 20 : Details of Elements of the Building Envelope

Building insulation level	U_{wall} [W/(m²K)]	$U_{windows}$ [W/(m²K)]	U_{roof} [W/(m²K)]	
K149	1.50	6.00	1.00	
K56	0.34	1.70	0.35	2 for horizontal, 2.5 for door
K45	0.30	1.50	0.29	2 for door
K33	0.14	1.10	0.14	1.5 for door
K20	0.07	0.40	0.07	0.8 for door

The effect of the thermal insulation of the CRM4 is shown in Figure 99. The insulation level of CRM4 was calculated to satisfy the K56 class. The K20 class would lead to a decrease of 55 % in the heating but an increase of 54 % in cooling. The total consumption (heating + cooling) would decrease by 8 %. The calculated heating demand (99 kWh/m²) is close to the measured heating consumption (91 kWh/m²) but the cooling demand (75 kWh/m²) is slightly overestimated (compare to 61 kWh/m² measured). In practice, the total consumption at K20 should be decrease by more than 8 %.

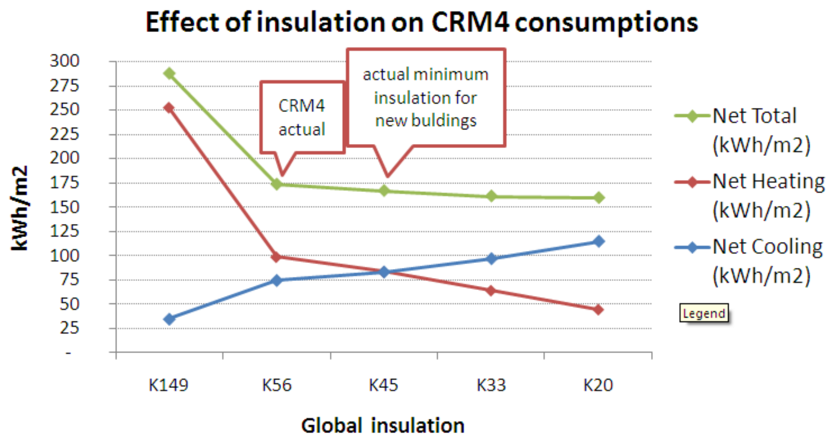


Figure 99: Effect of insulation level on the energy consumption of the building

It was difficult to reach low K values using only the thermal transmittance of the envelope elements. For example, the U values of the K56 class correspond more to a K45 house. Some non-realistic values ($U_{windows}$ = 0.4 W/(m²K)) were chosen to reach the K20 level. One explanation is the low density of the building (ratio of volume on the envelope surface, V/At), which is 1.56 m. The CRM4 building was designed with a large patio. The K values take the density into account. So the CRM4 K level is penalized by its poor density. A better density could have been realised with an atrium (protected space) instead of the open patio space.

<u>CTICM</u>

In this section, results of thermal and energy calculation for one of five examples of steel buildings are presented including the two buildings investigated by CTICM under WP1. CTICM has performed energy efficiency parametric variations on these buildings in order to evaluate the best financial benefits for building refurbishment.

Building 1: 'Hall Clermont-Ferrand': As an example of 5 buildings investigated

The thermal performance of the building was assessed in its initial state, and then with various solutions to improve its thermal performances. The solutions involve both higher levels of thermal insulation and air-tightness of the envelope. The building thermal performances (heating requirements and heating consumption) are calculated with the visual TTH 2005 software. The software allows the calculation of regular coefficients: Ubât, Uât-réf, Cep, Cep-réf, Tic and Tic-réf. The input calculation data are the U-values for various walls, thermal bridge coefficients and the equipment used for HVC.

The building is located in the Department 63 of France and has o floor area of 802 m². The external dimensions are length: 49.75 m, width: 12.90 m, height: 10.03 m, and volume: 6610 m³. The building is normally heated during the winter period. This building is 15 years old, and of medium quality.

Figure 100: Building in Clermont-Ferrand, France

Original building - Concrete facade and steel cladding: About 30% of the facade is in un-insulated concrete, which leads to high heat losses. The 2D thermal bridge due to steel column is about 0.6 W/(m·K).

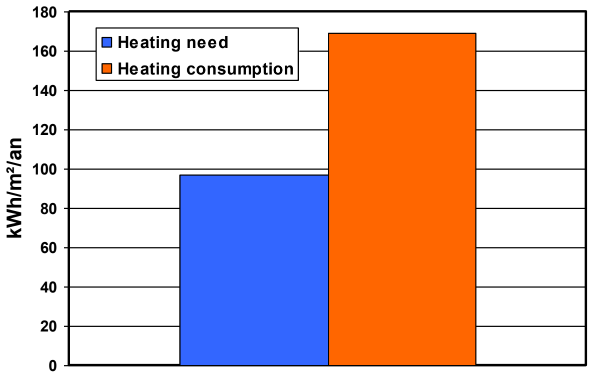


Figure 101: Energy consumption of the building in its original form

Improvements in the Insulation of the concrete wall have been proposed: Cladding with external insulation (PSX 10 cm, λ = 0.03 W/(mK) and plaster fixed by pins. This solution reduces thermal bridging of about 99 % (0.005 W/(mK)) compared to 0.6 W/(mK). The U-value is reduced by about 90% (0.30 W/m².K compared to 2.82 W/(m²K)).

Improving thermal insulation of the concrete wall: 0.30 W/(m²K)	**Improving the envelope air-tightness** to 3; 2 and 1 m³/h/m² (4 Pa)

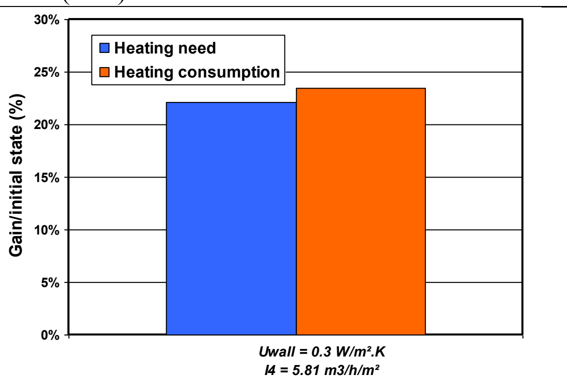
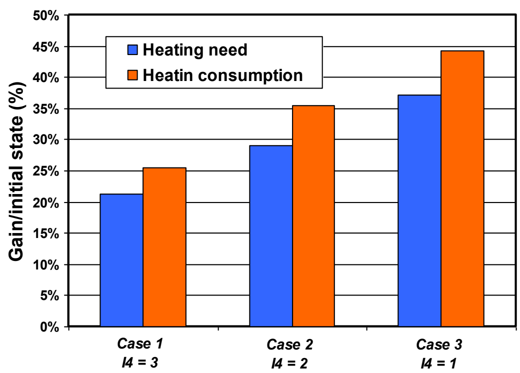

	

Figure 102: Potential gain for energy consumption due to thermal insulation	*Figure 103: Potential gain for energy consumption: due to improved air tightness*

Insulation of the concrete wall and improving the envelope air-tightness: Concrete wall: U = 0.30 W/(m²K); I4= 3 m³/h/m².

Table 21 : Result summary - Building 1: Hall Clermont-Ferrand – Industrial use – 802 m²

Proposal to reduce energy consumption	Heating needs (kWh/m²/y)	Heating consumption (kWh/m²/y)
Initial building - Concrete wall and steel cladding : I4 = 5.81 M^3/h/m²	97	165
Improvement 1: External thermal cladding : 100 mm: U_{wall} = 0.3 W/m².K	22% gains	23.5% gains
Improving air tightness: I4 = 3.0 M^3/h/m²	21% gains	25.5 % gains
Improving air tightness: I4 = 2.0 M^3/h/m²	29 % gains	35.5 % gains
Improving air tightness: I4 = 1.0 M^3/h/m²	37 % gains	39 % gains
Improving both U and air tightness: U=0.3 W/m².K: I4 = 3.0 M^3/h/m²	42.5 % gains	46 % gains

Arcelor Liège

This report describes the energy consumption parameters of the "Steel Centre" (ArcelorMittal Office Building in Liège, Belgium), in comparison with the PEB requirements. In a second part, a parametrical study of the building is presented; and the aim was to study the influence of air-tightness and thermal parameters on the building energy performance.

For an office building, the requirements of the PEB are:

- Maximum U-values depending on the wall type and R_{min} for floors in contact with the ground
- Global insulation level K limited to K45.
- Primary energy consumption compared to an equivalent reference building E_w, limited to 80.
- Minimum ventilation airflow, depending on the number of people, and the area of the room.

The results for the Steel Centre show that the global insulation level is K 42, which is less than the K45 limit but not all of the PEB requirements.

The curtain walls of the façade consist mainly of insulated glass and steel. The requirements for these elements are the taken as for windows (U_{max} = 2.5 W/m²K) and not for façades (U_{max} = 0.4 W/m²K). There is thus an ambiguity in the way of considering the types of façade elements.

A parametric study was performed using the PEB model, in order to highlight the key parameters improving the energy efficiency of an office building.

The following parameters were modified: U-values of walls; lighting; air-tightness of the envelope; external sun shading; ventilation system. The total energy consumption is 970 500 kWh/a and the proportion of the energy use according to these aspects of the building use is presented in Figure 104.

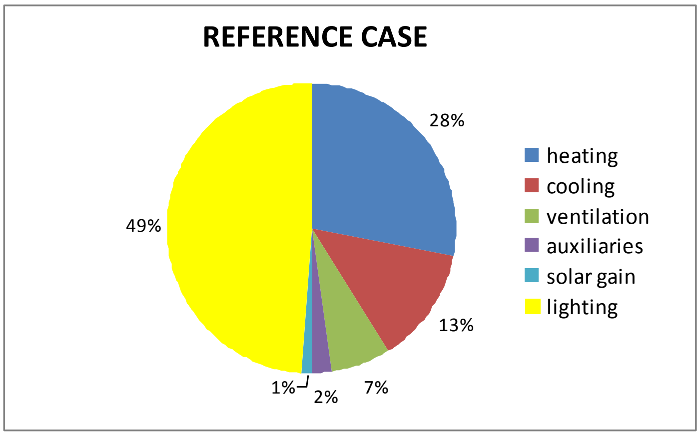


Figure 104: Proportion of total energy used of the Steel Centre building

Improvement of the consumption was carried out incrementally until a final acceptable result was achieved, see Table 22.

Table 22 : Successive improvements of thermal behaviour on the Steel Centre building

PEB requirements	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
U-values	Ok	Ok	Ok	Ok	Ok	Ok
K45	K39	K25	K42	K42	K42	K42
E_w 80	E_w 97	E_w 82	E_w 67	E_w 94	E_w 92	E_w 100
Ventilation	Ok	Ok	Ok	Ok	Ok	Ok
Energy consumption kWh	955 152	807 216	600 364	926 282	898 106	984 309

Figure 105 summarizes the main results of the parametric study of a commercial building located in Flemalle (Belgium).

The key parameter which leads to decrease the total energy consumption of this office building is essentially the lighting. A more detailed analysis shows that lighting and thermal resistance (U-values) are the main items improving the total energy consumption of a non-residential building. Air-tightness is less important for this type of building.

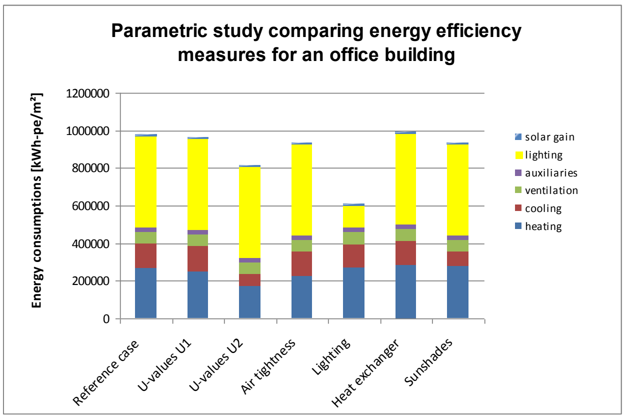


Figure 105: Energy consumption of the Steel Centre building with various measures

7.3 Recommendations for suitable energy and thermal improvement measures for non-residential buildings in steel.

There are a number of considerations to be taken into account in the selection of a building envelope or system, which includes durability, thermal performance, air tightness and environmental climate. Cost is a key factor, but should be viewed in terms of the whole life of the building. Other issues such as detailing, maintenance and disposal should also be considered.

As thermal insulation levels increase, so the influence of air leakage on the overall energy use becomes more important. In existing buildings, air tightness is often poor, mainly due to the porosity of the materials and imperfect joints between the components. Even in buildings constructed to recent standards, the air leakage rate can be higher than 10 $m^3h^{-1}m^2$ (at 50 Pa) and unwanted leakage of the warm internal air can represent 20% of the overall energy use for buildings constructed to higher modern thermal insulation standards, this level of air leakage can increase proportionately to 30 to 40 % of the overall energy use, and therefore it is important to reduce air leakage whilst maintaining good levels of air quality and controlling condensation. In new light steel framing construction, it is possible to achieve air-tightness levels of to 3 to 5 $m^3h^{-1}m^2$, provided that measures are taken to eliminate air leakage at service points and between the plasterboards.

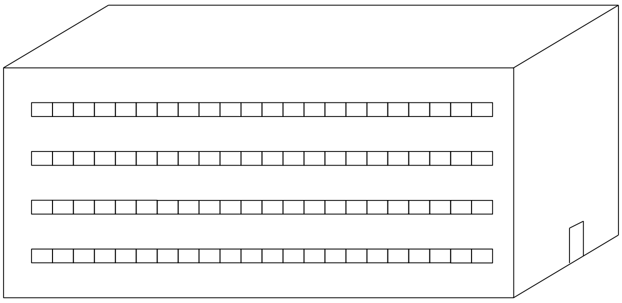
In over-cladding of existing buildings, the built up of external layers does not necessarily have a major impact on the air tightness of the renovated facade, especially if the major contributor to leakage is through the joints in the existing façade. Furthermore, if the over cladding is in the form of a 'rain screen', then ventilation behind the new cladding is required to achieve pressure equalisation. Also some ventilation through the existing façade is required to avoid condensation (in the absence of a vapour barrier on the inside of the building).

Therefore, it follows that reduction of air leakage in over cladding systems is technically difficult to achieve unless a strategy exists for improving the quality of the joints in the existing building. For low rise buildings, control of leakage at the wall roof junction is also important.

In cold climates, air leakage rates below 2 $m^3h^{-1}m^2$ are expected from very low-energy buildings and passive houses. The conversion of air leakage rate ($m^3h^{-1}m^2$) to air changes per hour (h^{-1}) for the reference building (Figure 106)

- $n_{50} = 10\ m^3h^{-1}m^2 = 3{,}2\ h^{-1}$
- $n_{50} = 5\ m^3h^{-1}m^2 = 1{,}5\ h^{-1}$
- $n_{50} = 3\ m^3h^{-1}m^2 = 1{,}0\ h^{-1}$
- $n_{50} = 1{,}8\ m^3h^{-1}m^2 = 0{,}6\ h^{-1}$ (passive house requirement)

The impact of air leakages on the heating demand of an energy-efficient building is shown in Figure 106. Air leakages can increase the total ventilation rate, but they can also decrease ventilation through heat recovery unit of the ventilation system. In both cases increased air leakage rates may have an impact of 40 – 50 % on the space heating demand of an energy-efficient building.



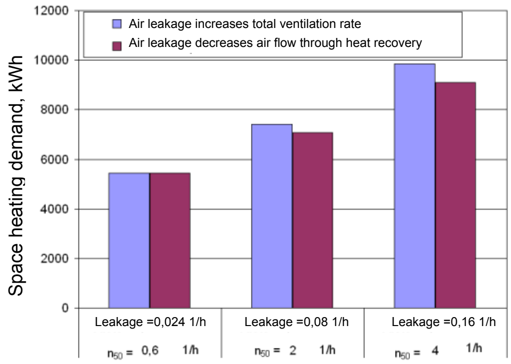


Figure 106: Reference building used in energy analysis. The total surface area is 3646 m^2 and indoor volume 11264 m^3.

Discussion:

The cooling energy needed in the simulated office building is only about 20 % of total electricity use. Therefore the potential for energy saving by night cooling is not very high. The electrical energy for HVAC (refrigeration cooling, fans and pumps) can be reduced about 10 % by exposing the massive floor and massive ceiling to cold night air. Increase of thermal mass by making the external walls of concrete has only a minor effect. On the other hand, the suspended ceiling has a clearly negative impact by reducing the thermal capacity effect of the floor. Increasing air flow rates at night reduces the cooling energy but care must be taken that the increased fan energy does not reduce the benefit of this cooling . This can be assured by sizing the air flow ductwork for increased air flow rate. Other possibilities are to use natural or hybrid ventilation which needs much less electric energy.

The energy saving by night cooling may be increased by fine-tuning the present control system. For example, the minimum room temperature might be lower than in the present study (22 °C). In northern and central Europe, the need for mechanical cooling can even be totally eliminated by night cooling. This possibility and the influence of different parameters on achievable indoor temperature have been studied by Artmann et al (2008). Also a study from (Gratia 2003) showed that in Belgian climate it is possible to gain good thermal comfort in terms of risk of overheating without a cooling system provided the internal gains are not too excessive and shading devices are used and the building is designed in a way that thermal mass can be used together with night ventilation.

Barnard, (1999) has shown that the surface heat transfer is a critical factor in effective storage of thermal energy by thermal mass. This suggests that a larger surface area for the thermal mass elements is helpful, Ribbed floor slabs are more effective than flat slabs, for example. Current research into improving heat transfer includes passing air through cores within the floor slab, or using water in embedded pipes to warm and cool the slab (Kendrick and Ogden, 2002).

Night cooling also lowers the operative temperature because the room surfaces are colder during daytime. This makes it possible to use about a 0.5degree higher room air temperature for the same thermal comfort.

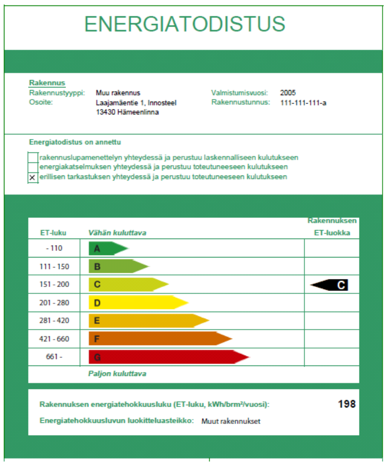
7.4 Energy certificates for selected commercial and industrial buildings in steel.

The European Directive on the Energy Performance of Buildings (EPB/PEB) requires Member States to establish a system for energy certification for buildings.

A certificate is issued by an accredited energy certifier, based on information collected during a visit of the building. It shows the theoretical energy consumption of the building (calculated based on standard conditions of use and climate) and propose general measures to improve the energy balance when that can be made. Energy certificate inform in a concise manner energy efficiency of a building on a scale at which various countries have introduced energy classes, usually from A to G.

WP 7.3 has edited the energy certificates from 7 non-residential buildings studied in the project with as example the one from VTT Finland as below.

Finland: The studied building is located in Hämeenlinna, Finland, about 100 km north from Helsinki. The measurement period was 2009-2010. The building is connected to district heating network. The gross floor area of the building is 4190 m² of which the industry hall corresponds to 3946 m². The building has an energy certification from 2010. The classification of the building was to level C corresponding total energy consumption of 198 kWh/m^2. The difference between measured result and energy certification comes from the backwards calculation since the user electricity is not included in the certification. However, the energy measurements cover only the total electricity consumption and total heating consumption. Thus, the energy certification value is estimation according to calculation rules by the Finnish energy certificate. Currently Finnish energy certification is under renewal and the new energy certification law comes most probably in year 2012.

Name of Project:	Innosteelfactory	
Location:	Hämeenlinna, Finland	**Energy certificate for this building**
Picture:		
Type of use:	Office and industrial	
Dimensions:	Gross floor area: 4190 m²; Building volume: 32 431 m³; number of storeys: 2	
Date of completion:	2005	
Description of construction.	Frame structure with thermal breaks (perforated steel columns), insulation between the profiles with optional exterior insulation.	
HVAC-system:	District heating with water circulation based radiator heating, balanced ventilation with heat recovery including defrosting	

Energy source:		Primary energy factor	CO_2 emissions			
	District heating	0.9 (Finnish building code 0.7)				
	Electricity from national grid	2.2 (Finnish building code 1.7)				
	Measured	Calculated	Official energy certification			
Heating energy	74 kWh/Gr m^2, a	72 kWh/Gr m^2,	68 kWh/Gr m^2			
Cooling energy	Is included in the electricity	Is included in the electricity	Is included in the electricity			
Electricity	156 kWh/Gr m^2,a (here includes also the cooling energy)	99 kWh/Gr m^2,a (here includes also the cooling energy)	120 kWh/Gr m^2			
Energy certification label	Class D 230 kWh/Gr m^2, a	Class C 171 kWh/Gr m^2, a	Class C 198 kWh/Gr m^2			

7.5 Guidance for Architects on Energy Efficient Solutions in Steel for Commercial and Industrial Buildings

The final work within WP 7 relates to “Guidance for Architects on Energy Efficient Solutions in Steel for Commercial and Industrial Buildings”. More details are presented in that document.

Guidance is given in terms of building systems and energy performance. All material is focused on non-residential buildings “mostly industrial envelope” with emphasis on the thermal performance of the envelope system in terms of thermal heat transfer behaviour and air tightness. Two envelope systems are discussed

The ‘Warm frame’ Approach: The two most important considerations for the designer are the type and amount of insulation and its placement in the building envelope in order to minimize thermal bridging. Thermal bridging is a naturally occurring phenomenon that is made complex to analyse, in part, by the addition of external fixings. The best approach to minimize the effect of thermal bridging is to adopt the ‘warm frame’ approach wherein the entire frame is enclosed in a insulation. A solid wall design approach showing external insulation as well as insulation between the C sections is shown in Figure 107 below. This wall has a U-value of 0.3 W/m²K. To attain a better U-value, a higher greater insulation thickness will be required. The use of slotted C sections to lengthen the heat-flow will also help minimize the effects of thermal bridging.

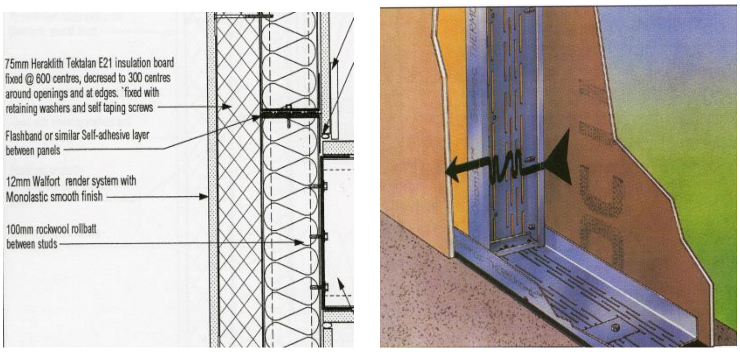


Figure 107: Wall section illustrating the warm frame, solid-wall construction with slotted steel studs

The ventilated envelope approach: Figure 108 shows a ventilated facade structure. It is important to remember that a separated facade structure is affected by the indoor environment if the air or vapour tightness of the insulated wall structure is not adequate. The long wave sky radiation cools the cladding at night and as thin sheet steel cools down easily, water vapour in the ventilation cavity may condense on the cladding surface facing the cavity. Moisture from the indoor air may increase the amount of condensed water by several orders of magnitude.

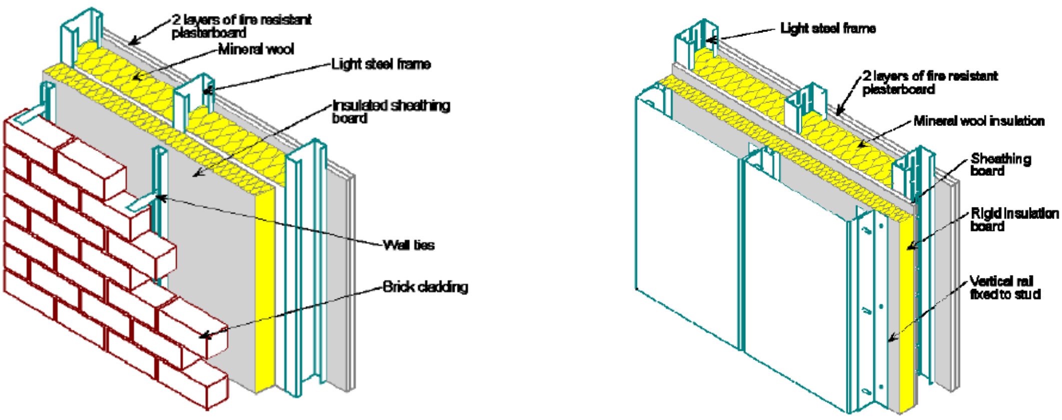


Figure 108: Ventilated facade systems using two types of cladding [SCI]

Thermal and Air Tightness Consideration for Commercial and Office Buildings

The use of light steel infill walls in structural steel frames is now very common, particularly in multi storey construction. Brickwork cladding is self-supporting in walls up to 12 m high (3-4 storeys), but requires additional support in taller buildings. In such cases, it is necessary to support the brickwork by stainless steel angles connected to the steel edge beams. Insulated render, boards, 'rain screen' cladding and metallic cladding are also increasingly used in taller buildings and are directly attached through insulation to the light steel infill walls.

Light steel infill walls can achieve a U-value of 0.25 W/m²K by:

- Closed cell insulation board of 50 to 70 mm thickness and placed external to the wall;
- Mineral wool of 100 mm thickness placed between the C section wall studs;
- C sections of 100 mm depth x 1.2 mm thickness placed at 600 mm centres;
- External cladding of a variety of types. Some cladding types possess little insulation value;
- Two layers of plasterboard internally.

Cold Bridging: Systematic 'cold bridging' occurs in these forms of construction due to the following reasons:

- The mineral wool is discontinuous vertically at the junction with the slab and edge beam, which reduces the insulation provided at these points, and adds to local heat loss at the edge beams;
- The stainless steel brackets used to support brickwork and welded attachment plates to the edge beams lead to direct heat loss through the steel beam and concrete;
- Columns located in the same plane as the edge beams also cause linear thermal bridging in the vertical direction as the mineral wool is discontinuous. The column flanges may also project into the closed cell insulation, which adds to the local heat loss.

Construction details affected by 'cold bridging': As an example, the following details provide typical interfaces between cladding and the supporting structure comprising steel edge beams of various types. Steel edge beams are generally designed to act compositely with composite slabs. Brickwork may be attached to stainless steel angles and brackets at 600 mm centres along the beams. The brackets are attached to plates welded at 600 mm centres to the side of the beams.

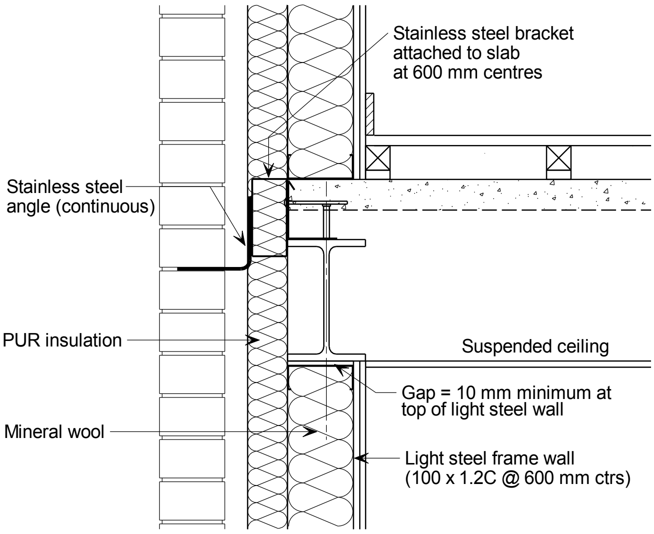


Figure 109: Brickwork attachment to the composite slab

Energy Efficient Solutions in Steel for Commercial and Industrial Buildings

Thermal and air tightness consideration for industrial buildings: The following table gives requirement for air tightness of industrial buildings in various countries Two types of cladding system are considered as seen in

Table 23.

Table 23 : Industrial buildings air tightness to national requirements

County	Equivalent air tightness at 50 Pa		Comment
	API [$m^3h^{-1}m^{-2}$]	Air changes [h^{-1}]	
UK	10.0	4.4	
Finland	9.1	4.0	
Norway	6.8	3.0	
France	4.3	9.9	Default
	3.6	8.2	Reference
Belgium	6.8	3.0	
Germany	6.8	3.0	Natural Ventilation
	3.4	1.5	Mechanical Ventilation
	1.4	0.6	Passivhaus standard
Netherlands	9.5	4.2	
Sweden	5.76	2.5	
Spain	31.6	13.9	Southerly, cooler areas
	17.1	7.5	Northerly, warmer areas

Test conducted at the RWTH laboratories have shown that the joints of sandwich panels are frequently not fully closed. Figure 110 shows an example of an internal joint which is not perfectly closed.

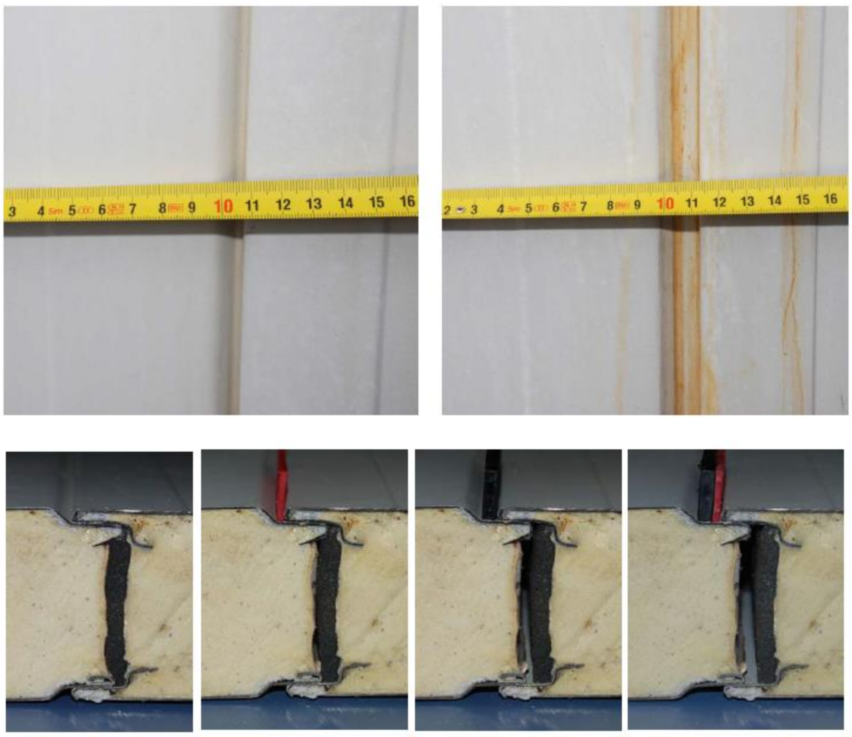


Figure 110: View of a sandwich wall with various gaps

Depending on the width of the joint and on the pressure difference the leakage rate was measured in a test rig (Figure 111). For this specimen, the requirements can be fulfilled for a gap up to 6 mm. This measurement procedure was repeated using various products, the air-tightness (leakage rate) of these products varies in a wide range; and a number of them do not fulfil the requirements for typical positioning on site (see also WP 1).

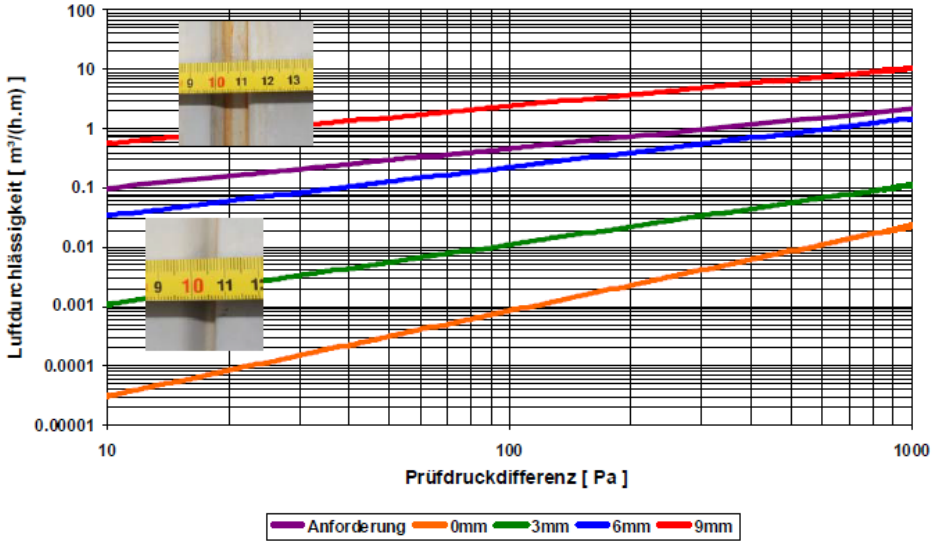


Figure 111: Results for air-tightness of joints (measurements in test rig). Air leakage rate depending of the air pressure difference and several gap widths

The following points have to be investigated to achieve air tightness when designing an envelope system: Air tight materials; Envelope systems; Built-up systems; Composite panels; Connecting devices; Air barrier layer; Durability requirements.

Considerations are given for all these points, as follows:

Durability concerns and requirements: In addition to developing criteria for air permeability and structural performance, the long life of an air tightness system depends on its compatibility with adjacent materials and environmental loads to which it is subjected. Exposure to ultraviolet (UV) under construction and deterioration due to ageing should be investigated. Among the climatic factors that may influence the durability include temperature, humidity, solar radiation, electrochemical factors and biological agents. It may be possible to extend the service life of a whole if repairs can be made a cost effectively, which usually depends on the accessibility of the air tightness system. However, the majority of air tightness systems are not directly accessible.

The recommendation concludes with some details aspect with the performance on air tightness considering:

- Built-up system side lap joints
- Built-up system end lap joints
- Built-up system side lap to flashing joints (as in a vertical corner)
- Built-up system end lap to flashing joints (as in ridge or eaves detail)
- Composite panel system side lap joints
- Composite panel system end lap joints
- Composite panel system side lap to flashing joints (as in a vertical corner)
- Composite panel system end lap to flashing joints (as in a ridge or eaves detail)

As an example: **Composite panel system side lap to flashing joints (as in a vertical corner)**. The joint is formed where panel edges overlap the edges of the folded flashing sheet. Flashings are normally 0.7 mm thick. The overlap joint is sealed using a sealant bead placed inside the overlap joint. The joint is reinforced with stitched screws or rivets, which also compress the sealant bead.

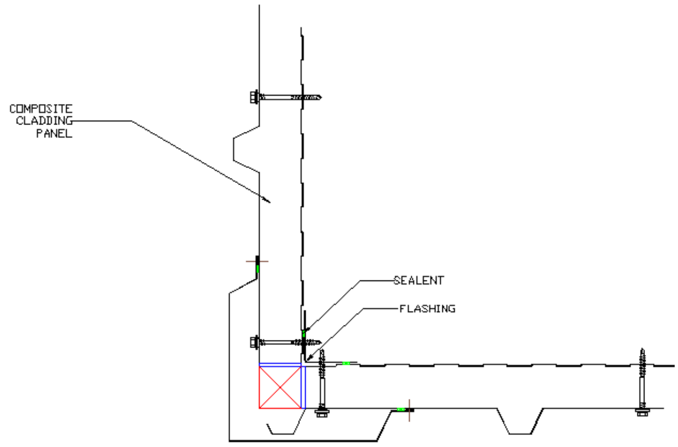


Figure 112: Example of composite panel system side lap to flashing Joints (as in a vertical corner)

The performance of the joint is very similar to a built-up system, liner sheet-flashing joint. Stitcher screws are essential to ensure adequate compression of internal sealant bead.

Conclusions

Air-tightness

The air-tightness performance of various building envelope interfaces using various composite panels system has been investigated to assess their contribution to overall building performance. The results show that no general statement regarding the air tightness of sandwich element joints is possible. The joint tightness depends on the particular joint geometry and joint width realized during the installation. At each joint there is a joint width, where the joint meets the requirements of the joint tightness.

Since the definition of the outer joint width allows no statement about the joint width within the joint and seals each joint in a different place the different joints cannot be compared among each other. In particular, the location, size and compression of a sealing strip within the joint lead to strongly different behaviour of joints with regard to the air-tightness. Only the variation of a joint can be compared and valued.

If the tested elements are installed with the minimum possible gap width, all the longitudinal joints are to be called airtight. In practice, after installation of up to 15 m long elements much larger fluctuations in the element and joint width occur. The variations in joint width can be based on the minimal realizable joint width up to 10 mm.

Leakage, where it occurs, tends to be attributable to inconsistencies in sealing and detailing of interfaces such as roof/wall junctions, openings and connections to other elements, e.g. floor slabs. Both generic and system specific guidance is being developed to allow building designers to have very high levels of confidence in the systems they specify.

Modeling has shown that reducing air infiltration is more effective than increasing levels of insulation, and savings in heating energy of over 10% achievable through more air-tight construction. For industrial buildings, cladding joints can contribute approximately 10% of overall air infiltration for a typical portal frame building, and development of air-tight seals and guaranteed joint integrity is essential for the new generation of cladding products.

Potential problem areas include the use of masonry dwarf walls and the interface of metal cladding system to these walls.

Steel construction can achieve efficient thermal performance using light steel walls of relatively low thicknesses compared with those of concrete walls. For example, with a steel based facade system, a 14 % improvement in thermal performance can be achieved in comparison to a concrete wall that is 18 % thinner (27 cm for the steel wall compared to 33 cm for the concrete wall).

Steel is an inherently air-tight material, so the only air-leakage paths in a steel building envelope are at junctions. Given that the target air-tightness is for the full building, including all openings, interfaces, floors, roof and walls, the techniques detailed here must be adopted.

Experience has shown that with close attention to detail, steel-clad buildings can achieve air-leakage rates less than 5 $m^3/h/m^3$, and often even less than 3 $m^3/h/m^3$. However, air-leakage is also highly dependent on building geometry, so for example simple, large buildings have less surface area in relation to the volume enclosed, and fewer details to compromise air-tightness.

Thermal performance

The thermal efficiency can be improved by the following strategies:

- Improvement should concentrate on the lowest performance factor as this will generate relative high thermal gains,
- Improving air tightness may be more effective than improving U-value for industrial buildings.
- Improving the U-value can be achieved by over-cladding and over roofing, or by replacing the external layer of thermal insulation by a more efficient and thicker layer
- Improving air tightness can be made by checking all possible air leak paths and improvements are made by introducing sealants and other soft linear joints.
- Improving both factors at the same time will save on work “and cost” because the operations are made on the same building elements.

In any case, both thermal insulation and air tightness require skilled installation processes, especially wall cladding and roofs.

Thermal comfort

Facades:

- Reducing the thermal transmittance decreases the heating demand almost direct proportionate.
- The cooling demand slightly increases as the thermal transmittance reduces.
- The most efficient façade system for a building depends on the external climatic conditions.
- The economic and environmental impact of improving the thermal insulation of the building envelope is recommended as the first consideration in the design process.

Roofs:

- The mild climatic conditions selected for the simulations make the cooling demand the critical case for design.
- Reducing the thermal transmittance of the roof produces the same effect as reducing the thermal transmittance of the facades. Because of the smaller surface, reducing the thermal transmittance of the roof leads to less improvement in terms of energy consumption than that of the facades.
- The heating demand reduces and the cooling demand increases as the roof insulation increases.

Windows:

- The heating demand increases when the window solar factor increases.
- The cooling demand decreases when the window solar factor increases.
- The selection of the most appropriate windows should take into consideration both the heating and the cooling demand as well as their cost

Both the measured and calculated studies showed that the light weight steel buildings are performing well. When the simulated and measured results were compared, clearly similar trends could be seen, but the absolute values in temperatures were different due to different actual weather data and internal loads.

The key aspects in thermal comfort in summer time is to avoid excess solar gains indoors by using shadings. In addition the ventilation/air conditioning systems air velocities should be low enough in the working/living areas. In the measured offices and lobby rooms the air velocity was acceptable levels and was not causing any problems. The only exception was in the lobby in extreme cold winter day. In winter time the key aspects are the heating system and ventilation air velocities. In measurements in indoor air temperatures were according to set point and the operative temperature was according to guidelines.

In simulations both light weight and heavy weight office building were compared in respect of thermal comfort by using a detailed human body model in dynamic simulations. The results indicated that the clothing level seems to have the greatest influence on thermal sensation and comfort and the thermal mass of the structures was playing only a minor role. The studied structures were not extreme massive and heavy structures but the typical structures used in office buildings. All cases have a relatively low predicted percentage of dissatisfied (PPD) with the right clothing for the season.

ECALTO

Considering, the ease and low data input required for ECALTO tool, the results are acceptable and the tool is useful for estimating building energy demand at pre-design stage.

Exploitation and impact of the research results

Due to the significance of saving energy and raising the thermal efficiency and performance of buildings and construction, researching in this whole area is necessary and important. In this context, the ETHICS project can be taken as a basement for other research projects.

The consequences of climate change, increasing dependence on fossil fuels, and rising energy prices make it inevitably not only to support the scientific research in this field, but also to pass new knowledge on into practical adoption.

Therefore the outcome of the ETHICS project has to be valued to be very interesting the one hand for designers, architects and engineers in the area of current practice and on the other hand for authorities and politics. Because of the mass of measured data, the wide range of different standards and the amount of different solutions for constructions that were collected and presented in this paper, the ETHICS project has to be considered as a big step forward.

In order to transfer the obtained results from science to economy, the developed design guides can be published. In this way engineers, architects and designer are able to get support and advice in creating new, efficient solutions for the upcoming challenges.

Beside this, another opportunity to make proper use of the experiences in practice is, to release the software tool "ECALTO". In general, "ECALTO" is an easily to use tool, so that first results and basic advices can be generated very fast. Program extensions, updates, add-ons and plug-ins are possible and of course useful, to keep it current.

Furthermore on basis of the measured data within this project proceeding results and advancements can be generated. The influence of different solutions e.g. on air-tightness can be seen and established within the measurement campaigns.

<u>Software-Tool:</u>

- ECALTO

<u>Design guides:</u>

- **Residential buildings:**
  Guidance for architects and engineers on energy efficient solutions in steel
- **Non-residential buildings:**
  Guidance for Architects on Energy Efficient Solutions in Steel for Commercial and Industrial Buildings

<u>Upcoming projects:</u>

- **TABASCO:**
  Thermal Bridging Atlas Of Steel Construction For Improved Thermally Efficiency Of Buildings
- **ZEMUSIC:**
  Zero Energy Solutions For Multifunctional Steel Intensive Commercial Buildings
- **BATIMASS:**
  Building In Active Thermal Mass Into Steel Structures

Publications:

- **Elguezabal, Peru (Tecnalia):**

  “Caracterización térmica en régimen dinámico de soluciones de fachada industrializada con perfilerías metálicas de baja inercia. Estrategias de mejora en la eficiencia energética mediante resolución de los puentes térmicos”

  “Transient thermal characterisation of steel industrialised envelope solutions with low thermal inertia. Strategies to improve the energy efficiency by minimising thermal bridges”

  Doctoral thesis; submitted and officially accepted on March 2012, to be finalised in 2013

- **Holopainen, Riikka (VTT):**

  “A Human Thermal Model for Increased Thermal Comfort”

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- **Kuhnhenne, Markus (RWTH):**

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- **Döring, Bernd; Feldmann, Markus; Kuhnhenne, Markus; Müller, Dirk (RWTH):**

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ETHICS is concerned with evaluating, measuring and making improvements in the thermal and energy performance of steel-clad and steel-framed buildings. It addresses basic building physics performance at a laboratory and full-scale level, and the preparation of design guidance for commercial, industrial and residential buildings. It includes the development of design tools to assist users in assessing whole-building performance, and calibrates these tools against whole-building measurements, which will be obtained from this research. Opportunities for renewable energy and other energy-saving features will be assessed.

This project focuses on objectives that are of particular interest for the design of new steel constructions regarding energy efficiency. ETHICS investigates the as-built performance by on-site tests regarding air tightness and heat transfer properties of the building envelope and by monitoring the energy consumption and thermal comfort of selected up-to-date steel buildings. As energy efficiency is a key requirement for design and construction of buildings in the future, this project provides well-founded scientific data, which prove the high energy performance of current steel constructions and work out details for further improvements to maintain and extend the position of steel products in the construction sector.

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