

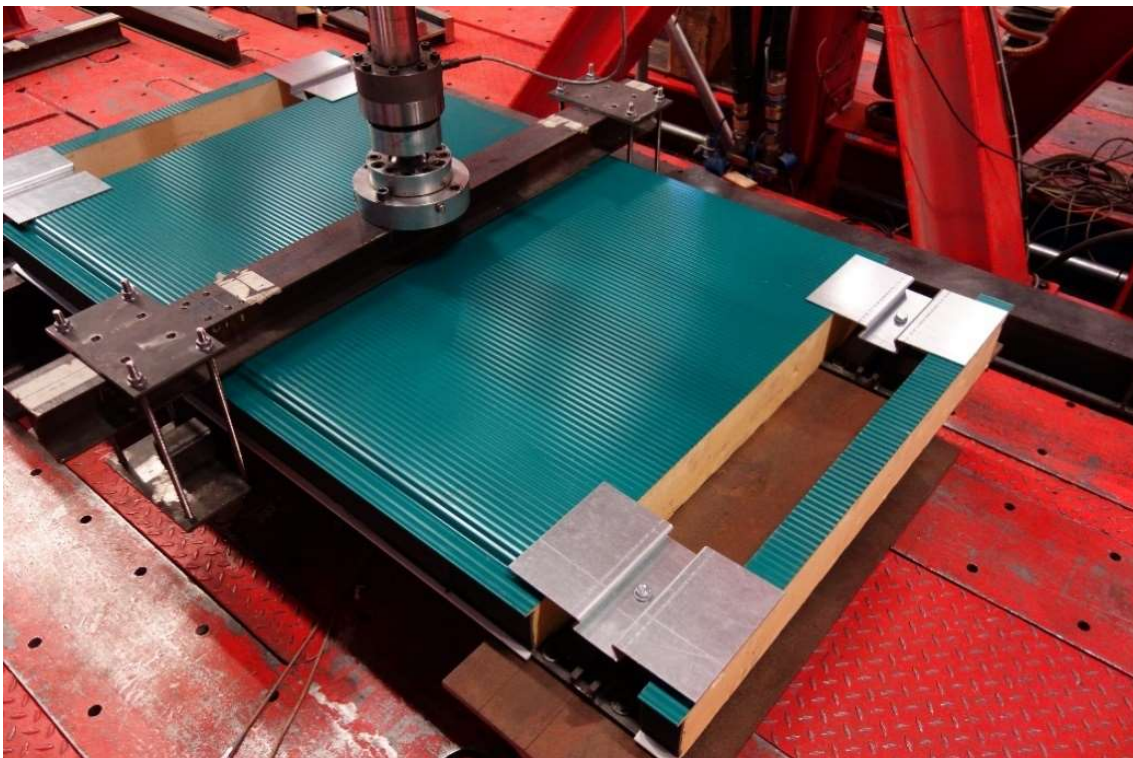
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Production and Testing of Prototypes

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Deliverable: D 4.3 Production and Testing of Prototypes

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Authors: **Markus Kuhnhenne, Dominik Pyschny, Kevin Janczyk**
RWTH Aachen University

Executive summary

This deliverable presents new hybrid solutions and joining methods for envelopes of single-storey steel-framed buildings for the research project “Provisions for Greater Reuse of Steel Structures” (PROGRESS) under the Research Fund for Coal and Steel Grant Agreement No: 747 847.

This deliverable builds on the findings of Deliverables 4.1 and 4.2. First, the structure of the Smart Flashing Connector and the hybrid façade consisting of a liner tray and a sandwich panel is explained. Afterwards, the installation of FRP profiles to reinforce the webs of the hybrid system is evaluated.

Structural tests are carried out on the Smart Flashing Connector, the hybrid façade and two systems with FRP reinforcement. Furthermore, a comprehensive thermal analysis of the systems is carried out in the following chapter.

Finally, the end product usability of the over-cladding from Deliverable 4.2 and the hybrid system is tested on buildings of RWTH Aachen University.

In summary, promising systems to promote the reuse of steel building envelopes in new and existing buildings in the future have been developed and evaluated in this Deliverable.

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1. Introduction

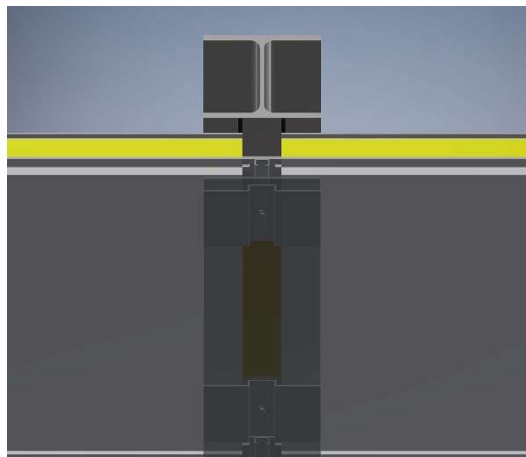
For many buildings, it is the failure or deterioration of the envelope that precipitates its premature demolition. This can be aesthetic deterioration, changing architectural design or, as is often the case, the need to update the envelope to modern standards of thermal performance. Therefore, the building envelope needs innovative hybrid elements, which allow an easy adaption to new requirements, an effortless dismantling and unmixed severability of the different components and thus ensure a future possible reuse of the components and recycling of the materials.

This deliverable evaluates the different possibilities of reusing the building envelope, which have been evaluated in previous deliverables. The focus is on the evaluation of the production, structural and thermal performance and the end product usability.

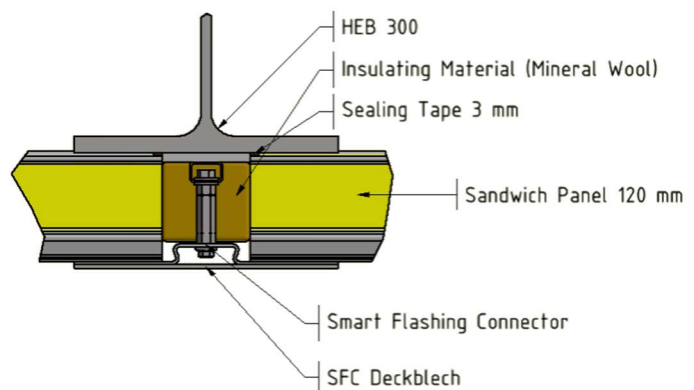
2. Manufacturing Prototypes

2.1 Clamping System for Sandwich Panels

The Smart Flashing Connector (SFC) was developed to enable the reuse of sandwich panels with a clamping solution. The SFC replaces the screws that are usually used to connect the sandwich panels to the substructure. Figure 1 shows a detailed view of the Smart Flashing Connector mounted on a HEB 300 including the clamped sandwich panels.



(a) Sketch of installed panels on HEB 300



(b) Details of connection

Figure 1 Smart Flashing Connector

Figure 2 shows the structure of a wall system in which the sandwich panels are clamped to the substructure by the SFC. Thereby, the substructure consists of HEB 300 columns. The wall consists of three horizontally mounted sandwich elements with a thickness of 120 mm. The hollow space at the vertical joint between the panels is filled with thermal insulation and is covered by a cover plate.

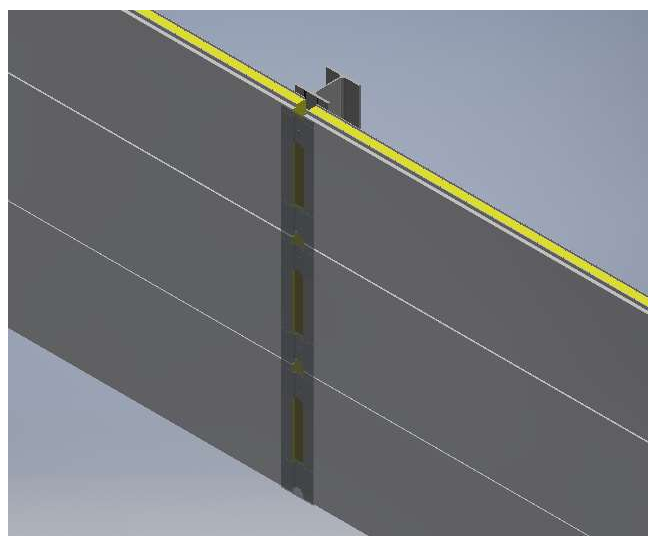
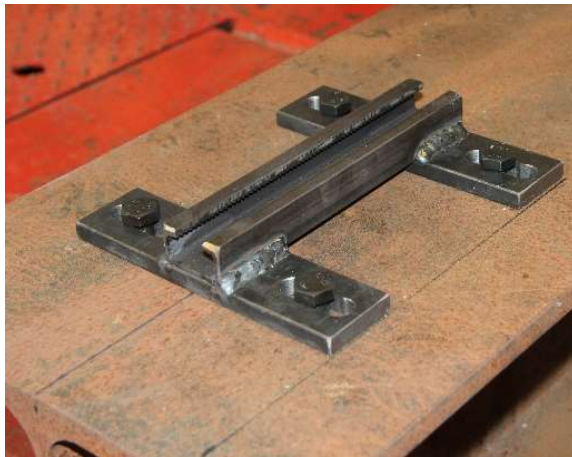


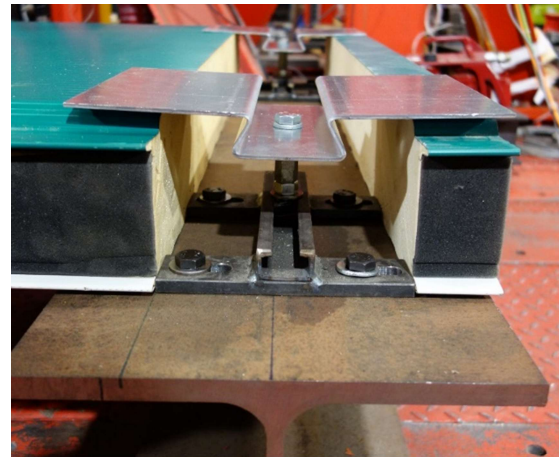
Figure 2 Sketch of clamped wall system

First, the manufacturability of the prototype was evaluated. The prototype was manufactured in the lab of RWTH Aachen. Great importance was attached to ordering the individual components in such a way that they can be adapted before assembly. The rail was ordered in sufficient length and the final cutting was then carried out at RWTH Aachen University. The adapter profiles were delivered as flat steel and the long holes were drilled afterwards. The clamping plate was manufactured by an external company, as this was the only way to ensure that the high quality of workmanship could be achieved. Once all the individual parts have been manufactured, the assembly is easy and can be done either in factory or directly on the construction site.

Another important requirement is the easy assembly on the construction site. The current method of fastening sandwich panels to the substructure with screws is a very quick procedure without much effort. The Smart Flashing Connector should also avoid high efforts of installation due to be competitive to existing systems. To ensure that this is the case, the Smart Flashing Connector was first mounted on a substructure consisting of a HEB 300. Figure 3 shows the complete system of the Smart Flashing Connector.



(a) Adjustment of Adapter Profile



(b) Fixing of bolt and sheet

Figure 3 Assembly of Smart Flashing Connector

As expected, the Smart Flashing Connector was very easy to attach to the HEB 300. There were no unexpected difficulties or problems. Based on the first good experience with the installation, a prototype wall was built for the structural tests. Again, it was found that the attachment of the sandwich panel to the substructure worked as expected. Figure 4 shows the structure of the whole system consisting of the Smart Flashing Connector, the substructure and the sandwich panel.

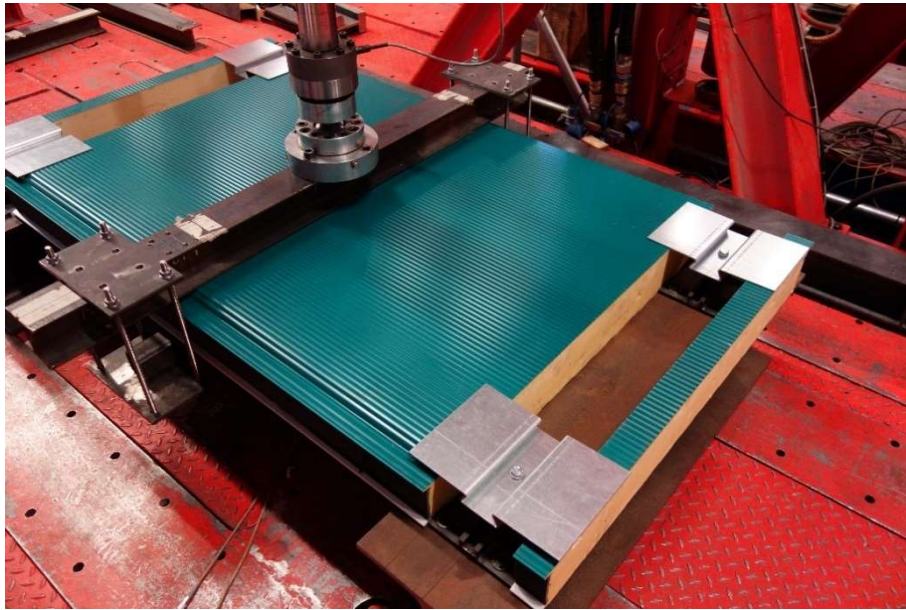


Figure 4 Prototype of clamped wall system

The theoretical considerations about the installation of the Smart Flashing Connector and the wall system, which took place in D4.2, could be confirmed by the practical setup. It was particularly pleasing that no additional difficulties were encountered. The construction of the wall system therefore does not pose any difficulties for the usability on the market. The following five steps of the installation could be confirmed:

1. Lose installation of adapter profile and rail with anchor bolt on substructure
2. Positioning of sandwich panels
3. Adjusting and fixing of connector to the substructure
4. Connecting threaded sleeve on anchor bolt
5. Mounting bolt with sheet on threaded sleeve

2.2 Hybrid System

The manufacturability of the hybrid system was evaluated during assembly in the hotbox at RWTH. In the following, the construction is described in the individual steps of the assembly.

Two test specimens in the dimensions of $w = 1.30$ m and $h = 2.50$ m were manufactured. These dimensions correspond to a sandwich element of the usual construction width of 1000 mm with two "edge pieces" to illustrate the longitudinal sandwich joint and in height to four of the selected liner tray profiles (600/100 mm). This represents the static system of a four-span beam with a span length of 600 mm.

The four liner tray profiles (600/100, length 1.30 m each) are screwed onto a steel beam HEB 120 in order to ensure a setup as close to reality as possible, see Figure 5.

The liner profiles are screwed together using self-drilling screws. The recommended maximum distance between them is 1000 mm. In the tests carried out, this distance is selected at 600 mm. This corresponds to three drilling screws per liner tray web. The liner trays profiles are filled with mineral wool ($\lambda_{MW} = 0.035$ W/(mK)).

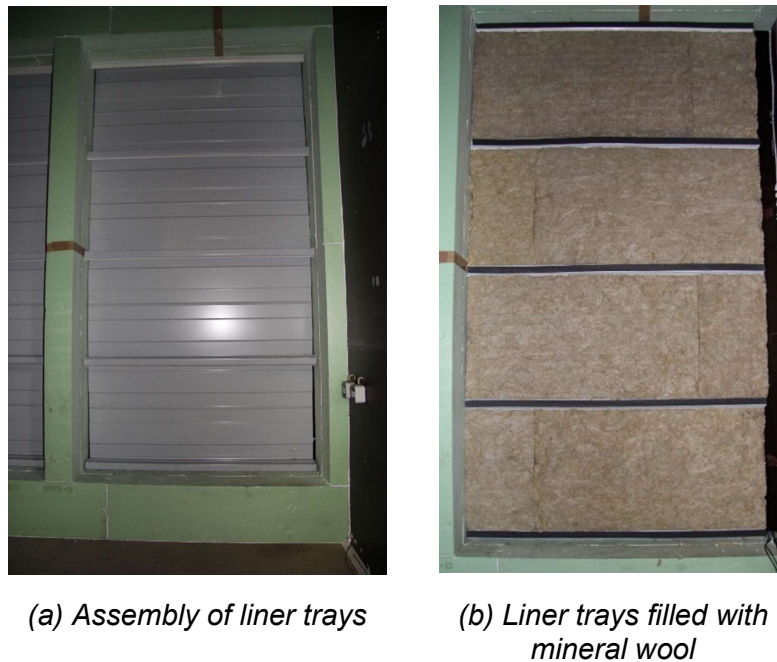


Figure 5 Assembly of hybrid system in the HotBox

The sandwich panels are fixed to the webs of the liner trays. In case of direct fixation, the distance between the fasteners is limited to $d \leq 200$ mm. Therefore, the distance between the fasteners is set at 200 mm. The use of load distribution plates prevents the failure of the surface layer. Figure 6 shows the front and back of the completed hybrid system



(a) „Inside“ liner tray



(b) „Outside“ sandwich panel

Figure 6 Installed hybrid system

Figure 7 shows the cross section of the installed hybrid system.



Figure 7 Cross section of hybrid system

2.3 Hybrid System with FRP Profiles

The hybrid system was also built with two variants of FRP reinforcements. These reinforcements serve to increase the load-bearing capacity of the hybrid system at the end support. As previous investigations have shown, the webs of the liner trays at the end support are extremely susceptible to buckling [3]. The load-bearing capacity of the liner trays at the end support was increased by

reinforcing the webs with FRP profiles. FRP was chosen as the reinforcement material because of its low thermal conductivity. For the FRP geometries two different approaches were followed. First, the buckling length of the web was reduced so that a higher load-bearing capacity could be achieved (V1). Secondly, the hybrid system on the web was designed in such a way that the load transfer occurs exclusively via the FRP profiles and the web of the liner tray has a subordinate role (V2).

Hybrid-FRP-System V1

The first variant of FRP reinforcement was chosen, as already mentioned, to reduce the buckling length. To make the system as resource efficient as possible, the FRP profiles are cut to the length of the support width and also only placed over the supports. The height of the profiles is based on the stiffener of the web. The FRP thus reinforces the area of the web below the stiffener and reduced the buckling length. The profiles are attached on both sides of the web and thus prevented the lower part from deviating in both directions. Both, the two FRP profiles and the web are pre-drilled and connected by a bolt. This type of installation is found to be the most practical way to enable an in-situ solution on existing buildings. Figure 8 shows the FRP profiles V1 and the bolt connection of the profiles to the web of the liner tray.



(a) FRP Profile

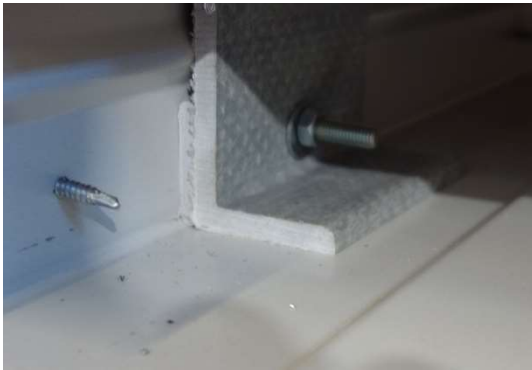


(b) Reinforcement of liner tray web

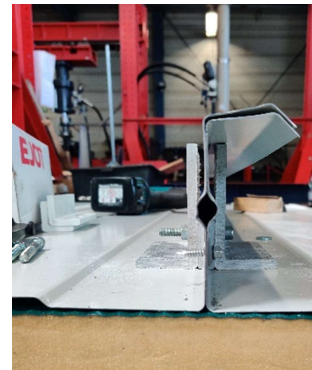
Figure 8 Hybrid System with FRP Profile V1 for reinforcement

Hybrid-FRP-System V2

The second variant of the FRP reinforcement was aimed at ensuring the load transfer via the reinforcement profile. Therefore, the profile should cover the entire height of the web. To ensure that the stiffener of the web is not an obstacle, an additional flat FRP profile is used, which allows the actual reinforcing profile to pass the stiffener unhindered. The flat profile is also made of FRP to ensure the good thermal performance of the structure. As with the first variant, the profiles and the web are pre-drilled and connected with a bolt. The profiles of the V2 version are also attached to both sides of the web. Figure 9 shows the FRP profiles V2 and the screw connection of the profiles to the web of the liner tray.



(a) FRP profile



(b) Reinforcement of Liner tray web

Figure 9 Hybrid System with FRP Profile V2 for reinforcement

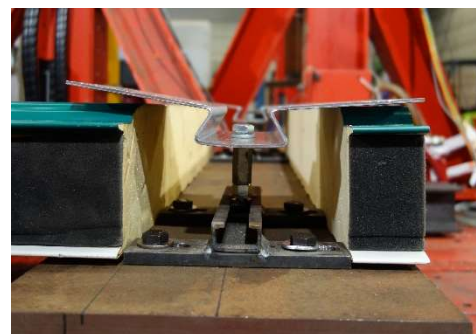
3. Testing of Structural Performance

3.1 Clamping System for Sandwich Panels

The evaluation of the load-bearing behaviour of the Smart Flashing Connector was carried out in these deliverables on a component test. A wind suction load was simulated, which acts on the sandwich panel and has to be absorbed by the Smart Flashing Connector. The panel is fixed horizontally and held by four Smart Flashing Connectors. These are each attached to the outer corners of the element. This means that two SFCs are installed per running meter for the joint that is created at the support. In this test, unlike the test in D4.2, the SFCs are not symmetrically loaded. Since the wind load is simulated on only one element, this means for the SFC that only one flank of the clamping plate is loaded at a time. To ensure that the SFC remains stable throughout the test, the subsequent panels are simulated by small strips of the elements. Figure 10 shows the deformation behaviour of the Smart Flashing Connector during and after the test.



(a) During test



(b) After test

Figure 10 Failure mode of Smart Flashing Connector

During the test, the loaded flank of the clamping plate is plastically deformed, while the other side, which is aligned with the panel strip, is loaded in compression and thus does not deform. The

remaining part of the Smart Flashing Connector is hardly stressed by the arising forces and remains perpendicularly fixed to the substructure as expected. The load-deformation diagram is shown in Figure 11. The results of the tests are shown in Table 1.

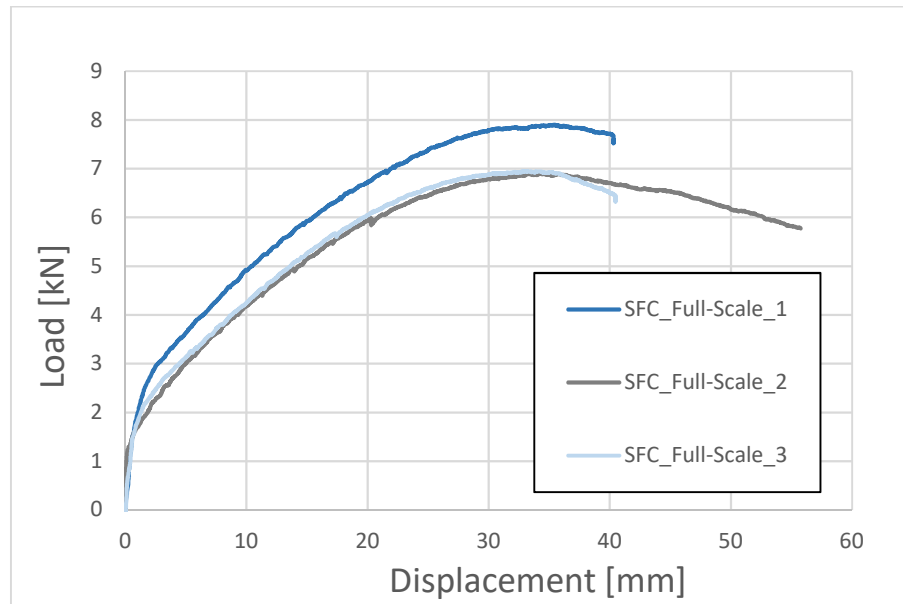


Figure 11 Load-Displacement-Diagram of clamped panel under tensile load

Table 1 Test results Smart Flashing Connector

Specimen	Max. Load [kN]	Displacement [mm]
SFC_1	7.88	36.19
SFC_2	6.75	39.18
SFC_3	6.94	34.04
Average	7.19	36.48

The results show that the load bearing capacity of the Smart Flashing Connector is at a satisfactory level. This means that it is possible to use the Smart Flashing Connector as a connecting element for reusable sandwich panel systems. The maximum loads are definitely comparable with conventional screw connections. A sample calculation has shown that a building to be erected in northern part of Germany is designed with wind loads of 0.81 kN/m^2 . Taking into account the necessary safety factors, sandwich panels can be safely installed up to a span width of 4.8 m. This means that in some cases the maximum span width is not dependent on the Smart Flashing Connector but on the load bearing capacity of the sandwich panels.

Table 2 shows the maximum spans of a selected sandwich panel depending on wind loads. Figure 12 shows the utilization line of the spans that occur under the restriction of the

Smart Flashing Connector. It can be seen that up to a wind load of approx. 0.6 kN/m^2 the span length is limited by the panel itself. 75 % of the maximum span length of the panel could be realized up to a wind load of 1.1 kN/m^2 and 50 % of the span length up to over 1.5 kN/m^2 .

Table 2 Wind load - relative span length - relation

Max. Wind load in relation to Span Length	
Span Length [m]	Char. Wind Load [kN/m^2]
100 %	0.6
75 %	1.1
50 %	≥ 1.5

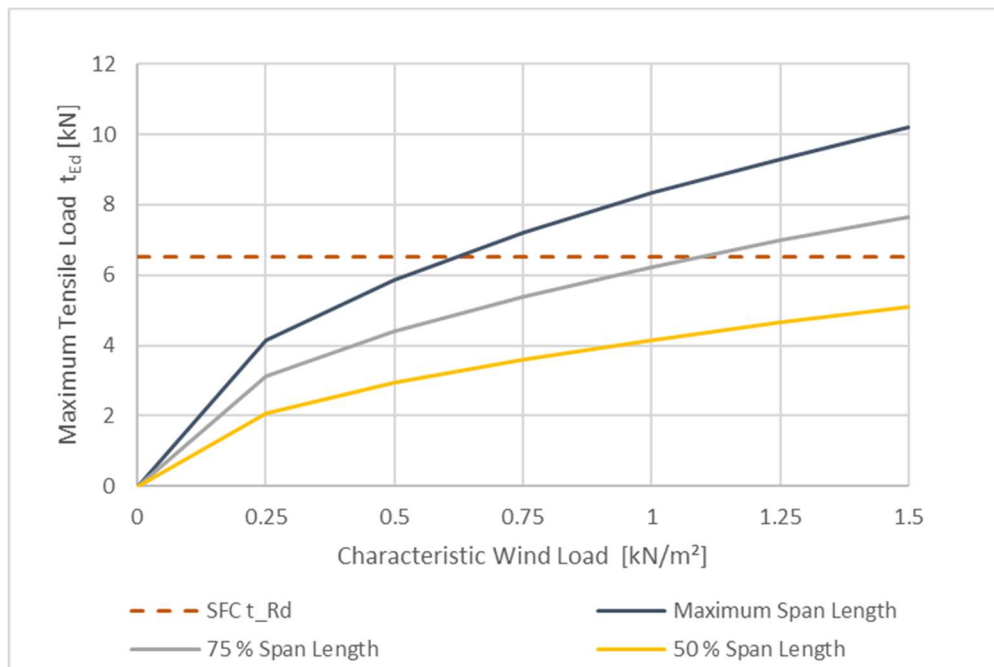
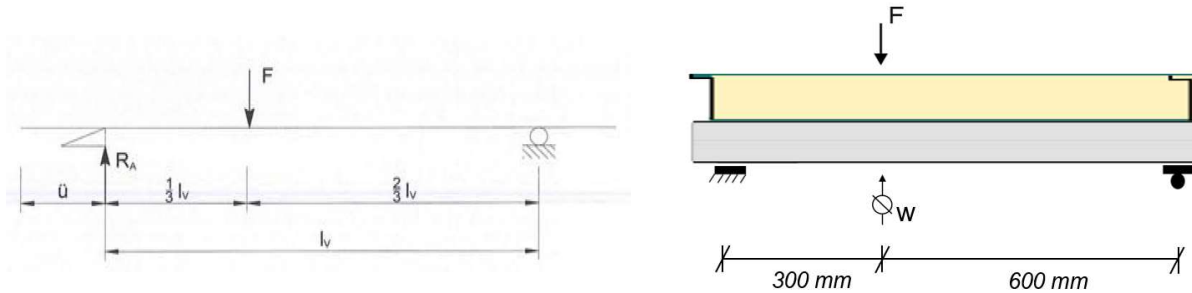


Figure 12 Relationship between wind load and span length

3.2 Hybrid Systems

The test setup for investigating the load-bearing capacity of the end bearing is shown in Figure 13. The end support of the hybrid system should be investigated. The sandwich panel, which is stretched over the liner tray, then functions as a multi-span beam whose span length corresponds to the width of the liner tray. A sandwich panel stretched over several spans and subjected to high temperatures generates tensile forces in all central supports. The two end supports are loaded by compressive forces. In the case of the hybrid system, previous investigations have shown that this is a weak point that needs to be investigated separately [3].

The support to be investigated is installed on a fixed bearing and represents the end support of the actual construction. The second support in the test only describes the centre of the beam and is therefore fixed on a roller bearing. The load is introduced at a distance of 300 mm from the fixed bearing. This ensures that the majority (2/3) of the load is transferred to the end support.



(a) Test Setup according to DIN 18870 [2]

(b) Modified Test Setup

Figure 13 Test Setup for End-Support Testing

The installed test specimen for the test series of the hybrid system is shown in the following. The load is applied via the sandwich panel. The support and the detailed picture of the web of the liner trays are shown in Figure 14.



(a) Test Setup

(b) Detail of Liner Tray Web

Figure 14 Hybrid System Specimen

The failure of the test specimen is shown in Figure 15. The expected load-bearing-behaviour of the bars was clearly shown in the test. After reaching their maximum load-bearing capacity, the webs start to buckle. This failure should be significantly delayed or eliminated by the reinforcements in the hybrid FRP system.



(a) Failure mode at the webs



(b) Detailed failure mode

Figure 15 Failure mode of hybrid system at the end-support

The load-deformation diagram is shown in Figure 16. It can be seen that a linear progression can be seen until the specimen fails.

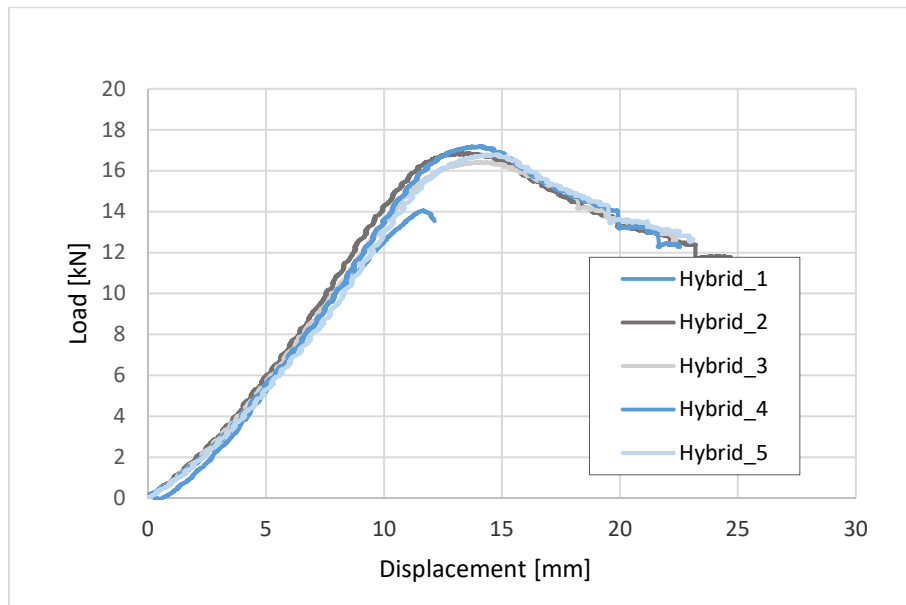


Figure 16 Load-Displacement-Diagram hybrid-system

Table 3 shows the individual results of the five tests performed. It can be seen that the scattering is extremely small, both in terms of load and displacement. Since the load is distributed differently over the two supports, this must be taken into account when determining the maximum load capacity. The load arrives 2/3 in the end support. Furthermore, in the actual installation situation only the outermost web is loaded in compression, so that the load distributed over each web must be considered individually.

Table 3 Test results hybrid system

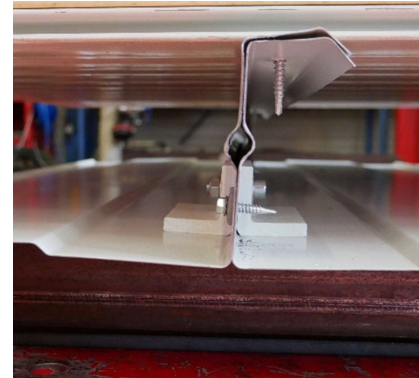
Specimen	Displacement [mm]	Max. Load [kN]	Reaction Force End-Support [kN]	Reaction Force on one web [kN]
Hybrid_1	11.5	14.2	9.5	4.7
Hybrid_2	13.4	16.8	11.2	5.6
Hybrid_3	12.8	16.2	10.8	5.4
Hybrid_4	14.2	17.1	11.4	5.7
Hybrid_5	13.1	16.4	10.9	5.5
Average	12,98	16.14	10.76	5.38

3.3 Hybrid System with FRP Profiles

The experimental setup of the hybrid system with the first version of the FRP V1 reinforcement is shown in Figure 17. The resource-saving punctual attachment of the FRP profile is clearly visible. The easy and handy installation of the reinforcement allows a precise attachment.



(a) Test setup



(b) Detail of liner tray web reinforcement

Figure 17 Reinforcement with FRP profiles V1

Figure 18 shows the failure of the specimen after the test. It can be seen that the FRP profile stabilizes the lower part of the webs. No deformations are visible up to the area of the stiffener, i.e. virtually over the entire area of the reinforcement. Above the stiffener area, however, the expected buckling sets in. Due to the behaviour of the test specimen observed in the test, especially of the two webs, the reinforcement FRP profiles can be interpreted as a success. This success is confirmed by the recorded data.



(a) Failure Mode at the webs



(b) Detailed failure mode

Figure 18 Failure mode of hybrid system with FRP profiles V1

The load-deformation diagram is shown in Figure 19. It can be seen that a linear progression can be seen until the specimen fails.

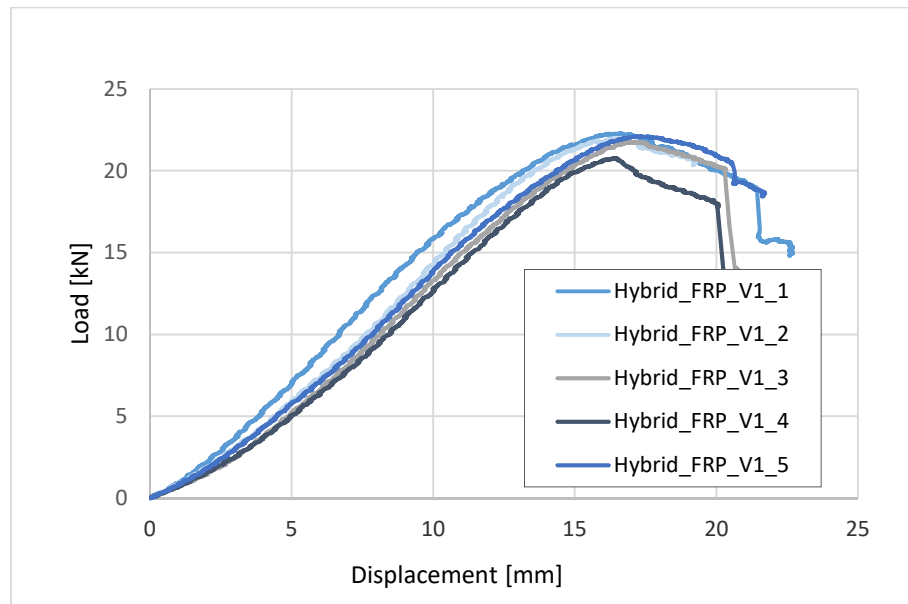


Figure 19 Load-Displacement-Diagram V1

Table 4 shows the individual results of the five tests performed. It can be seen that the scattering is extremely small, both in terms of load and displacement. In addition, the increase in the load capacity of the reinforcement measures is evident. The load-bearing capacity of one of the webs here is on average 7.1 kN. The average load capacity of the hybrid system without FRP reinforcement is 5.4 kN. This means that the FRP profile achieves an increase in load-bearing capacity of 31.7 %. Since FRP profiles are a reinforcement with low material input and installation costs, an increase in load-bearing capacity of 31.7 % is extremely remarkable.

Table 4 Test results hybrid system with FRP reinforcement V1

Specimen No.	Displacement [mm]	Max. Load [kN]	Reaction Force End-Support [kN]	Reaction Force on one web [kN]
Hybrid_FRP_V1_1	16.7	21.9	14.6	7.3
Hybrid_FRP_V1_2	16.5	21.2	14.1	7.1
Hybrid_FRP_V1_3	17.1	20.9	13.9	7.0
Hybrid_FRP_V1_4	16.9	20.2	13.5	6.7
Hybrid_FRP_V1_5	17.4	22.1	14.7	7.4
Average	16.92	21.26	14.2	7.1

The test setup of the second variant of the reinforcement of the FRP profile V2 is shown in Figure 20 below. The test setup is the same as in the two previous test series. The FRP profile extends over the entire height of the web.



(a) Test setup



(b) Detail of liner tray web reinforcement

Figure 20 Reinforcement with FRP profiles V2

Figure 21 shows the failure of the specimens reinforced with FRP profile V2. This failure is fundamentally different from the two types of failure of the previous test series. In this test series, the failure was not determined by buckling of the web as in the other two test series. After the test, the web including the FRP profiles did not show any significant deformations or other characteristics that would indicate failure or overstressing of the web. However, the sandwich panel, which is placed on the liner tray, is stressed to such an extent that shear fracture of the core material occurs. This shear fracture occurs between load introduction and end support. It shows the typical failure mode of a sandwich panel, which is tested for shear for the approval according to EN 14509 [1]. The shear fracture develops across the specimen from the load introduction to the support and leads to delamination of the cover layers. This typical shear failure can also be seen in the tests on sandwich

panels in Deliverable 7.1b. The special feature here is that the failure occurred in the transverse direction of the panel. The determination of the shear strength of the panels is not included in EN 14509 [1] and therefore initially unknown. The average shear strength determined in the tests is here 0.158 MPa. The declared design value of the shear strength in the approval of the element is given as 0.13 MPa. As the results of all five tests are significantly higher than the declared shear strength value, it can be assumed that it is possible to perform the design with the declared value. This has the advantage that the design value is known from the beginning and no additional tests have to be performed.



(a) Shear failure in core of sandwich panel



(b) Liner tray web after test

Figure 21 Failure mode of hybrid system with FRP Profiles V2

The force-displacement diagram of the individual tests is shown in Figure 22. The low scattering of the test series is very noticeable. As a result, the failure can be determined unambiguously and therefore the design may be based on the shear strength of the sandwich panel from the approvals.

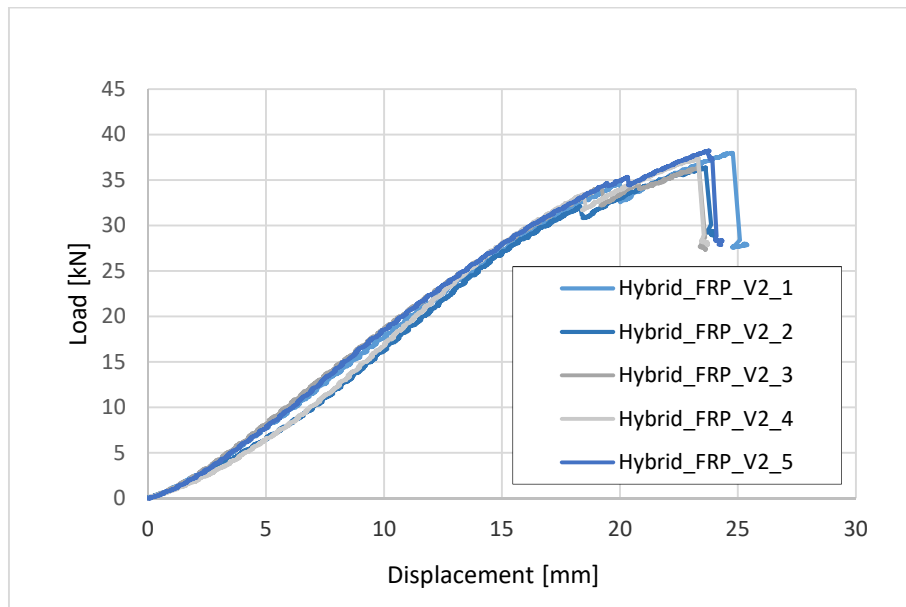


Figure 22 Load-Displacement-Diagram V2

Table 5 shows the individual results of the tests. It contains the displacement, the maximum force and the shear stress $\tau_{\max}$ in the sandwich panel when failure is reached.

Table 5 Test results Hybrid System with FRP reinforcement V2

Specimen	Displacement [mm]	Max. Load [kN]	T _{max} [MPa]
Hybrid_FRP_V2_1	19.7	34.5	0.160
Hybrid_FRP_V2_2	20.9	35.1	0.163
Hybrid_FRP_V2_3	18.2	34.8	0.161
Hybrid_FRP_V2_4	17.8	33.2	0.154
Hybrid_FRP_V2_5	18.1	32.7	0.151
Average	34.06	34.1	0.158

3.4 Conclusions

The results of the tests on the end support of the hybrid system consisting of liner tray and sandwich panel are very successful. In the first series of tests, the reference values of the load-bearing capacity of the hybrid system at the final support were determined. The second and third series of tests were carried out with components of the hybrid system, in which the webs of the liner tray were additionally reinforced with FRP profiles. This resulted in a further hybrid solution consisting of steel and FRP profile. The first variant of the FRP Profile V1 consisted of angles that reinforced the lower half of the web and thus reduced the buckling length. In the second variant V2, the FRP profiles extended over the entire height of the webs. The reinforcement with the FRP profiles was very successful. The V2 reinforcement resulted in a 31.7 % increase in the load-bearing capacity and the V2 reinforcement even resulted in an increase of 111.3 %. The V2 variant even led to a new load bearing capacity, as it was not the webs of the liner tray that were decisive, but the sandwich panel. The occurred shear failure has the benefit, that a design using the declared shear strength from the approvals of the sandwich panels is possible.

4. Evaluation of Thermal Performance

4.1 Thermal Simulation of Clamping System

The joint created in the area of the Smart Flashing Connector has an influence on the heat transfer coefficient of the entire outer wall construction. Analogous to the classic, planar joints of sandwich constructions, the joint leads to an increase in the nominal value of the heat transfer coefficient. The nominal value of the heat transfer coefficient U in $[W/(m^2 \cdot K)]$ of a construction is given by (Gl. 1)

$$U = \frac{1}{R_{Si} + R + R_{Se}} \quad \text{Gl. 1}$$

with:

R_{Si} Internal surface resistance according to EN ISO 6946 in $[m^2 \cdot K/W]$,

R	Thermal resistance of the wall structure according to Gl. 2 in [m ² ·K/W],
R_{se}	External surface resistance according to EN ISO 6946 in [m ² ·K/W].

$$R = \sum \frac{d_i}{\lambda_i} \quad \text{Gl. 2}$$

with:

d_i	Thickness of the component layer „i“ in [m],
λ_i	Thermal conductivity of the component layer „i“ in [W/(m·K)].

The design value of the heat transfer coefficient of a construction is given by (Gl. 3):

$$U_d = \frac{U \cdot A + \sum \Psi_j \cdot \ell_j + \sum \chi_k}{A} \quad \text{Gl. 3}$$

with:

U	Nominal value of the heat transfer coefficient according to Gl. 1 in [W/(m ² ·K)],
A	Wall area in [m ²],
Ψ_j	linear thermal transmittance of the joint „j“ per metre length of panel in [W/(m·K)],
ℓ_j	Reference length of the thermal bridge e „j“ in [m],
χ_k	Point-related heat transfer coefficient of the regular, punctiform thermal bridge „k“ in [W/K].

Regularly occurring thermal bridges must be taken into account as part of the heat transfer coefficient.

Individual components can be neglected in numerical thermal insulation calculations according to EN ISO 6946 [4], provided that their influence on the heat transfer coefficient is less than 3 %. Therefore, elements such as fasteners are often not taken into account in numerical investigations, as their effect on the thermal behaviour of the entire component is usually only marginal.

According to EN ISO 14683 [5], the influence of punctiform thermal bridges (as far as they result from the intersection of linear thermal bridges) can be neglected.

To determine this, three-dimensional numerical FEM calculations (finite element method) according to EN ISO 10211 [6]. are used to determine the heat flows in the thermal influence area of the various constructions. Based on these calculations, the design values of the area-related heat transfer coefficients can be determined.

Sections through the joint area insulated with mineral fibre and through the screw of the SFC are shown below.

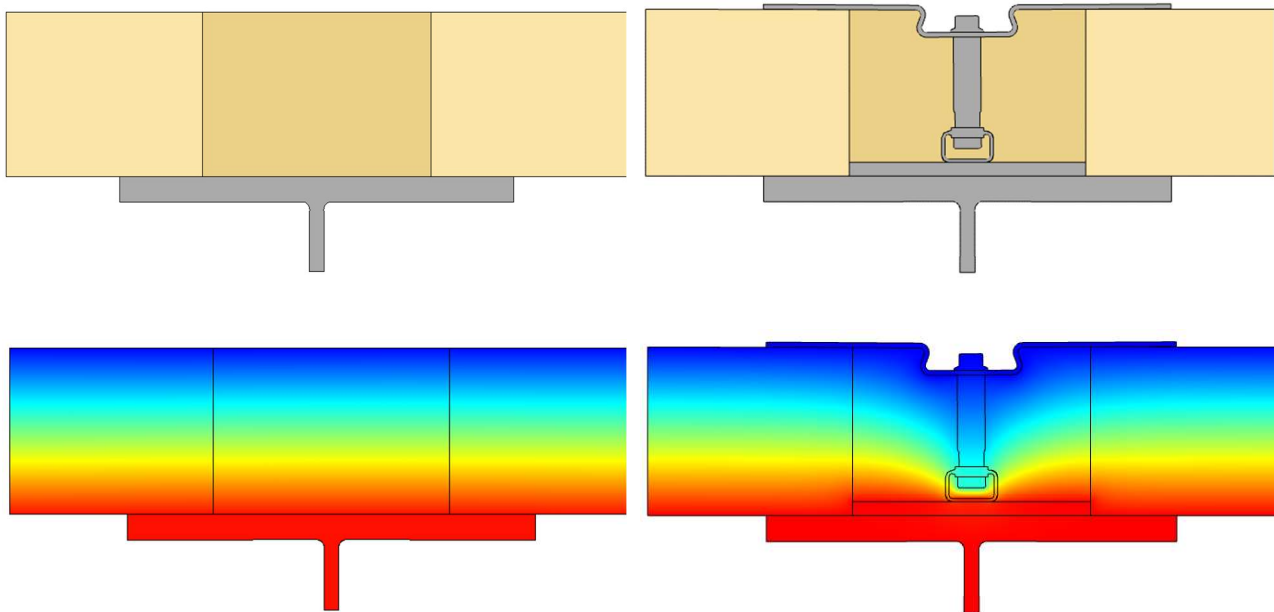


Figure 23 Thermal Performance of Smart Flashing Connector

The nominal value of the heat transfer coefficient of the sandwich elements is $0.197 \text{ W}/(\text{m}^2 \cdot \text{K})$ with a 12 cm thick thermal insulation core. The Psi-value of the mineral fibre joint determined by FE simulation is $\text{Psi} = 0.03 \text{ W}/(\text{m} \cdot \text{K})$ and must be taken into account with a length of 0.8 m. The length corresponds to the clear dimension between two SFCs with a construction width of the sandwich elements of 1 m. The Chi value of the SFC is $0.05 \text{ W}/\text{K}$. One sandwich element is held by four SFCs. Thermally effective is the half of one SFC, which results in a calculated number of two SFC per sandwich element. With a maximum span width of 4.5 m, this results in the rated value of the heat transfer coefficient of $U_d = 0.23 \text{ W}/(\text{m}^2 \cdot \text{K})$.

4.2 Thermal Simulation of Hybrid System

To determine the design value of the heat transfer coefficient as a measure of thermal quality, it was first checked by means of numerical methods whether the values determined with a simplified manual calculation method were sufficiently accurate. For a liner tray wall with a thickness of 90 mm and insulation of WLS 035 and a sandwich element with a thickness of 60 mm with WLS 025 (joint type I), a finite element model of the hybrid element was created and then the exact heat transfer coefficient was determined.

The numerically determined design heat transfer coefficient is $U_{HYB,d} = 0.283 \text{ W}/(\text{m}^2 \cdot \text{K})$. For comparison between manual calculation and FEM calculation, all steel profile sheet thicknesses are assumed to be 0.75 mm.

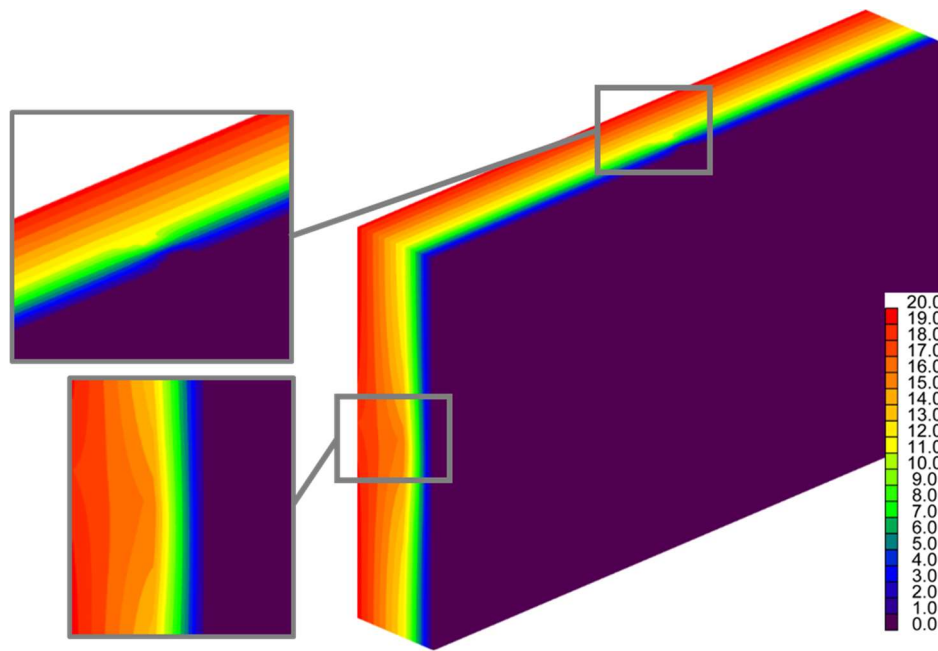


Figure 24 Temperature distribution of the hybrid element

For the existing liner tray wall, a heat transfer coefficient of $U_{LT,d} = 0.727 \text{ W}/(\text{m}^2 \cdot \text{K})$ can be assumed based on the separating strip variant. From this a thermal resistance of the liner tray wall of $R_{LT} = 1.206 \text{ m}^2 \cdot \text{K}/\text{W}$ can be determined.

With the help of EN 14509 [1] a heat transfer coefficient of $U_{SP,d} = 0.431 \text{ W}/(\text{m}^2 \cdot \text{K})$ (when using a joint coefficient $f_{\text{joint}} = 0.083$) can be determined for the sandwich panel. This corresponds to a thermal resistance of the sandwich element including the joint of $R_{SE} = 2.148 \text{ m}^2 \cdot \text{K}/\text{W}$.

Based on the thermal approach of the series connection of the thermal resistances, the hand calculation method yields a thermal resistance of the hybrid element of $R_{HYB} = 3.354 \text{ m}^2 \cdot \text{K}/\text{W}$. From this, in conjunction with the heat transfer resistances, a rated value of the thermal transmittance of $U_{HYB,d} = 0.284 \text{ W}/(\text{m}^2 \cdot \text{K})$ can be determined.

The comparison of the numerically determined with the simplified calculated heat transfer coefficient shows that only very small deviations occur. Therefore, the manual calculation method is used in the following to assess the thermal quality since the achievable heat transfer coefficients of the different hybrid elements.

Table 6 and Table 7 contain the values determined on this basis for the two different liner tray profile thicknesses 0.75 and 1.50 mm.

Table 6 Thermal transmittance for liner tray elements refurbished with sandwich panels
($t_{N,LT} = 0.75 \text{ mm}$)

		Thermal transmittance, U [W/(m²·K)]									
		Liner tray profile height, d _{LT} [mm]									
		90	100	120	130	145	160	180	200	220	240
Sandwich panel thickness	60	0.284	0.277	0.266	0.261	0.253	0.247	0.238	0.231	0.224	0.217
	80	0.230	0.225	0.218	0.214	0.209	0.205	0.199	0.194	0.189	0.184
	100	0.194	0.191	0.185	0.183	0.179	0.176	0.171	0.168	0.164	0.160
	120	0.168	0.165	0.161	0.159	0.157	0.154	0.151	0.148	0.145	0.142
Liner Tray: t _{n,LT} = 0.75 mm; d _{LT} = 90 ... 240 mm; λ _{WD,LT} = 0.035 W/(m·K)											
Sandwich: t _{n,SP} = 0.75 mm; d _{SP} = 60 ... 120 mm; λ _{WD,SP} = 0.025 W/(m·K); joint type I											

Table 7 Thermal transmittance for liner tray elements refurbished with sandwich panels
($t_{N,LT} = 1.50 \text{ mm}$)

		Thermal transmittance, U [W/(m²·K)]									
		Liner Tray profile height, d _{LT} [mm]									
		90	100	120	130	145	160	180	200	220	240
Sandwich thickness d _{SP} [mm]	60	0.300	0.295	0.286	0.282	0.277	0.272	0.266	0.260	0.255	0.250
	80	0.240	0.237	0.231	0.229	0.225	0.222	0.218	0.214	0.210	0.207
	100	0.201	0.199	0.195	0.193	0.191	0.188	0.185	0.182	0.180	0.177
	120	0.173	0.172	0.169	0.167	0.165	0.164	0.161	0.159	0.157	0.155
Liner Tray: t _{N,LT} = 1.50 mm; d _{LT} = 90 ... 240 mm; λ _{WD,LT} = 0.035 W/(m·K)											
Sandwich: t _{N,SP} = 0.75 mm; d _{SP} = 60 ... 120 mm; λ _{WD,SP} = 0.025 W/(m·K); joint type I											

4.3 Hygrothermal Investigations on Hybrid System

To evaluate the hygric quality of liner tray wall elements that were energetically renovated with sandwich panels, a liner tray wall with a thickness of 145 mm was first considered, which was renovated with two sandwich panels of different thickness. In the first case the element thickness is 60 mm, in the second case 80 mm. In each case one PU element was used. The heat transfer coefficients that can be achieved after the renovation are, according to Table 6, 0.253 and 0.209 W/(m²·K). The hygric test is carried out in accordance with the DIN 4108-3 method, the material properties used are listed in Table 8.

Table 8 Hygrothermal material properties for hybrid elements

	Thermal conductivity λ [W/(m·K)]	Vapour diffusion resistance factor μ [-]
Steel	50	100 000
Mineral wool	0.035	1
Polyurethane	0.025	200

As a summary of the results, the determined course of the relative humidity in the cross section is shown below. Figure 25 and Figure 26 show the corresponding curves. In the first case (liner tray 145 mm + sandwich 60 mm), the relative humidity both in the area of the liner tray cross-section and in the sandwich-cross-section exceeds the limit value of 100 %. For the second variant (liner tray 145 mm + sandwich 80 mm) the limit value is only exceeded in the area of the sandwich cross-section. The reasons for this are the material properties, the geometric boundary conditions and the hygrothermal relationships between heat and moisture.

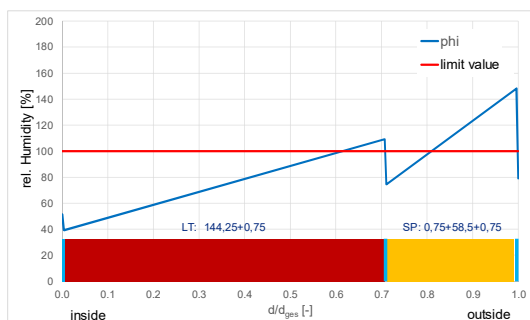


Figure 25 Distribution of relative humidity for hybrid element (LT 145 + SP 60)

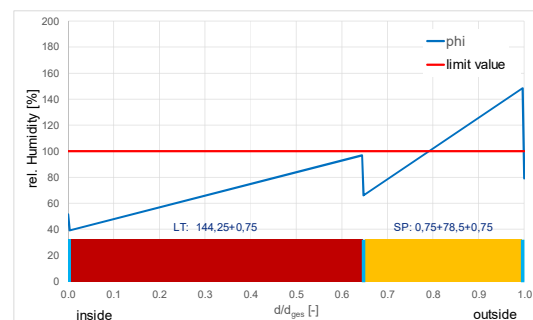


Figure 26 Distribution of relative humidity for hybrid element (LT 145 + SP 80)

Structures with several layers of steel lying one behind the other - generally layers with an almost infinite water vapour diffusion resistance factor - are at the limit of the scope of application of the methods; in the control range of such component structures, it appears practically impossible for moisture to enter the cross-section. However, it is quite conceivable for the hybrid constructions under consideration that in the joint area of the liner tray elements, water vapour diffusion leaks may occur in addition to air leaks. Since it is often not possible to make a reliable statement regarding the

presence of seals (sealing tapes) in older existing liner tray walls, these defects may cause water vapour diffusion into the insulation cross-section.

On the other hand, the water vapour impermeability of the sandwich element or the longitudinal joints can be achieved during the renovation measure, provided that the appropriate planning and implementation is carried out. Thus, vapour diffusion into this part of the cross-section can be reduced very reliably.

The results of the two calculations are assessed against this background. Exceeding the relative humidity of 100 % in the liner tray cross-section should be avoided, while in the sandwich cross-section it is considered harmless. In the specific case, the second variant should therefore be carried out, as it is thermally more favourable and hygrically safer.

Based on these designs, investigations were carried out for different combinations of liner tray and sandwich elements, which deal with the question of the position of the dew point. The aim was to find the (minimum) required thickness of the sandwich element to prevent condensation between the liner tray and sandwich elements (in the liner tray cross-section).

The results obtained for the different liner tray profile heights are shown in Figure 27 to Figure 30. One liner tray wall element each with five different sandwich panels was considered. In the case of a 90 mm high liner tray profile, at least one 60 mm thick sandwich panel is required to prevent condensation from forming in the liner tray cross-section.

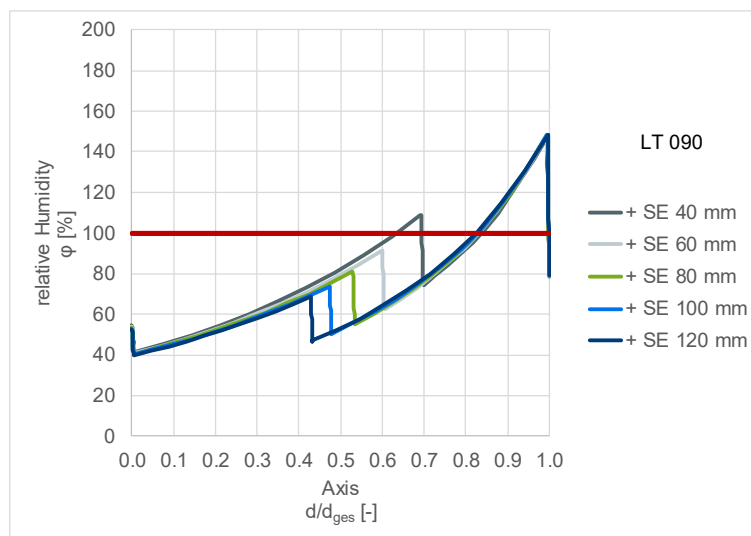


Figure 27 Distribution of relative humidity for hybrid element (LT 90 + SP)

For a 120 mm high cassette profile there is a minimum sandwich element thickness of 80 mm, so that the relative air humidity in the cassette cross-section does not rise above 100% by calculation.

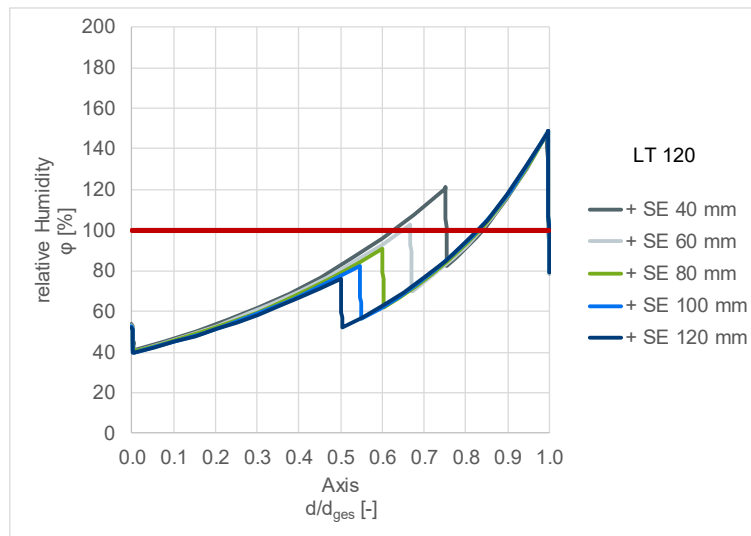


Figure 28 Distribution of relative humidity for hybrid element (LT 120 + SP)

A sandwich panel with a thickness of at least 100 mm is required so that, in combination with a 160 mm high liner tray profile, a relative humidity of 100 % is not exceeded in the liner tray cross-section.

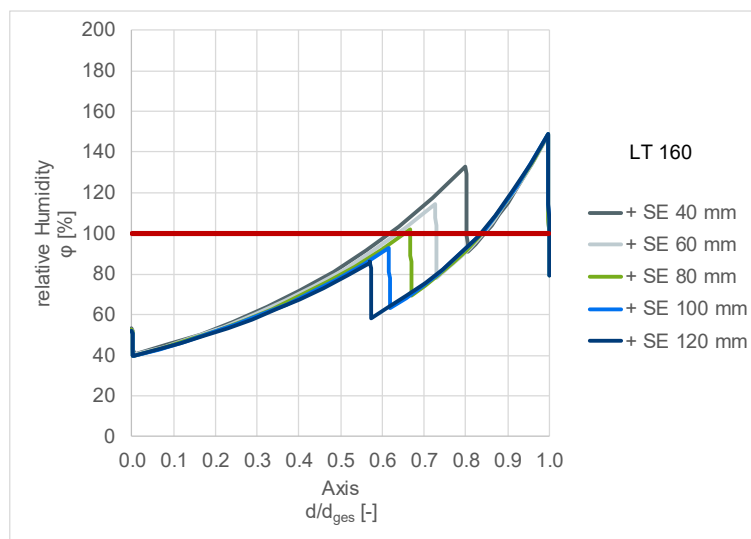


Figure 29 Distribution of relative humidity for hybrid element (LT 160 + SP)

When reusing a 200 mm high liner tray profile, at least one sandwich panel with a thickness of 120 mm is required in order to avoid the calculated exceeding of the dew point in the liner tray cross-section.

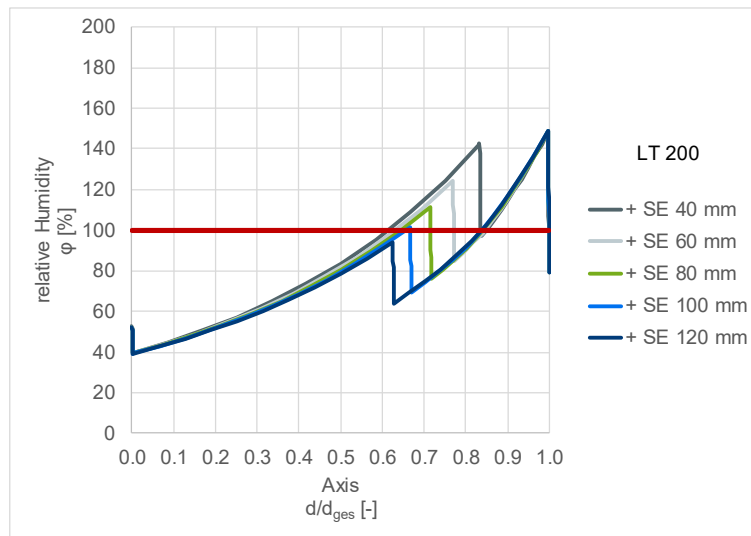


Figure 30 Distribution of relative humidity for hybrid element (LT 200 + SP)

The individual results that can be derived from the calculations performed are summarised in Figure 31.

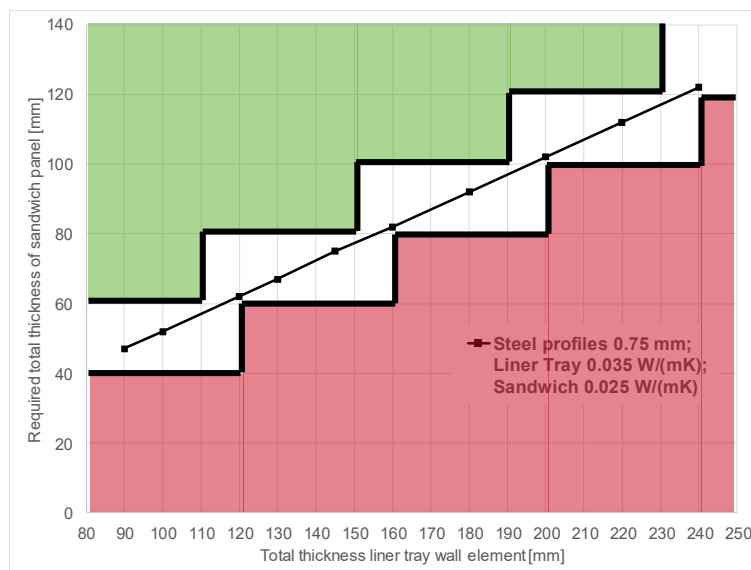


Figure 31 Hygric required sandwich thickness for hybrid element

The minimum calculated total thickness of the sandwich panel as a function of the liner tray profile height is shown. The areas above the straight line are considered permissible. Based on the commercially available sandwich panel thicknesses, the green-shaded area can be derived from this. As can be seen, a sandwich panel thickness of 120 mm fulfils the specifications regardless of the actual liner tray profile.

In addition to the investigations according to DIN 4108-3, numerical calculations according to DIN EN 15026 were also carried out. Geometrically, the model was created with reference to the statements and results regarding the hygrically required sandwich thickness of the hybrid element from a 100 mm liner tray profile and a 120 mm sandwich element (Figure 32). The joint in the liner tray web was varied between 0 and 9 mm during the investigation.

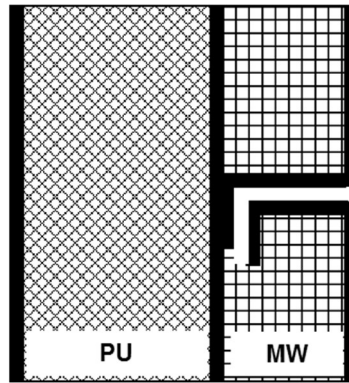


Figure 32 Cross section of hybrid element for method according to DIN EN 15026

The climate conditions were based on DIN 4108-3 [7]. A 90-day dew period followed by a 90-day evaporation period was chosen as the period under consideration.

If the integral water content is determined in the two cross-sectional parts as well as in the entire hybrid cross-section, an increase tends to occur with increasing joint spacing. However, an exact distinction between dew and evaporation periods can no longer be determined. Figure 33 contains a corresponding time-dependent evaluation.

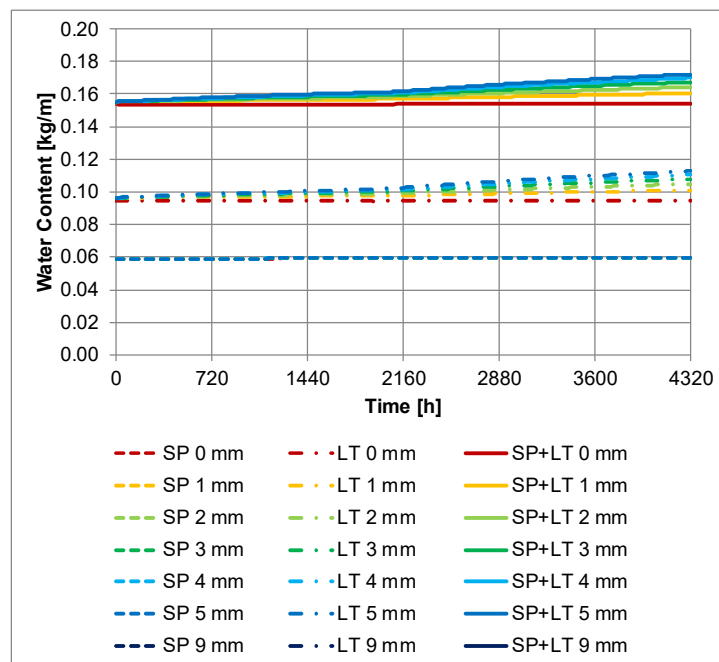


Figure 33 Results "hybrid element w_{tot} " for method according to DIN EN 15026 [8]

For the practical investigation of hybrid elements experiments were carried out. For this purpose, a hybrid element was selected that consists of a liner tray wall element with a thickness of 100 mm and thermal conductivity of $0.045 \text{ W}/(\text{m}\cdot\text{K})$ and a sandwich panel with a thickness of 100 mm and thermal conductivity of $0.025 \text{ W}/(\text{m}\cdot\text{K})$.

The liner tray cross-section has a heat transfer coefficient of $0.85 \text{ W}/(\text{m}^2\cdot\text{K})$, the sandwich cross-section of $0.25 \text{ W}/(\text{m}^2\cdot\text{K})$. For the hybrid element, this results in a design value of the heat transfer coefficient of $0.20 \text{ W}/(\text{m}^2\cdot\text{K})$. Figure 34 shows the test setup.



Figure 34 Test set-up for hybrid element testing

The material properties are listed in Table 9 below.

Table 9 Material properties for hybrid element testing

		Liner tray wall element	Sandwich panel
Insulation	Type	Mineral wool	Polyurethane
	Thickness d [mm]	100	100
	Thermal conductivity λ [W/(m·K)]	0.045	0.025
	Water vapour diffusion -		
	- resistance factor μ [-]	1	40
Steel profile sheet	- conductivity δ [kg/(m·s·Pa)]	2 E-10	5 E-12
	Thickness d [mm]	0.5	0.5
	Thermal conductivity λ [W/(m·K)]	50	50
	Water vapour diffusion -		
	- resistance factor μ [-]	∞ (100 000)	∞ (100 000)
	- conductivity δ [kg/(m·s·Pa)]	2 E-15	2 E-15

For the warm side, a temperature of 30 °C and a relative humidity of 30 % were used; on the cold side, in contrast, a temperature of 5 °C with a relative humidity of almost 100 % was selected. This

ensured that a water vapor partial pressure gradient of approx. 400 Pa from the warm to the cold side occurred.

Various constellations of element sealing were considered for the test. For the liner tray element, a distinction was made between the two cases "with sealing tape" and "without sealing tape" regarding the liner tray web. For the sandwich longitudinal joint, three variants were considered: without gap ("tight"), with small gap (10 mm) and with large gap (20 mm). The test duration was chosen at 48 hours in each case.

Based on the procedure according to DIN 4108-3, the expected results were determined in advance. The temperature and relative humidity curves for the two areas "Insulation / Sandwich Liner tray" and "Web / Sandwich Liner tray" were examined as limit values. As can be seen in Figure 35, the temperatures at the two measurement points "Liner Tray" or "Sandwich" correspond to the assumed boundary conditions for both areas, while for the measurement point "Limit" 21 or 30 °C occur, depending on the area. The relative humidity at the inner surface (point "Liner tray") corresponds to the boundary condition of 30 %. At the boundary layer, values of 20 or 45 % are obtained and on the cold side the (theoretically) calculated humidity is between 100 and 110 %.

Figure 35 shows the comparison between the test carried out in advance according to DIN 4108-3 and the results obtained in the test. The values determined for the three measuring points are entered in the diagrams as individual points for the sandwich variants "without gap" and "with small gap".

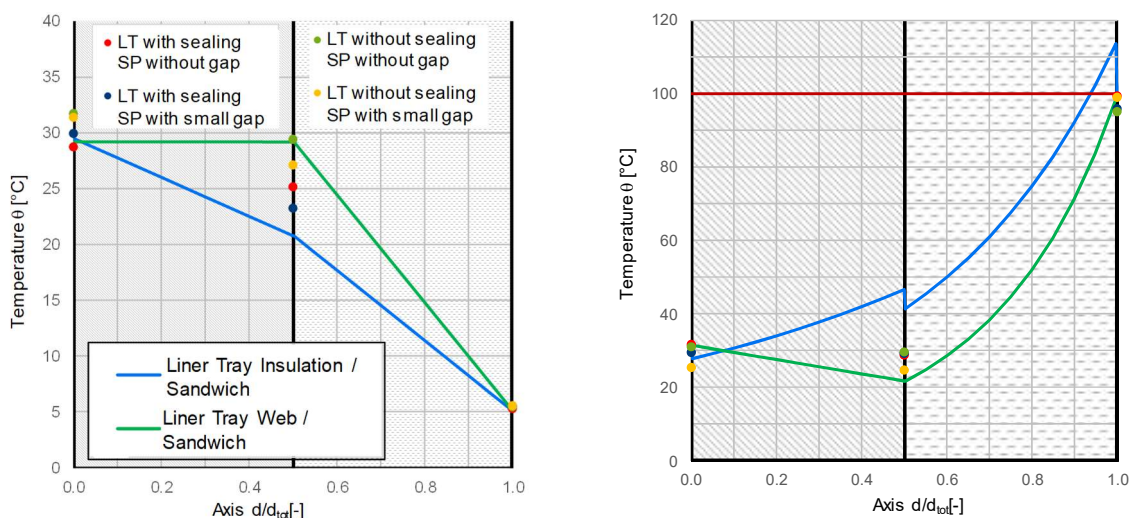


Figure 35 Comparison of pre-investigations and test for hybrid element testing

Both the temperatures and the relative humidities measured are all within the range of the pre-determined corridor. Since the measured values were only determined at specific points at the respective location, no well-founded statement can be made about the course between the points. As the values for the points "liner tray" and "sandwich" were measured on the side facing the environment, statements for the correspondingly other side of the steel profile sheets are only possible to a limited extent. It can be assumed that the temperatures are only marginally influenced by the highly heat-conducting material steel, so that almost identical thermal conditions prevail on both sides of the steel profile sheets. However, this conclusion is not admissible for the water vapour

partial pressures; it is presumably greatly reduced by the vapour-tight steel profiled sheets, although the extent of the reduction is not known.

To be able to make a statement in this respect, the test was subsequently also examined using the procedure in accordance with DIN EN 15026 [8]. The results of the calculations are again shown in Figure 36 as minimum and maximum values occurring in a cross section in a simulation period of 48 hours for the temperature and relative humidity and additionally for the water content. The two cross-sectional areas "Liner Tray" and "Sandwich" are marked in colour for clarification.

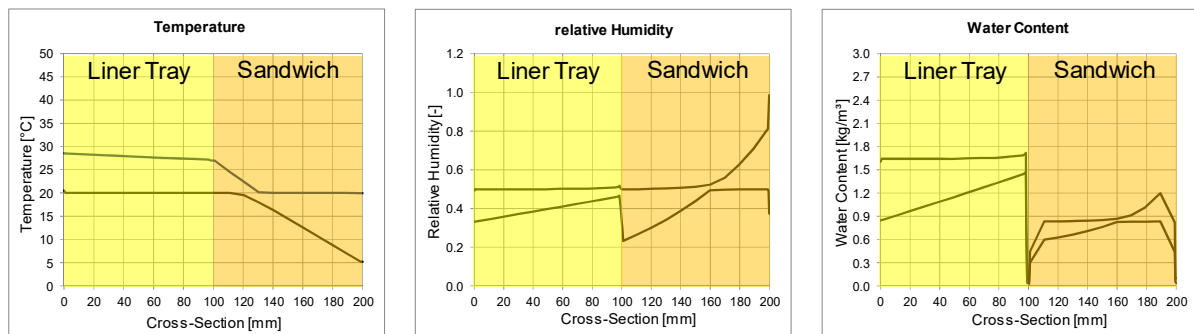


Figure 36 Results of numerical investigation of hybrid element testing

If the end of the simulation period (after 48 hours) is selected for a comparison between the curves determined in the preliminary examination according to DIN 4108-3 [7] and the results determined numerically according to DIN EN 15026, the diagrams shown in Figure 37 are obtained. The numerical values are shown in black.

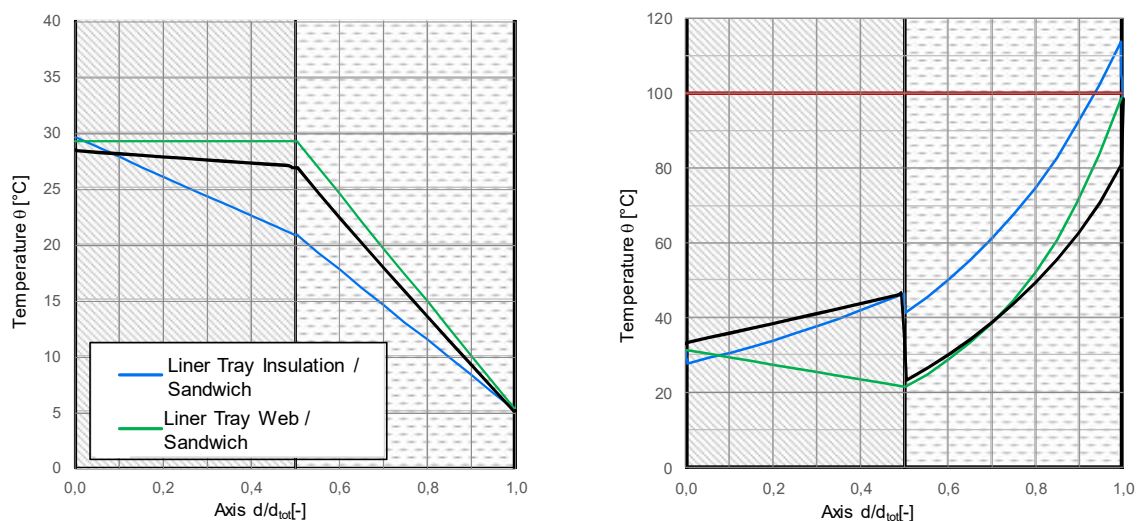


Figure 37 Comparison of pre-investigations and numerical investigation for hybrid element testing

The temperature curve shows good agreement. Deviations can be traced back to the multidimensional thermal bridge effects that occur, which can be considered in the numerical calculations. The course of the relative humidity can also be shown in good approximation with both

methods. In addition to the multidimensional thermal and hygric effects, it should also be noted that the results of the preliminary investigation show no time dependency, whereas in numerics the concrete point in time of consideration is important. After sufficient simulation time, a stable state in equilibrium with the environmental conditions is reached. The occurring deviations indicate that this state is not yet finally reached after 48 hours.

4.4 Testing of load case temperature for Hybrid System

The load case resulting from a temperature difference can be decisive for statically indeterminate (multi-field beam) systems. This load case thus represents an example of the interaction between the thermal behaviour of a building component in terms of building physics on the one hand and structural design methods on the other.

As a result of the different temperatures on the inner and outer component surface, constraint stresses occur within the component. For an appropriate design of steel sandwich elements, a temperature difference of $\Delta T = 55 \text{ K}$ must be applied in accordance with EN 14509 [1] or the specific General Building Inspectorate Approval. This results from the stored temperature boundary conditions of $\theta_i = 25 \text{ °C}$ on the room side and $\theta_e = 80 \text{ °C}$ on the outside due to solar radiation effects.

In the case of the single component sandwich element, which carries as a composite cross-section, the entire temperature gradient within the sandwich cross-section must be reduced. Accordingly, the complete temperature difference $\Delta T = 55 \text{ K}$ generates stress.

For liner tray elements considered in isolation, there is a stress-generating temperature difference $\Delta T = 0 \text{ K}$, since here there is a load-bearing behaviour as a single cross-section.

The joining of the two individual components in the hybrid element suggests that the load-bearing behaviour is also a combination of single and composite cross-sections. The temperature difference is proportionally reduced in the liner tray and sandwich cross sections. Therefore, the proportion that acts as a stress generator for the sandwich cross-section is also reduced.

In this context, experimental and numerical investigations were carried out to show the suspected effects.

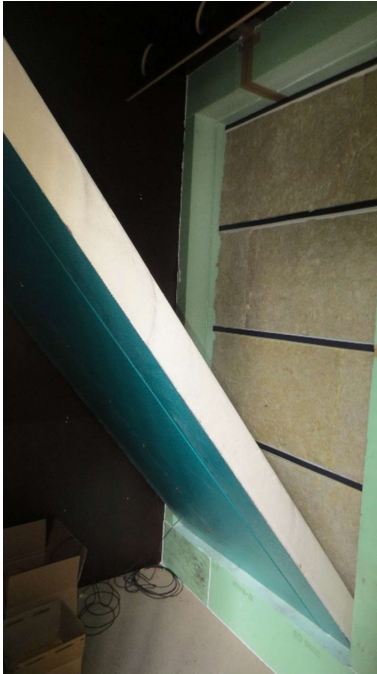
For the experimental investigations, a hybrid construction was chosen, which consisted of a 100 mm existing liner tray facade ($t_n = 0.75 \text{ mm}$) and a 120 mm renovation sandwich element (joint type III). The MW liner tray insulation corresponded to WLS 035, the PU sandwich insulation core to WLS 025. The design values of the heat transfer coefficients of the two components are $U_{d,KAS} = 0.69 \text{ W/(m}^2\cdot\text{K)}$ and $U_{d,SE} = 0.21 \text{ W/(m}^2\cdot\text{K)}$; according to Table 6, the heat transfer coefficient after refurbishment is $U_{d,HYB} = 0.16 \text{ W/(m}^2\cdot\text{K)}$.

Regarding the thermal behaviour of the hybrid element, a distinction can be made between four cross-sectional areas. In the case of the liner tray element, the two areas "field" and "web" can be identified; for the sandwich element, a distinction must be made between "field" and "joint area". Four different areas can be derived from this. The test setup is shown in Figure 38.

The temperatures were measured on the component surfaces and on the boundary layer between the two individual components, for all four areas.

The boundary conditions were chosen according to the normative specifications on the warm side to $\theta = 80\text{ }^{\circ}\text{C}$ and on the cold side to $\theta = 25\text{ }^{\circ}\text{C}$.

Wall construction



Measurement technology



Figure 38 Load case temperature for hybrid element – test set-up

The measured temperatures are listed in Table 10. The influence of the different areas is only very small. The reason for this is, among other things, the steel profile sheets directly adjacent to the measuring points, which means that the heat is distributed correspondingly evenly within a plane. The numerical values are shown graphically in Figure 39. It was assumed that the temperature curve in the cross-sectional profile is linear between the measuring points.

Table 10 Load case temperature for hybrid element – test results

Area	Temperature θ [°C]				
	Warm side	Sandwich		Liner Tray	
		Position in cross-section [mm]			Cold side
		0	120	220	
CS 1 (field / field)	80.0	78.0	37.6	27.9	25.0
CS 2 (field / web)	80.0	78.5	37.3	28.4	25.0
CS 3 (joint / web)	80.0	77.8	35.5	28.8	25.0
CS 4 (joint / field)	80.0	77.7	37.6	27.9	25.0
averaged	80.0	78.0	37.0	28.3	25.0

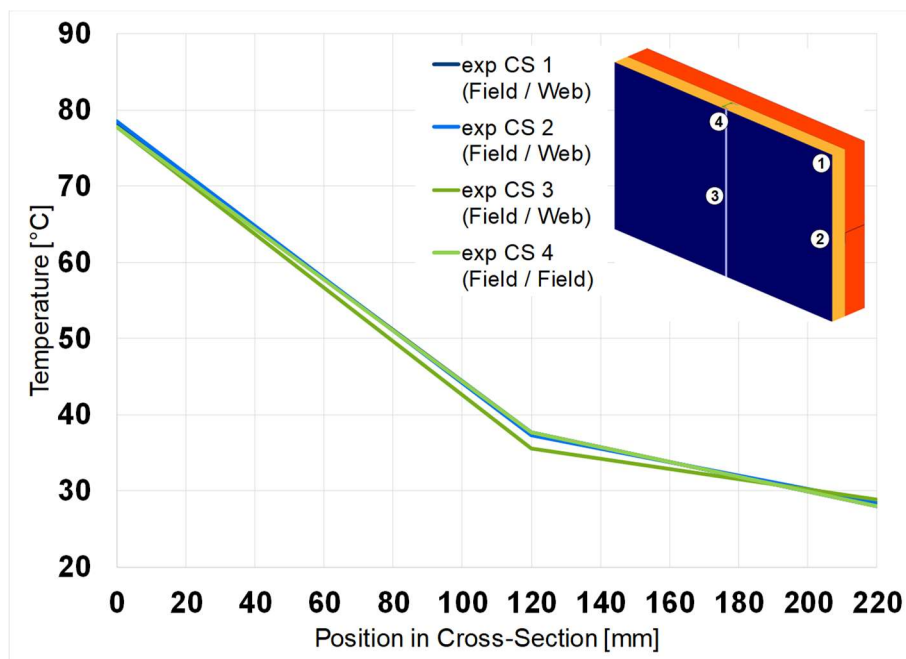


Figure 39 Load case temperature for hybrid element – visualisation of the test results

In the case considered in the test, the average temperature at the boundary layer between the liner tray and the sandwich is approx. 37 °C. From this, a temperature gradient of $\Delta T = 43$ K can be derived, which is stress generating for the sandwich cross-section. Compared to the original 55 K, this corresponds to a reduction of 24 %.

Based on the experimental tests, additional accompanying numerical investigations were carried out using FEM calculations. Table 11 summarises the results already averaged on this basis.

Table 11 Load case temperature for hybrid element – numeric results

	Temperature θ [°C]					
Area	Warm side	Sandwich		Liner tray		Cold side
		Position in Cross-Section [mm]				
		0	120	220		
Averaged	80.0	78.9	37.0	25.4	25.0	

Figure 40 shows a representation of the determined temperature curve, already in direct comparison with the measured values.

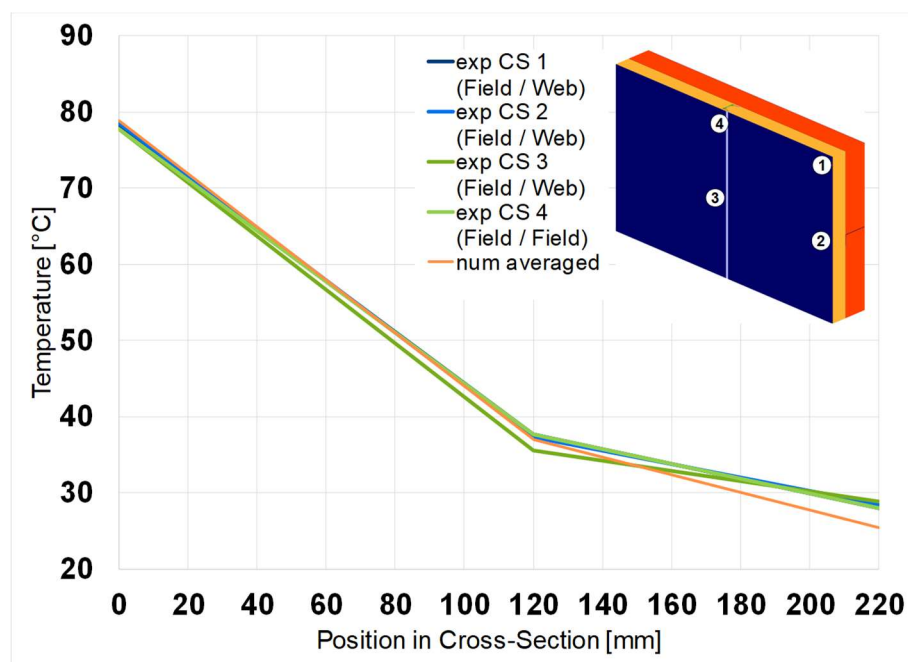


Figure 40 Load case temperature for hybrid element – visualisation of the results

The experimentally determined and the numerically determined values agree very well. Only in the area of the surface on the cold side some deviations occur, which can be attributed to different heat transfer resistances. For the numerical calculation, the values with reference to DIN EN ISO 6496 were chosen as 0.13 and 0.04 m²·K/W. It is not possible to conclusively assess the extent to which the values obtained in the test correspond to those applied.

Based on the comparison between numerical and experimental investigations, further numerical calculations were carried out. The aim was to determine the respective stress-generating temperature differences to be applied for the design of the sandwich panel.

The thickness of the liner tray element arranged on the room side - i.e. in this case on the colder side - was varied between 90 and 240 mm. Thicknesses of 40 to 200 mm were considered for the sandwich elements located accordingly on the outside - warm side. Using the boundary conditions of $\theta = 80\text{ }^{\circ}\text{C}$ (warm side) and $\theta = 25\text{ }^{\circ}\text{C}$ (cold side), the boundary layer temperatures listed in Table 12 could be determined.

Table 12 Load case temperature for hybrid element – further numeric results

		Temperature between liner tray and sandwich $\theta_{\text{CAS-SE}}\text{ [}^{\circ}\text{C]}$						
		Thickness of the sandwich element (warm side) $d_{\text{SE}}\text{ [mm]}$						
		40	60	80	100	120	160	200
Thickness of the liner tray element (cold side) $d_{\text{CAS}}\text{ [mm]}$	90	52	46	42	39	37	35	33
	100	53	46	42	40	37	35	33
	120	54	48	44	41	39	36	34
	130	55	48	44	41	39	36	35
	145	56	49	45	42	40	37	35
	160	57	50	46	43	41	38	36
	160	58	51	47	44	42	38	36
	180	58	52	48	45	42	39	37
	200	59	53	48	45	43	40	37
	220	60	54	49	46	44	40	38
	240	52	46	42	39	37	35	33

In conjunction with the temperature boundary conditions, the temperature differences occurring in the sandwich can be determined from this (see Table 13).

Table 13 Load case temperature for hybrid element – further numeric results

		Temperature difference in the sandwich element ΔT_{SE} [K]						
		Thickness of the sandwich element (warm side) d_{SE} [mm]						
		40	60	80	100	120	160	200
Thickness of the liner tray element (cold side) d_{CAS} [mm]	90	28	34	38	41	43	45	47
	100	27	34	38	40	43	45	47
	120	26	32	36	39	41	44	46
	130	25	32	36	39	41	44	45
	145	24	31	35	38	40	43	45
	160	23	30	34	37	39	42	44
	160	22	29	33	36	38	42	44
	180	22	28	32	35	38	41	43
	200	21	27	32	35	37	40	43
	220	20	26	31	34	36	40	42
	240	28	34	38	41	43	45	47

Figure 41 shows a diagram showing the results of the numerical considerations. In addition to the concretely determined temperature differences, the constant 55 K limit line is also entered as a reference value.

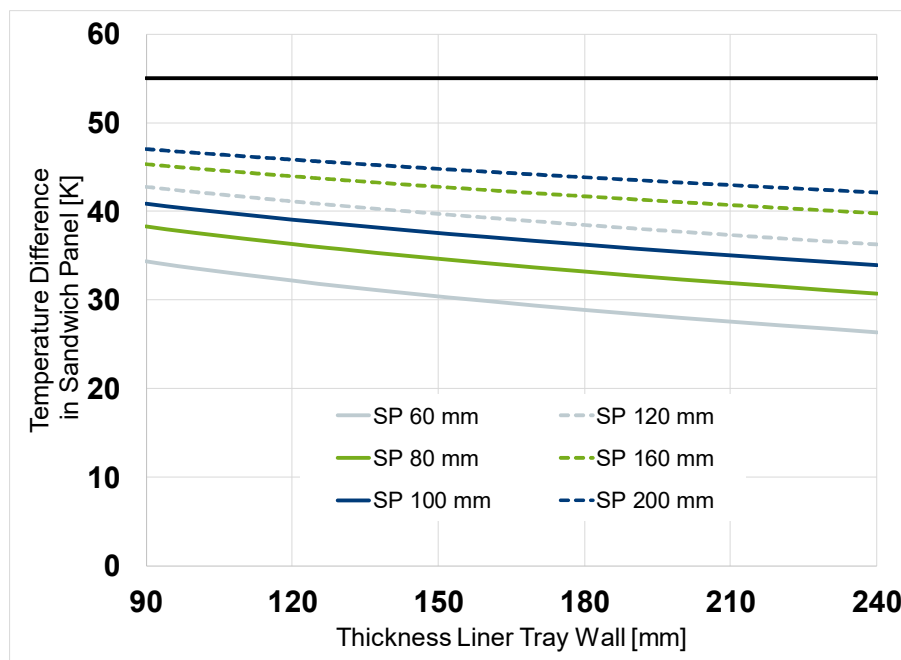


Figure 41 Load case temperature for hybrid element – visualisation of the numeric results

The calculations can be used to determine temperature gradients between 26 and 47 K that occur in the sandwich element. In relation to the original gradient of 55 K, this corresponds to a reduction of 15 to 53 %.

4.5 Airtightness

Experimental methods are usually used to evaluate or investigate the quality of airtightness. At component level, quantitative measurements and evaluation can be carried out with standardised air tightness test rigs, which are based on laboratory procedures according to EN 12114 [9]. To determine and evaluate the air tightness of entire buildings, BlowerDoor measurements are used as on-site procedures according to EN 13829 [10]. Particularly in combination with infrared measurements, defects in the building envelope can be identified.

The air-tightness of the lightweight steel construction systems considered in the research project depends to a large extent on the planning and execution quality of the connection details in general and of the longitudinal sandwich and cassette butt joints in particular, due to the standard cross-sectional area which is to be regarded as air- and vapour-tight (see EN 14509 [1]).

4.6 Conclusions

Due to their modular construction, liner tray profile facades are ideally suited for reuse combined with energy-efficient refurbishment without complete demolition. If the existing outer shell is replaced by standard sandwich panels, the facade is referred to as a hybrid facade. When planning hybrid facades with vertically installed sandwich panels, it must be taken into account that if the sandwich panels are not visibly fixed in the longitudinal joints, the distance of the lateral support of the narrow liner tray flanges, which is permissible according to the general building authority approvals of many liner tray profiles installed in the existing building, is exceeded. In addition, the load case temperature

difference at the sandwich panel must be considered when designing hybrid facades. Previous design approaches for this load case lead to a clear overestimation of the constraining forces occurring in hybrid facades, which means that the static proof of the liner tray profiles often cannot be provided. Suitable approaches for recording the constraining forces actually occurring in hybrid facades due to temperature differences at the sandwich element have been provided within the framework of this research project. Due to the small sheet thicknesses of the liner tray profiles, the installation of the sandwich elements on the liner tray profiles is prone to errors. It should therefore always be carried out very carefully. The new construction of hybrid facades is also possible from a static point of view.

Due to the complexity of the component "hybrid element", it seems to make sense for further research approaches not only to examine the combination of several components, but also to examine fundamental aspects of the isolated individual components - in this case sandwich elements or liner tray profiles - in detail.

The direct fastening of sandwich elements to liner tray profiles with conventional sandwich fasteners is technically possible, but is not yet covered by the general building authority approvals for sandwich fasteners, because in this case the fastening is carried out on two narrow liner tray belts per crossing point. Consequently, the general building authority approvals of the sandwich fasteners should be extended for fastening to two components.

5. End Product Usability

5.1 One-sided fixation and over-cladding of sandwich panels

A prototype building envelope was constructed with the developed over-cladding system. First six profiles were mounted on the vertically laid south wall, then six profiles on the horizontally laid west wall. Special profiles were used to attach the sidings. After the profiles were fixed, the sidings could be mounted. Two lifting platforms and a vacuum suction cup were used for this purpose. Finally, angle profiles were attached to the west-south corner of the building. This completed the construction project.

In principle, the amount of work required to apply the over-cladding system is relatively low. Since the profiles used as the substructure for the sidings are light, they are also easy to handle. It is only necessary to ensure that the substructure is absolutely straight. To ensure this, the use of a water trolley is sufficient. The profiles are fixed in the sandwich panel by the one-sided fixing. The screw spacing was 300 mm. This corresponds to the geometry of the specimens from the tests in Deliverable 4.2. The attachment of the profiles to the sandwich panel is shown in Figure 42.



Figure 42 Installation of profiles with one-sided fixation

5.2 Hybrid System

In order to consider possible aspects of the application, the façade of the testing laboratory of the Institute for Steel and Metal Lightweight Construction at the RWTH, consisting of cassette profiles and trapezoidal profiles, was partially replaced by a sandwich panel. Relevant points in this case result from the circumstances which would arise in contrast to an assembly in a new building.

Dismantling usually involves few complications, as the trapezoidal profiles are fastened with self-drilling screws and rivets and can therefore be removed almost non-destructively by unscrewing/drilling the fasteners. Attention should be paid to connections on roofs, corners, window reveals and similar.

For the installation of the sandwich panel various complications have to be considered, which can be caused by the existing situation. In order to ensure the impermeability of the building envelope, any old dirt from insulation, weather and other circumstances on the cassette profiles must be removed to allow the sandwich panels to be fitted. In the case of trapezoidal profiles, this occurs when the insulation material slips into the profile.

In addition, when positioning the new elements, it must be taken into account not to use the same screw pattern. If the fasteners are placed in the area of existing drill holes, problems in the exact positioning of the element can occur because the fasteners "slip" into old drill holes.

If the above-mentioned aspects are taken into account during installation, the sandwich panel can be easily attached to existing structures.

Figure 43 shows the existing wall and the process of installing the new sandwich panel, up to the finished building situation.



Figure 43 Installation of hybrid system

6. Conclusion

Deliverable 4.3 deals with a variety of aspects and systems that enable the reuse of building envelopes in light metal construction. Systems that deal with the reuse of existing building envelopes as well as systems that can be used for future buildings have been developed and investigated.

For existing buildings a distinction was made between a building envelope made of liner trays and sandwich panels. For liner trays, a hybrid system was developed in which the outer shell can be replaced by a sandwich element, thus enabling aesthetic and thermal upgrading in the case of an in-situ reuse. For a wall consisting of sandwich elements, over-cladding was investigated, which offers the same advantages.

For future buildings, the Smart Flashing Connector was investigated, which makes it possible to clamp sandwich elements to the substructure and thus ensures the possibility of reuse.

The investigations carried out with regard to manufacturability, structural and thermal performance and end-product-usability were very successful. These investigations have shown that there are many possibilities to reuse the building envelope of single storey steel buildings in the future.

References

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- [10] EN 13829 – *Blower-Door-Messung für Hallen*