PROJECT FINAL REPORT

PUBLISHABLE SUMMARY REPORT

(including Plan for Use and Dissemination of Foreground - PUDF)

December 2011

- ***Grant agreement number***: **213302**
- ***Project acronym***: **EASIE**
- ***Project title***: **Ensuring Advancement in Sandwich Construction Through Innovation and Exploitation**
- ***Funding scheme***: **FP7 Collaborative Work Programme, Theme 4 Nanosciences, Nanotechnologies, Materials and New Production Technologies, Activity 4.0-6 Innovative added-value construction product-service**.
- ***Period covered***: **1 October 2008 to 31 December 2011**
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The **EASIE Consortium** included the following Participants:

No	Name	Short name	Country
1	**Fachhochschule Mainz, Institut für Sandwichtechnik**	**ISM**	**Germany**
2	**Karlsruhe Institute of Technology**	**KIT**	**Germany**
3	**Aalto University**	**Aalto**	**Finland**
4	**Syndicat National du Profilage des Produits Plats en Acier**	**SNPPA**	**France**
5	**Technical University Darmstadt**	**TUD**	**Germany**
6	**Pan and Pro Europe**	**PAPE**	**France**
7	**European Quality Assurance Association for Panels and Profiles**	**EPAQ**	**Germany**
8	**Panelco**	**PAN**	**France**
9	**ArcelorMittal Construction Polska**	**AMC**	**Poland**
10	**ECP–Gesellschaft f.GfK Lösungen mbH**	**ECP**	**Germany**
11	**M-Profile Zabok d.o.o**	**MPRO**	**Croatia**
12	**Fech Fenstertechnik GmbH & Co. KG**	**FECH**	**Germany**
13	**Asociacion Paneles de Poliuretano Inyectado**	**APIPNA**	**Spain**
14	**Engelbert Ritsch GmbH**	**ITP**	**Italy**
15	**LHH consulting Oy AB Ltd**	**LHH**	**Finland**
16	**RBM Europe BV**	**RBM**	**Netherlands**
17	**ColdKit Ibérica S.A.**	**NGP**	**Portugal**
18	**Europa Media**	**EUMED**	**Hungary**
19	**ThyssenKrupp Bausysteme GmbH**	**TKS**	**Germany**

The **E**nsuring **A**dvancement in **S**andwich Construction through **I**nnovation and **E**xploitation (EASIE) was a European collaborative project targeted at SMEs funded by the European Commission under the FP7 Collaborative Work Programme, Theme 4 Nanosciences, Nanotechnologies, Materials and New Production Technologies, Activity 4.0-6 Innovative added-value construction product-service.

EASIE was governed by the European Grant agreement No 213302 between Fachhochschule Mainz University of Applied Sciences and the Commission of the European Communities.

The Project started on 1 October 2008 and was due for completion on 30 September2011 (36 months duration). The work extended until 31st December 2011.

The project was composed of seven work packages, the first four of which have created new knowledge and design tools in areas where there had been previously little or no research. The fifth and sixth work packages disseminated and exploited both new and existing information in practice. The seventh work package dealt with management and governance.

The key topics dealt with in the project were linked directly to the needs of industry not only for technological innovation and training but also but also for standards and guidelines.

The overall goal of EASIE was for SMEs to make the use of a range of high-technology construction products focusing on sandwich panel technology more effectively and more innovatively to improve the quality and energy-efficiency in building and to allow easier retrofitting and maintenance and to improve the competitiveness of a key EU industrial sector dominated by SMEs.

1. IMPROVEMENT OF THERMAL AND STRUCTURAL BEHAVIOR IN OPENINGS AND JOINTS (WP1)

Wall sandwich panels form the envelope of a building. Due to various requirements it is usually necessary to cut openings into the façade. For example changing windows or cutting new openings into walls or roofs are typical demands that come up in refurbishing or retrofitting industrial buildings. Joints and openings can have a downgrading effect on the wall or roof made from sandwich panels. On one hand they can reduce the thermal insulation and water tightness on the other hand they lead to a decrease of structural strength. Today, there is only one way to manage the problem of structural integrity, a modification in the substructure diverts the loads around the opening. Such procedure is costly and labor intensive. A major part of this work is dedicated to thermal losses through joints and openings, a major point in the goal of reducing CO2 emissions in Europe.

A sandwich panel with an opening can be designed without any additional stiffening elements. A calculation model has to be developed, which describes the load transfer over the longitudinal joint into the neighboring elements. For the modeling of the panel interconnection, information about the rigidity of the longitudinal joint, about the rigidity of the panel in the transverse direction and about the torsional rigidity of the panel is needed.
A further possibility is to use stiffening, load transferring frame around the opening. The frame is integrated into the opening and designed to form a tight and loadbearing system. Investigations on the connection between the additional frame and the sandwich panel have to be made. Due to the large variation and complexity of the detailing of this connection, an experimental study will provide a better insight in the structural behavior than the development of a mechanical model.

Joints between panels are usually optimized for fabrication by the panel manufacturer. Due to the fact that the joints are fabricated in an industrial process very small tolerances can be allowed and sophisticated solutions may be applied. Therefore this task will focus on the assessment of existing solutions, find their strong and weak points in tests under laboratory conditions, and will check whether certain solutions show advantages compared to others with regard to fabrication and maintenance cost.

Sandwich structures have to be fit to windows, doors or openings for ducts. These connections are very sensible to good or poor craftsmanship. Therefore the erection team has to be equipped with very good and easy to apply guidelines and rules. In task 1.2 a critical survey of existing solutions will be made. These will be tested under laboratory conditions and from this excellent details calculation models will be derived and explained.

The product standard for sandwich panels, EN 14509 focuses on sandwich panels as they are put on the market. There are very few official requirements for specific topics concerning the use of sandwich panels. This is valid also for cutting openings in panels and installation related topics.

This work was focusing on two problem areas: air permeability of panel joints (causing thermal losses) and effect of openings on panel assembly. The aim was to give guidelines on good practice for panel joints with regard to water and air permeability and to develop models for the assessment of strength of panels with openings as well as distribution of loads between panels with openings in a wall panel assembly. The aim is also to study the effect of reinforcement around the openings either as separate or integrated solutions. Based on feedback from industry the programme was extended to cover openings in roof panels. In the area of effect of openings on strength close collaboration exists with ECCS TWG 7.9/CIB W56.

At the inception of the work, the decision was made to send out a questionnaire to manufacturers of panels and windows to get their views on the targets which had been set. It was further decided to contact a number of key companies for more detailed technical discussions.

1.1 Thermal losses in joints

This work involved an investigation into thermal loss in joints between panels focusing on the assessment of proposed new solutions, finding their strong and weak points in tests under laboratory conditions, and checking whether certain solutions show advantages compared to others with regard to fabrication and maintenance cost.

Tests were performed at Technische Universität Darmstadt (TUD) to study the effect of thermal losses due to air leakages in panel to panel joint. Several types of panel joints were studied with variation in installation accuracy. Results were compared to European Standard requirements as well as national German requirements.

Fig. 1.1: Tests on panel assembly to measure joint air tightness

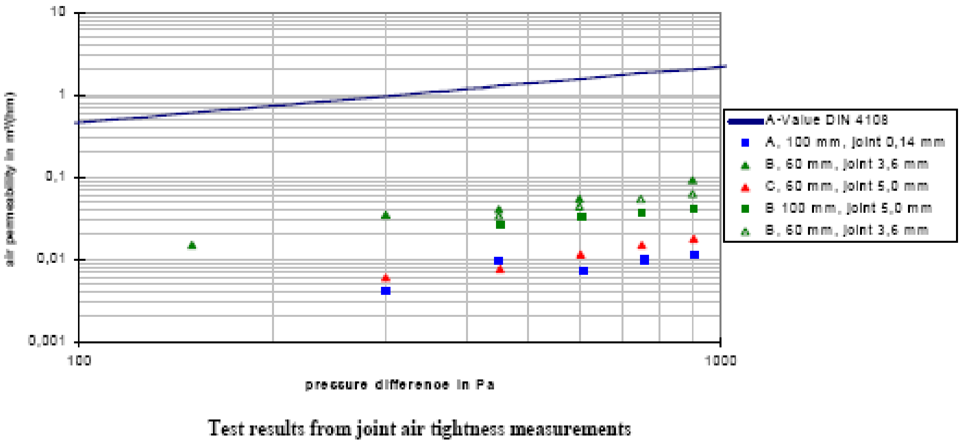


Fig. 1.2: Test results from joint air tightness measurements

1.2 Thermal losses in windows, doors, openings

This task involved an investigation of thermal loss in connection to windows, doors and openings for ducts. Being installed on site, the applied sealing technologies differ significantly from the one described above and need special consideration including testing under laboratory or on-site conditions. Panel window assembly tests have been done at Technische Universität Darmstadt to study the air leakages and water tightness. Altogether, three different window systems have been tested regarding the air and water tightness. Very good water tightness can be stated for all the systems with and without windows. In all tests the highest class of tightness according to EN 14509 was reached.

Fig. 1.3: Examples of different window-systems which were tested

The air permeability is very dependent on an exact mounting of the sealing tapes. If attention is paid to a correct mounting, excellent air tightness is possible. In Deliverable D 1.1 "Design guidelines for good panel joints and joints sealing openings focusing on air and water tightness" the important test results have been included and key instructions for the industry regarding the fabrication and the mounting are given.

1.3 Strength of panels with small openings

This work was aimed at the development of a model for the determination of strength of sandwich panels with comparably small openings. The load-deflection characteristic of sandwich panels with openings has to be assessed with mechanical models that have to be derived from experiments. For wall panels models developed in earlier studies have been evaluated. The evaluation was also done based on work done in the committee ECCS TWG 7.97/CIB W56. Based on the results for wall panels, tests on roof panels with profiled faces and small openings were performed. The load bearing capacity regarding bending moments and shear forces was investigated and calculations were developed. All the results were summarized in a report entitled "Design model to the effects of small openings", which was published in April 2011. In the evaluation of the original working programme an extension was done to cover also roof panels with profiled faces.

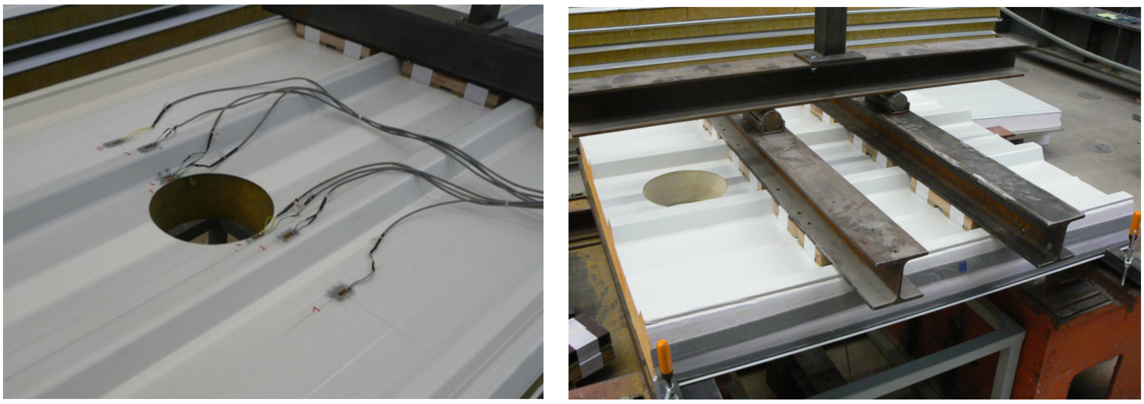
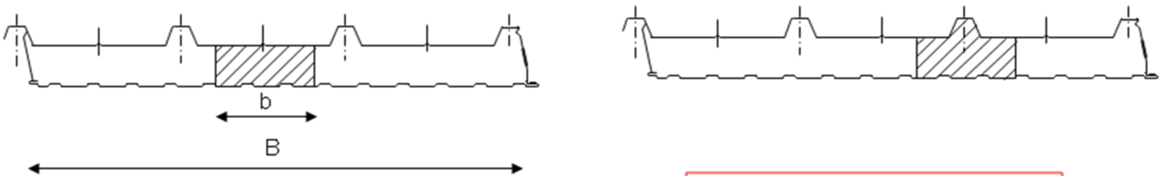


Fig. 1.4: Tests on roof panels with openings



$$M_{Od}(x) \leq (1 - 0{,}5 \cdot \beta) \cdot M_{Rd}$$

$$M_{Od}(x) \leq \frac{(k - a)}{k} \cdot M_{Rd}$$

Fig. 1.5: Calculation model for the bending moment capacity of profiled panels with openings

1.4 Strength of panels with large openings

This work was aimed at the prediction of mechanical strength of panels with openings larger than those under Task 1.3. The load transfer to neighboring elements by the joints or the use of a frame structure assembled into the sandwich panel itself can lead to major improvement. Therefore this work coveeds sandwich structures and the interaction of panels with regard to their load bearing capacity. Typical sandwich structures with windows and doors were assessed by mechanical tests. A new system applied on site by FECH, which had been designed to optimize tightness properties was investigated for mechanical purposes.

Tests with a two-panel system were performed to investigate the load transfer to neighboring panels together with tests regarding the torsional stiffness of sandwich panels. Based on the results of these tests calculation models for systems of panels with large openings were developed. Nearly all large openings have some kind of reinforcement. Here a distinction was made between three groups: adapter profiles, punctual fixings and bonded window frames.

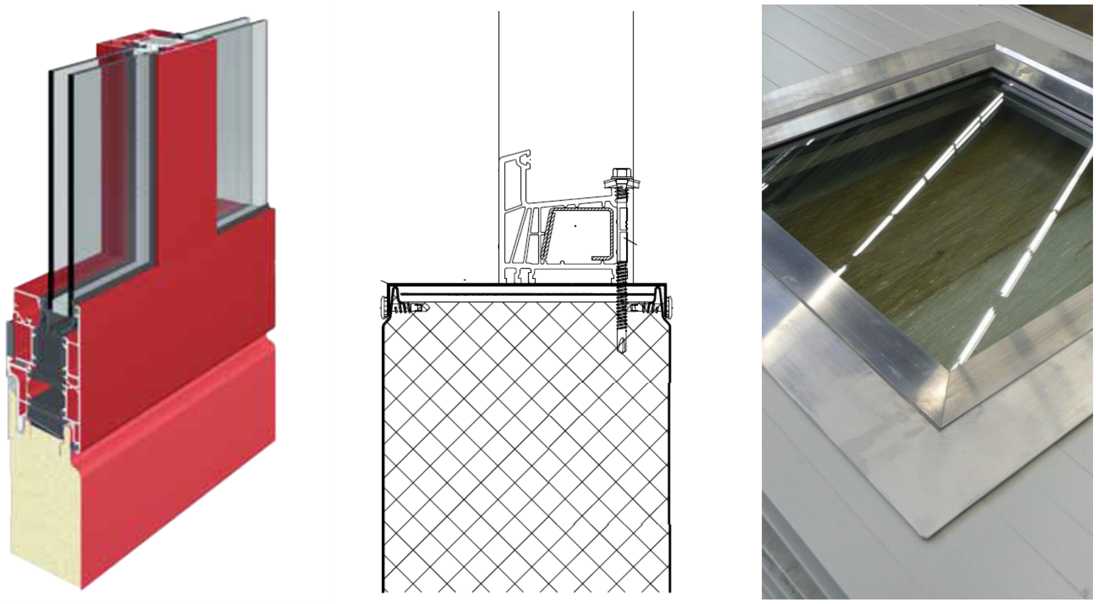
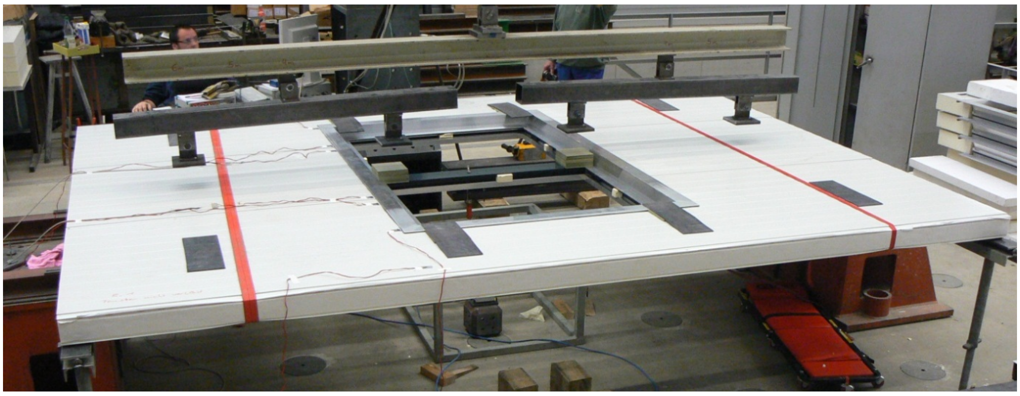


Fig. 1.6: Three types of reinforcement: adapter profiles, punctual fixings, bonded frames

For each of these groups calculation models were developed and described in report D 1.2: “Calculation Model determining mechanical strength of sandwich panels with opening with and without additional internal frame structure”. In report M 1.4 “Design model to the effects and strengthening of large openings, includes model application” a calculation example for one of the groups was given. Some of the models were validated experimentally. For others further investigations will be necessary beyond the EASIE project.



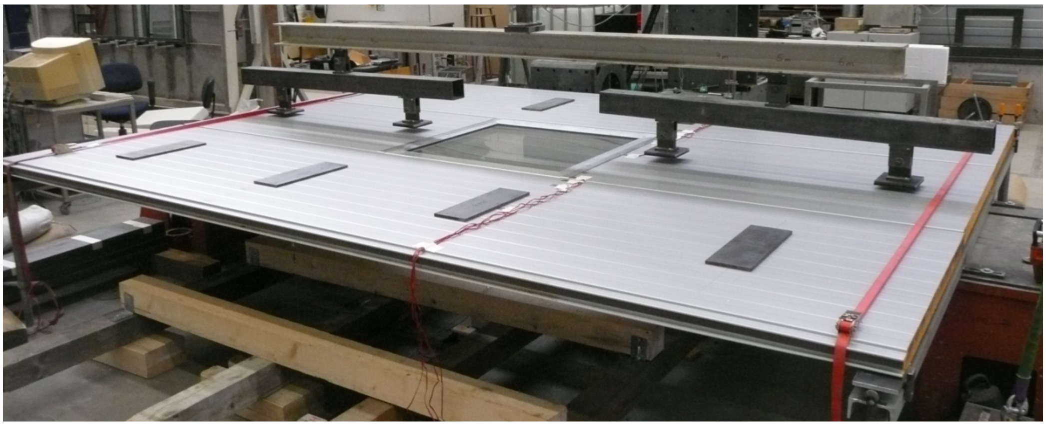


Fig. 1.7: Test set ups with large openings

1.5 Key results

Thermal behavior

Very good water tightness could be stated for all tested systems with and without windows. In all tests the highest class of tightness according to EN 14509 was reached.
Air permeability is very dependent on some details. Three points are of major interest. First, the geometry of the joint plays an important role, second the right sealing tape is of particular importance and perhaps the most relevant items are the tolerances of fabrication and mounting. If attention is paid to all of these points it is possible to design joints with excellent air and water tightness.
In report D 1.1 "Design guidelines for good panel joints and joints sealing openings focusing on air and water tightness" the important test results and key instructions for the industry regarding the fabrication and the mounting are given.

Structural behavior

New calculation models for roof panels with small openings were developed, based on experimental and numerical investigations.
Tests on wall panels with small openings and window frames showed that frames improve the load bearing capacity of panels with openings clearly. Further the tests showed that the frames do not carry parts of the load by themselves but stabilize the faces in the high stressed regions around the opening. Therefore it is necessary that the frame stabilizes the face in a region of at least 5 cm around the opening.
For large openings with reinforcement three different calculation models were developed depending on the kind of reinforcement.

All the calculation models were described in report D 1.2: "Calculation Model determining mechanical strength of sandwich panels with opening with and without additional internal frame structure".

1.6 Potential impact and use of results

The development of safe and scientifically verified rules for the design and detailing of openings in sandwich panels will bring a major improvement of the energy saving building component. It will eliminate the cost for structural components that are currently needed to take the loads in the area of openings. This will further improve the economic aspects of sandwich panel construction.

The possibility to strengthen sandwich panels with stiffening frames or even better to calculate the effects of new or changed openings in respect to the load bearing capacity of the used cladding or roof panels establishes the potential to retrofit or to refurbish "used" buildings. Not to have to replace major parts of the building's skin because the strength of the panels can be restored if necessary reduces the consumption of material, work and energy. This means a great advantage for the customer and boosts the sustainability of sandwich panel constructions. The complete building system becomes more modifiable, constructional methods for refurbishment or retrofit will be more economic and ecologically friendly.

The product standard for sandwich panels EN 14509 is focusing on sandwich panels as they are put on the market. There are very few official requirements for specific topics concerning the use of sandwich panels. This is valid also for cutting openings in panels and installation related topics. In the area of effect of openings on strength close collaboration has existed between EASIE and ECCS TWG 7.9/CIB W56 were the results will be discussed and ultimately included in the European Recommendations for Sandwich Panels.

1.7 Conclusions

Principles of good practice for the design of joints against thermal losses have been summarized and presented in this part of the EASIE work. Regarding the thermal aspect a very helpful guideline now exists for the industry to freely use and apply.
Regarding the structural behavior of panels with openings further investigations are necessary. New calculation models have been derived from test results for roof panels with small openings and for wall panels with large openings and different kind of reinforcement. To verify these calculation models more experimental and numerical investigations are needed. At TU Darmstadt the research in this field will be continued.

2. END USER FOCUSED DESIGN STRATEGIES (WP2)

The aim of the work was to develop a design by testing method for the sandwich panels so as to complement the design by calculation already included in the European standard EN 14509.
This method was developing also with a view to optimize the performances of the panel especially for 2-span-elements.

The goals were:

- To produce a thermal test method
- To carry out an experimental test programme based on large scale tests done on PU and MW sandwich panels on 2 and 3 supports, downward and uplift load, with and without thermal gradient: The cladding panel tests were carried out at Karlsruhe Institute of Technology, the thermal tests on cladding panels were carry out at Technical University Darmstadt and the thermal tests on roof panels at Aalto University in Finland.
- To produce a theoretical guidance to analyze the test results in view to produce load/span tables usable by companies and in particular SMEs.
- To produce a series of numerical examples on panels with 2 and 3 supports, uplift and downward load, with and without thermal gradient (roof and cladding panels)
- To carry out a parametric study to compare the design by testing and the design by calculation methods.
- To produce an excel software in the form of several simples modules (bending and shear rigidities, strength capacities, load tables) calibrated with the numerical examples easily accessible and usable by SMEs.
- To prepare the text of a future Draft annex F to EN 14509 "Design by testing" as a basis for discussion by the relevant standardization committees of CEN TC 128 SC11.

2.1 Thermal test methods

Two methods were developed, one to calibrate the theoretical results with the real behavior of the panels below a thermal gradient alone (factor $\beta\Delta T$ between 0.92 and 1.03), and one to carry out and analyze large scale tests were simultaneously are applied a thermal gradient and a mechanical loading.
These two methods were applied by Technical University Darmstadt in Germany and by Aalto University in Finland.
The two methods are now operational and are available on the project website at www.easie.eu.

2.2 Theoretical guidelines

Two theoretical guidelines were developed: one for the cladding panels with two flat facings and one for the roofing panel with one face ribbed and one face flat. In these guidelines, the strength of material formula are developed in view to cover panel on 2 and 3 supports, uplift and downward load, with and without thermal gradient. These formula were programmed in the excel software and the final results were compared with the design by calculation methods. The good correlation of the results were seen on the panel tested (Roof PU panel see 3 example below).
The two guidelines are available on the project website at www.easie.eu

Numerical examples of the design by testing method
Examples were done manually to cover the field of application of the design by testing method including cladding panels on 2 and 3 supports, uplift and downward load, with and without thermal gradient with a PU or MW core. It also included roof PU panels on 2 and 3 supports, uplift and downward load, with and without thermal gradient.
These numerical examples were checked by the software modules themselves and by the Is-Mainz calculations done on a complete roof panel.
The 31 numerical examples are available on the project website at www.easie.eu

2.3 Parametric study

A parametric study was done based on the 31 examples detailed above. In this document the load span tables obtained with the design by testing method and obtained with the design by calculation method are compared.

In all the cases, the correlation was found to be good with the two methods having the same level of safety.

2.4 Excel sheets software for Design by Testing

An Excel software based on 3 modules (one for the design of the bending and shear rigidities, one for the design of the strength capacities, and one for the determination of the load/span tables) were done.

These software were checked via a roof panel example simultaneously calculated following the EN 14509 standard via the design by calculation method and following the design by testing method via these excel software.(see figures below)

A good correlation of the results was seen.

These Excel sheets are available on the project website at www.easie.eu with a SNPPA copyright.

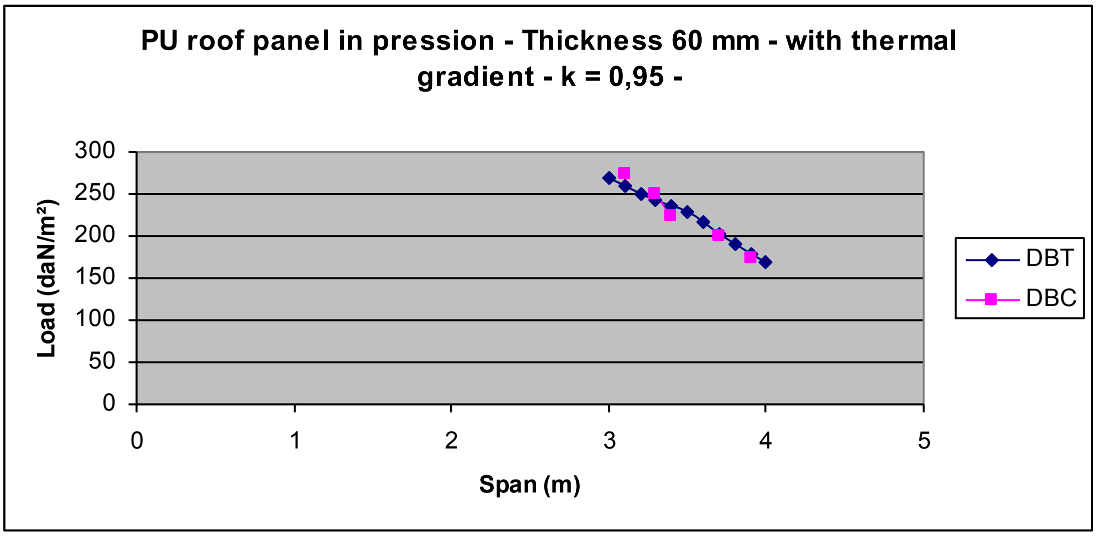


Fig. 2.1: PU Roof Panel , one span, downward load, thickness 60 mm (DBC IsMainz-DBT DI)

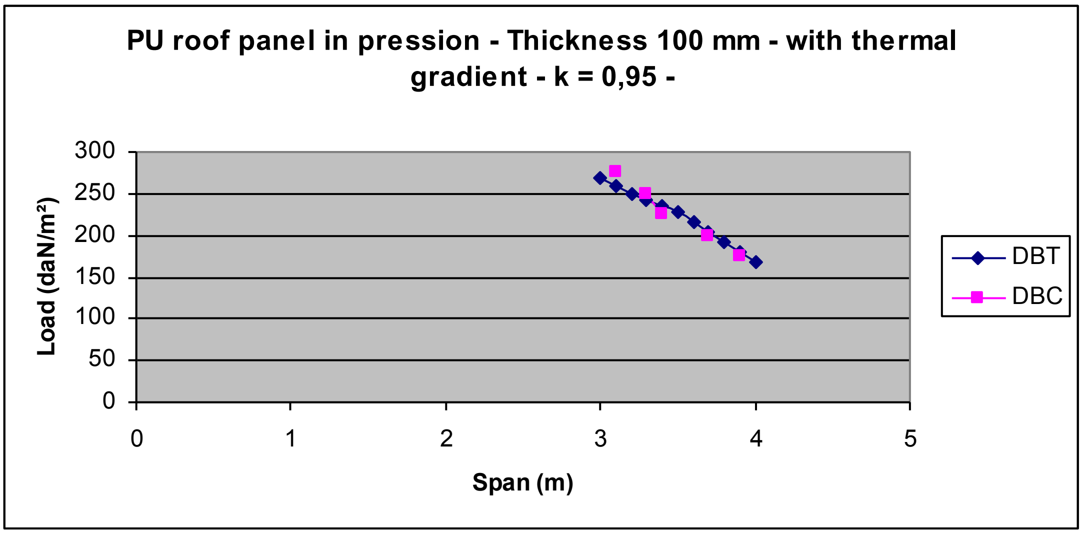


Fig. 2.2: PU Roof Panel, one span, downward load, thickness 100 mm(DBC IsMainz-DBT DI)

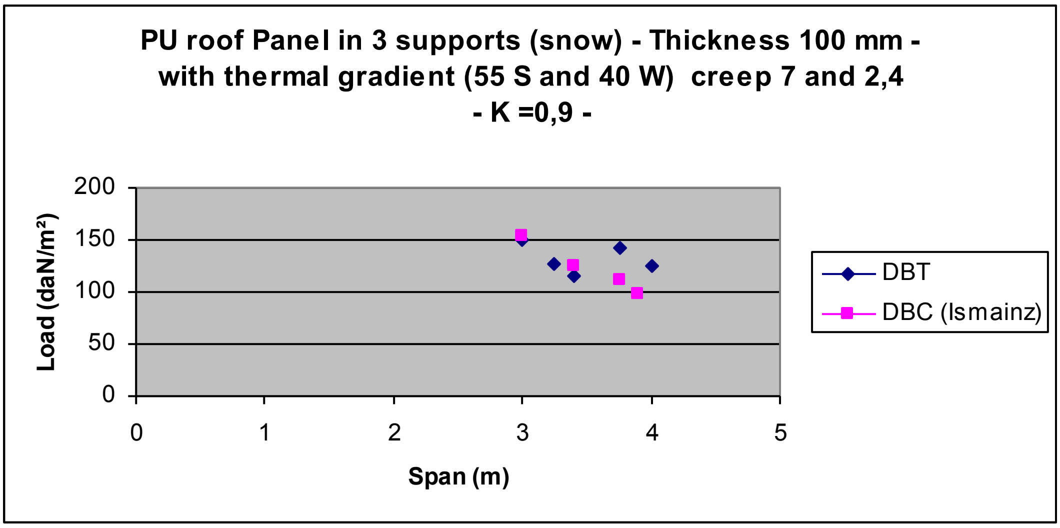


Fig. 2.3: PU Roof Panel, two span, downward load, thickness 100 mm

2.5 Draft annex design by testing

A draft annex design by testing has been drafted. This document defines all the principles necessary to apply the design by testing method.

This document which is available on the project website at www.easie.eu must now be discussed inside the relevant committees of the CEN TC 128 SC11.

2.6 Simplified computer program for calculation of actions and stresses of sandwich panels

Calculation of actions and stresses

On the base of an existing Excel-Program for calculation of single actions, published sometimes ago of iS-mainz as free ware, a new extended Excel tool, so called SandEXCEL I, is developed as part of the EASI project for calculation of internal actions and stresses due to normal loading and temperature gradient for one and two span sandwich panels with flat and profiled faces. A print out of the input page is shown in Fig. 1.

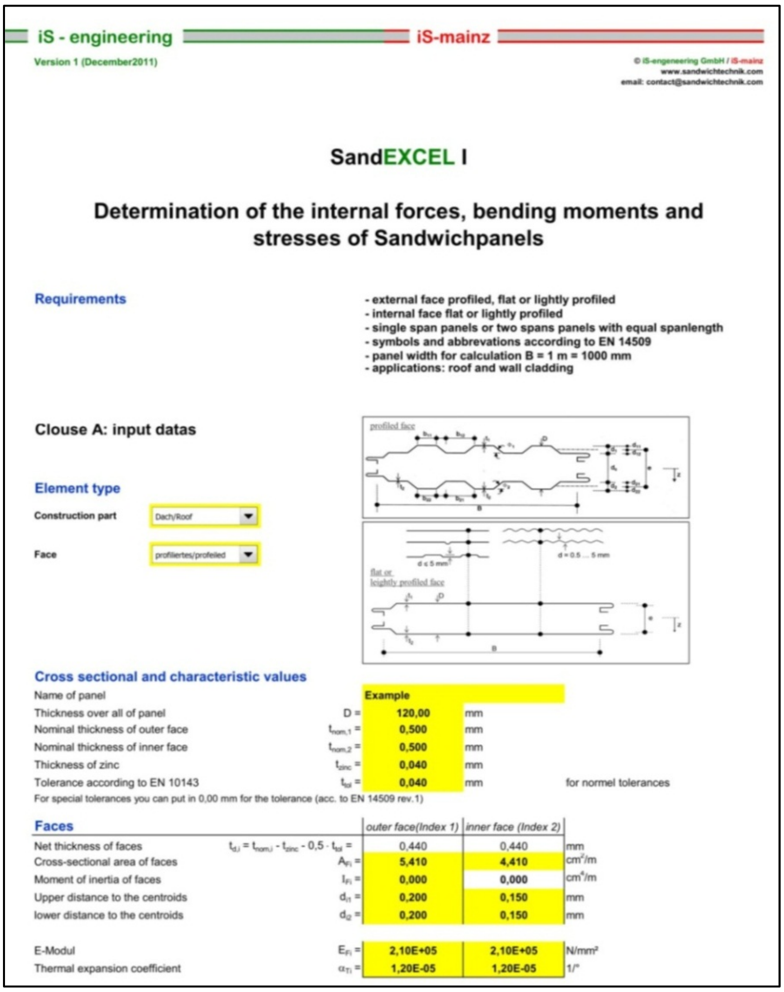


Fig. 2.4: Input Excel-Program

The bases of the computer program are official published formulas given in the EN 14509. For using this Computer Program, it is very important to state, that all values, which are needed for the design, are declared values gathered from the CE-mark, which shall always be available for the defined panel (s. Fig. 2). Only the values of area and moment of inertia of the metal faces have to be calculated in advance, a very simple task, because only the nominal geometry (without any reduction of the cross section) of the faces is relevant.

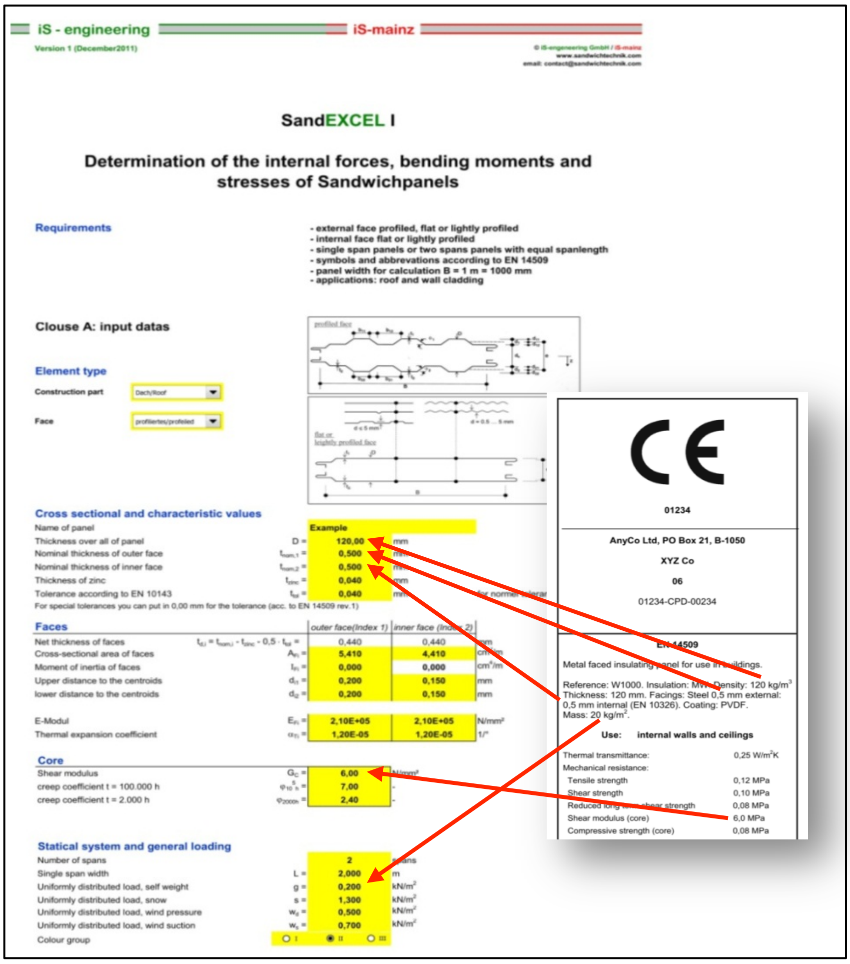


Fig. 2.5: values gathered from the CE mark

Calculation of all relevant deflections, also for two span panels

One important and technical complex enhancement is (on the base of a special derivation) the possibility for mathematic exact calculation of all relevant deflections also for two span panels is obtained.

Generating of tables of all relevant values actions and stresse for all load cases

The different load cases, e.g. self weight, snow, wind, but above all also temperature gradient in the faces and creeping effects, raise different stresses in the face and in the core with corresponding deflections.

In the design procedure it must be shown that the sum of the design values of all relevant actions is smaller or equal to the design value of the resistance. For this the actions of the different load cases must be well known. To have a good overview over the different actions as a base for the required superposition according to the safety concept of the EN 14509 the computer program generates automatically a table of all relevant values. An example of results is given in Fig. 3 (Input s. Fig. 1). For the declaration of the Symbols see EN 14509 Fig. E3 to Fig. E6.

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Clause C: Output of the results
for the actions of g, s, w, T

Table of all internal foces and stresses:

Internal force		unit	g	s	w_d	w_s
Bending moment (sandwich part)	M_S	kNm/m	-0,055	-0,357	-0,137	-0,192
Bending moment (part of outer face)	M_{F1}	kNm/m	-0,003	-0,021	-0,008	-0,011
Bending moment (part of inner face)	M_{F2}	kNm/m	0,000	0,000	0,000	0,000
Shear force in the core	V_S	kN/m	0,226	1,467	0,564	0,790
Shear force in the outer face	V_{F1}	kN/m				
Shear force in the inner face	V_{F2}	kN/m				
End support reaction	R_E	kN/m	0,171	1,111	0,427	0,598
Reaction on intermediate support	R_M	kN/m	0,458	2,978	1,146	1,604
Normal stress outside of outer face	$\sigma_{F1,1}$	N/mm²	0,852	5,538	2,130	2,982
Normal stress inside of outer face	$\sigma_{F1,2}$	N/mm²	0,852	5,538	2,130	2,982
Normal stress inside of inner face	$\sigma_{F2,1}$	N/mm²	-1,045	-6,794	-2,613	-3,658
Normal stress outside of inner face	$\sigma_{F2,2}$	N/mm²	-1,045	-6,794	-2,613	-3,658
Shear stress of the core	τ_C	N/mm²	0,0019	0,0123	0,0047	0,0066
maximum deflection	w_{max}	cm	0,017	0,114	0,044	0,061
point of maxinum deflection	$x/l = \xi_{max}$	-	0,500	0,500	0,500	0,500
deflection at midspan	$w_{(\xi=0,5)}$	cm	0,017	0,114	0,044	0,061

Internal force		unit	ΔT_s	ΔT_W	$\Delta T_{W,s}$
Bending moment (sandwich part)	M_S	kNm/m	2,478	-2,478	-1,239
Bending moment (part of outer face)	M_{F1}	kNm/m	0,018	-0,018	-0,009
Bending moment (part of inner face)	M_{F2}	kNm/m	0,000	0,000	0,000
Shear force in the core	V_S	kN/m	-1,248	1,248	0,624
Shear force in the outer face	V_{F1}	kN/m			
Shear force in the inner face	V_{F2}	kN/m			
End support reaction	R_E	kN/m	1,248	-1,248	-0,624
Reaction on intermediate support	R_M	kN/m	-2,496	2,496	1,248
Normal stress outside of outer face	$\sigma_{F1,1}$	N/mm²	-38,417	38,417	19,208
Normal stress inside of outer face	$\sigma_{F1,2}$	N/mm²	-38,417	38,417	19,208
Normal stress inside of inner face	$\sigma_{F2,1}$	N/mm²	47,128	-47,128	-23,564
Normal stress outside of inner face	$\sigma_{F2,2}$	N/mm²	47,128	-47,128	-23,564
Shear stress of the core	τ_C	N/mm²	-0,0105	0,0105	0,0052
maximum deflection	w_{max}	cm	-0,116	0,116	0,058
Shear stress of the core	$x/l = \xi_{max}$	-	0,450	0,450	0,450
maximum deflection	$w_{(\xi=0,5)}$	cm	-0,114	0,114	0,057

Internal force		unit	creeping g_t	creeping s_t	Difference -forces/ -stresses/ -deflections creeping Δg_t	creeping Δs_t
Bending moment (sandwich part)	M_S	kNm/m	-0,013	-0,171	0,042	0,186
Bending moment (part of outer face)	M_{F1}	kNm/m	-0,008	-0,036	-0,005	-0,015
Bending moment (part of inner face)	M_{F2}	kNm/m	0,000	0,000	0,000	0,000
Shear force in the core	V_S	kN/m	0,202	1,366	-0,024	-0,101
Shear force in the outer face	V_{F1}	kN/m				
Shear force in the inner face	V_{F2}	kN/m				
End support reaction	R_E	kN/m	0,189	1,196	0,019	0,085
Reaction on intermediate support	R_M	kN/m	0,421	2,808	-0,037	-0,171
Normal stress outside of outer face	$\sigma_{F1,1}$	N/mm²	2,530	12,931	1,678	7,393
Normal stress inside of outer face	$\sigma_{F1,2}$	N/mm²	-2,129	-7,624	-2,981	-13,162
Normal stress inside of inner face	$\sigma_{F2,1}$	N/mm²	-0,246	-3,255	0,799	3,538
Normal stress outside of inner face	$\sigma_{F2,2}$	N/mm²	-0,246	-3,255	0,799	3,538
Shear stress of the core	τ_C	N/mm²	0,002	0,011	-0,0002	-0,0008
maximum deflection	w_{max}	cm	0,112	0,330	0,094	0,216
deflection at midspan	$w_{(\xi=0,5)}$	cm	0,112	0,330	0,094	0,216

Fig. 2.6: Output Excel-Program, table of all relevant values

In a second and third step this Computer Program Sand EXCEL I is used as the base of two new Excel tools (SandEXCEL II and SandEXCEL III).

Design of sandwichpanels

With the program SandEXCEL II it is possible to make on the base of the safety concept (s. EN 14509, Annex E) and with the actions and stresses calculated according SandEXCEL I an exact practical design for a panel with a defined cross section, the declared values out of the CE-mark, the static system with the relevant loads and the demanded load- and material-safety factors. The big enhancement is the compilation of all relevant load cases with the corresponding safety factors (which can be chosen separate for the different nations). A remarkable result, beside the output of the relevant design equation, is an overview of the course of evaluation (utilization factor). With this output it is very easy to see, which effects are relevant for the design.
(More information see www.is-eng.de/downloads-e.html)

Calculation of allowed span table

An additional enhancement of the program results in SandEXCEL III. With this tool it is possible to calculate for defined sandwich panel (flat or profiled) automatically allowable span tables for wall and roof, for one and two span panels (with equal spans) with free definable safety factors. The most notable importance of this tool is that all possible load cases with all associated safety factors are included. The easy input is the same as for SandEXCEL I and II.
(More information see www.is-eng.de/downloads-e.html)

Checking of calculated results by comparison with test results

To be sure, that the design procedure (given in Annex E, EN 14509) and the Computer Program (based on this) are working in a satisfying way in the following is shown, that the results achieved out of tests and the calculation conform in principle.

The test results used for comparison are retained out of the following documents:
- EASIE test report, Doc. 59
Test series A
- EASIE test report, Doc 80 temperature (temperature gradient) for two span panels Test series C - Thermal Tests

Work package 2 (WP2)
Tests performed in Helsinki University of Technology (TKK)
Draft 12.3.2010

To compare the belonging test results with the calculated results all values are determined with the Computer Program SandEXCEL I especially for the different test specimens according to the test report. The input data for the calculation are directly taken from the test reports.

For checking the results two values are of interest

- In the serviceability limit state: the elastic limit load and the deflection dependent on the loads
- In the ultimate limit state: the ultimate failure load

The comparison of the results is shown on the base of the original diagrams with the test results.

From the beginning of the discussion regarding design of sandwich panels it was at any time clear that the influence of a temperature gradient shall be taken into account. The temperature gradient is well defined for design in EN 14509. For design by calculation the basic principles and the design procedure on the base of given formulas in the standard EN 14509 (s. Annex A) are well known. For design by testing it is necessary to make full scale tests with loads and temperature gradient. Such tests are made in the EASIE-researching and compared also with the results of the calculated values..
In the following only few of the results are shown.

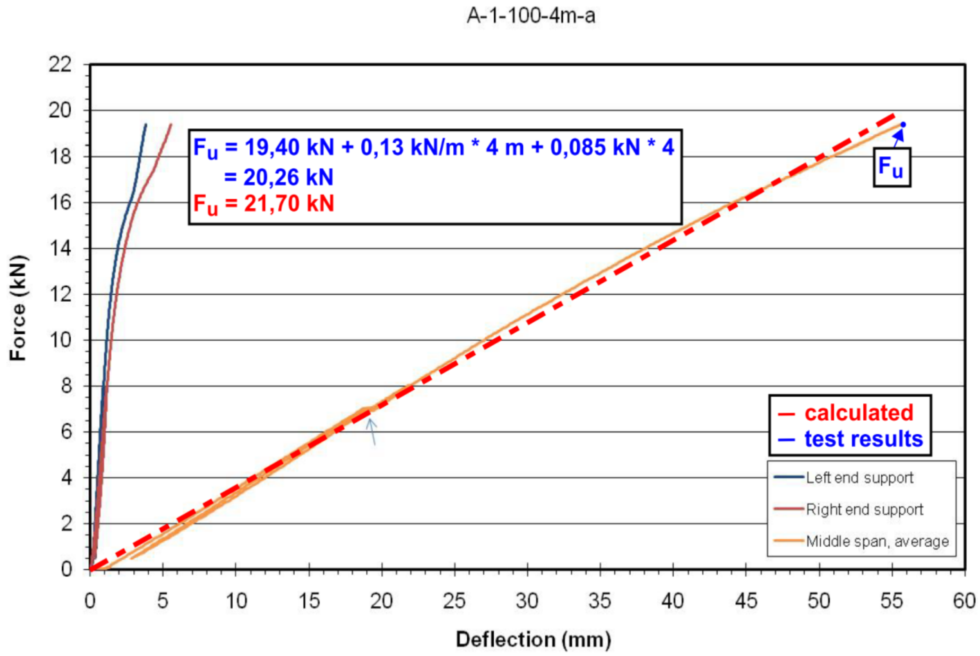

Fig. 2.7: Comparison of the results of test A-1-100-4m-a with the calculated values

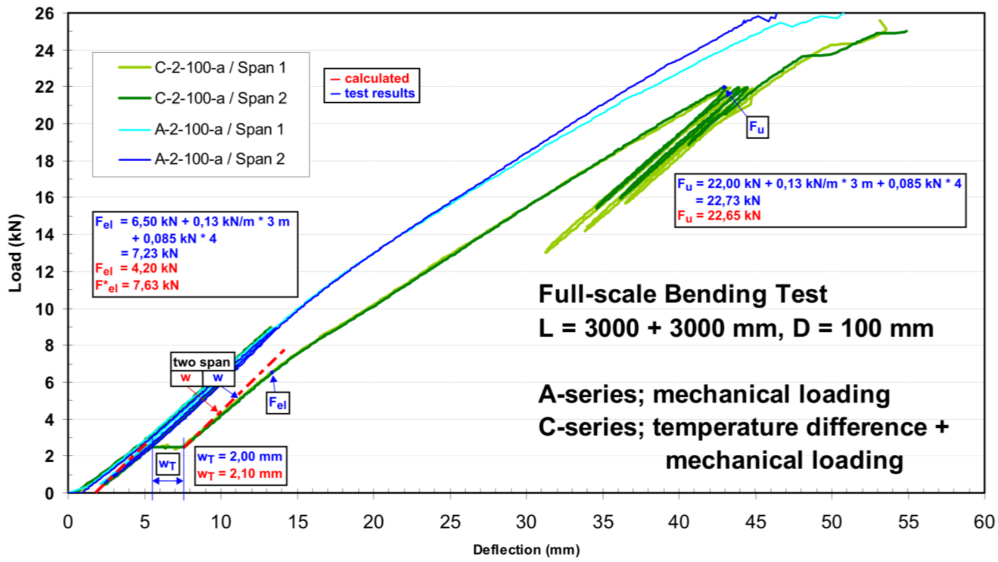

Fig. 2.8: Comparison of the results of test C-2-100-3m-a with temperature with the calculated values

F^{*}_{el} : with rounded bending moment at the internal support

The evaluation of the results:
For the serviceability limit state it is apparently visible the increase of the deflection and the actions, generated of the temperature in the test. It is the point of the load/deflection curve relevant at which the linearity of load/deflection line is not anymore given, because of yielding in the metal faces.

As a summary it can be stated:

- In all cases there is a very good correspondence between the tested and the calculated results.
- The procedures for design by calculation regarding the actions due to temperature effects are absolutely suitable for the practice.

Design by calculation in comparison with Design by testing
It is nearly impossible to make a direct comparison between Design by calculation (DC) and Design by testing (DT) because of the very voluminous documents (see deliverables for WP2) with a big number of formulas, reduction- and increasing-factors and an intransparent handling of the temperature- and creeping effects. In principle it is only possible to compare the results of both procedures on the base of allowable spans for identical sandwich panels, taken in account the same load- and material-safety-factors. According to the EASIE project, Task 2.3 Validation of Annex I, “Description of work” in a first step all tests, performed in the Helsinki University (Test series A) are checked (see also chapt. 3), to make sure, that the results achieved out of tests and the calculations conform in principle.

The absolute good accordance between the tested and the calculated values in any case (s.chapt.2) is the proof, that there cannot be a big difference between DT and DC. If the results on the base of testing and calculation are nearly the same, also the allowable span tables shall be nearly the same, unless there is a different handling with load cases, e.g. temperature and creep effects, statistical evaluation or safety factors. The result is that in principle there are no severe differences between DC and DT, also no benefit for DT.
If we compare the design procedures it must however said the following for the fair competition:

1. First of all it is necessary to look on the state of art regarding the legal requirements according to the valid standard. In chapter 5.3.1 of the standard EN 14509 first of all it is required, that the safety of the product shall be verified by design, based on the safety concept. It is also clear defined that the design shall be done with design by calculation according to the Annex E of the standard. There is nothing mentioned for design by testing.

2. Another very important general remark for a comparison between DC and DT is the amount of tests. For this it is necessary to look not only on one or two panels. Every manufactures has not only one or two panel types but a whole panel family with a lot of panel types, for which he need allowable span tables. Even for a small panel family with two cross sections (one for wall and one roof panels) and different panel- and face-thicknesses at least 150 types can be of interest. The test program for DC is for such a panel family very well defined in the standard, chapt. 6.2, Table 4. The required number of the tests according to the standard are in a passable range, e.g. for the mentioned panel family 25 full scale tests. But which test program is valid for DT. No test program for DT is official defined; no proposal is given for discussing in the standard committees. But it is very clear that the test program for DT must include tests with different spans and temperature tests. And this is the big difference to the required test for DC and imply, that time and effort for the tests, which are necessary for design by testing are much higher.

2.7 Potential impact and use of results

The potential impact is an application of the design by testing method by the SME's and other types of company. In France for example, the design by testing method is officially included in the Avis technique procedure since the 18 October 2011. This confirm the economical and scientist interest of the method.
So each company will have the choice to choose the design by calculation or design by testing method.

2.7 Conclusions

Some works remains to do, especially the introduction of the design by testting method inside the body of the EN 14509 after discussion with the relevant committee of the CEN TC 128 SC11.

3. USE OF SANDWICH TECHNOLOGY TO OPTIMIZE THE GLOBAL RESISTANCE OF BUILDINGS (WP3)

Sandwich panels are traditionally used as covering and isolating elements, thus being secondary structural components of the building. Because of their high resistance to in-plane shear and axial forces sandwich panels can also improve the structural behaviour of steel structures. As a recent development for the construction of small buildings, sandwich panels are used even without any substructure.
The overall aim of this work was to provide design models and calculation procedures, which enable to utilize the high resistance of sandwich panels to in-plane shear and axial forces with the objectives of:

- Developing a mechanical model for considering torsional restraint by sandwich panels including panels with various cores and faces as well as effects of creep and elevated ambient temperature.
- Providing calculation procedures to enable to use the high in-plane shear stiffness of sandwich panels for stabilisation (beams, columns) and bracing (diaphragm action). In this context, generalised calculation procedures for determining the stiffness of fastenings of sandwich panels had to be developed.
- Developing a design formula for axially loaded sandwich panels including global design as well as local design of the load application area.
- Working out basic principles for the design of frameless structures for the transfer of horizontal loads.
- Preparing a Design and Construction Guideline and calculation examples to enable end-users to design frameless structures made of sandwich panels.
- Building of a practical example of a frameless structure made of sandwich panels (Demonstrator) and monitoring its long-term behaviour.

3.1 Stabilisation of beams and purlins by torsional restraint

Sandwich panels increase the resistance of beams and purlins against lateral torsional buckling by restraining rotations and lateral displacements. For design, the torsional restraint can be taken into account by a rotational spring with the stiffness c_ϑ, which prevents rotation of the beam around the longitudinal axis.

The spring stiffness c_ϑ is a combination of the bending stiffness of the attached panel $c_{\vartheta C}$, the stiffness of the connection $c_{\vartheta A}$ and the distortional stiffness $c_{\vartheta B}$ of the beam to be stabilised.

$$\frac{1}{c_\vartheta} = \frac{1}{c_{\vartheta A}} + \frac{1}{c_{\vartheta B}} + \frac{1}{c_{\vartheta C}}$$

The stiffness's $c_{\vartheta C}$ and $c_{\vartheta B}$ depend on the geometry of the sandwich panels and type of beams used, see EN 1993-1-1 and EN 1993-1-3. The calculation of $c_{\vartheta A}$ was part of the investigations done within the framework of the EASIE project. Therefore, tests and additional numerical investigations have been performed. (In the following text, the stiffness $c_{\vartheta A}$ will be simply denoted as c_ϑ to ease reading and to reduce the number of subscripts.)

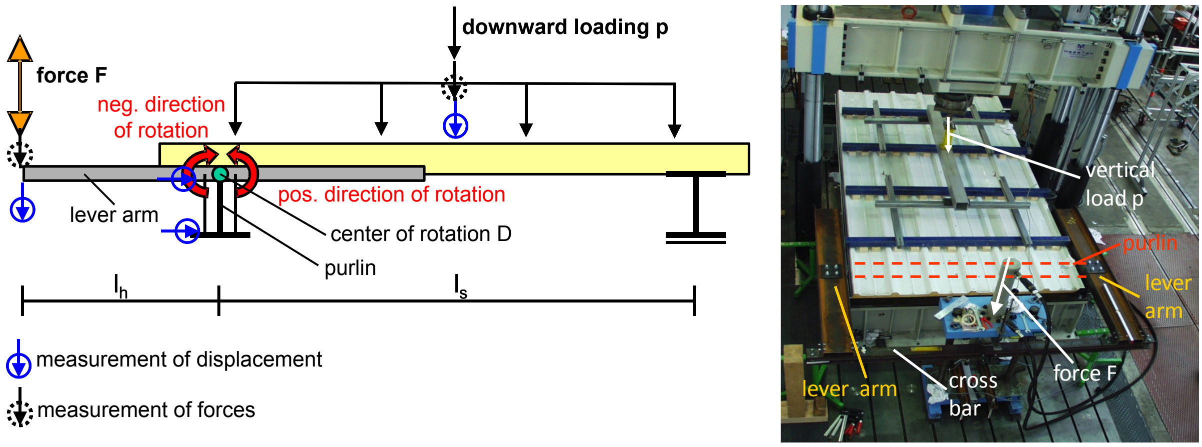

Fig. 3.1: Test set-up for downward loading

Figure 3.2 shows a typical moment-rotation-relation and its generalized form for designing the spring stiffness of the connection of a sandwich panel under downward loading.

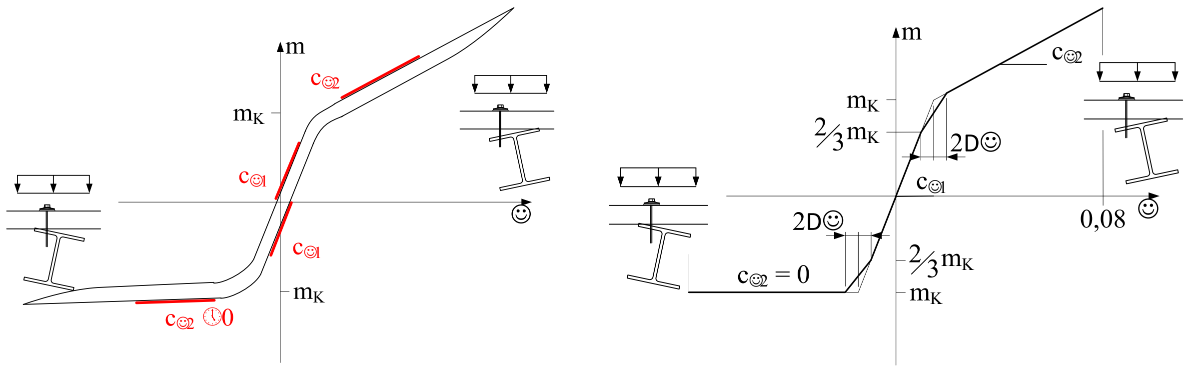

Fig. 3.2: Typical moment-rotation-relation and generalised design moment-rotation-relation

Using the simplified moment-rotation relation shown in Fig. 3.2 a secant value Fig. 3.3 of

$$c_{\vartheta} = \frac{m_K}{\vartheta(m_K)}$$

can be taken into account for downward loading. For uplift loading, no torsional restraint is given.

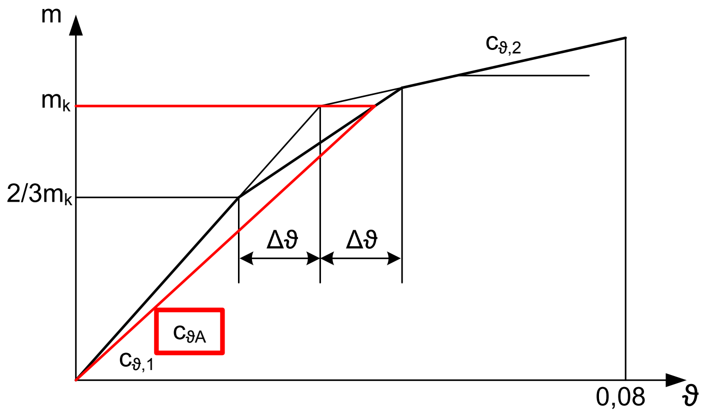

Fig. 3.3: Definition of c_ϑ

The necessary values and parameters are given in the following tables.

Table 3.1: Values $c_{\vartheta 1}$ and $c_{\vartheta 2}$

	Double-symmetric beams	Z- or C-section
$c_{\vartheta 1}$	$c_1 \cdot c_F \cdot E_{C,t,\theta} \cdot b^2$	$c_1 \cdot c_F \cdot E_{C,t,\theta} \cdot b^2$
$c_{\vartheta 2}$	$c_2 \cdot c_F \cdot n \cdot E_{C,t,\theta} \cdot b_K^2$	0
$E_{C,t,\Theta}$	$E_{C,t,\theta} = \frac{E_C}{1+\varphi_{C,t}} \cdot \sqrt{k_1^3} = \frac{E_C}{1+\varphi_{C,t}} \cdot \frac{E_{Ct,+80°C}}{E_{Ct,+20°C}}$	
m_K	$q_d \cdot \frac{b}{2}$	$q_d \cdot b$

Table 3.2: Parameters

c_1, c_2	Parameters according to Table 3
c_F	parameter depending on the face material c_F = 1.00 face materials steel and aluminium c_F = 0.38 face material GFRP
$\varphi_{C,t}$	parameter depending on the duration of loading $\varphi_{C,2000}$ =1.29 core materials PUR and EPS $\varphi_{C,100000}$ =1.83 core materials PUR and EPS $\varphi_{C,2000}$ =1.35 core material mineral wool $\varphi_{C,100000}$ =2.31 core material mineral wool
b [mm]	width of the flange of the beam
b_K [mm]	distance between governing line of fixing and contact line, see Fig. 3.3
n [m^{-1}]	number of fasteners per meter length in the governing line of fixing (n = 0.0 for hidden fixings and for $b_K < 0.5$ b)
q_d	design value of the downward load to be transferred from the panel to the beam

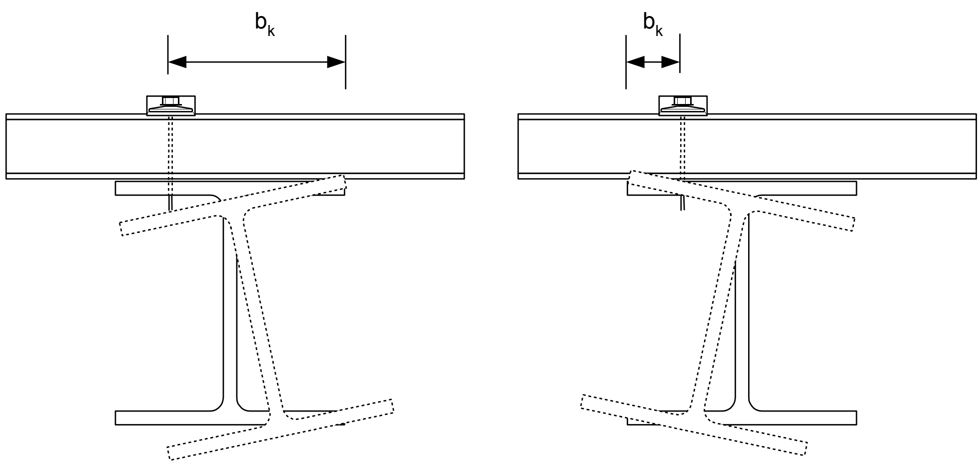

Fig. 3.3: Definition of b_K

Table 3: Parameters c_1 and c_2

Core material	geometry of outer face (at the head of fasteners)	c_1	c_2
PUR/EPS	profiled	0.180	0.052 m
	lightly profiled/flat	0.142	0.040 m
Mineral wool	profiled	0.089	0.027 m
	lightly profiled/flat	0.048	0.027 m

The application range of the formulae given above is shown in the following table.

Table 4: Application range

$60\text{ mm} \le b \le 180\text{ mm}$	for double-symmetric beams
$60\text{ mm} \le b \le 80\text{ mm}$	for Z- or C-sections
$2.0\text{ N/mm}^2 \le E_C \le 8.0\text{ N/mm}^2$	Young’s modulus of the core material
$0.38\text{ mm} \le t_K \le 0.71\text{ mm}$	sheet thickness of the face layers (steel)
$0.50\text{ mm} \le t \le 0.65\text{ mm}$	sheet thickness of the face layers (aluminium)
$1.7\text{ mm} \le t \le 2.0\text{ mm}$	sheet thickness of the face layers (GFRP)
$1\text{ m}^{-1} \le n \le 4\text{ m}^{-1}$	number of fasteners per meter length in the governing line of fixing
q_d	torsional restraint is only provided with downward loading and only for predominantly static loading
$d_W \ge 16\text{ mm}$	diameter of washer
$\vartheta \le 0.08\text{ rad}$	rotation

A detailed documentation of the tests was given in report D3.2 – part 1. The evaluation of the tests, the numerical investigations and the resulting design model were presented in report D3.3 – part 1.

3.2 Bracing and stabilisation by in-plane shear resistance

When loaded by in-plane shear forces, sandwich panels have a very high stiffness and load-bearing capacity. The high in-plane shear stiffness can be used for two different stabilising effects. Sandwich panels can restrain the lateral displacement of beams and columns and thus, they can prevent flexural and lateral torsional buckling. By acting as diaphragm, sandwich panels can also be used for global stabilisation of complete building structures and for transferring horizontal loads, e.g. wind loads.

A mechanical model for determining the stiffness of shear diaphragms made of sandwich panels was developed in a former research project by Baehre and Ladwein [see: Baehre, R., Ladwein, Th.: Tragfähigkeit und Verformungsverhalten von Scheiben aus Sandwichelementen und PUR-Hartschaumkern (Projekt 199), Studiengesellschaft Stahlanwendung e.V., Düsseldorf 1994]. Based on this model, calculation procedures for determining the forces of fastenings, which are decisive for the load bearing behaviour, and capacity of shear loaded sandwich panels, were developed. They were given in report D3.3 – part 2, which also included calculation examples.

To utilise the potential of in-plane shear loaded panels, knowledge of stiffness and resistance of the fastenings is mandatory. Small scale tests on shear loaded fastenings of sandwich panels were performed and evaluated.

Based on a mechanical model (Fig. 3.4) the following design expressions for fastenings of sandwich panels to a steel substructure were developed. The symbols and the application range of the formulae are given in Table 5.

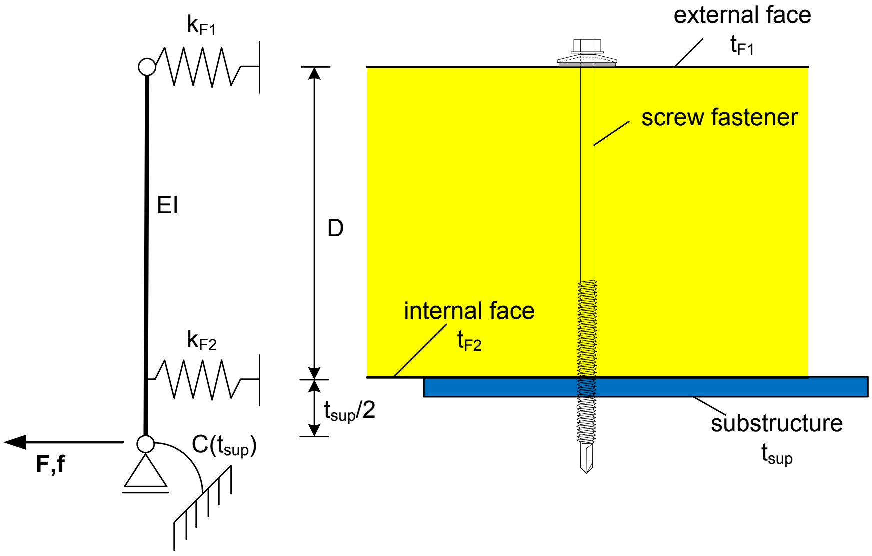

Fig. 3.4: Mechanical model of a direct fixing

Load bearing capacity

$$F_{Rk} = 4.2 \cdot \sqrt{t_{F2}^3 \cdot d_1} \cdot f_{u,F2}$$

Stiffness

$$k_v = \frac{1}{\frac{x_F}{k_{F2}} + \frac{t_{\sup}^2 + 2 \cdot (1 - x_F) \cdot D \cdot t_{\sup}}{4 \cdot C} + \frac{3 \cdot (1 - x_F) \cdot D \cdot t_{\sup}^2 + t_{\sup}^3}{24 \cdot EI}}$$

with

$$x_F = 1 - \frac{\frac{1}{k_{F2}} - \frac{D \cdot t_{\sup}}{2 \cdot C} - \frac{D \cdot t_{\sup}^2}{8 \cdot EI}}{\frac{1}{k_{F2}} + \frac{D^2}{C} + \frac{D^2 \cdot (2 \cdot D + 3 \cdot t_{\sup})}{6 \cdot EI}}$$

Bending stiffness of the fastener

$$EI = 200000 N / mm^2 \cdot \frac{\pi \cdot d_S^4}{64}$$

Stiffness of clamping in the substructure

$$C = 2400 N / mm^2 \cdot \sqrt{t_{\sup} \cdot d_1^5}$$

Stiffness of internal face sheet (hole elongation)

$$k_{F2} = 6.93 \cdot \frac{f_{u,F2} \cdot \sqrt{t_{F2}^3 \cdot d_1}}{0.26mm + 0.8 \cdot t_{F2}} \qquad 0.40mm \le t_{F2} \le 0.70mm$$

$$k_{F2} = \frac{4.2 \cdot f_{u,F2} \cdot \sqrt{t_F^3 \cdot d_1}}{0.373mm} \qquad 0.70mm \le t_{F2} \le 1.00mm$$

Table 5: Symbols and application range

0.40 mm ≤ t_{F2} ≤ 1.00 mm	thickness of internal face sheet
$f_{u,F2}$	tensile strength of internal face sheet
40 mm ≤ D ≤ 200 mm	thickness of a panel at point of fastening
1.50 mm ≤ t_{sup} ≤ 10.0 mm	thickness of steel substructure
5.5 mm ≤ d ≤ 8.0 mm	nominal diameter of fastener (self-drilling or self-tapping screw made of stainless steel)
d_1	minor diameter of the threaded part of the fastener
d_S	diameter of unthreaded shank

Also for fastenings of longitudinal joints of roof panels tests have been performed and evaluated. The following design formula for the stiffness of this kind of fastening was developed.

$$k_v = 1900 \frac{N}{mm^3} \cdot t_{F1} \cdot d$$

Table 6: Symbols and application range for fixing at longitudinal joints

4.8 mm ≤ d ≤ 6.3 mm	nominal diameter of fastener (self-drilling screw with sealing washer)
0.40 mm ≤ t_{F1} ≤ 1.00 mm	thickness of external face sheet

The load bearing capacity of a fastening of a joint can be calculated according to EN 1993-1-3.

A detailed documentation of all tests is given in test report D3.2 – part 2. The evaluation of the tests and the resulting calculation procedures are presented in report D3.3 – part 3.

3.2 Design of axially loaded sandwich panels

Global design

As a recent development, sandwich panels have been used to design small buildings– such as cooling chambers, climatic chambers and clean rooms – without any load-transferring substructure. In this application in addition to moments and transverse forces resulting from transverse loads, the wall panels transfer normal forces arising from the superimposed load from overlying roof or ceiling panels.
Within the framework of the EASIE project a design concept for axially loaded sandwich panels was derived. The design concept is based upon the existing design model for panels subjected to transverse loads according to EN 14509. The developed design method has the advantage that there is no necessarily of any additional test. To design axially loaded sandwich panels only the parameters used for the design of panels subjected to transverse loads have to be known (e.g. wrinkling stress and creep coefficients). To verify the design method buckling and long-term tests on axially loaded sandwich panels have been performed. Especially in the long-term tests panels with different core materials have been considered.

By the buckling tests and additional numerical investigations it has been shown that sandwich panels subjected to axial loads can be designed according to 2nd order theory using the conventional amplification factor α. When determining the elastic buckling load N_{cr} of the panel, the bending part N_{ki} as well as the shear part GA has to be taken into account.

$$\alpha = \frac{1}{1 - \frac{N}{N_{cr}}}$$

with

elastic buckling load of a sandwich panel $$N_{cr} = \frac{N_{ki}}{1 + \frac{N_{ki}}{GA}}$$

bending part of elastic buckling load $$N_{ki} = \pi^2 \cdot \frac{B_S}{L^2}$$

shear part of elastic buckling load $$GA = G_C \cdot A_C$$

bending stiffness of the panel $$B_S = E_F \cdot \frac{A_{F1} \cdot A_{F2}}{A_{F1} + A_{F2}} \cdot e^2$$

Furthermore, the wrinkling stress determined by bending tests can be used as ultimate compression stress for axially loaded sandwich panels.

In creep tests, which are usually performed on panels with transverse load, the panels are loaded by a constant load, and the time-dependent deflection is measured. To test panels with axial load this is an inapplicable procedure. So the long-term tests with axial load were not performed as classical creep tests but as relaxation tests, i.e. a constant displacement is applied and the resulting time-dependent forces or stresses are measured. At first, the axial load was applied to the tested panel. After that, a deflection was applied to the panel via an additional support in mid-span. The support was fixed and the deflection was kept constant over the test period. The reaction force of the mid-support and the strain of the face sheet subjected to tension were continuously recorded.
Using these long-term tests it could be verified that the effects of creeping of the core material can be considered by the creep coefficients φ_t, which are known from the design of transverse loaded panels. The creep coefficient φ_t describes the increase of the shear deformation only. For some calculation procedures it is more reasonable to use a coefficient φ_{St}, which refers to the whole cross-section.

$$\varphi_{St} = \frac{k}{1+k} \cdot \varphi_t$$

with

$$k = \frac{w_{lt,v}}{w_{lt,b}} = \frac{B_S}{GA} \cdot \frac{\int V\overline{V}dx}{\int M\overline{M}dx}$$

The factor k represents the relation between the shear part $w_{lt,v}$ and the bending part $w_{lt,b}$ of the deflection caused by long-term loads. Unlike the creep coefficient φ_t, the coefficient φ_{St} is not a material parameter. It also considers the loads acting on the panel. Therefore, it has to be calculated for each single load case.

If effects of 2nd order and creeping are considered, e.g. the bending moment of a sandwich panel loaded by transverse and axial loads are calculated to

$$M_t^{II} = \left(M_W^I + M_{\Delta T}^I + M_S^I \cdot (1 + \varphi_{S2000}) + M_G^I \cdot (1 + \varphi_{S100000})\right) \cdot \alpha$$

with

M^I_W moment caused by wind load
$M^I_{\Delta T}$ moment caused by temperature difference*)
M^I_S moment caused by snow load
M^I_G moment caused by self-weight load

*) It is assumed that temperature differences are caused by climatic effects and therefore can be assumed to be short-term loads.

The buckling and long-term tests on axially loaded sandwich panels have been documented in report D3.2 – part 3 and Deliverable D3.2 – part 4. The evaluation of the tests, the numerical investigations and the derivation of the design concept were presented in report D3.3 – part 4.

Local design of load application areas

In addition to the global load-bearing capacity, the local load-bearing capacity at the areas of load application, i.e. at the lower ends of the panel and at the connection between wall and roof, is to be considered. At this area, the superimposed loads from the roof are applied to the wall panels as normal force. Load-application areas have been investigated by tests and numerical calculations. The failure mode is crippling of the face sheet at the free cut edge of the panel. This failure mode is strongly related to wrinkling of a compressed face sheet in mid-span. Crippling as well as wrinkling are stability failure modes. In both cases, the face sheet can be regarded as a plate, which is elastically supported by the core material. In mid-span both ends of the plate are supported, whereas at the load application area the load is introduced into a free edge.

Fig. 3.5: Crippling of the load application area

A design model based on the wrinkling stress, which has to be determined by tests according to EN 14509, was developed. The crippling stress of the free edge is calculated by buckling curves. Therefore, for the considered panel the imperfection factor α is determined by re-calculation of the wrinkling stress. The imperfection factor α depends on imperfections resulting from the production process, e.g. local geometrical imperfections of the face sheet, as well as on the quality of the bond between core and face.

$$\alpha = \frac{1 + \chi_w \cdot \lambda_w^2 \cdot (\chi_w - 1) - \chi_w}{\chi_w \cdot (\lambda_w - \lambda_0)} \geq 0.21$$

with

reduction factor for wrinkling stress	$\chi_w = \frac{\sigma_w}{f_{y,F}}$
elastic buckling stress (wrinkling)	$\sigma_{cr,w} = \frac{3}{A_F} \cdot \sqrt[3]{\frac{2}{9} \cdot EI_F \cdot G_C \cdot E_C}$
slenderness of the face for wrinkling	$\lambda_w = \sqrt{\frac{f_{y,F}}{\sigma_{cr,w}}}$
plateau value of slenderness	$\lambda_0 = 0.7$
wrinkling stress (determined by tests)	σ_w
tensile strength of face sheet	$f_{y,F}$
cross sectional area of face	A_F
bending stiffness of face sheet	EI_F

If the imperfection factor of a panel is known, the crippling stress σ_c* of the free edge can be calculated.

$$\sigma_c^* = \chi_c \cdot f_{y,F}$$

with

slenderness of the face for crippling $\qquad \lambda_c = \sqrt{2} \cdot \lambda_w$

reduction factor for crippling stress $\qquad \chi_c = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_c^2}} \leq 1$

$$\phi = \frac{1}{2} \cdot \left(1 + \alpha \cdot \left(\lambda_c - \lambda_0\right) + \lambda_c^2\right)$$

Similar to the imperfection factor, the crippling stress σ_c* only considers imperfections, which are available at mid-span. At a free edge, however, there are further imperfections, which are mainly caused by cutting of the panel, e.g. contact imperfections resulting from an uneven cut edge. These imperfections cause a further decrease of the crippling stress and must therefore be considered in the design of the load application area. Thus, an additional reduction of the crippling stress is necessary. The value of this reduction was determined by a statistical evaluation of the test results. Based on the stress σ_c*, the characteristic value of the crippling stress is calculated to

$$\sigma_{c,k} = 0.54 \cdot \sigma_c^*$$

A detailed documentation of the tests on load-application details can be found in Deliverable D3.2 – part 5. The evaluation of the tests and the numerical investigations are presented in Deliverable D3.3 – part 5.

3.3 Bracing of frameless buildings

If sandwich panels are used without load-transferring substructure, the panels have to transfer horizontal wind loads to the foundation and to stabilise the building. Horizontal wind loads act directly on the wall panels of a building. The wall panels are usually single span elements with one support at the foundation and the other support at the roof, so half of the horizontal wind load is introduced into the roof. The second part is transferred directly to the foundation. Through the roof, the load is introduced into the walls and finally into the foundation. Depending on the relation of direction of load and span of roof panels, a circumferential shear force occurs at the connections between wall and roof. For these connections, where shear forces are introduced from the roof into rectangular adjacent wall panels, usually steel or aluminium angles, which are mechanically fastened to the face sheets, are used.

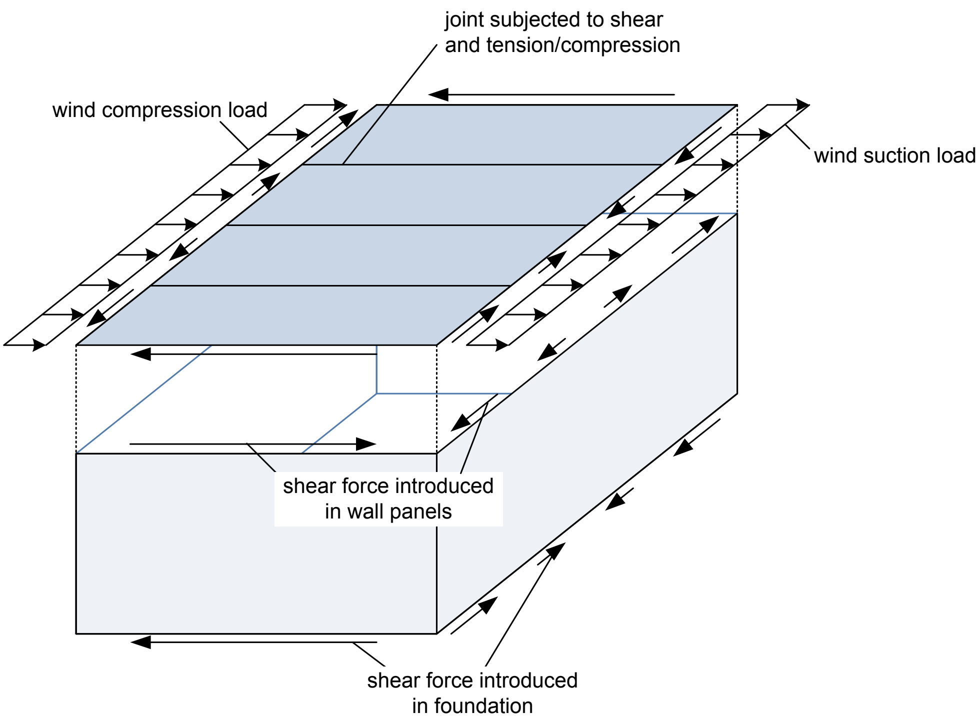

Fig. 3.6: Transfer of horizontal loads in a frameless building

For the transfer of horizontal loads, the high in-plane shear stiffness and capacity of the panels is used. Both, stiffness and load bearing capacity are very much higher than the corresponding values of the fastenings. Because of that, the deformation of the panels can be neglected for design purposes. Only the flexibility of the fastenings has to be considered. Also for the load-bearing capacity the fastenings are decisive. Thus, if a frameless structure is loaded by horizontal wind loads, the fastenings have to be designed for this load.
Within the project basic principles for the design of frameless structures for the transfer of horizontal loads have been worked out. An effective method to determine the forces, the fastenings have to be designed for, are numerical calculations. The panels are modelled as rigid bodies and the connections are presented by longitudinal springs. For some simple applications calculation procedures, which allow an analytical determination of the forces, have been developed. It could be shown that the displacements, which are caused by horizontal wind loads, are quite small. Also the forces of the fastenings are so small that they can be transferred by conventional mechanical fasteners without any problems.
The investigations are presented in report D3.3 – part 6.

3.4 Design and Construction Guideline for frameless structures

Based on the different investigations on frameless structures presented above, a Design and Construction Guideline was prepared and published as report D3.4. The first part of the Guideline deals with the design of sandwich panels for axial and in-plane shear load. All design procedures concerning buildings without substructure are presented in an end-user focused compilation.
The second part is a construction good practise guideline presenting a collection of typical construction details of frameless buildings. The guideline provides a structured series of construction examples for the components to be connected (roof / ceiling, wall, floor). Facing material specific features and building climate aspects are taken into account. The presented construction details are based on the long experiences of the EASIE partners, especially the panel manufacturers.

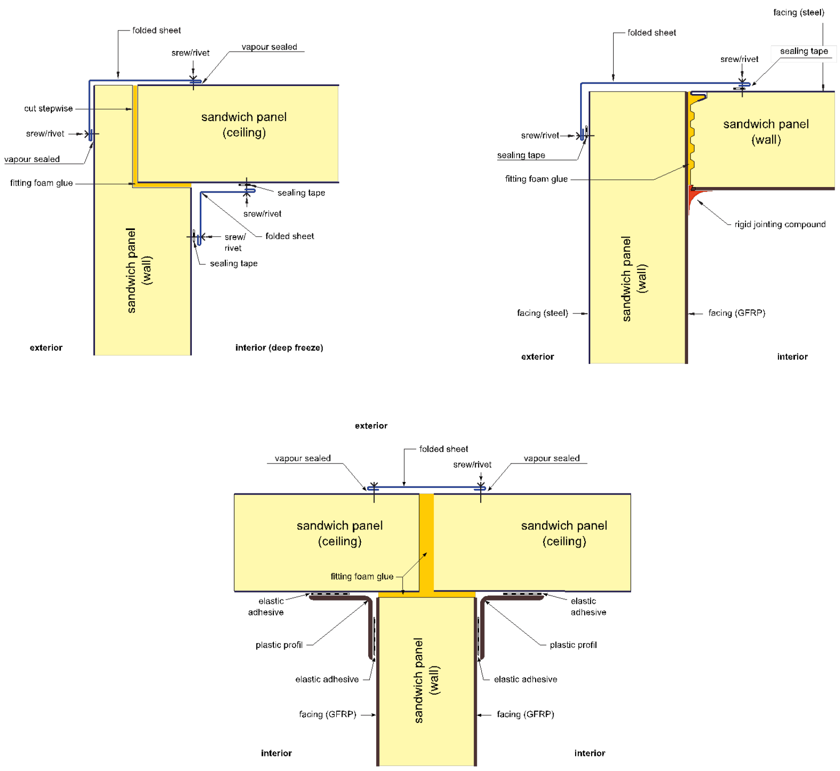

Fig. 3.7: Construction details (examples)

In addition, calculation examples for the design of frameless buildings made of sandwich panels have been worked out and published as report D3.5. All examples show that for small buildings without substructure the transfer of loads through axially and in-plane shear loaded sandwich panel is not a problem.

3.5 Demonstrator

In order to allow for the long timescales involved in the measurement of time-dependent effects, it was decided at the inception of the project that a demonstrator had to be built right at the beginning of the project. ECP built a large demonstrator made of sandwich panels without substructure with a 6 x 3.6 x 3 cubic meters usable volume.

Fig. 3.8: Demonstrator

The demonstrator was loaded with deadweight and was exposed to outdoor conditions. During the project, the loading conditions were changed.

- First step: Permanent load 2 x 570 kg axial load during 17 months
- Second step: Permanent load: 75 kg/m² distributed load during nearly 4 months

A long-term monitoring was conducted, including the regular measurement of deformations. No significant deflections have been observed, and the overall performance of the demonstrator promises some good opportunities for the industry.

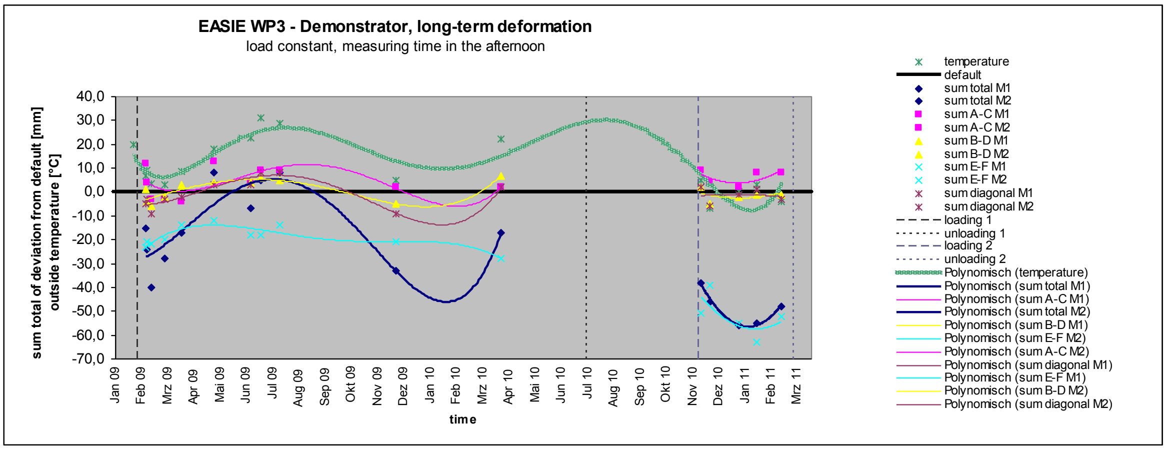

Fig. 3.9: EASIE Demonstrator long-term deformation

Measuring method used:

- by laser device
- summation of deviations from default value

Analysis of measurements:

- deformation caused by axial load on wall insignificant
- changes depend on outdoor temperature
- both stretch and shrink can be observed
- influence of creep not identifiable until now

3.6 Potential impact and use of results

The European Joint Committee on Sandwich Constructions consisting of ECCS TWG 7.9 Technical Working Group and CIB W56 Working Commission decided to produce “*European Recommendations on the Stabilisation of Steel Structures with Sandwich Panels*”. This document will deal with the stabilisation of beams and purlins by torsional restraint and with the utilization of the in-plane shear stiffness of sandwich panels for bracing of buildings and stabilisation of building components. The results of this work are due to be incorporated in the document.

The European Standard for sandwich panels EN 14509 has a lack of rules or requirements for the application of sandwich panels in frameless building, i.e. for axially and in-plane shear loaded panels. The design methods, which were developed here will enable to design sandwich panels also for these kinds of loading and thus to extend the field of application of sandwich panels.

3.7 Conclusions

Traditionally, sandwich panels are used as covering and isolating elements, this field of application has been considerably extended by the project with the detailed investigation of the use of sandwich panels for bracing and stabilisation of steel structures and of the use of sandwich panels for frameless buildings. For these new applications, design models and calculation procedures are now available to industry.

In frameless buildings the wall panels have to transfer axial loads. Often the load application area, where the axial force is introduced, is decisive for the load bearing capacity of the panels. In addition, these connections have to transfer in-plane shear forces resulting from the transfer of horizontal loads through the building to the foundation. Therefore, a task for further research is to develop improved connection details, especially for the connections between wall and roof and between wall and foundation.

4. RETROFITTING, DURABILITY AND MAINTENANCE OF SANDWICH PANELS (WP4)

Long-term behavior and principles of design for long-term loads have been in the interest sandwich panel industry from the very beginning of the industrial production of the panels. In earlier research projects, the focus has been in the shear creep and creep rupture problems of the core layer, on repeated loading such as walkability and on the methods to verify the suitability of the product to external use. The cross-panel tensile strength has been found to be an excellent parameter because it measures the strength of the core and bond simultaneously and the small-size specimens are easy to prepare and test. However, the tensile strength is not a direct design parameter; it does not exist in the design expressions of sandwich panels. In EASIE project, the scope has been extended to cover the development of the resistance to all essential failure modes. The goal is to find connection between the cross-panel tensile strength used in current factory production control and the essential design parameters such as the wrinkling stress of the face, and the shear and compression strength of the core.
Second objective has been the retrofitting of sandwich panels. Existing facades and roofs may need repairing actions because of defects or technical weaknesses, new higher requirements or needs of update. The actions may include cleaning and painting of surfaces, improving of joints and fastenings, repairing of defects and faults or cladding of whole façade or replacements of panels. The aims of the retrofitting are the technical and /or architectural improvements and extension of the service life of the façade and roof.

4.1 Literature survey
Industrial application of sandwich structures has started in early 1940's in aircaft and transport industry. First industrially produced sandwich panels for walls and roofs of buildings were made in the 1960's. First European Recommendations for the design and use were written by CIB W056 in late 1970's. The Recommendations were redrawn and updated by ECCS TWG 7.4 and 7.9 together with CIB. The Recommendations have made the basis for the European Product Standard EN 14509. In addition to the Recommendations, two major European research projects have provided information in the content of EN 14509. The major sources of information concerning the long-term behavior and resistance to long-term loads have been described in the report D4.1. Further, the needs of new information, techniques and modelling concerning the design and testing for long-term loads, and the retrofitting and repair have been detailed in the report D4.1.

4.2 Experimental programme
To fill caps of information, an experimental programme has been created to cover the most essential needs of information. Several drafts of the experimental programme have been distributed for discussion and comments in the WP4 meetings and in the meeting of the Management Committee. In addition, the questionnaire of WP1 has been extended to cover aspects of WP4. Important part of the task has been the delivery and transport of the test specimens, which has been made mainly by the partners of the EASIE project. A set of durability test specimens, the fastenings for the cladding tests and the adhesives for the development of the repairing actions has been made by companies, which are not partners of EASIE project. Old sandwich panels from walls and roofs of existing buildings have been transported to Karlsruhe for testing, which work has been done partially by companies outside the EASIE project. The experimental tasks have included the division of the testing activities between four laboratories in Darmstadt, Mainz, Karlsruhe and Espoo. Real temperature and relative humidity inside rock wool cored sandwich panels has been measured in four places in Europe by the partners of EASIE project, which work has required organization and guiding of the measurements and reporting.

The loading history of the durability test specimens followed the DUR1 and DUR2 history given in EN 14509 to find connection to the results of the current cross-panel tensile tests. However, the times of exposure were modified to take into account the ageing of full-scale specimens. The fulfillment of the experimental goals has required development of the small-scale wrinkling test set-up and building of a new climate chamber.

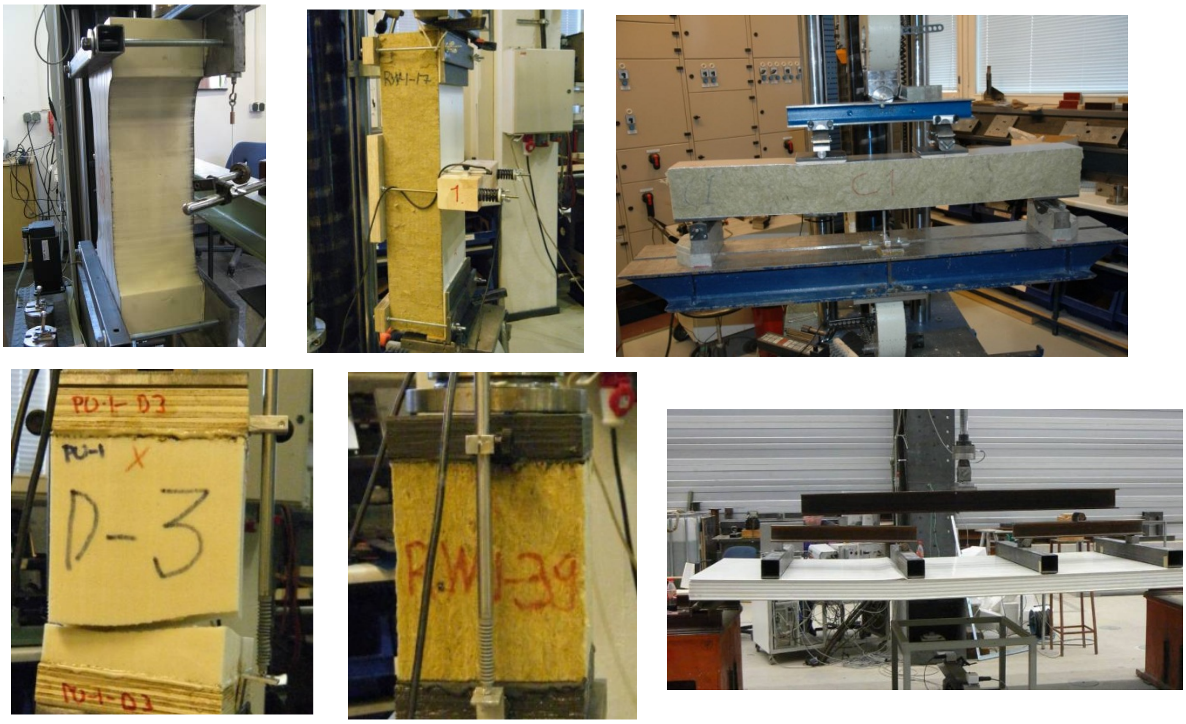

Fig. 4.1: Bone-shaped and rectangular wrinkling test specimens, shear test specimen, cross-panel tensile and compression test specimens and full-scale specimens made of PU- and ESP-foam cored and stone-wool cored sandwich panels were used in the durability studies.

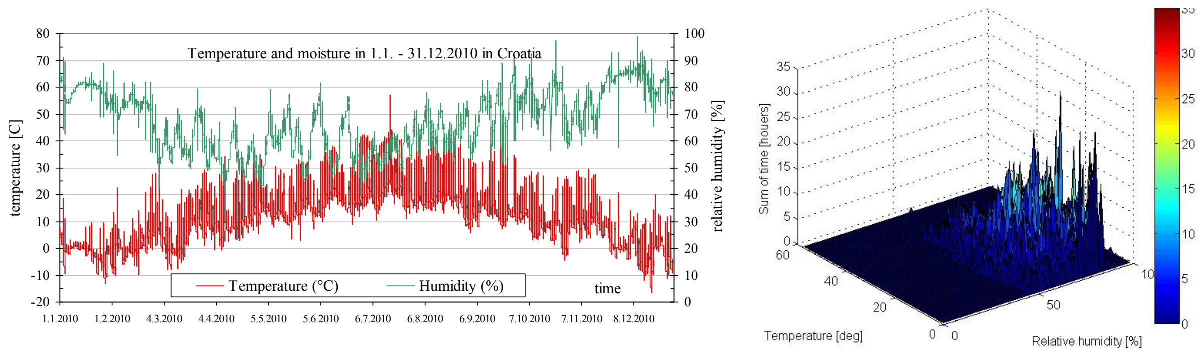

Fig. 4.2: Temperature and relative humidity was measured in four places in Europe. The graph shows the history inside a stone-wool cored sandwich panels measured in Zabok, Croatia during the year 2010. The second graph shows the sum of the measured combinations in hours in steps of 1°C and 1%.

Test specimens, test arrangements and results of the tests have been introduced in ten confidential test reports. Eight reports concern the testing of small-scale and full-scale ageing specimens and testing of old panels removed from existing buildings from Karlsruhe and Traun. Two reports concern the testing of "new to old concept" which mean the fixing of an additional light-weight cladding based on purlins and sheetings or on thin sandwich panels and monopanels to the external face of the ordinary façade. Content of the experimental programme and content of the ten test reports has been summarized in the delivery reports D4.5-1 and D4.5-2.

4.3 Incorporation of ageing parameters in existing design expressions

Ageing of sandwich panels mean in practice the clouding, contamination and loosing of the painting and other coatings, corrosions of steel faces and fastenings, defects, faults and blistering in the faces and possibly reduction of the resistance to different failure modes. The effects have been described in the first part of the report D4.2-1. The report includes observations and experiences on the causes and existence of the defects in practice. The second part of the report D4.2-2 includes the results of the ageing tests made in three laboratories. The graphs in the report show the development of the strength and modulus of the eight different combinations of the core and face in the course of the time to exposure to ageing in the climate chambers.

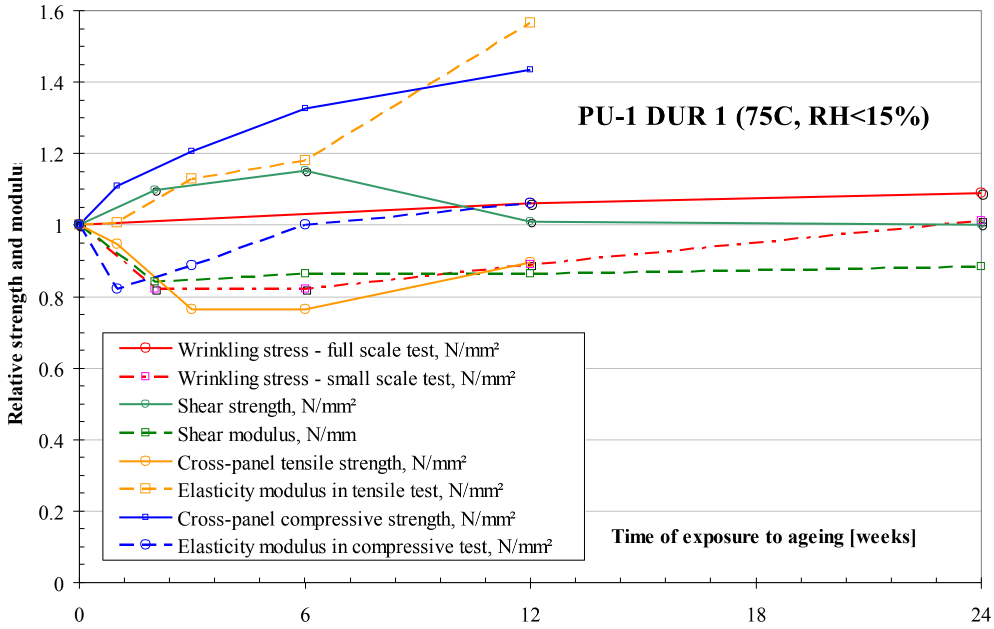

Fig. 4.3: Development of the wrinkling stress of the face and the shear and cross-panel tensile and compression strength of the core and the corresponding modulus of elasticity in the course of time to exposure to high temperature and humidity in climate chamber. Picture shows the development of the strength and modulus of the PU-1 specimens.

4.4 Design expressions

Classification of sandwich panels is based today on the outcome of the DUR1 and DUR2 tests describing the development and level of the cross-panel tensile strength when the small-scale specimens are exposed to high temperature and humidity. In the task, the connections between of the cross-panel tensile strength to the wrinkling stress of the face and to the shear and compression strength of the core were studied. The available calculation models for the wrinkling stress have been compared to tests results. In addition, experimental connections between the tensile strength and the shear and compression strength have been found. There are no analytical models available up to now. The failure model between the tensile, compression and shear depends on the anisotropy and on the plastic properties of the core material and further, on the properties of the bond. The failure model is product dependent.

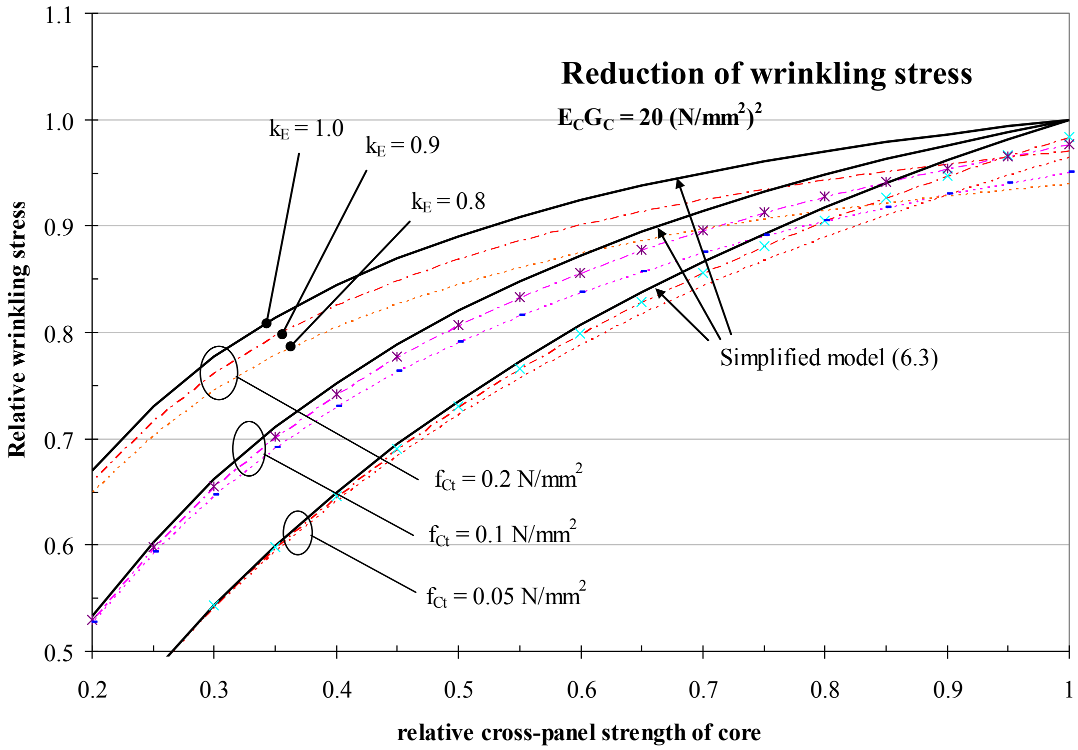

Fig. 4.4: Reduction of the wrinkling stress can be modeled on the basis of the reduction of the cross-panel strength and modulus. In the graph, the product of the modulus of elasticity E_C and shear modulus G_C is E_CG_C=20 $(N/mm^2)^2$, which represent properties of typical current sandwich panel products.

4.5 Resistance and service life

Evaluation of the service life means the estimation of the time, when the resistance of the sandwich panel equals the action affects to the panel. The evaluation shall be made at the ultimate limit state as well as at the serviceability limit state due to the reduction of the resistance and stiffness. Both the resistance and the action effects can be assumed to change with the service time. In addition, the required safety factors may be different in modelling of the service life. Thus, there are altogether three subject areas to be investigated; action effects *S*, safety factors γ and resistance *R*. The expression (1) is the known design expression for sandwich panels. The expression (2) defines the moment of time when the resistance of the panel equals the actions effects.

$$E_d = \sum_i \gamma_{fi} \psi_i S_{ki} \le R_d = \frac{R_k}{\gamma_M} \qquad (1)$$

$$\sum_i \gamma_{fi}(t_s) \psi S_{ki}(t_s) \equiv \frac{R_k(t_s)}{\gamma_M} \qquad (2)$$

Based on the experimental results of EASIE project and the models given in earlier research documents, evaluations about the service life of sandwich panels have been made. The models show principles of evaluations. The work shall be continued in order to produce realistic results for practice.

4.6 Principles of retrofitting

The subject retrofitting has been divided in two parts. The first part concerns the "new to old concept", which means the cladding of existing old or a new façade with new lightweight cladding system. First cladding system in the investigation has been a traditional system based on thin-walled cold-formed purlin profiles and sheeting, which are fixed to the external face using mechanical screw fastenings. In practice, there are a large variety of light-weight components on the market and thus, the traditional system provides many possibilities for further developments. The second cladding system used in the investigations consisted of additional thin three-layer sandwich panels or of two-layer monopanels, which are fixed to the external face of the ordinary wall panel with screws and rivets. Adhesive jointing is also possible. This new system provides further benefits because of additional thermal insulation power and air and water tightness. It consists of fewer amounts of components and thus, may provide an effective alternative to retrofitting. In both cases mechanical properties of the principal solutions have been studied to show the benefits and risks for further development work.

The second part of the subject retrofitting consists of development of methods to repair defects, faults and blisters in the faces of existing facades. Important point of the study has been the determination of the remaining resistance of the faces to compare the properties of the panel after the repairing actions to the initially required resistance. Artificial defects and faults have been made and repaired in the laboratory after which actions the specimens have been loaded up to ultimate limit state to compare the resistance of the repaired specimen to the initial resistance and to resistance before the repairing actions. An important point has been the suitability of the methods for the use on building sites. Methods to repair blisters have been developed in the laboratory of RBM Europe BV and on building sites.

Two guidelines have been written for retrofitting. The guideline on cladding D4.6-1 gives the essential results and observations of the research and shows principles of design of the cladding systems. The guideline on repairing of faults and defects D4.6-2 shows the effects of four different repairing methods, which have been developed and selected on the basis of the pre-tests and knowledge of RBM Europe BV.

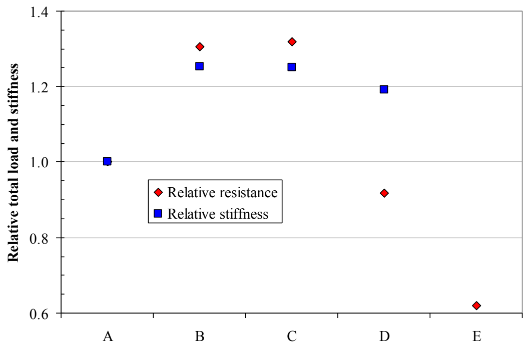

Fig. 4.5: Effect of traditional cladding systems on the load-bearing capacity and total stiffness of the ordinary sandwich panel. In the graph A represents the properties of the ordinary sandwich panel, B of the panel covered directly installed with sinusoidal sheet, C of the panel covered with two longitudinally installed hat-profiles, D of the panel with transverse hat profiles and a sheeting and E panel with transverse Z-profiles.

Fig. 4.6: Repairing of artificial defects in the laboratory and real defects on building site by E.Rustemeijer.

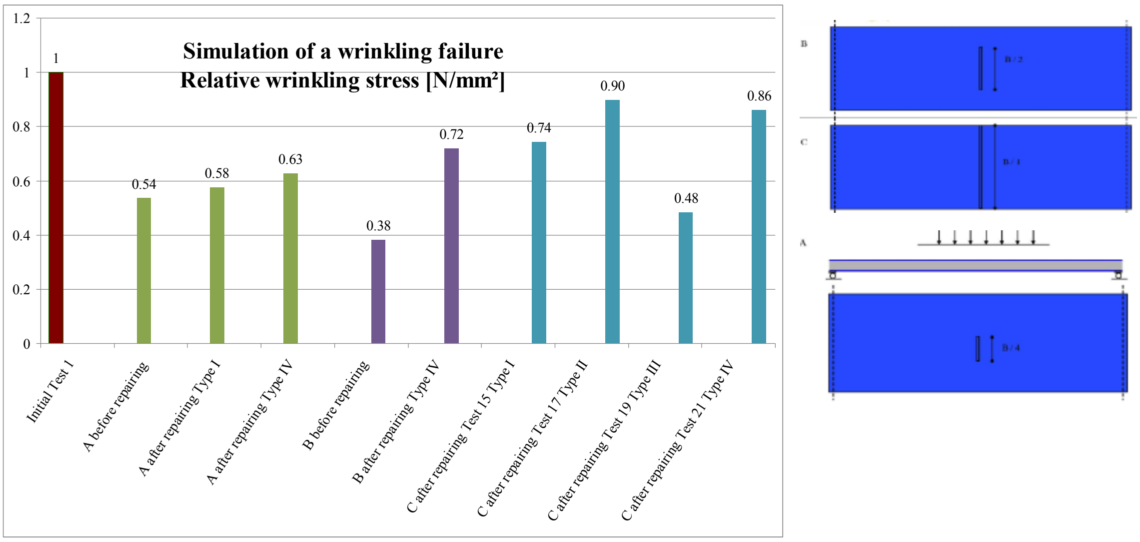

Fig. 4.7: Results of the repairing actions based on four different methods (I, II, III and IV) and three different artificial defects (A, B and C).

4.7 Key results

Behavior, testing and design of sandwich panel product for long-term loads has been relative new item to small-size companies before the publishing of the European product standard EN 14509. Experimental work of WP4 has produced essential information about the resistance of the product and about the testing in practice. This is highly valuable information in practice.

This research has resulted in connections between the cross-panel tensile strength and wrinkling stress and shear and compression strength of the core. The results show the development of direct design parameters in the course of the time to artificial ageing. The results make basis for the evaluation and development of the design expressions and of the models to evaluate the service life. An important end result is also the observation that the cross-panel tensile strength seems to be a good measure to the long-term behavior and resistance of sandwich panels. Thus, it can be used as a classification parameter also in future revisions of the product standards.

Tests of the old panels and specimens show the remaining resistance of sandwich panel products exposed to real natural environmental loads. These results make the comparison points to find the connection between the artificial ageing conditions in the laboratory and the real natural ageing conditions. The results are highly important in practice.
Experimental and analytical work on the cladding systems has shows benefits and risks of the systems based on traditional thin-walled components and on additional thin sandwich panels fixed with mechanical fastenings to the external face of the sandwich panels. The results can be utilized directly in the product development work of new cladding systems. The results make basis for quidelines and recommendations.
Alternative to replace the damaged wall panels is to repair the panels on site. Requirement for the repair is typically the complete return of the external appearance and at least a partial return of the resistance. The work of WP4 has shown possibilities and limits to return the mechanical resistance. The methods have been tested on building site in practice. The information is highly important to current repairing work and to further development of the methods.

4.8 Potential impacts and use of results

Durability test results can be utilized in product development of new more effective core layers. Test results, experimental observations and models can also be utilized in revisions of the European product standard EN 14509, especially in revisions of the Annex B of the standard.
Results have made a basis for evaluation of the service life of different sandwich panel products in different environments.
Results of tests and analysis on cladding and repairing of defects can be utilized in product development work of new cladding system and in evaluation of the effects of the existing cladding systems. The results can be utilized directly in the new guidelines and European Recommendations. This work can be done in the European Joint Committee on Sandwich Constructions.

4.9 Conclusions

Experimental programme of WP4 has provided a wide platform to partners to discuss and develop the testing practices and the properties of the products. The network has been important to SME companies but also to research laboratories. It has been a challenge to find the joint interest and the essential points for investigation in practice. In workshops, the network has extended further outside the partners of the EASIE project. This all will support the further development work after the EASIE project.

The work has produced important results for future revisions of the European product standard. Results and documents on retrofitting can be directly utilized in new European Recommendations.

Analysis and modelling of the service life of sandwich panels shall be continued after the EASIE project in order to crate reliable results for use in practice. The resources in EASIE project have been limited because of the much more extensive test programme as planned and because of the product dependency of the test results.

5. HOLISTIC, E-LEARNING BASED EDUCATION ON SANDWICH CONSTRUCTION (WP5)

This work was focused on the production of resources for the improvement of knowledge of sandwich panels in buildings. The core element of this was the production of eLearning modules. These can be downloaded by interested users and they can improve their knowledge of various aspects of this structural element.

The main achievements over the period have were as follows:

- The lectures were recorded
- Literature and codes on sandwich panels were collected.
- A list of relevant literature was collected.
- All lectures were made available on the Project website at www.easie.eu

The following lectures have been recorded:

- Load Bearing Behaviour - How is a sandwich panel working? (in English and Polish)
- Ohutlevypintaiset sandwich-elementit (in Finnish) Light weight sandwich panels with thin - gauge faces
- Actions and loads - Special Aspects of Sandwich Structures
- Core Material - Mineral Wool
- Chemistry and Processing of PU Metal Sandwich Panels
- Sustainability in Sandwich Panel Construction
- Thermal and structural behaviour in openings and joints
- Thermal bridges and Air tightness of Sandwich Construction
- Connections of Sandwich Panels
- Theory in fire design - material properties and testing
- Fabricating and Designing Sandwich Panels for Fire
- Erection - From the factory to the final building
- Allowable span tables on the base of the CE-mark
- Experimental studies on Duration of Sandwich Panels
- Repair and Retrofitting
- Sandwich panels and architecture
- Detailing

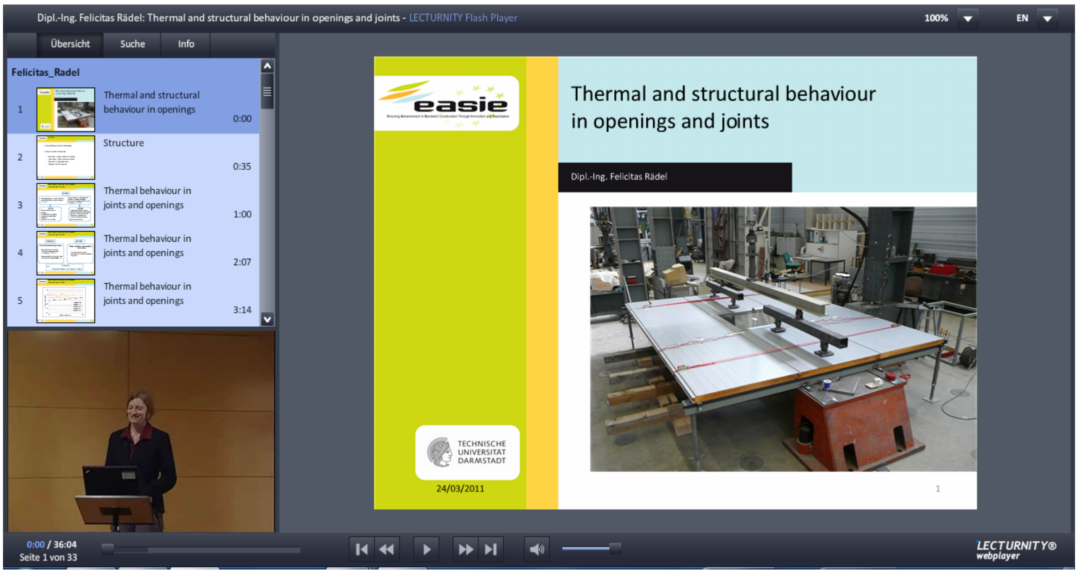

Fig. 5.1: Screenshot of an EASIE lecture recording

In addition the following information is also available online:

- A list of relevant literature. For important articles, an abstract has been produced and made available.
- Guidelines and examples of good practice
- List of relevant standards and regulations.

6 TRAINING, SKILL DEVELOPMENT AND DISSEMINATION (WP6)

The objectives of this work were to pass on the knowledge and academic information to the market for its improvement and development, to promote wide adoption of the project's output by industry and in particular by SMEs, by regulators and by standards organizations and to develop a post-project strategy to ensure project legacy, ownership of the process and continuous implementation and use of the project's results.

Ten **e-newsletters** were published in English and Spanish during the project. They were circulated to an extensive list of industrial contacts and made available online.

Three **user-focused industry workshops** on the theme "Building with sandwich panels fast, safe and energy saving" have were held in Zagreb, Croatia on 17th June 2010, in Barcelona, Spain on 24th March 2011, and in Krakow, Poland on 9th June 2011, with special regards to the needs of local industries.
All the workshops were recorded on video "and are available on the EASIE web site. They were organized by local companies, M-PROFIL in Croatia and Acelor Mittal in Poland, and in Spain by APIPNA the industrial professional association of the polyurethane sandwich panel producers of Spain.
More than 200 people attended the workshops. End-users represented 48% of the participants, 18% of the participants were producers and 14% were suppliers. The rest of the participants came mainly from universities and research laboratories. They were all very interested in improving their knowledge about sandwich panels.

Fig. 6.1: EASIE Workshop, Barcelona, 24 March 2011.

The following lectures were given by speakers from Germany, Holland, Poland and Finland:

- *Load Bearing Behaviour. How is a sandwich panel working. Comportamiento de los paneles bajo carga. ¿Cómo trabaja un panel sándwich? Jak działa płyta warstwowa - zachowanie pod obciążeniem.* Prof. Dr.-Ing. Jörg Lange – TU Darmstadt- Inż. Aneta Kurpiela - TU Darmstadt, Niemcy (po polsku)

- *Actions and loads. Special Aspects of Sandwich Structures. Oddziaływania i obciążenia. Specjalne aspekty dla płyt warstwowych*. Prof. Dr inż. Klaus Berner - iS engineering, Niemcy- Prof. Dr.-Ing. Klaus Berner - IS Mainz

- *Allowable span tables on the base of the CE-mark.* IS- Prof. Dr.-Ing. K. Berner - IS Mainz

- *Tablas de carga con los datos del nuevo marcado CE*. IS- Prof. Dr.-Ing. K. Berner – Mainz

- *Sustainability in Sandwich Construction.* Dr.-Ing. Markus Kuhnhenne – RWTH Aachen

- *Sostenibilidad en la construcción con paneles sándwich*. Dr.-Ing. Markus Kuhnhenne – RWTH University Aachen

- *Connections of Sandwich Panels.* Prof. Dr.-Ing. Thomas Ummenhofer – KIT, Karlsruhe

- *Fabricating and Designing Sandwich Panels for Fire*. Dr. Maciej Klosak - ArcelorMittal, Poland

- *Produkcja i projektowanie płyt warstwowych w kontekście problematyki przeciwpożarowej.* Dr inż. Maciej Klósak – ArcelorMittal Construction Polska, dr inż. Jacek Tasarek – Politechnika Poznańska (po polsku)

- *Erection .Form the Factory to the Final Building.* Dr.-Ing. Ralf Möller, Pöter & Möller, Siegen

- *Thermal Bridges and Air Tightness of Sandwich Construction*. Dr.-Ing. Ralf Podleschny – EPAQ

- *Puentes térmicos y impermeabilidad en la construcción con paneles sándwich*. Dr.-Ing. Ralf Podleschny – EPAQ (European Quality Assurance Association for Panels and Profiles)

- *Mostki termiczne oraz szczelność płyt*. Dr inż. Ralf Podleschny - EPAQ, Niemcy

- *Sandwich panels and architecture*. Mr. Cohen - Architectenbureau CEPEZED B.V

- *Arquitectura con paneles sandwich*. Mr. Cohen - Architectenbureau CEPEZED. B.V.

- *Płyty warstwowe i architektura*. Michiel Cohen - Architekt, Holandia

- *Repair and retrofitting*. Dr. Paavo Hassinen – Aalto University

- *Mantenimiento y reparación*. Dr. Paavo Hassinen – Aalto University

- *Repair and retrofitting of sandwich panels*. Eric Rustemeijer, RBM, The Netherlands

- *Naprawa i modernizacja płyt warstwowych*. Eric Rustemeijer - RBM, Holandia

- *Experimental studies on durability of sandwich panels*. Dr. Paavo Hassinen – Aalto University

- *Thermal and structural behaviour in openings and joints*. Ing. Rädel – TU Darmstadt.

- *Comportamiento térmico y estructural en las juntas y oberturas de las construcciones con paneles sándwich*. Ing. Rädel – TU Darmstadt.
- *Wytrzymałość otworów i połączeń z uwzględnieniem działania temperatury*. Inż. Felicitas Rädel - TU Darmstadt, Niemcy
- *Detailing*. Dr.-Ing. Ralf Möller and Dipl.-Ing. Pöter - Pöter & Möller, Siegen, Germany
- *Thermal loads of sandwich panels-DAFA*. Polish Association of Roofing and Cladding Makers, Poland
- *Obciążenie płyt warstwowych na skutek różnicy temperature*. Stowarzyszenie DAFA, Polska

All the presentations were recorded and are available on www.easie.eu

The **EASIE Final conference** was associated to the EPAQ/Pan and Pro Europe Congress in Rome on 22 and 23 September 2011 as this was a major and well attended annual event for the sandwich panel industry in Europe. With over 120 participants from 20 different countries (in majority from the European Union) this provided the best showcase possible for the dissemination of the EASIE research to as wide a spectrum of companies as possible. A major proportion of the Congress programme was devoted to the presentation of the Project's results with nine different papers covering all the EASIE work packages. The conference proceedings are available on the EASIE website.

A **User Guide** targeted at industrial users has been produced. The purpose of the Guide is to present the Project's research findings in a simplified, accessible way and to demonstrate their application to users in industry and commerce and in particular to SMEs. The Guide is in the form of a document entitled "User Guide EASIE Research Programme-Building with Sandwich Panels: Fast, Safe and Energy Saving" in two parts with one booklet outlining the Partners competencies and their role in the Project and the second detailing the research results and focusing on ten bestsellers. The Guide is available online on the EASIE website.

A **database** of industrial contacts across Europe relevant to the sandwich panel industry and including manufacturers and users has been established with over 350 entries available by the end of the 2011.

A **post-project strategy** was agreed by the Participants in order to manage the Project's legacy. The Industrial Associations agreed to take a leading role in this process which involved the maintenance of the website while turning it into a central industry portal for the European Sandwich industry.

PLAN FOR USE AND DISSEMINATION OF FOREGROUND

Final
December 2011

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- ***Period covered*: 1 October 2008 to 31 December 2011**
- ***Project Coordinator*: Professor Dr.-Ing. Bernd Naujoks**
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PP	*Restricted to other Framework programme participants (including the Commission Services)*	
RE	*Restricted to a group specified by the Consortium (including the Commission Services)*	
CO	***Confidential, only for members of the Consortium (including the Commission services)***	**Section B**

Verification and Approval	
Michel Decabane, Chair Industrial Committee	
European Commission	

Deliverable	
n/a	*Due date :* *Completed :*

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TABLE OF CONTENT

1. Introduction

The Plan for Use and dissemination of Foreground ("The Plan") summarises the EASIE Consortium overall strategy and concrete actions to protect, disseminate and exploit the foreground and more generally the results generated by the Project.
It is one of the compulsory reports that Beneficiaries in Seventh Framework Programme (FP7) projects are required to present to the European Commission.

The EASIE project aimed at increasing the use of sandwich panels for residential, industrial and office buildings, as well as enriching the current European Standard for sandwich panels EN 14509. The problem areas where the project has made a significant contribution are:

- Lack of knowledge in some countries, which prevents end users from accepting sandwich panels, and engineers and designers from prescribing or using it
- Lack of common set of rules at European level, which can hinder the standardisation process, or lead to barriers for end users

The project has focused on three main elements:

- Improvement of sandwich panel design and design tools to promote and simplify the use of sandwich products
- Improvement of energy consumption both, during production process and after application to the building
- Prediction of the product lifecycle to ensure safe design and efficient retrofitting and replacement

The project aimed not only at generating knowledge, but also at developing training tools so as to make the resources available for designers and end users. Dissemination of the results by industry associations present in the consortium was an essential aspect of the project.

In order to achieve its ultimate objectives, the Consortium aimed at ensuring that the knowledge and expertise developed in the project were accepted by end users. Therefore, an important aspect of the EASIE industrial strategy and of the activities of the project's Industrial Committee has been to assess the readiness of the results (methods and guidelines sufficiently validated, and software tools with a sufficient degree of maturity) to know how transferrable they were, and to be ready to further develop the results if needed.

The project had also a relevant component of private exploitation, either by industry associations or SMEs in the consortium and the Participants have tried to ensure that the right balance was struck between wide dissemination of output and protection of exploitable.

2. SECTION A: Dissemination of Knowledge

For
- TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS
- TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

see first part of the final report.

The promotion of the wide adoption of the project results by the industry through training, skill development and dissemination actions were a strategic goal of the EASIE project. This was achieved through the promotion of a number of activities including the development of a project website, the production of quarterly internet-based newsletter, the organization with support from all major Industrial associations and groupings active in the field of three EU training workshops, an active publication programme in academic and trade journals, contribution to codification, the preparation of a User Guide, the development of various elearning tools, the organization of a final EASIE conference and the development and implementation a post-project strategy to ensure continuous dissemination and use of project results

2.1 Web activities

The EASIE website, www.easie.eu, was set up at the inception of the project and was developed and improved continuously during the work. A steady increase in the number of hits per month was observed over the whole duration of the project with a record of 36 716 hits being reached on March 2011. The most popular key words were: "sandwich panel" and "EN 14509".

2.2 E-Newsletters

Ten e-newsletters were published on a quarterly basis during the course of the project: n°1 (January 2009), n°2 (April 2009), n°3 (July 2009), n°5 (January 2010), n°6 (June 2010), n°7 (July 2010), n°8 (November 2010), n°9 (February 2011) and n°10 (April/May 2011). On proposal from the WP6 Steering Committee, the Management Committee agreed to cancel e-letter No 11 and to replace it with the User Guide.
All the e-newsletters were circulated to a list of over 300 named contacts and were posted on the EASIE website. They were also translated in Spanish and sent to South American panel producers to disseminate new knowledge about sandwich panels.

2.3 Workshop and conferences

Three user-focused industry workshops on the theme "Building with sandwich panels fast, safe and energy saving" were held in Zagreb, Croatia on 17th June 2010, in Barcelona, Spain on 24th March 2011, and in Krakow, Poland on 9th June 2011, with special regards to the needs of local industries.
All the workshops were recorded on video "and made available on the EASIE web site. They were organized by local companies, MPROFIL in Croatia and AcerlorMittal in Poland, and in Spain by APIPNA the industrial professional association of the polyurethane sandwich panel producers of Spain.
More than 200 people attended the workshops. End-users represented 48% of the participants, 18% of the participants were producers and 14% were suppliers. The rest of the participants came mainly from universities and research laboratories.

The following lectures were given by speakers from Germany, Holland, Poland and Finland:

- *Load Bearing Behaviour. How is a sandwich panel working. Comportamiento de los paneles bajo carga. ¿Cómo trabaja un panel sándwich? Jak działa płyta warstwowa - zachowanie pod obciążeniem.* Prof. Dr.-Ing. Jörg Lange – TU Darmstadt- Inż. Aneta Kurpiela - TU Darmstadt, Niemcy (po polsku)

- *Actions and loads. Special Aspects of Sandwich Structures*. *Oddziaływania i obciążenia. Specjalne aspekty dla płyt warstwowych*. Prof. Dr inż. Klaus Berner - iS engineering, Niemcy- Prof. Dr.-Ing. Klaus Berner - IS Mainz

- *Allowable span tables on the base of the CE-mark.* IS- Prof. Dr.-Ing. K. Berne- ISMainz

- *Tablas de carga con los datos del nuevo marcado CE*. IS- Prof. Dr.-Ing. K. Berner – Mainz

- *Sustainability in Sandwich Construction.* Dr.-Ing. Markus Kuhnhenne – RWTH Aachen

- *Sostenibilidad en la construcción con paneles sándwich*. Dr.-Ing. Markus Kuhnhenne – RWTH University Aachen

- *Connections of Sandwich Panels.* Prof. Dr.-Ing. Thomas Ummenhofer – KIT, Karlsruhe

- *Fabricating and Designing Sandwich Panels for Fire*. Dr. Maciej Klosak - ArcelorMittal, Poland

- *Produkcja i projektowanie płyt warstwowych w kontekście problematyki przeciwpożarowej.* Dr inż. Maciej Klósak – ArcelorMittal Construction Polska, dr inż. Jacek Tasarek – Politechnika Poznańska (po polsku)

- *Erection .Form the Factory to the Final Building.* Dr.-Ing. Ralf Möller, Pöter & Möller, Siegen

- *Thermal Bridges and Air Tightness of Sandwich Construction*. Dr.-Ing. Ralf Podleschny – EPAQ

- *Puentes térmicos y impermeabilidad en la construcción con paneles sándwich*. Dr.-Ing. Ralf Podleschny – EPAQ (European Quality Assurance Association for Panels and Profiles)

- *Mostki termiczne oraz szczelność płyt*. Dr inż. Ralf Podleschny - EPAQ, Niemcy

- *Sandwich panels and architecture*. Mr. Cohen - Architectenbureau CEPEZED B.V

- *Arquitectura con paneles sandwich*. Mr. Cohen - Architectenbureau CEPEZED. B.V.

- *Płyty warstwowe i architektura*. Michiel Cohen - Architekt, Holandia

- *Repair and retrofitting*. Dr. Paavo Hassinen – Aalto University

- *Mantenimiento y reparación*. Dr. Paavo Hassinen – Aalto University

- *Repair and retrofitting of sandwich panels*. Eric Rustemeijer, RBM, The Netherlands

- *Naprawa i modernizacja płyt warstwowych*. Eric Rustemeijer - RBM, Holandia

- *Experimental studies on durability of sandwich panels*. Dr. Paavo Hassinen – Aalto University

- *Thermal and structural behaviour in openings and joints*. Ing. Rädel – TU Darmstadt.

- *Comportamiento térmico y estructural en las juntas y oberturas de las construcciones con paneles sándwich*. Ing. Rädel – TU Darmstadt.

- *Wytrzymałość otworów i połączeń z uwzględnieniem działania temperatury*. Inż. Felicitas Rädel - TU Darmstadt, Niemcy

- *Detailing*. Dr.-Ing. Ralf Möller and Dipl.-Ing. Pöter - Pöter & Möller, Siegen, Germany

- *Thermal loads of sandwich panels-DAFA.* Polish Association of Roofing and Cladding Makers, Poland

- *Obciążenie płyt warstwowych na skutek różnicy temperature*. Stowarzyszenie DAFA, Polska

A special presentation was made in Krakow by Rene Broer from RBM Europe on panels repair methods. The well attended live show initiated a wide discussion over possibilities of saving damaged panels. The technique presented during the show could help to avoid an expensive panel replacing.

All the presentations were recorded and made available on www.easie.eu

In addition a number of targeted workshops were organized to disseminate the EASIE research results:

- Organization of the European Congress “Advancements for Metal Buildings” in Helsinki, with 95 participants from 17 countries. 2009-11-12/13. Presentation of WP1 EASIE Project at the EPAQ Conference in Helsinki, 13th November 2009 by J. Lange and L. Heselius.
- Workshop “EASIE – New European Research Project on sandwich panel technology, New European standard EN 14509 and EPAQ Quality Label”. Place: company Brucha, Austria. 20 participants, amongst them sales people of 6 countries, listened to the presentations of Prof. Klaus Berner from the University of Applied Science, Mainz and Dr. R. Podleschny, EPAQ, 2009-03-05
- Workshop “EASIE – New European Research Project on sandwich panel technology, New European standard EN 14509 and EPAQ Quality Labe”. Place: company TKS, Germany. 35 participants, sales people and technicians of 3 countries, listened to the presentations of Prof. Klaus Berner from the University of Applied Science, Mainz and Dr. R. Podleschny, EPAQ, 2009-06-05
- Workshop “EASIE – New European Research Project on sandwich panel technology, New European standard EN 14509 and EPAQ Quality Labe”. Place: company Romakowski, Germany. 25 participants, sales people and technicians of 3 countries, listened to the presentations of Prof. Klaus Berner from the University of Applied Science, Mainz and Dr.R. Podleschny, EPAQ, 2009-11-27
- Workshop “EASIE – New European Research Project on sandwich panel technology, New European standard EN 14509 and EPAQ Quality Labe”. Place: Oberaula, Germany for company SAB, Netherlands. 40 participants, sales people and technicians of 2 countries, listened to the presentations of Dr. R. Podleschny, EPAQ, 2010-02-05
- Workshop “EASIE – New European Research Project on sandwich panel technology, New European standard EN 14509 and EPAQ Quality Labe”. Place: Oberaula, Germany for company SAB, Netherlands. 25 participants, sales people and technicians from Germany, listened to the presentations of Dr. R. Podleschny, EPAQ, 2010-03-19.
- Participation on the conference Isotècnicaocho on 2009-05-26/27 in Montevideo, Uruguay with 200 participants from South and Central America. Main subject: EPAQ-presentation on thermal bridges in sandwich panel constructions. Additionally: Information was given to manufacturers of sandwich panels about the aims of EASIE project.
- Participation on the conference Isotècnicamex III on 2010-03-23 in Mexico-City with 100 participants from Central America. Main subject: EPAQ-presentation on Protection against lightning impact with sandwich panel roofs. Additionally: Information was given to manufacturers of sandwich panels about the ongoing EASIE project.

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SNPPA workshop at JORIS IDE. May 2011 and August 2011
EPAQ workshop at JORIS IDE. August 2011
SNPPA workshop at DAGARD. April and September 2011
SNPPA workshop at PANELCO. April 2011
EPAQ workshop at BASF. September 2011

The **EASIE Final conference** was held in association with the EPAQ/Pan and Pro Europe Congress in Rome on 22 and 23 September 2011 as this was a major and well attended annual event for the sandwich panel industry in Europe. With over 120 participants from 20 different countries (in majority from the European Union) this provided the best showcase possible for the dissemination of the EASIE research to as wide a spectrum of companies as possible. A major proportion of the Congress programme was devoted to the presentation of the Project’s results with nine different papers covering all the EASIE work packages.

2.4 Standards and codification

The EASIE project was pre-normative in character however one of its key industrial aims was to homogenise and strengthen European industry views within the main standardisation groups.

The project contributed to standards in a number of ways including in particular, through personal contacts and overlapping membership, by regular feedbacks to the European Committee for Standardisation (CEN) TC 128/SC11 and especially WG1, WG2 and WG5 who were dealing with the European standard EN14509 and to the European Joint Committee on Sandwich Constructions formed of ECCS TWG 7.9 Technical Working Group and CIB W 56 Working Commission. This very useful and active role was formally acknowledged by CEN and by ECCS.

New information produced by EASIE will be incorporated into an Annex of EN 14509 during the revision 2 of the standard once discussion inside the WG1 and 5 of the TC 128/ SC11. CEN TC 128 / SC11 concerning the update of the EN 14509 are completed. The update concerns mainly editorial improvements. Results concerning the long-term behaviour and resistance created in EASIE project may be taken into account in the next revisions of the standard. An additional deliverable D2.6 was introduced into the work programme of WP2 in order to provide the information for a new annex on design by testing to EN14509. This issue has still to be fully discussed and appraised by the competent mirror groups, working groups – in particular TC128 WG5- and committees within CEN. It is likely that more comparative work will be necessary between the design by testing and design by calculation.
The European Joint Committee on Sandwich Constructions consisting of ECCS TWG 7.9 Technical Working Group and CIB W56 Working Commission has produced a state of the art report “Effect of openings in the behavior and resistance of sandwich panels”, which is also a European Recommendation for the Design of Sandwich Panels with Openings. In close cooperation with ECCS TC7/CIBW56, the design model presented in deliverable D1.2 was incorporated in the revision of the Preliminary European recommendations for Design of Sandwich Panels with Openings. A Draft proposal for preliminary European Recommendations “Effect of openings in sandwich panels” (WP1 work) was produced in September 2010 in cooperation with ECCS TC7/CIB W56. The document has been discussed in Barcelona, Spain on 23 and 24 March 2011 and is due to be published as an ECCS document in 2012. The Joint Committee has also plans to produce recommendations on the stabilization of steel structures using sandwich panels and further, on the design of claddings fixed in one face of the sandwich panels. This work will incorporate the results of the work of WP3 and WP4 of EASIE.

2.5 E-Learning tools

The project has produced a comprehensive library of eLearning modules. These can be downloaded by interested users and they can improve their knowledge of various aspects of sandwich panels' technology and their applications.
The following lectures have been completed:

- Load Bearing Behavior - How is a sandwich panel working? (in English and Polish)
- Ohutlevypintaiset sandwich-elementit (in Finnish) Light weight sandwich panels with thin - gauge faces
- Actions and loads - Special Aspects of Sandwich Structures
- Core Material - Mineral Wool
- Chemistry and Processing of PU Metal Sandwich Panels
- Sustainability in Sandwich Panel Construction
- Thermal and structural behaviour in openings and joints
- Thermal bridges and Air tightness of Sandwich Construction
- Connections of Sandwich Panels
- Theory in fire design - material properties and testing
- Fabricating and Designing Sandwich Panels for Fire
- Erection - From the factory to the final building
- Allowable span tables on the base of the CE-mark
- Experimental studies on Duration of Sandwich Panels
- Repair and Retrofitting
- Sandwich panels and architecture
- Detailing

These were complemented by a list of guidelines and examples of good practice, a compilation of EU standards and regulations and a list of relevant literature with abstracts.

2.6 User Guide

The project produced a User Guide targeted at industrial users. The purpose of the Guide was to present the research findings in a simplified, accessible way and to demonstrate their application to users in industry and commerce and in particular to SMEs. This was a document entitled "User Guide EASIE Research Programme-Building with Sandwich Panels: Fast, Safe and Energy Saving" in two parts with one booklet outlining the Partners competencies and their role in the Project and the second detailing the research results and focusing on ten bestsellers. The Guide was distributed to each of the participants and the Final conference in Rome and has been uploaded on the project' website.

2.7 Scientific/Peer reviewed publications

A comprehensive list of scientific publications in peer reviewed journals which have resulted from the project is given in Table A1 below

2.8 Technical publications and presentations

The following publications were prepared and presentations made by the project team:

- Information about EASIE project in APIP’ÑA newsletter (*APIP’ÑA Informa nº5*) sent to all Spanish polyurethane sandwich panel producers, Spanish administration, Spanish labs and also to some European institutions. (February 2009)
- Information about EASIE project in Panama International newsletter n°8 sent to the European members in December 2008
- Information about EASIE project in Panama International newsletter n°9 sent to the European members in March 2009
- Information about EASIE project in APIP’ÑA newsletter (*APIP’ÑA Informa nº6*) sent to all Spanish polyurethane sandwich panel producers, Spanish administration, Spanish labs and also to some European institutions. (May 2009)
- Information about EASIE project in APIP’ÑA newsletter (*APIP’ÑA Informa nº7*) sent to all Spanish polyurethane sandwich panel producers, Spanish administration, Spanish labs and also to some European institutions. (August 2009).
- Information about EASIE in Lettre d’Information du Syndicat National du Profilage des Produits Plats en Acier, Paris, July 2009
- Ritsch (ITP), Lecture on curved panels, 14 Nov.2009, EPAQ congress, Helsinki, Finland
- Ritsch, (ITP), Presentation on low cost housing, University of Mainz, 2 July 2009.
- Presentation EASIE WP2 work, technical seminar of the European Profile and Panels Federation, 8 June 2009 at Brussels.
- Presentation EASIE WP2 work, codification meeting CEN TC 128 SC11, 27 may 2009, Mainz, Germany.
- Third FP7 - Untold Stories Conference, 3-4 December 2009, Budapest, Hungary (EASIE poster prepared by EUMED and placed in the poster session).
- Presentation of EASIE Project an the task of APIP’ÑA in this project, Neus Comas, General Assembly of APIP’ÑA, 28 May 2009
- Presentation of EASIE Project, L. Pfeiffer, Panama International European Congress of Sandwich Panels Manufacturers, Edinburgh, Scotland, 23 October 2008.
- Dr. Lars Pfeiffer, Introduction of EASIE project. Meeting of the Finnish Mirror Group of CEN/TC128/SC11 "Sandwich Panels". Meeting room of the Finnish Plastics Industries Federation, Helsinki. 29 January 2009
- Prof. Dr.-Ing. J. Lange, Presentation of the EASIE project to the German Mirror Group of CEN/TC128/SC11 "Sandwich Panels". Meeting of the Mirror Group in Darmstadt, 10 March 2009
- Prof. Dr.-Ing. J. Lange, Presentation at the Conference “Dach + Wand” in Stuttgart, Germany, 17 February 2009
- P. Hassinen, Introduction of EASIE project and full-scale tests of WP2 to Research Assessment Panel of TKK, Espoo, Finland, 11 June 2009
- Prof. J.Lange, D. Izabel, Dr. T. Misiek and P.Hassinen, Introduction of the current activities of EASIE in the meeting of the ECCS TWG 7.9 / CIB W56 Joint Committee on Sandwich Constructions in Hämeenlinna, Finland, 26 June 2009
- Prof. K. Berner, Presentation of EASIE project, EPAQ Workshop, March 2009.
- Prof. K. Berner, Presentation of EASIE project, EPAQ Workshop, June 2009.
- Prof. K. Berner, Presentation of EASIE project, EPAQ Workshop, November 2009.
- Prof. B. Naujoks, Report on EASIE WP1 and WP4, Panama International European Congress of Sandwich Panels Manufacturers, Brussels, June 2009
- Prof. B. Naujoks, Forschung an Fachhochschulen Erfolgreich in Europa, in Europe, Bonn, June 2010.

- Presentation by Ms Rädel on "Openings in sandwich panels" at the CIB World Conference in Salford, UK in May 2010
- Presentation by Ms Rädel on "Thermal and structural behavior in openings and joints" at The EASIE Workshop in Krakow, Poland on June 9th, 2011.
- Presentation of EASIE Project and of the role played by APIP'ÑA in EASIE, General Assembly of APIP'ÑA, 10 June 2010.
- Prof Lange gave presentations on "Sandwich panels" at Stahlbau Kalendertag in Stuttgart, Germany on June 11th, 2010 and at Deutscher Stahlbautag in Weimar, Germany on October 7th, 2010.
- Presentation by Ms Rädel on "Openings in sandwich panels" at the Conference on Steel and Composite Structures in Sydney, Australia in July 2010
- Ms Rädel gave a presentation on "Eccentrically loaded sandwich elements" at the Eurosteel Conference 2011 in Budapest, Hungary on August 31, 2011
- EASIE partners participation at Pan&Pro/EPAQ World Congress, Porto, Portugal, 16 to 17 Sept. 2010
- IPO Construiracire, 20 Sept 2010
- French Fire brigade Annual Congress, 22 to 25 Sept. 2010
- Dinner, Ministère de l'Intérieur, Paris, 22 Sept. 2010
- Meeting with Monsieur Hortefeux, Ministre de L'Intérieur, Paris, 29 Sept. 2010
- Meeting of PU industry, Paris, France 29 Sept. 2010
- Meeting SNPPA Steering Committee, 30 Sept. 2010.
- Presentation by K. Berner and M. Rippel on Air and water permeability of sandwich panel joints-Requirements and state of research to the EPAQ/PAN&PRO Europe Fourth European Congress on Sandwich Panel and Profile Technology, 17 to 17 Sept. 2010, Porto
- Presentation by B. Naujoks and D. Isabel on Design by Testing and Design by Calculation of Sandwich Panels to the EPAQ/Pan&Pro Europe 4th European Congress on Sandwich Panel and Profile Technology, 17 to 17 Sept. 2010, Porto
- Presentation of EASIE Project and the task of APIP'ÑA in this project, N. Comas, General Assembly of APIP'ÑA, 16 June 2011, Madrid.
- Professor Lange and Ms. Rädel gave a presentation on "Structural behavior of openings with and without frames" at the EPAQ Congress in Rome, Italy on September 22nd, 2011.
- Presentation of the design by testing methods (WP2) at the CSTB in France, 18 march 2011
- Presentation of the method and the software at the French manufacturer (WG sandwich panel 19 January 2011)
- Presentation and validation of the design by testing method during SNPPA training at Dagard, Panelco, CORUS, Joris Ides.
- At the Stahlbau-Kalendertag in Stuttgart on June 11th 2010 in Stuttgart, Germany a presentation on sandwich panels in construction incorporating outputs from the project was given.
- At the "Deutscher Stahlbautag" on October 7th 2010 in Weimar, Germany a presentation on sandwich panels in construction incorporating outputs from the project was given.
- List of lectures and lecturers were placed on the EASIE WIKI site.
- List of publications on sandwich panels was placed in the public domain, posted on www.easie.eu and updated twice.
- All the lectures on sandwich panels recorded were placed in the public domain and posted on www.easie.eu.
- Workshops on sandwich panels were conducted in Zagreb, Croatia, in Barcelona, Spain and in Krakow, Poland in cooperation with WP6.
- Discussions concerning the fasteners and the fixing technology of the cladding panels with SFS Intec, Henkel, Sika-Bond and Montana Bausysteme AG.
- Supply by Paroc Oy of panels for testing.

- Supply by Pflaum&Sohne Bausysteme GmbH of used panels for testing
- Presentation by Th. Misiek on “Stabilisation of beams by sandwich panels – new regulations and recent research results” at the CIB World Conference in Salford, UK in May 2010
- Presentation by S. Käpplein on “Introduction of tensile forces with mechanical fasteners in sandwich panels” at the Conference on Steel and Composite Structures in Sydney, Australia in July 2010
- Presentation by S. Käpplein on “Classification of stability failure modes of sandwich panels under compression loading: global and local buckling, crippling at support line” at the International Colloquium Stability and Ductility of Steel Structures in Rio, Brazil in September 2010
- Presentation by Th. Misiek on “Stabilisation of beams by sandwich panels – Lateral and torsional restraint” at the Eurosteel Conference 2011 in Budapest, Hungary in August 2011
- Presentation of WP3 of EASIE Project at Colloquium “90 Years Research Centre for Steel, Timber and Masonry” in Karlsruhe, in September 2011
- Presentation by Th. Misiek on “New applications for sandwich panels: stabilization and load transfer” at the EPAQ/PAN&PRO Fifth Congress on Sandwich panels and Profiles technology, Rome, Italy, 21 and 22 September 2011.
- Presentation D.Isabel Comparison of design by testing and design by calculation at the EPAQ/PAN&PRO Fifth Congress on Sandwich panels and Profiles technology, Rome, Italy, 21 and 22 September 2011.
- Presentation by Hassinen, P, Misiek,T. and Naujoks, B. Cladding systems for sandwich panels for refurbishment of walls and roofs, Proceedings Eurosteel 2011, Budapest, Hungary August 31-September 2, 2011.

2.9 Collaborations and contact with stakeholders

A number of new scientific and/or industrial collaborations were initiated by the project including:

- Henkel AG, RBM Europe, ThyssenKrupp Steel AG – Development of a new glue system for sandwich panels repair.
- Industrial collaboration of TUD with Paroc, Finland to test and improve their system of window in sandwich panels for façade.
- Periodic monitoring by ITP of humidity in panels with unit from company G. Luff-Fellbach.

Regular ccontacts were maintained by the project team with relevant stakeholders and potential users of the project results in academia, industry amd government wthin and outside the EU including:

- The EASIE newsletter, translated in Spanish, is sent to South America sandwich panel producers and is posted on the public open part of the project website.
- Presentation by EPPF on EASIE developments given at several meetings of EPAQ: General Assembly, Managing Committee, Quality Committees, Working Groups with 20 European producers and more than 10 European testing laboratories who are testing sandwich panels.
- Presentations by EPPF of the EASIE works in the French mirror group of the EN 14509 Commission P34X, 29 May 2009 and 27 November 2009.
- Presentation by Aalto University of WP4 results to CEN TC128, SC11, WG2, 22/02/2010, Espoo, Finland.
- Presentation of EASIE to Council of European Producers of Materials for Construction (EPMC), Nov. 2008 and March 2009.
- Presentation of EASIE to Groupe LGA France, Dec.2008.
- Presentation of EASIE to Ministry of Civil Security, France, March 2010.
- Regular exchange of information with European Committee for Standardisation (CEN)

2.10 Flyer

An EASIE flyer has been produced and uploaded at www.easie.eu.

2.11 Post-project strategy

A post-project strategy was been agreed by the EASIE Participants in order to manage the project's legacy. This has secured the maintenance of the project website which is being converted into a central industry portal for the European Sandwich industry.

3. SECTION B EXPLOITABLE KNOWLEDGE AND ITS USE

For
- TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

- TEMPLATE B2: TYPE OF EXPLOITABLE FOREGROUND

see first part of Final Report

The EASIE project aimed at increasing the use of sandwich panels for residential, industrial and office buildings, as well as enriching the current European Standard for sandwich panels EN 14509. The problem areas where the project has made a significant contribution were:

- Lack of knowledge in some countries, which prevents end users from accepting sandwich panels, and engineers and designers from prescribing or using it
- Lack of common set of rules at European level, which can hinder the standardisation process, or lead to barriers for end users

The project was focusing on three main elements:

- Improvement of sandwich panel design and design tools to promote and simplify the use of sandwich products
- Improvement of energy consumption both, during production process and after application to the building
- Prediction of the product lifecycle to ensure safe design and efficient retrofitting and replacement

The project not only aimed at generating knowledge, but also at developing training tools, in order to make new resources available to stakeholders and end users. Dissemination of the results by the Industry Associations present which participated in the work was an essential aspect of the project.

In order to achieve its ultimate objectives, the Consortium focused a lot of its efforts on making sure that the knowledge and expertise developed in the project were known to, and accepted by, end users.

The project had also a relevant component of private exploitation, either by industry associations or SMEs in the consortium. An adequate balance was found between dissemination of principles and protection of exploitable results.

The project has given emphasis to several areas of improvement, which have been transferred as results to industry, creating a range of new opportunities, either in terms of an increased consumption of sandwich panels, or the use of the guidelines and tools (some of them commercial) that are currently under development. These areas are:

- Design: The project has developed design procedures that will expand the scope and applicability of sandwich panels

- Energy balance: The project has explored and highlighted advantages such as reduced overall CO_2 emissions in the whole life cycle, manufacturing and transport (reduction in bulk and weight), installation and dismantlement (less reliance on heavy lift equipment), and reduced heating requirements thanks to better insulation

- Sustainability: The project has developed procedures to allow easier incorporation or retrofitting of sandwich panels in the fabric of existing buildings and replacement or easier repair of defective elements. This has resulted in a product which is consistent and better understood, with a reduction in raw material consumption

- Durability: the project has enabled an accurate prediction of the product lifecycle by determining "fit for purpose" state at any given time allowing the determination of remaining service time for existing constructions

Industry associations have committed themselves to transfer the knowledge generated in the project to their own industrial areas of influence, promoting a wider use of sandwich panels in new construction applications.

The participants were acutely aware of the fact that sandwich panels are still considered a new or untried technology by some end users and that this is partly due to the fact that sandwich technology is not part of the curriculum of most engineering courses yet, and to a chronic lack of suitable materials for the training of the current workforce. The project proved it had the capacity to resolve this limitation, by putting in motion the transfer of a wealth of knowledge to academia and to designers and other players in the industry.

3.1 Identification of exploitable results

The project has generated a steady stream of industrially relevant results and has made the bulk of them freely available on the website www.easie.eu. This website is being developed as a portal for the European sandwich panel industry with additional resources being provided by a number of industrial associations led by SNPPA and PAPE.

The project can therefore be considered as the starting point of a continuous stream of innovation and production of information in the sandwich panel area. Some of the industrial participants in EASIE felt that this was "the right place to be" in order to generate and access innovation. This positive impression could, in future, be extended to a large proportion of organisations related to sandwich panels, at different levels, such as manufacturing, building, industry associations, and academia among others.

3.2 Characterization of exploitable results

- **DESIGN GUIDELINES FOR GOOD PANEL JOINTS AND JOINTS SEALING OPENINGS FOCUSING ON AIR AND WATER TIGHTNESS**
- **DESIGN MODEL DETERMINING MECHANICAL STRENGTH OF SANDWICH PANEL WITH OPENING WITH AND WITHOUT ADDITIONAL INTERNAL FRAME STRUCTURE**

These results give design guidelines for taking into account the weakening effects of openings and joints on the strength of sandwich panels.
The primary end-users are panel manufacturers, builders and planners. It will enable them to have a better knowledge on the behaviour of sandwich panel assemblies, to, in many case, leave out additional supporting structures with enhanced performances and to impart to their products optimum thermal insulation and water tightness of the entire construction frame and in particular the corners.
These results are protected by copyright which is vested in the authors of the guideline. It is freely on www.easie.eu
The participant Fech Fenstertechnik Gmbh&co has already exploited this innovation by incorporating the guidelines into its Fech-Jet-System ® which is a combination of a window/door system and a welded

aluminium frame and is targeted at the food industry, the car industry and the construction industry both new build and renovation markets.

- **THERMAL TEST METHOD**

This is a test method to calculate the thermal behaviour of a building constructed with sandwich panels and to determine the influence on temperature on sandwich panels. It accurately measures the influence of temperature on sandwich panels.
The change in temperature leads to increase deflection and stresses in the panel. These are measured in a new test which exposes the panel to different temperatures. With the thermal test method exact results for the type of panel being tested can be determined without calculation of temperature influence. Method to test panels below a thermal gradient and punctual loads (simultaneous loading).
The users of this test method are sandwich panel manufacturers, engineers, designers and laboratories.
This output is available at www.easie.eu

- **DESIGN BY TESTING MODEL**

This model is in the form of a series of Excel sheets to determine by testing the bending and shear rigidity of the panel, its strength and capacity and its practical load table.
The prime end-users are panel manufacturers.
The model enables the quick definition and optimisation of the performance of the panel.
The model is being used by panel manufacturers especially in Spain, France, and Poland.
The Excel sheets can be freely downloaded from www.easie.eu

- **CALCULATION AND DESIGN MODEL FOR THE USE OF SANDWICH PANELS FOR STABILIZATION OF BEAMS AND PURLINS**
- **CALCULATION AND DESIGN MODEL FOR THE USE OF IN-PLANE SHEAR RESISTANCE OF SANDWICH PANELS FOR STABILIZATION OF BUILDINGS**
- **CALCULATION AND DESIGN MODEL FOR THE USE OF AXIALLY LOADED SANDWICH PANELS FOR BUILDINGS**

These results make it possible to take into account the contribution of sandwich elements for reinforcing of beams and purlins and leads to the structural analysis.
They allow leaner structures and thus lower construction costs and a better use of resources.
The end-users are all those involved in the construction process.
These results are freely available at www.easie.eu

- **MODULAR DESIGN TOOL FOR SMALL AND SIMPLE BUILDINGS**
- **GUIDELINE FOR DESIGN AND CONSTRUCTION GOOD PRACTICE**

The design tool is in the form of a series of Excel sheets.
This simple tool makes it possible to carry out a pre-design or structural analysis for small and simple buildings built of sandwich panels without any substructure. It shows how easy building with sandwich panels is.
This result can be incorporated into complex software solutions for structural analysis.

- **GUIDELINE FOR DESIGN AND CONSTRUCTION GOOD PRACTICE**

This result provides guideline for the cladding of sandwich panels including techniques to fasten additional cladding sheets and elements to the external face of the ordinary panel.
The service life of old sandwich panels can be extended with cladding providing technical and visual improvements. This could increase the demand for panels for the refurbishment of old buildings, in particular those publicly owned, across the European Union. The proposed European Directive on energy efficiency,

COM (2011)370, 22 June 2011 will give a major incentive for the expansion of the renovation market for public buildings across the European Union by stipulating, in its Art.4, a duty on Member States to “ensure that as from 1 January 2014, 3% of the total floor area owned by their public bodies is renovated each year to meet at least the minimum energy performance requirements”.

- **DESIGN CONCEPT FOR COLD/CHILL ROOM**

This result gives an overview about relevant construction details and help to design cold/chill rooms.

- **IN-SITU REPAIR TECHNIQUE FOR SANDWICH PANELS**

This is an innovative technique for the repair of blistering and wrinkling failures in sandwich panels in-situ. It removes the need to replace such panels thereby lowering costs to customers, avoiding the need to interrupt the use of the building during remedial works and is environmentally beneficial in extending the service life of old panels.
The end-users are manufacturers, builders, developers, architects.
The technique is already in use and improvements are on-going.

- **GUIDELINE GOOD PRACTICE FOR REPAIR OF FAULTS ON SANDWICH PANELS**

- **TEST METHOD TO ASSESS DURABILITY OF SANDWICH PANELS**

This tool provides information about the development of the resistance of sandwich panels including new knowledge about testing and about the evaluation of the development of the essential failure mode during service life. It provides new more accurate information about the changes in the resistance of sandwich panels.
End-users are manufacturers and standard authorities.

- **NUMERICAL TOOL/SOFTWARE TO ASSESS REMAINING SERVICE LIFE/EFFECT OF AGEING FOR SANDWICH PANELS.**

This result provides new information on the service life of sandwich panels and includes models to evaluate the development of the resistance of panels over time and in different environments in north and south Europe.

4. Section C Risk assessment and action plan

The risk profile of the project has been assessed and discussed by the participants. The following risks have been identified and possible solutions proposed:

- *Significance dependence on other technologies*

In the case of openings, the sandwich panels depend also on other industries for successful implementations, such as windows and doors. If they do not participate in the implementation of the solution, the advantages may remain at theoretical level

Action plan: Discussions with players in the areas above and every related industry as soon as possible, in order to obtain their feedback in terms of applicability of the guidelines, and the compatibility with their practices and systems.

- *Replacing existing and well entrenched technologies*

Construction can be considered a traditional industry, particularly considering that concrete has been used for almost two centuries, and cement has been used by the early human civilisations. In many cases, the design rules, problems and solutions are well known by engineers, architects, designers, and the construction industry, and there may be reluctance to change, as this will require an effort by the innovators.

Action plan: The Participants, and in particular the Industrial Associations, have start disseminating the improved guidelines and the advantages of sandwich panels early in the project. This has been reinforced by continuous standardisation work, and the publicizing of success stories in end users. The User Guide has been a major element of this strategy. Dissemination materials have been prepared so as to allow comparison with competing construction materials and techniques so as to demonstrate the superiority of the solutions arrived at in EASIE.

- *Litigation risks*

The idea that there are alternative developments elsewhere cannot be ignored, and there could be a possibility that a company or institution claims ownership of the exploitable results.

Action plan: The existing IPR in the area is being monitored by the participants. A preliminary search did not show apparent threats in this aspect, but more specific searches and alternative means of intelligence gathering such as conversations with other players in the industry are being explored.

- *Ill-timed disclosure and leaks of confidential information.*

This is a constant danger for any exploitable know-how and could lead to the loss of commercial opportunities, or could adversely affect protection of results. Also, in the result with public and private components, if it is not clear what information should be disseminated and what is going to be protected or commercially exploited, this could lead to misunderstandings or mistakes.

Action plan: the participants have put in place at the start of the project in the Implementation Plan and in the Industrial Plan clear procedures to address this issue. These procedures and in particular the one applicable to the publication of project’s outputs have been adhered to during the whole duration of the project.

- *Influence of legislative and regulatory framework*

Given that regulators, many relevant prescribers, or influencers are in the public sector, and this is a new technology, the lack of standards could prevent decision makers, who are usually risk averse, to use or promote this technology. In the case of sandwich panels, the public sector / government is not perceived as an agent that has favoured much this technology.

Action plan: The creation of a set of standards could be an important accelerator for this technology, and would facilitate implementation and acceptance. The starting point is the design guidelines and methods described in the project, which could be gradually accepted and formally recognised, and become standards. In order to be successfully developed, standards have to grow in parallel with market implementation, therefore implementations and feedback from the construction companies and end users are essential. Also, standards in one given country (e.g. Germany), could contribute to the acceptance in another country (with the caution related to the differences in construction practices).