Research Programme of the Research Fund for Coal and Steel

FIre and Seismic performances of Hybrid fire WALLs in case of single-storey industrial and commercial steel buildings (FISHWALL)

Current practice for single storey steel framed buildings and review of fire and seismic regulations

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WP 2: Technical report on the assessment of the existing rules for the span extension of sandwich panels

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ABSTRACT

It is well known that the intrinsic fire resistance of single-storey unprotected steel-framed buildings is largely sufficient to guarantee the evacuation of occupants in the event of fire. In consequence, for this type of building, the main concern of national fire regulations in Europe is how to prevent the spread of fire to the whole building. To achieve this objective, two performances shall be usually satisfied, namely, the appropriateness of constructive systems to ensure that there is no progressive collapse between fire compartments, and the efficiency of fire walls to stop the fire inside the initial compartment regardless of the state of structures exposed to fire. In practice, many constructional solutions can be implemented in order to preserve the integrity of the fire walls, while accepting that the fire exposed part of the structure may collapse. One of the most common solutions is to place a non-load bearing wall between two independent steel structures and to connect it to them by means of "fusible" links. In fire situation, these fusible links have to allow the wall to be disconnected from the structure affected by fire without endangering the separating function of the wall, which shall remain fixed to the steel structure on the other side of the wall and therefore not exposed to fire. However, due to the lack of corresponding scientific evidence, questions are being very often raised about the real efficiency of such systems in fire situation, which, in certain cases, have also to provide an adequate seismic resistance, if they are used in seismic areas.

Today, concrete or masonry wall solutions are frequently used for the compartmentation of buildings, predominately for low-rise commercial and industrial steel buildings. However, as an alternative, lightweight sandwich panels (comprising two thin flat metal faces and an insulated core) could become an appropriate steel fire wall solution, offering numerous benefits in comparison to other solutions, including fire resistance, durability, flexibility, easy dismounting and fast construction times. But, there is an evident lack of technical information about the adequate fire performance of such type of wall solutions when they are implemented in single-storey buildings with unprotected steel structure, which constitutes a major obstacle for their large use.

In this context, the overall goal of the FISWHALL project is to develop a design guidance and recommendations for an innovative hybrid fire wall solution based on lightweight steel-faced sandwich panels associated with unprotected steel structure under both fire and seismic actions, but considered individually. This will be achieved through the following specific tasks: i) Establishing of a full range of experimental evidence about the fire and seismic behaviour of the investigated hybrid fire wall solution by carrying out a number of tests; ii) Investigating intensively the fire and seismic performances of the above hybrid fire wall solution in combination with unprotected single-storey steel structures through a variety of parametric numerical studies by means of validated FE numerical models; iii) Developing both cost-effective and innovative "fusible" connection systems for fire walls to be used in combination with unprotected steel structures of single-storey buildings; and iv) Developing a design guidance and practical recommendations for the studied hybrid fire wall and fusible links solutions, on the basis of above studies, from which engineers can carry out very efficient design.

The objective of this report is to review the state of the art of methods and rules for extending the spans of sandwich panels with a mineral wool core and two steel facings and to propose new rules if necessary (cases where the level of insecurity is demonstrated by the comparison of fire resistance performances obtained both by large-scale laboratory tests (5m to 6m span) and by small-scale laboratory tests (3mx3m). For this purpose, the available fire tests on the one hand and the FISHWALL fire tests on the other hand, are used in this report to test the old, current and future rules for range extrapolation envisaged in the framework of the evolution of the EN 15254-5 standard currently being revised at the date of this deliverable.

1 INTRODUCTION

In the context of the fire resistance of non-structural sandwich panels with a mineral wool core and two steel facings under the EN 14509 standard [18], span extension rules have always been a key issue in the market as laboratory tests are generally 3m×3m while the actual spans required on fire walls are more than 6m.

The problem is that the possibility of carrying out full-scale tests at such dimensions in laboratories was exceptional and very expensive in the past, and that the number of cases to be tested quickly became significant depending on the thickness of panels, facings, insulation density, etc. This approach of testing very large quantities (5m to 6m of span) was therefore not industrially accessible.

The standardizer has therefore tried, through several versions of the EN 15254-5 standard [2] to [5], to propose various different methods of range extension based solely on the results obtained on tests carried out on small spans of 3mx3m (EN 1364-1) [1], which can only be tested at reasonable costs. These different methods were first based on measurements of panel joint openings, then on significant minimum reserve time safety margins in relation to the required fire resistance performance and recently on decreases in fire resistance time per meter of additional span counted since the reference test of 3m span.

Then, as the offer of laboratories in full-scale tests evolved, it proved possible to test some panels with long spans of 5m to 6m on the one hand, and to see at the same time whether, for these few cases, the rules for extrapolating the span were satisfactory on the other hand.

A consortium made up of PPaeurope/DIBT/IFBS [15] was the first to make this comparison approach and it was realized that the scope extrapolation rules proposed by the current EN 15254-5 but also the previous ones had to be reviewed.

In this context, the present report aims to remind these different rules of span extrapolation and to assess them from existing standard fire tests on small-scale fire walls (3m×3m) and fire tests performed on large-scale walls (5m×6m) in the task 2.1 of the project. The comparative study allowed to confirm or not the current representativeness in terms of performance of the different span extrapolation approaches developed in EN 15254-5 [2] to [5] on the one hand, and to assess the future rules proposed in the draft prEN 15254-5 (confidential for the moment) built on the research of the PPaeurope/DIBT/IFBS consortium [15] on the other hand.

2 DIRECT AND EXTENDED FIRE RESISTANCE APPLICATION RULES FOR SANDWICH PANELS

Prior to tests analysis, a review of existing information relevant to existing extended application rules for sandwich panels was carried out.

2.1 Generalities

The rules for direct fire resistance application to the span of sandwich panels in horizontal or vertical tests cases are established according to the EN 1364-1 standard [1] and allow, under certain conditions, the extension of the tested panels' spans from 3 m to 4 m. The relevant paragraphs are 13.2 for the width direct extended application and 13.3 for the height direct extended application.

The rules are as follows:

If 3 m length tested:

The rules of the Annex B of the EN 1364-1 [1] are:

- For horizontal installation with horizontal free edge:
  * +1m of the tested height if the panels are fixed
  * +1/3 of the tested height if the panels are self-supporting
- -For vertical installation:
  * +1m of the tested height with conditions

Standard EN 1364-1 also provides guidance for width extensions.

The extended fire resistance application rules for the span of sandwich panels in horizontal or vertical test cases are established according to EN 15254-5.

The extended fire-resistance application rules for the span of sandwich panels aim, based on test results from a 3 m x 3 m or larger specimen, to expand the spans without additional tests up to a maximum of 10 m. These extensions apply to both horizontally and vertically installed panels.

These span extrapolation rules have evolved during the different versions of the EN 15254-5 standard (2007 [2], 2009 [3], 2013 [4], 2018 [5]). The crucial point of validating the span extrapolation rules is the simultaneous availability of notified laboratory tests in furnaces according to the EN 1364-1 standard (ISO 834 curve) in small dimensions (3 m × 3 m or 4 m × 4 m) and in large dimensions (3 m × 6 m, 6 m × 5 m, 10 m × 5 m etc., ...), allowing to identify in a specific and renewable way the key parameters and the span extrapolation rules for the fire resistance performance.

In this document, we will study the current rules (EN 15254-5 standard of 2018 [5]) and the previous versions mainly based on the analysis of the measurements of Δc and Δf (see Figures 1 and 2), which are envisaged in the EN 15254-5 standard of 2018 but not developed due to the lack of cross-checking tests. It should be noted that scope extension criteria based on Δc and Δf were included in former versions of the EN 15254-5 standard (2013) [4]and are not included in the 2018 version due to the lack of supporting tests.

We will also consider the new extended application rules proposed in the PPA/IFBS/DIBT 2019 project [15].

The examples of application of the current span extension rules in the Annex are detailed according to the current version of the EN 15254-5 norm (2018) and the previous version of the EN 15254-5 standard (2013).

The EGOLF document TC2 n°1672 [6] also gives some results about the value of Δc and Δf.

2.2 Targeted fire performance

The target performance is fire integrity and thermal insulation for a specified period of minutes and for a given fire direction (e.g. EI 120 from the inside to the outside). This performance is usually specified in the classification report according to the EN 13501-2 standard [18], which is linked to the test report according to EN 1364-1. It is required on the CE label and the Declaration of Performance (doP) when the panel is implemented in a state where fire regulations require fire resistance performance. The establishment and monitoring of this performance is related to an AVCP1([1]) within the meaning of the Construction Product Regulation.

[1] Assessment and Verification of Constancy of Performance level 1

2.3 Reminder of the direct application rules in force for width and height span extensions according to the EN 1364-1 standard (direct application)

The test model for EN 1364-1 is usually 3 m × 3 m (cf. Article 6).

Direct width span extensions are possible if the specimen is tested with a free vertical edge, according to Chapter 13.2 of the EN 1364-1 standard conditions.

Extract from the EN the 1364-1 standard, § 13.2. Width extension:
«For specimens tested without a supporting construction, the width of an identical construction may be increased if the sample has been tested at a minimum of nominally 3 m wide with one vertical edge unrestrained».

Direct span extensions of height are possible if the tested specimen complies with Chapter 13.3 of the EN 1364-1 standard.

Extract from the EN 1364-1 standard, § 13.3 Height extension:

« The height of the construction may be increased by 1,0 m under the following conditions:
a) The minimum tested height is 3 m when tested without a supporting construction or 2.8 m when tested with a supporting construction;
b) The maximum lateral deflection of the test specimen shall not exceed 100 mm (see 9.3);
c) The expansion allowances are increased proportionally ».

The rules to carry out span extended applications are given in Appendix B:

Appendix B: Specific requirements for the testing of external and internal non-loadbearing walls designed to extend horizontally between two independently tested vertical fire-resistant structural elements.

2.4 Reminder of the current extended application rules for span extensions according to EN 15254-5 of 2018 (extended application)

2.4.1 Scope extension criteria

The extended applications for scope extension rules are given in the EN 15254-5 standard, § 5.3.1.

To extend the scope, **two criteria must be checked:**

1) The resistance capacity of the panel assemblies on the structure (fastening) must be greater than or equal to the acting forces in a fire situation for the duration stated in the classification report (the acting and load-bearing forces are given at the end of Annex B and listed in Annex B of this document);
2) The joints between adjacent panels shall be of sufficient resistance to ensure that they are sealed against flames and hot gases for the indicated duration in the Classification Report and in the doP.

Appendix B of this report provides summary flowcharts on direct and extended application criteria for scope extensions.

2.4.2 Minimum requirements for establishing a scope extension

A span extension is only possible in wall if:

- During the test carried out on a small-scale specimen according to the EN 1364-1 standard, it is shown that the target performance time is exceeded. This exceeding of duration compared to the target time is at least 10 minutes. In other words, during this **minimum 10%** exceedance of the classification time, no flames or smokes must pass through the wall on the one hand, and no temperature exceedance (140° on average and 180° punctually) must be observed on the wall on the other hand.
- If the scope extension is only for the panel's orientation that has been tested according to the EN 1364-1 standard.

NOTE EN 15254-5, Table 4 allows extrapolation for overrun time. These rules from EXAP standards for metal sandwich panels are currently used.

2.4.3 Quantification of span extensions based on duration overruns

2.4.3.1 Generalities

In order to spread the scope of test results obtained in accordance with EN 1364-1, section 5.3.1 of the 15254-5 standard of 2018 applies. When these rules are used, the direct application rule for Δc and Δf distortions (see standard 15254-5 of 2009 and 2013 EGOLF TC2 n°1672) should not be considered.

2.4.3.2 Case of the rule in force according to the EN 15254-5 standard (2018)

Extract from the EN 15254-5 standard (2018)

« In order to extend the scope for test results obtained in accordance with EN 1364-1, clause 5.3.1 of 15254-5 (2018) applies. When these rules are used, the direct application rule regarding deformations shall not be taken into consideration. »

Table 4 of EN 15254-5, therefore, provides the scope extensions directly according to the time overruns observed during the test following the EN 1364-1 standard.

Examples of applications are given in Annex B of EN 15254-5. They are reproduced and detailed in Appendix A of this report.

Table 1: Extension of tested span length from 15254-5 (2018)

Tested span length	Extrapolation
3 m	Up to 6 m if 20 % overrun, minimum 10 min.
3 m	Up to 7,5 m if 35 % overrun, minimum 10 min.
> 4 m	Up to tested length + 2 m, if 20 % overrun, minimum 10 min.

2.4.4 Maximum achievable span extension

In any case no extension of span length is permitted above **10 m.**

2.5 Reminder of former rules for span extrapolations based on joint opening measurements Δc and Δf

2.5.1 Generalities

These rules are mentioned in the EN 15254-5 standard of 2007, 2009, 2013 and implemented in the EGOLF document. They have been removed from the 2018 version. However, at the end of Annex B of 15254-5 (2018), the joints' measured displacement approach is possible. (See foot note at the end of Annex B).

NOTE from 15254-5 (2018) Annex B. The measurements of Δc and Δf - values are required for a future calculation method for the extension of span lengths based on these values.

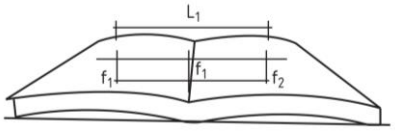
2.5.2 Reminder of former rules

Extract from Annex B of the EN 15254-5 standard (2007, 2009, 2013).

« In order to extend the span above 4 m, there shall be an overrun of at least 20 % with a minimum of 10 minutes compared to the classification. »

For the assessment of the scope extension, the following measurements and calculations should be carried out:

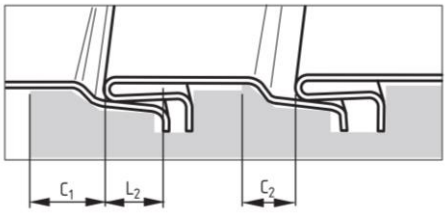
a) During the reference test, the mid-span deflection difference between the junction and the adjacent panel centres shall be measured throughout the test. This difference is called Δf, and the calculation method is given in Figure 1 below;



$$\Delta f = (f_j - 0.5*(f_1 + f_2))/L_1$$

Figure 1: Calculation of Δf

b) During the reference test, the joint opening shall be measured at the exact locations as above during the test. This is referred to as Δc, and the calculation method is given in Figure 2 below;



$$\Delta c = (c_2 - c_1)/L_2$$

Figure 2: Calculation of Δc

c) If no seams are used in panel-to-panel connections, in the reference test at a height of 3 m, the following rules shall apply;

d) Extensions are only allowed if $\Delta c < 0,5$:

1) If $\Delta f < 0,01$, the span can be increased up to 12 m with the same classification as those tested;

2) If $\Delta f > 0,06$, the span can be increased up to 4 m with the same classification as the panel tested according to the direct application field;

3) Values between 0.01 and 0.06 can be obtained by linear interpolation. Measurements for the calculation of Δf and Δc shall be carried out during the entire test period. When assessing the acceptable span, measurements at the time of the appropriate fire class shall be used.

This means that for the same panel, different spans can be allowed for various classes. To do this, the criteria on Δc must be met.

If the seam is used in panel-to-panel joints in the reference test, the span can be increased up to 12 m with the same type of fixing and the same distance between the axes as in the tested set:

a) If no stitching is used in panel-to-panel joints in the reference test, the span can be increased up to 12 m with stitching every 3 m;

b) Spans greater than 12 m are not allowed;

c) The extension of the span length is only authorised with the orientation tested panel;

d) The required quantity of fasteners must always be calculated in accordance with the formulas in this Annex B.

2.6 New extended application rules proposed from IFBS/DIBT/PPA-Europe 2019 project

The new extended application rule proposed in project [15] is given below in Table 2 for horizontal orientation and Table 3 for vertical orientation:

Table 2: New extended application rule for horizontal application proposed in the IFBS/DIBT/PPA Europe project

Tested span length	**Extrapolation**
From 3 m to 6 m	-20 minutes by span meter
From 6 m to 7.5 m	-35 minutes by span meter
From x meter to x+2 m$\leq 10\,m$	-35 minutes by span meter

Table 3: New extended application rule for vertical application proposed in the IFBS/DIBT/PPA Europe project

Tested span length	**Extrapolation**
From 3 m to 6m	-35 minutes by span meter

3 EXISTING FIRE RESISTANCE TEST RESULTS FOLLOWING EN 1364-1

This section shortly presents the results of standard fire tests performed on small-scale (3mx3m) partition fire walls built with the same sandwich panels than those tested in the scope of the task 2.1. The sandwich panel manufacturer Euroclad Ltd (subcontractor to sandwich panel manufacturer JORISIDE on the FISHWALL project) delivered the tested panels.

The test results are issued in the official fire resistance test report and classification report established by PAVUS, a. s. FIRE TESTING LABORATORY VESELÍ NAD LUŽNICÍ.

3.1 Panels laid in a vertical position - 3 m ×3 m specimen

3.1.1 Reference test report

The fire resistance performance of the considered non-loadbearing partition wall was tested in accordance with CSN EN 1364-1:2015. The test was carried out the 20 January 2023, leading to the test report n°Pr-22-2.232-EN [8].

3.1.2 Description of the test specimen

The tested non-loadbearing wall had overall dimensions of 3035m high, by 3.035m wide and 175 mm thick and was formed form panels installed vertically. The wall was mounted into a rigid construction with low density, thickness 250 mm and density 550 kg/m^3, placed in the front of the vertical furnace. Thus, the wall was exposed to fire on one side only.

A description of the construction is given in Figure 3 and Figure 4.

The wall consisted of 3 pieces of Eurobond Rockspan Extra sandwich panels with mineral wool as the insulation core, nominal density of mineral wool was 120 kg/ m^3. Each panel had the following dimensions: 1 200 mm (width of stock) × 3000 mm (length) × 175 mm (thickness). On exposed face EF, the panels had a metal sheet, 0.5 mm thick (inner side) and on unexposed face UF, they had metal sheet, 0.5 mm thick (outer side); both sheets were galvanized and coated (See Figures 3a and 3b below).

On both horizontal sides and on the right part of the rigid construction, L-profiles 100x50x2 were mounted on EF (and also on UF in the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using carbon steel screws TutFast HTF-6.3 × 57 (producer Fixfast Ltd) in spacing of 450 mm. The left part of the specimen was without mechanical fixing.

Particular panels were anchored to the L-profiles using stainless screws DrillFast DF2-SS-LS-A15-6.3 × 25 (producer Fixfast Ltd) in the direction from EF, in spacing of 300 mm.
The structural gaps between the test specimen and the rigid construction were filled up with mineral wool POWER-TEK BD 660 (manufacturer Knauf Insulation, spol. s r.o.), nominal density 100 kg/m$_3$, width of the gap between 20 and 30 mm.

The left vertical edge was left unrestrained in order to enable free specimen moving. The gap between the specimen and the rigid construction of width 50 mm was filled up with mineral wool.

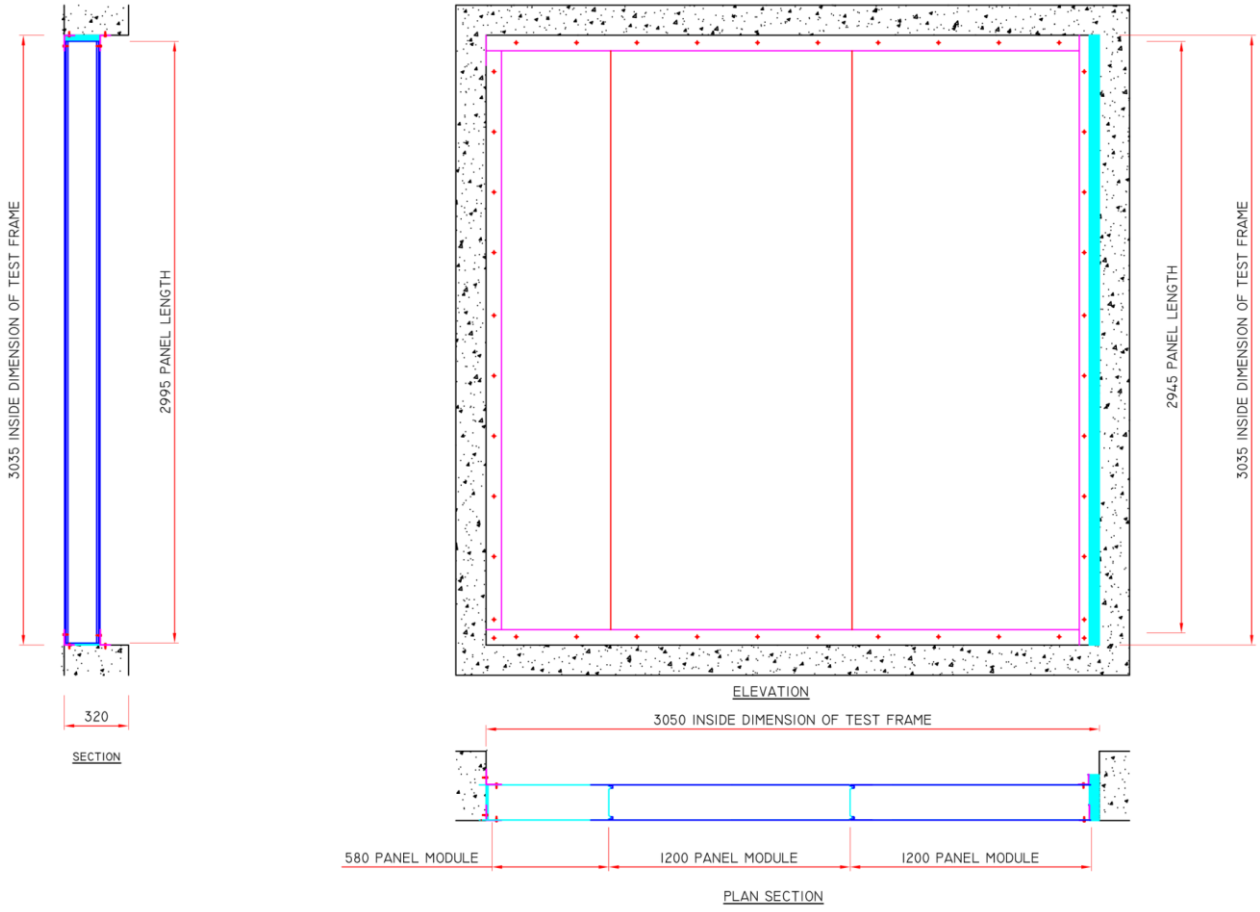


Figure 3: Elevation of the wall sandwich panel specimen (vertically laid) [8]

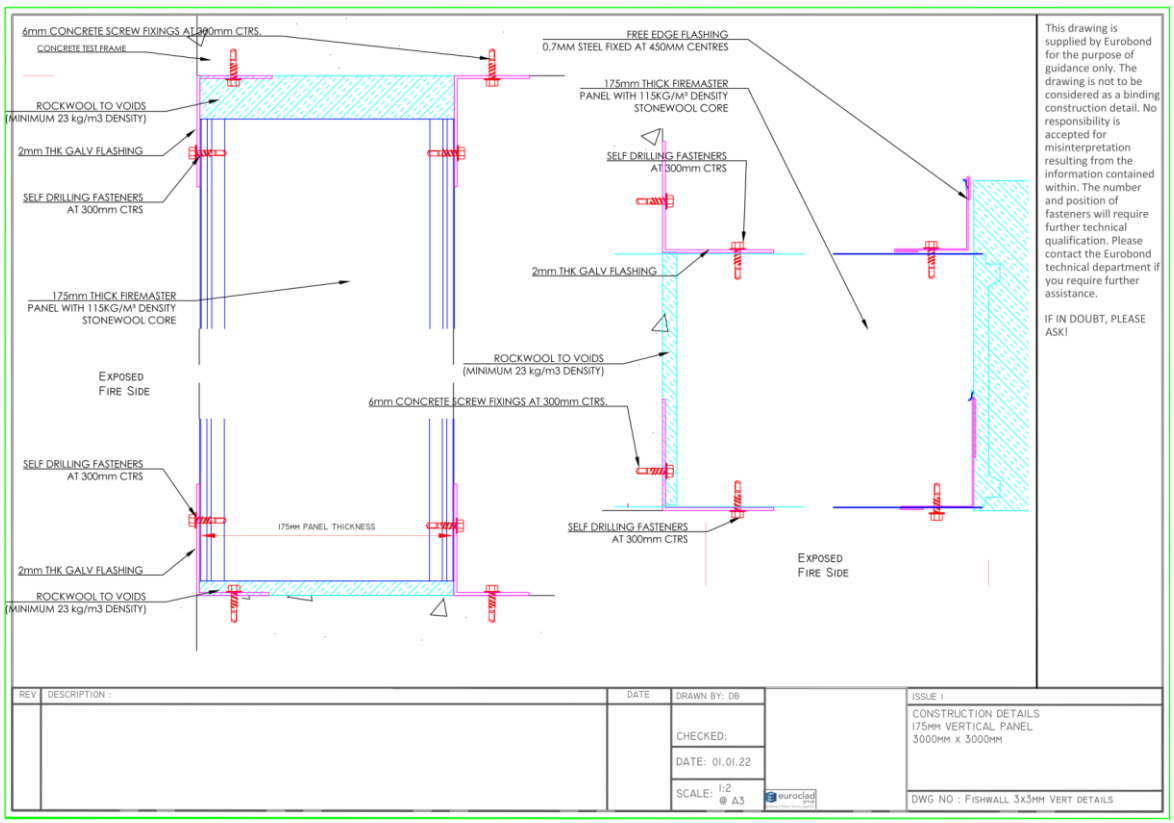


Figure 4: Details of the wall sandwich panel specimen (vertically laid) [8]

3.1.3 Fire resistance test results

Figure 5: Vertical sandwich panel test results (laid) [8]

Conclusion

The panel tested spanning vertically is EI 180 minutes in accordance with the Pavus report PK 2-06-22-017 -E-0 delivered the 24 January 2023 [8].

NOTE: The classification reports were issued in November 2022 and January 2023, it means according to older version of the classification standard EN 13501-2:2016. There were no classes E 180. When Pavus issues classification according to EN 13501-2:2023, it is possible to write E 180 / EI 180.

3.2 Panels laid in a horizontal position - 3 m × 3 m specimen

3.2.1 Reference test report

The fire resistance performance of the considered non-loadbearing partition wall was tested in accordance with CSN EN 1364-1:2015. The test was carried out the 30 September 2022, leading to the test report n°Pr-22-2.170-EN [9].

3.2.2 Description of the test specimen

The tested non-loadbearing wall had overall dimensions of 3035m high, by 3.035m wide and 175 mm thick and was formed form panels installed horizontally. The wall was mounted into a rigid construction with low density, thickness 250 mm and density 550 kg/m^3, placed in the front of the vertical furnace. Thus, the wall was exposed to fire on one side only.

A description of the construction is given in Figure 6 to Figure 7.

The non-loadbearing external wall consisted of 3 pcs of sandwich panels Eurobond Rockspan Extra with mineral wool as an insulation core, nominal density of mineral wool was 120 kg/m3. Each panel had dimensions of 1 200 mm (stock width) × 2 995 mm (length) × 175 mm (thickness). One panel was reduced to ½ in width, and it was mounted to the upper edge of the wall, so that the horizontal contact of panels was 500 ± 150 mm far from the upper edge. On EF, the panels had profiled metal sheet, th. 0.5 mm (interior side) and on UF, they had profiled metal sheet, th. 0.5 mm (exterior side), both sheets were galvanized and coated.

On both vertical sides and on the bottom part of the rigid construction, L-profiles 100x50x2 were mounted on EF (and on UF in the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using carbon steel screws TutFast HTF-6.3 × 57 (producer Fixfast Ltd) in spacing of 450 mm. The top part of the specimen was without mechanical fixing.

Panels were anchored to the L-profiles using stainless screws DrillFast DF2-SS-LS-A15-6.3 × 25 (producer Fixfast Ltd) in the direction from EF, in spacing of 300 mm.

The structural gaps between the test specimen and the rigid construction were filled up with mineral wool, width of the gap between 20 and 30 mm.

The upper horizontal edge was left unrestrained in order to enable free specimen moving. The gap between the specimen and the rigid construction of width 50 mm was filled up with mineral wool.

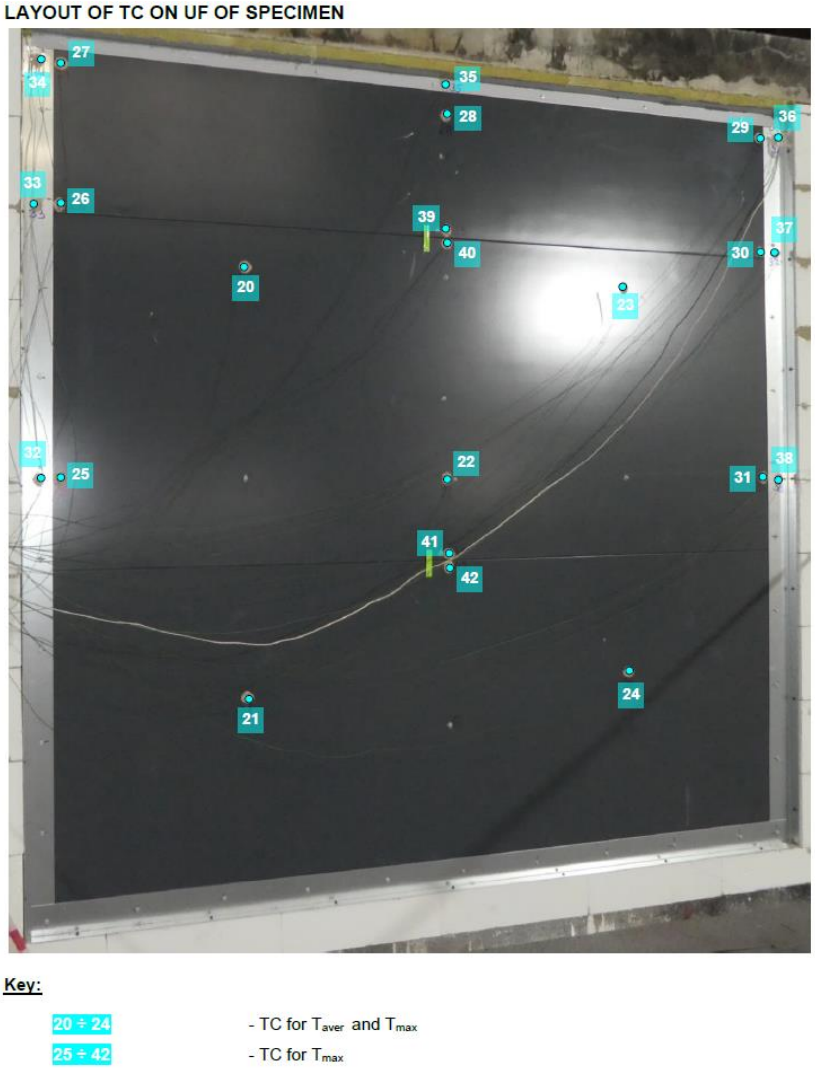


Figure 6: Elevation of the test specimen (panels laid horizontally) [9]

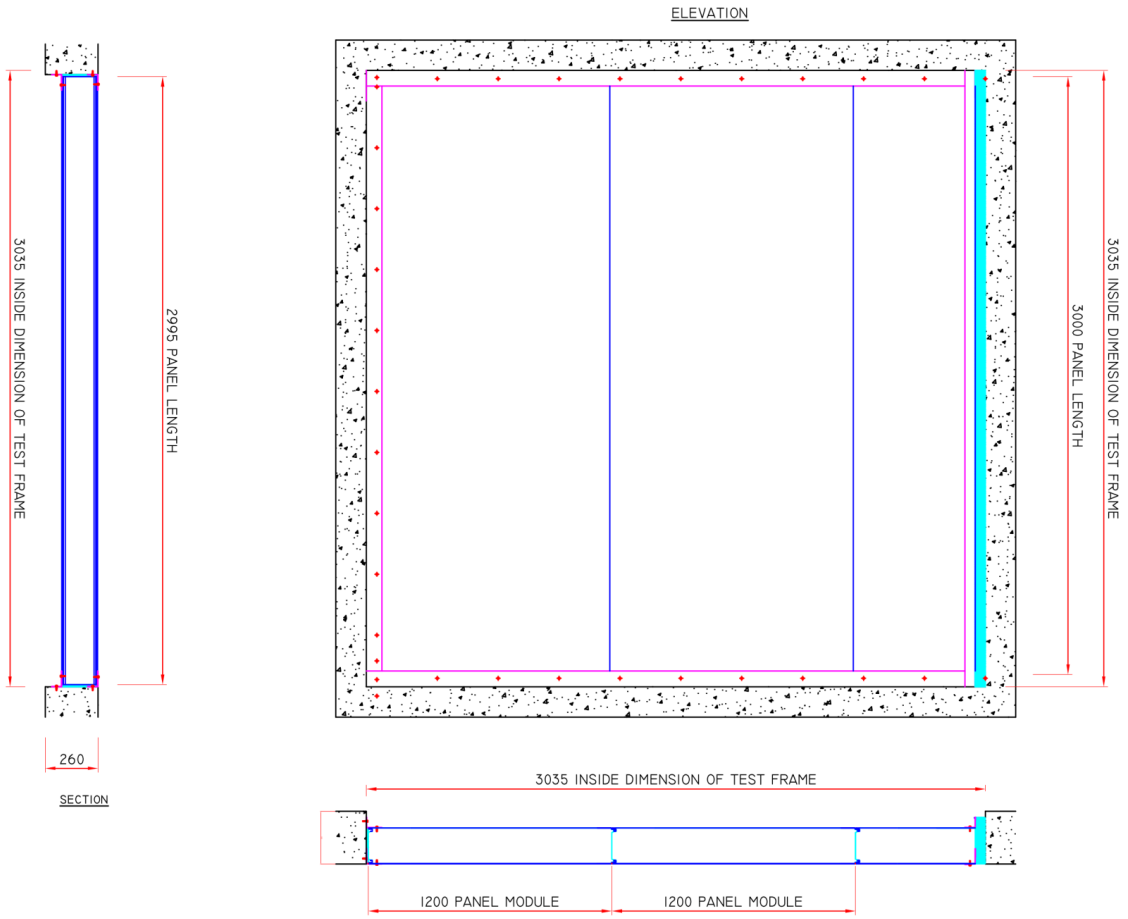


Figure 7: Elevation of the wall sandwich panel specimen (horizontally laid) [9]

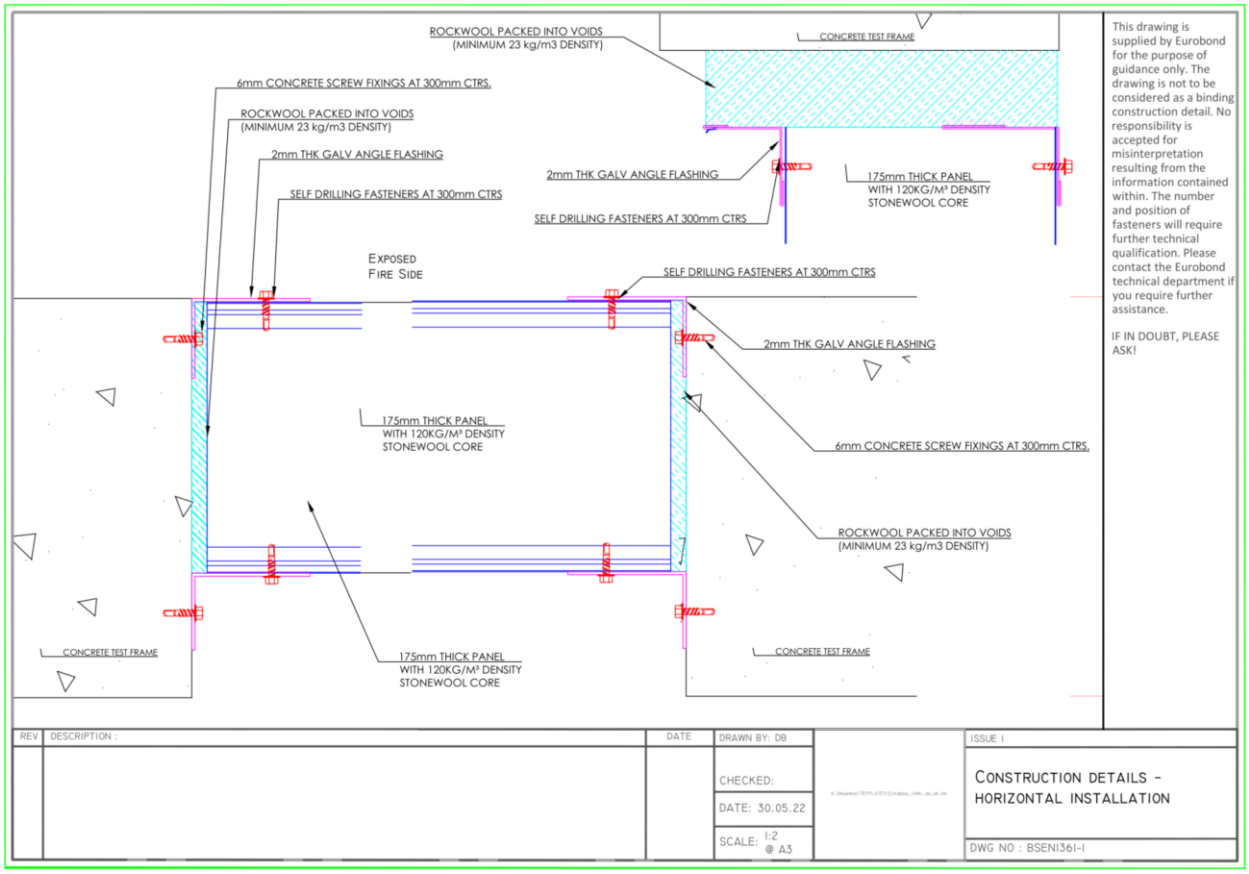


Figure 8: Detail of the wall sandwich panel specimen (horizontally laid) [9]

3.2.3 Fire resistance test results

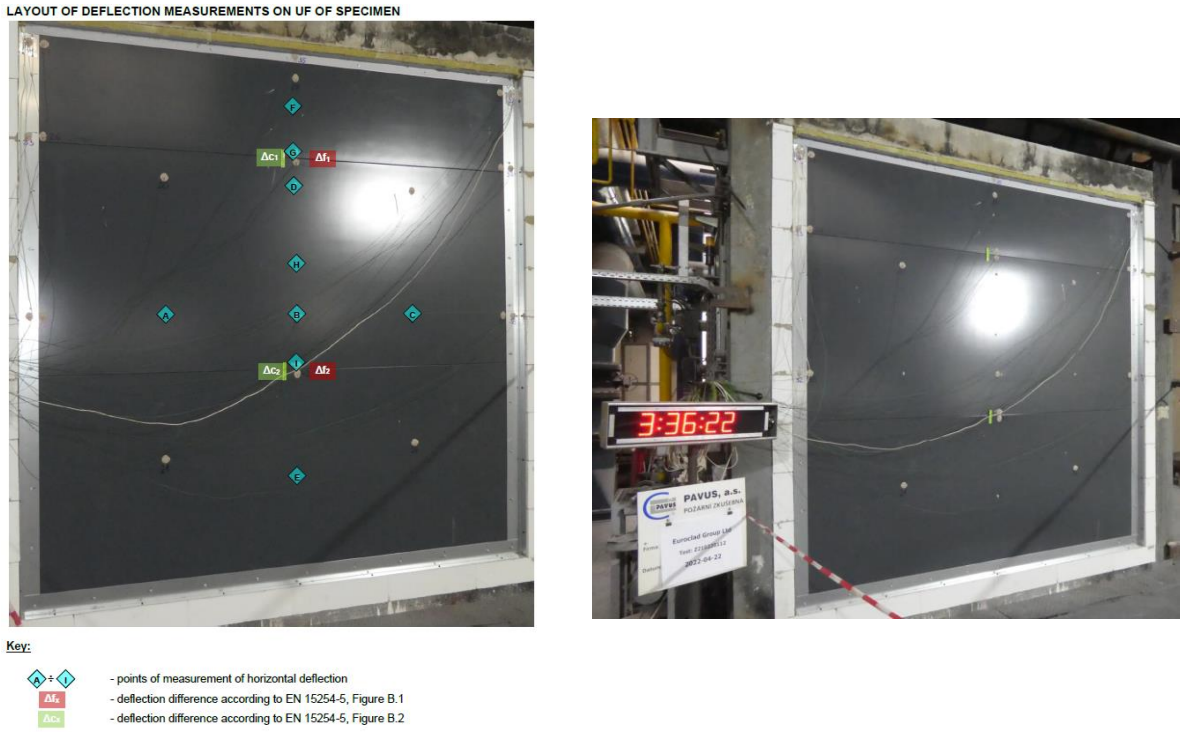


Figure 9: Results of horizontal sandwich panel test panels [9]

Conclusion

The panel spanning horizontally is EI 180 minutes following the Pavus report PK2 06-22-012-E-0 of the 23 November 2022 [9].

NOTE: The classification reports were issued in November 2022 and January 2023, it means according to older version of the classification standard EN 13501-2:2016. There were no classes E 180. When Pavus issues classification according to EN 13501-2:2023, it is possible to write E 180 / EI 180.

4 NEW FIRE TESTS PERFORMED ON LONG-SPAN WALLS

A set of four standard fire tests on partition fire walls made of sandwich panels with large spans was carried out in task 2.1 of the FISHWALL project.

All panels purchased by JorisIde through its subcontractor Euroclad Ltd have been tested:

- Horizontally with and without intermediate vertical frame support;
- Vertically with and without intermediate horizontal frame support.

In view:

- To check the extended application rule (without intermediate frame) to pass to :
    - the span 3 m at 6m vertically: test n° Pr-22-2.085 [10];
    - the span 3 m at 5m horizontally: test n°Pr-22-2.084 [11];
- To confirm the overall REI 120 performance of the sandwich panels and supported frame and the first point:
    - the span 3 m at 5.0m vertically: test n° Pr-22-2.231[12];
    - the span 3 m at 4.5m horizontally: test n° Pr-22-2.086 [13];

Two types of boundary conditions have been considered:

- Panels fixed on a concrete frame in view to check the extended application rules (EN 15254-5) to increase the span from 3m (existing data) to 5 m vertically and to 6 m horizontally based on an EN 1364-1 test.
- Panel fixed to a steel purlin or column protected by a panel encasement to confirm that:
    - the type of fixing of sandwich panels to a protected metal frame (cladding rail) compared to concrete frame does not change the EI120 performance of the panels,
    - the association of an EI 120 cladding with a R120 frame (temperature inside the box panel protecting the frame remains under 400°) keeps a REI120 system based on an EN 1364-1 test.

The four tests conducted during the FISHWALL project are described in the Table 4.

Table 4: List of fire tests carried out on walls in FISWALL Project

Test	Wall configuration	Performance	Standard	Comments
1	1 × vertically laid long span (6m)	EI90	EN 1364-1	To allow using Annex B of EN 15254-2
2	1 × vertically laid long span (with 1 support) (5.0+1.0m)	EI90 E120 + Columns/beam temperatures	EN 1364-1	Compare to laboratory appreciation (eg in France)
3	1 × horizontally laid long span (5m)	EI 120	EN 1364-1	To allow using Annex B of EN 15254-2
4	1 × horizontally laid long span (with 1 support) (4.5+0.5m)	EI 120 + Columns/beam temperatures	EN 1364-1	Compare to laboratory appreciation (eg in France)

4.1 Tests set-up

4.1.1 Test without supporting steel member

4.1.1.1 Test n°1: Panel laid vertically with 6m span (no stitching)

The test specimen is described in Figure 10 and Figure 11.

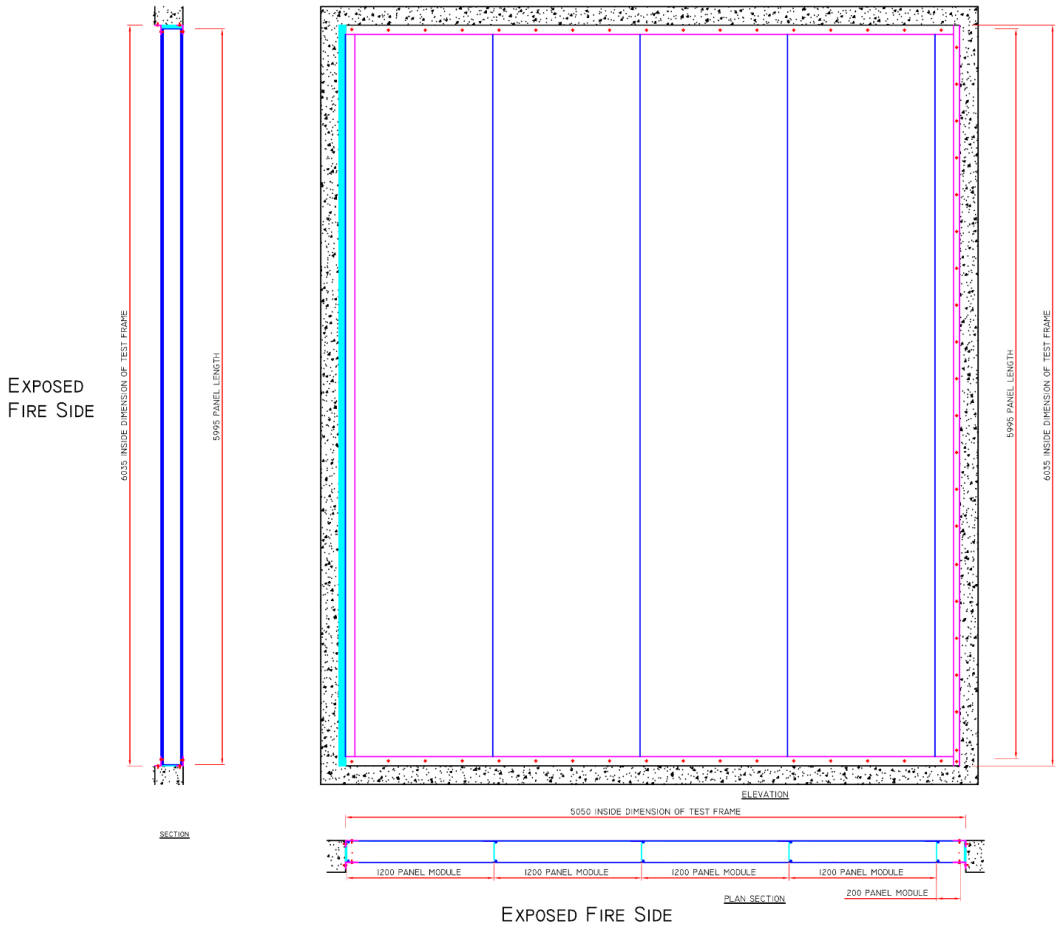


Figure 10: Elevation view of the test specimen n°1 [10]

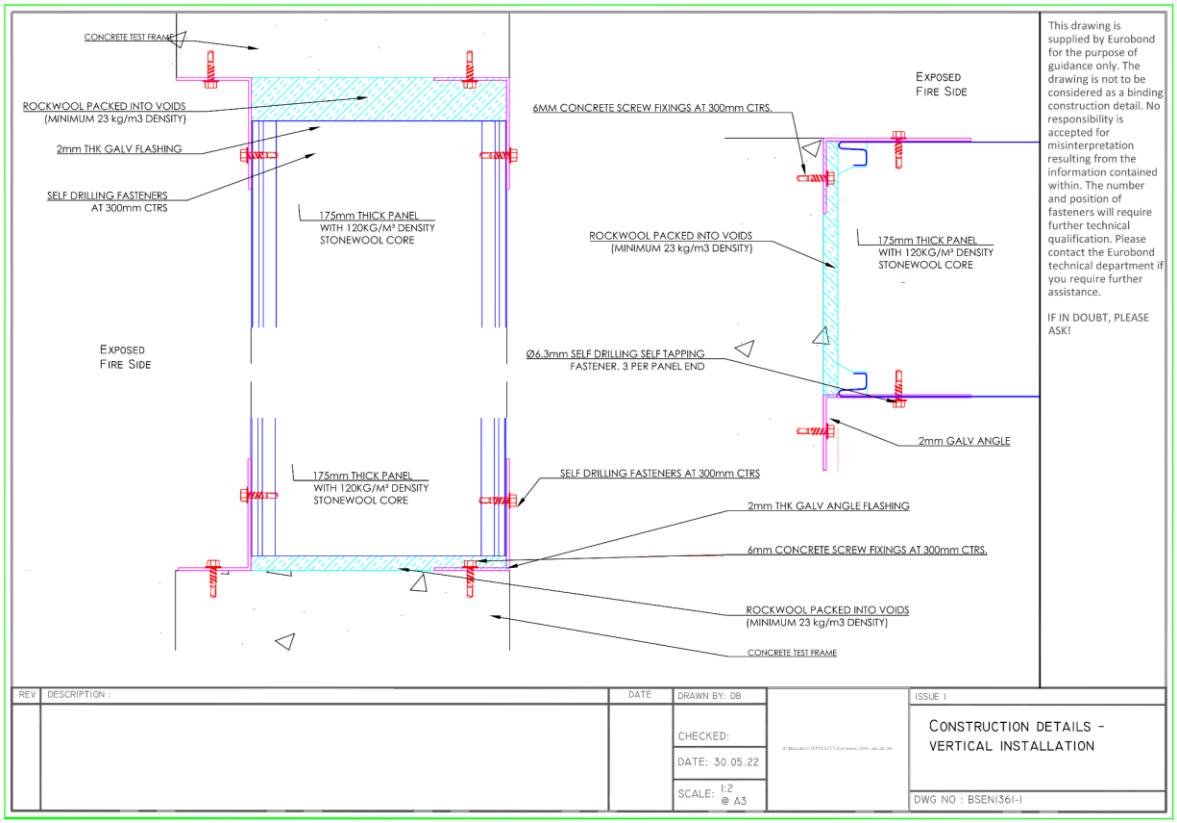


Figure 11: Constructional details of the test specimen n°1 [10]

The test protocol of EN 1364-1, supplemented by EN 1363 and EN 14509, was followed. Details of the test set-ups are shown in Figure 10 above. The test report (Pavus report N°. Pr-22-2.085-En issued on 2022-06-13 [10]) and classification report PK2-06-22-010-E-0 provide details of the assembly and classification level **E 90 / EI 90.**

During the horizontal installation test, the following were measured.

- The oven temperature using plate thermometers:
- Temperatures of the unexposed fire face of the sandwich panels using thermocouples;
- Temperatures of the steel elements supporting the sandwich panels;
- The difference in deflection at the relevant locations between the interlocking joint and the adjacent panel centres;
- The joint opening at the appropriate points Δc, Δf.

4.1.1.2 Test n°3: Panel laid horizontally with 5m span (no stitching)

The test specimen is described in Figure 12 and Figure 13.

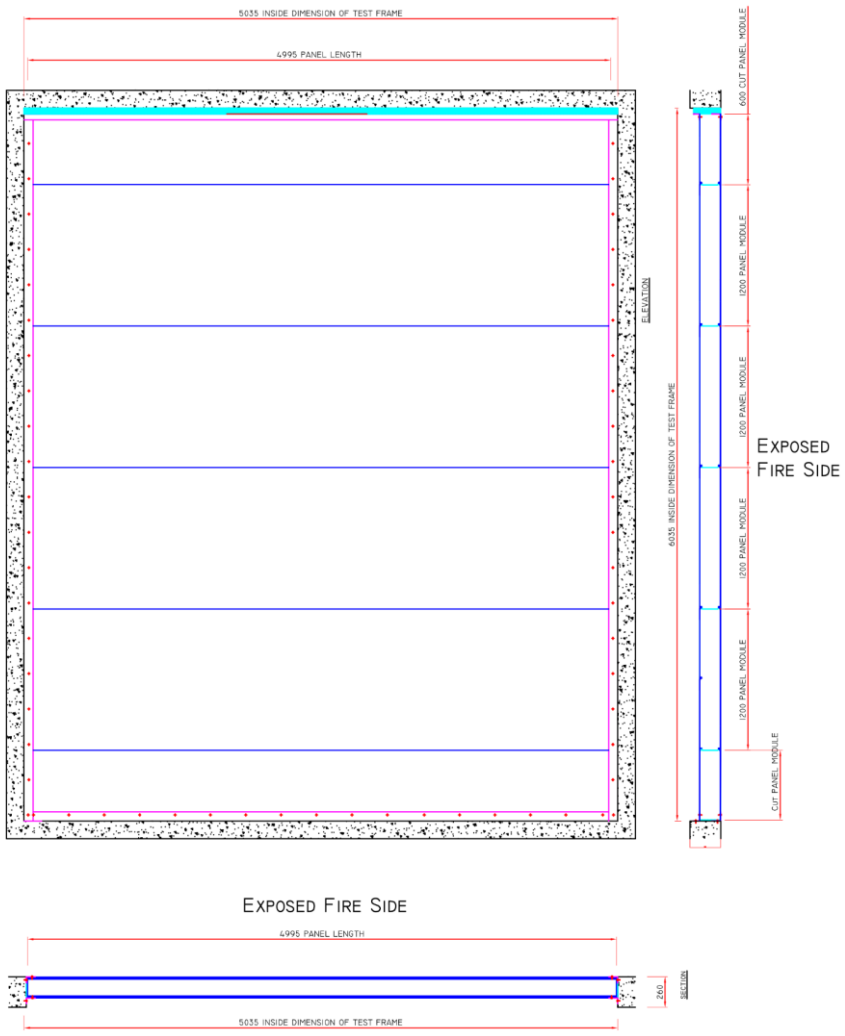


Figure 12: Elevation view of the test specimen n°3 [11]

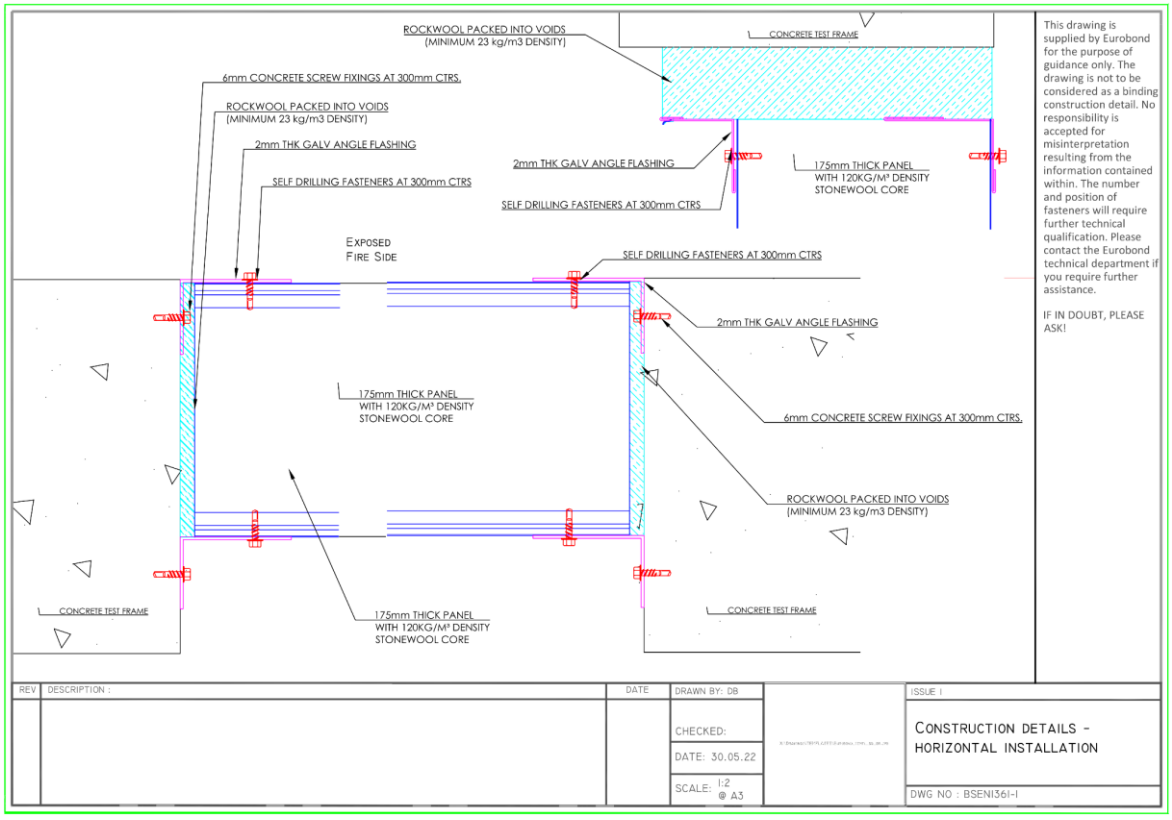


Figure 13: Constructional details of the test specimen n°3 [11]

The test protocol of CSN EN 1364-1 supplemented by CSN EN 1363 and CSN EN 14509 was followed. Details of the test set-ups are shown in Figure 12 above The test report (test report N°. Pr-22-2.084-En dated on 2022-06-13 [11]) and classification report PK2-06-22-009-E-0 provide details of the assembly and classification level **E 120 / EI 120.**

During the vertical installation test, the following were measured:

- The oven temperature using plate thermometers:
- Temperatures of the unexposed fire face of the sandwich panels using thermocouples;
- Temperatures of the steel elements supporting the sandwich panels;
- The difference in deflection at the relevant locations between the interlocking joint and the adjacent panel centres;
- The joint opening at the appropriate locations Δc, Δf.

4.1.2 For the test with supporting steel member

4.1.2.1 Test n°2: Panel laid vertically with 5m span

The test specimen is described in the Figure 14 and Figure 15.

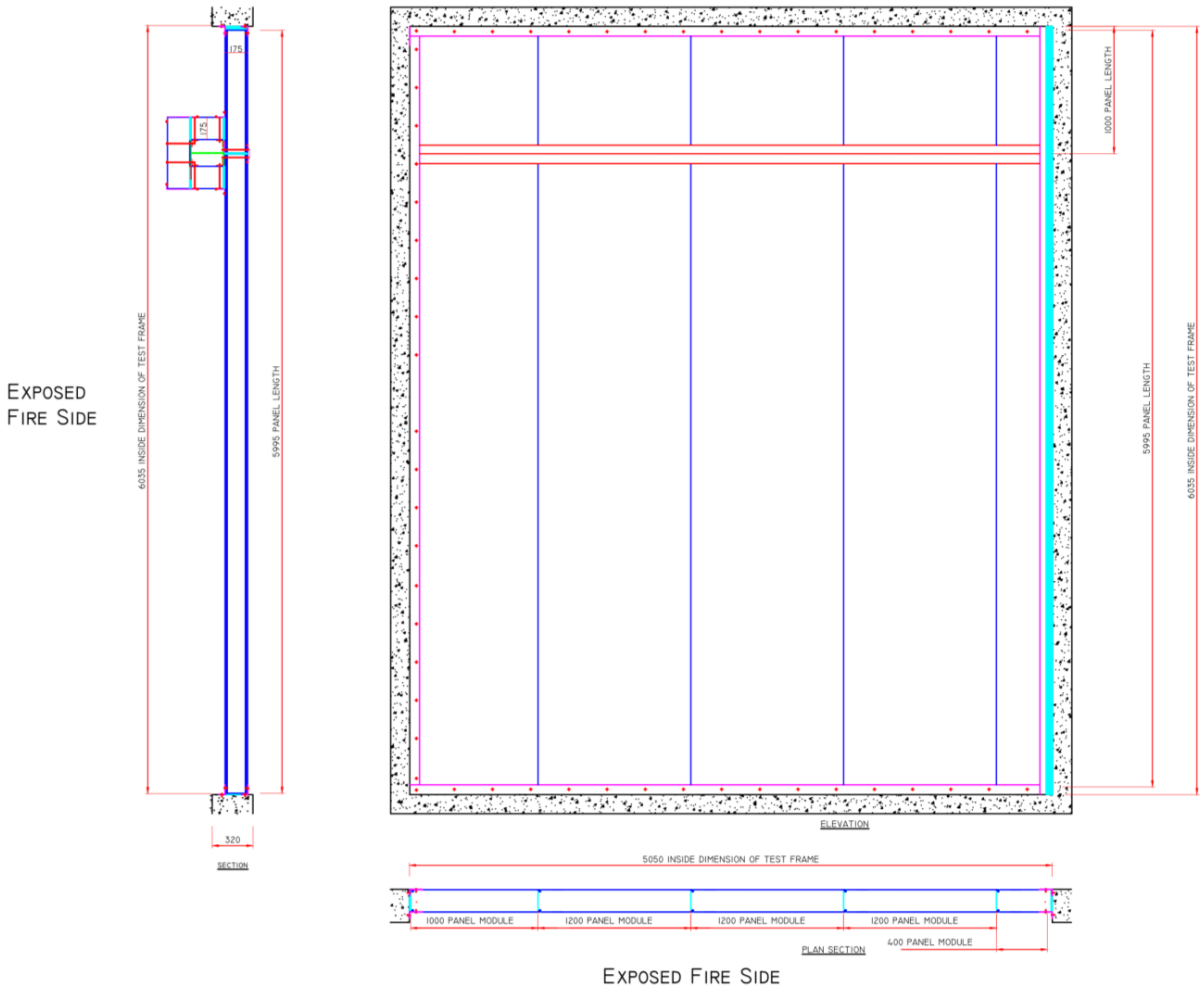


Figure 14: Elevation view of the test specimen n°2 [12]

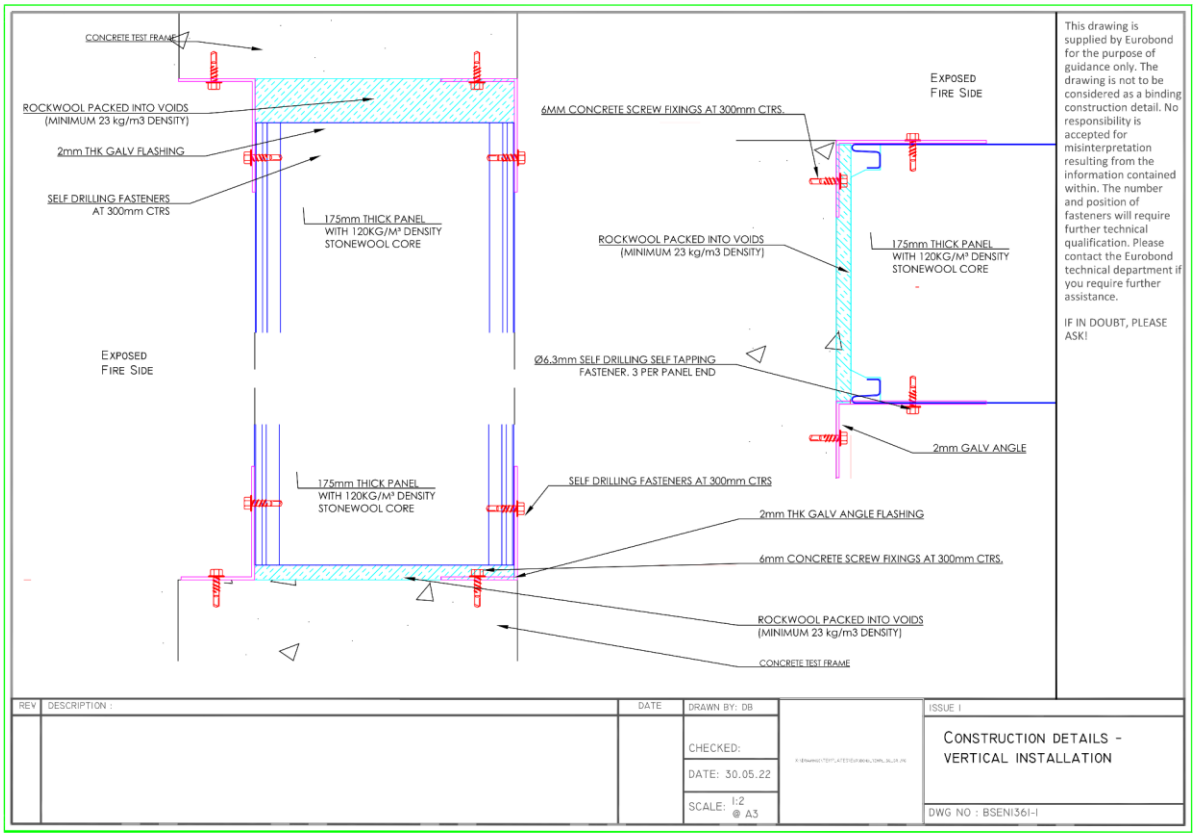


Figure 15: Constructional details of the test specimen n°2 [12]

The test protocol of CSN EN 1364-1 supplemented by CSN EN 1363 and CSN EN 14509 was followed. Details of the tests set-ups are shown in Figure 14 above The test report N°. Pr-22-2.231-En dated 2023-01-17 [12] and Classification Report PK2-06-22-016-E-0 provide details of the assembly and classification level **E 120 / EI 90.**

During the horizontal installation test, the following were measured.

- The oven temperature using plate thermometers:
- Temperatures of the unexposed fire face of the sandwich panels using thermocouples;
- Temperatures of the steel elements supporting the sandwich panels;
- The difference in deflection at the relevant locations between the interlocking joint and the adjacent panel centres;
- The joint opening at the appropriate points Δc, Δf.

4.1.2.2 Test n°4: Panel laid horizontally with a 4.5m span

The test specimen is defined in Figure 16 and Figure 17.

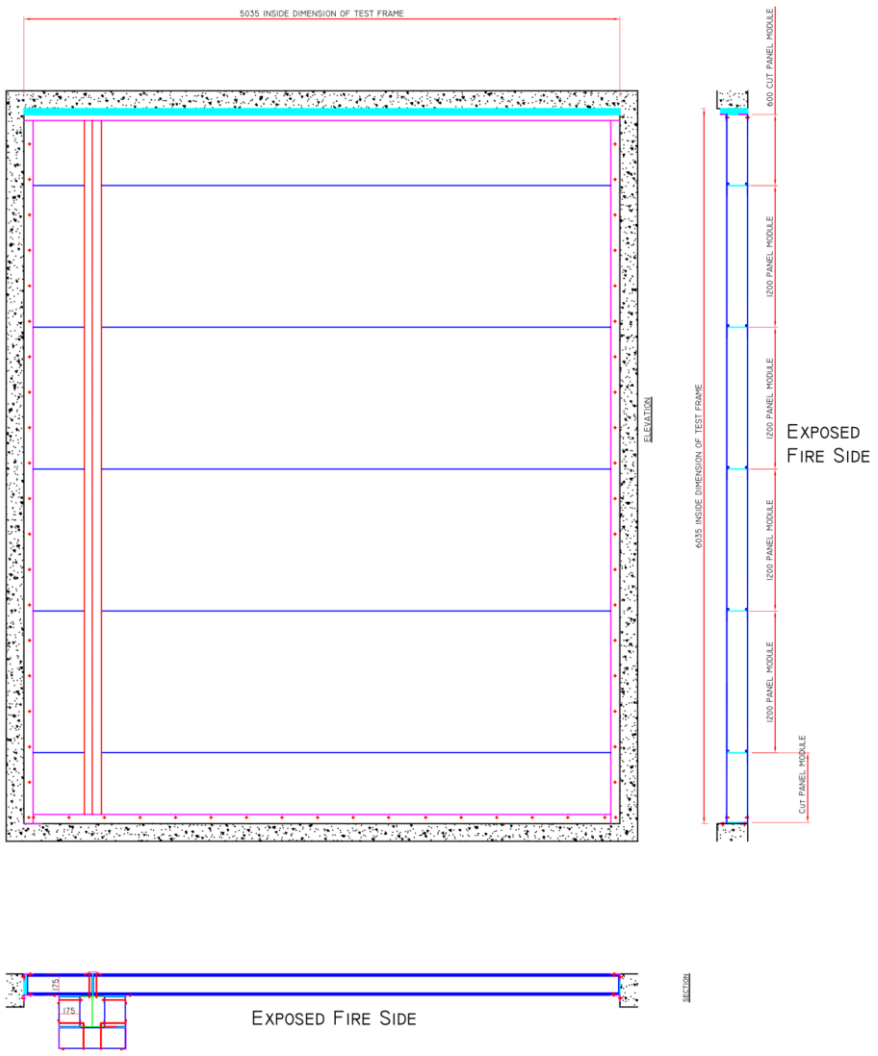


Figure 16: Elevation view of the test specimen n°4 [13]

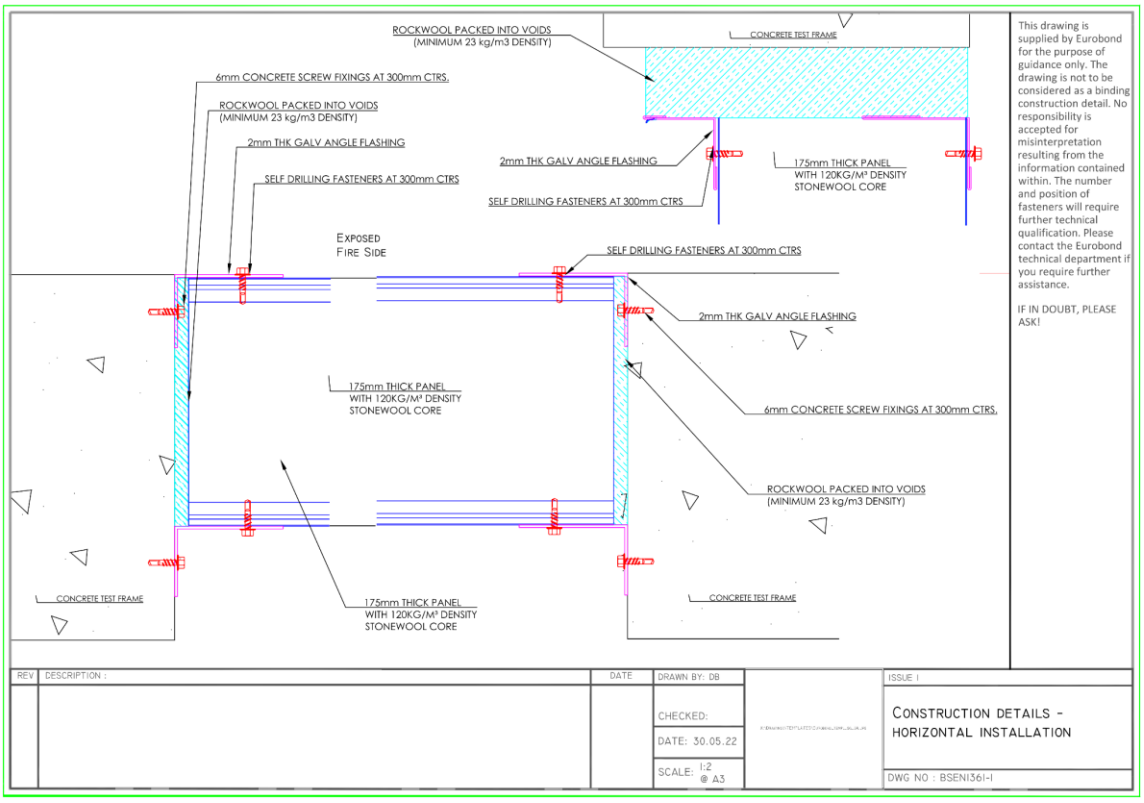


Figure 17: Constructional details of the test specimen n°4 [13]

The test protocol of CSN EN 1364-1 supplemented by CSN EN 1363 and EN 14509 was followed. Details of the set-ups are shown in Figure 16 above. The test report N°. Pr-22-2.086-En issued on 2022-06-13 [13] and classification report PK2-06-22-011-E-0 provide details of the assembly and the classification level **E 120 / EI 120.**

During the vertical installation test, the following were measured.

- The oven temperature using plate thermometers:
- Temperatures of the unexposed fire face of the sandwich panels using thermocouples;
- Temperatures of the steel elements supporting the sandwich panels;
- The difference in deflection at the relevant locations between the interlocking joint and the adjacent panel centres;
- The joint opening at the appropriate places Δc, Δf.

4.2 Definition of tested panels and fixings

4.2.1 Sandwich Panel tested horizontally

4.2.1.1 Panel laid horizontally

The panel tested was as follows:

- Rock wool core cladding panel with through fixings, thickness: 175 mm
- Nominal thickness of the oven facing: 0.5 mm
- Nominal elasticity limit of the oven facing: 280 MPa
- Nominal thickness of external facing: 0.5 mm
- Nominal elasticity limit of external facing: 280 MPa
- Mineral wool density: 120 kg/m^3

The panel is marked CE in accordance with the EN 14509 standard of 2013.

4.2.1.2 Fasteners fixed to the structure

For the cases without intermediate frame:

On both vertical sides and on the bottom part of the rigid construction, L-profiles 100 × 50 × 2 were mounted on EF (and on UF at the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using TutFast HTF-6.3 × 57 carbon steel screws (Producer Fixfast Ltd) in spacing of 450 mm. The upper part of the specimen was without mechanical fixings.

Special panels were anchored to the L-profiles using stainless DrillFast DF2-SS-LS-A15-6.3 × 25 screws (producer Fixfast Ltd) in the direction from EF at 300 mm spacing.

For the cases with intermediate frame:

On both vertical sides and on the bottom part of the rigid construction, L-profiles 100 × 50 × 2 were mounted on EF (and also on UF at the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using TutFast HTF-6.3 × 57 carbon steel screws (producer Fixfast Ltd) at 450 mm spacing. The upper part of the specimen was without mechanical fixings.

Specific panels were anchored to the L-profiles using stainless screws DrillFast DF2-SS-LS-A15-6.3 × 25 (producer Fixfast Ltd) in the direction from EF, in spacing of 300 mm. On one side, the panels were anchored to the steel column with stainless screws DrillFast DF3-SS-HT-A15-5.5 × 225 (producer Fixfast Ltd) in spacing of 500 mm.

See Pavus test reports for details of junctions at the periphery of the specimen

- N°. Pr-22-2.084 issued on 2022-06-13 for horizontal panel without intermediate column.
- N°. Pr-22-2.086 issued on 2022-06-13 for horizontal panel with intermediate column.

4.2.2 Sandwich Panel tested vertically

4.2.2.1 Panel laid vertically

The panel tested was as follows:

- Rock wool core cladding panel with through fixings, thickness: 175 mm
- Nominal thickness of the oven facing: 0.5 mm
- Nominal elasticity limit of the oven facing: 280 MPa
- Nominal thickness of external facing: 0.5 mm
- Nominal elasticity limit of external facing: 280 MPa
- Mineral wool density: 120 kg/m^3

The panel is CE marked in accordance with the EN 14509 standard of 2013.

4.2.2.2 Fasteners fixed to the structure

For cases without intermediate frame:

On both horizontal sides and on the left vertical edge of the rigid construction, L-profiles 100 × 50 × 2 were mounted on EF (and also on UF at the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using TutFast HTF-6.3 × 57 carbon steel screws (producer Fixfast Ltd) at 450 mm spacing. The right vertical edge of the specimen was without mechanical fixings.

Specific panels were anchored to the L-profiles using stainless DrillFast DF2-SS-LS-A15-6.3 × 25 screws (producer Fixfast Ltd) at 300 mm spacing in the direction of the EF.

The structural gaps between the test specimen and the rigid construction were filled with mineral wool POWER-TEK BD 660 (manufacturer Knauf Insulation, spol. s r.o.), nominal density 100 kg/m^3, gap width between 20 and 30 mm.

The right vertical edge was not restrained to allow free movement of the specimen. The gap between the specimen and the rigid construction, with a width of 50 mm, was filled with mineral wool.

For cases with intermediate frame:

On both horizontal sides and on left vertical edge of the rigid construction, L-profiles 100 × 50 × 2 were mounted on EF (and also on UF at the end of the assembly), aligned with the edge of the rigid construction. The profiles were anchored to the rigid construction using TutFast HTF-6.3 × 57 carbon steel screws (producer Fixfast Ltd) at 450 mm spacing. The right vertical edge of the specimen was without mechanical fixings.

Specific panels were anchored to the L-profiles using DrillFast DF2-SS-LS-A15-6.3 × 25 stainless screws (producer Fixfast Ltd) at 300 mm spacing from the EF. On one side, the panels were anchored to the steel beam with DrillFast DF3-SS-HT-A15-5.5 × 225 stainless screws (producer Fixfast Ltd) at 500 mm spacing.

The structural gaps between the test specimen and the rigid construction were filled with mineral wool POWER-TEK BD 660 (manufactured by Knauf Insulation, spol. s r.o.), nominal density 100 kg/m^3, gap width between 20 and 30 mm.

The left vertical edge was left unrestrained to allow free movement of the sample. The gap between the specimen and the rigid construction, with a width of 50 mm, was filled with mineral wool.

Refer to Pavus test reports for details of junctions at the specimen periphery.

- N°. Pr-22-2.085-En issued on 2022-06-13 for vertical panel without intermediate beam.
- N°. Pr-22-2.231-En issued on 2023-01-17 for vertical panel with intermediate beam.

5 TEST RESULTS

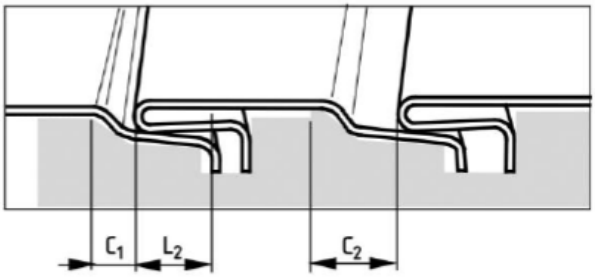
5.1 Test results of small-scale tests 3 m × 3 m

5.1.1 Vertical installation

During the test, flame and hot gas tightness was demonstrated for 198 minutes (integrity) and 198 minutes of insulation.

Displacements Δc and Δf were measured over time (cf. Figure 18 and Figure 19 below).

Measurement according to EN 15254-5, Annex B:



$\Delta c = (c_2 - c_1)/L_2$

Figure B.2 — Calculation of Δc

L_2 = 17 mm

c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)	
	Δc_1	Δc_2
0	0.000	0.000
15	0.000	0.000
30	0.000	0.000
45	0.000	0.000
60	0.000	0.000
75	0.000	0.000
90	0.000	0.000
105	0.118	0.059
120	0.176	0.059
135	0.294	0.118
150	0.471	0.118
180	0.765	0.176
188	0.882	0.235

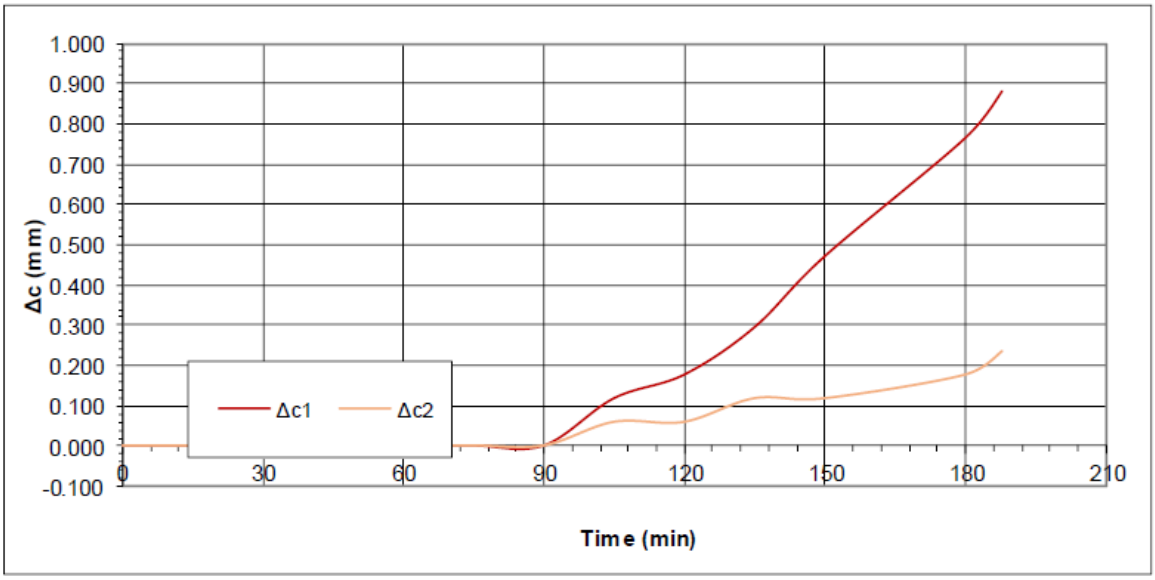
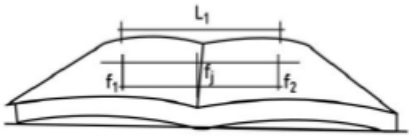


Figure 18: Displacement measurements Δc – horizontal installation 3 m × 3 m [8]

Measurement according to EN 15254-5, Annex B:



$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm) Δf_1	Δf_2
0:00:00	0.000	0.000
0:05:00	0.006	0.002
0:10:00	0.005	0.002
0:15:00	0.005	0.002
0:30:00	0.004	0.002
0:45:00	0.004	0.003
1:00:00	0.004	0.003
1:15:00	0.004	0.003
1:30:00	0.003	0.004
1:45:00	0.001	0.005
2:00:00	-0.011	0.007
2:15:00	-0.019	0.006
2:30:00	-0.021	0.003
2:45:00	-0.023	0.000
3:00:00	-0.023	-0.003
3:15:00	-0.024	-0.007
3:18:20	-0.024	-0.008

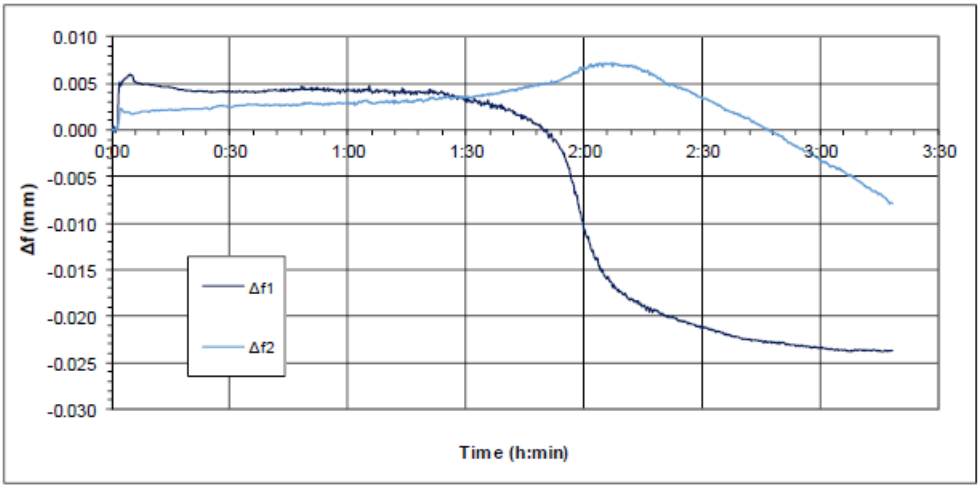


Figure 19: Displacement measurements Δf – horizontal installation 3 m × 3 m [8]

Results obtained:

During the test, flame and hot gas tightness was demonstrated for 198 minutes.

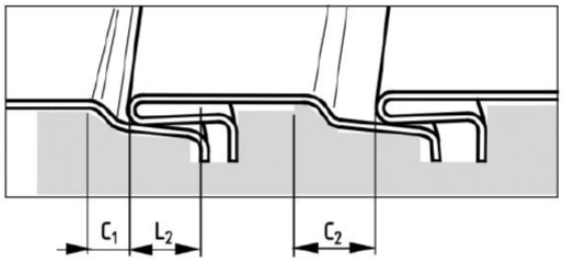
The vertically spanning panels are EI 180 according to § 5.2.4 of EN 13501-2.

5.1.2 Horizontal installation

During the test, flame and hot gas tightness was demonstrated for 216 minutes (integrity) and 216 minutes insulation.

Displacements Δc and Δf were measured over time (cf. Figure 20 and Figure 21 below).

Measurement according to EN 15254-5, Annex B:



$$\Delta c = (c_2 - c_1)/L_2$$

Figure B.2 — Calculation of Δc

L_2 = 17 mm

c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)	
	Δc_1	Δc_2
0	0.000	0.000
15	0.000	0.000
30	0.000	0.000
45	0.059	0.059
60	0.059	0.059
75	0.059	0.059
90	0.118	0.118
105	0.118	0.118
120	0.059	0.059
135	0.059	0.059
150	0.059	-0.118
180	0.059	-0.118
210	0.059	-0.059
217	0.059	-0.059

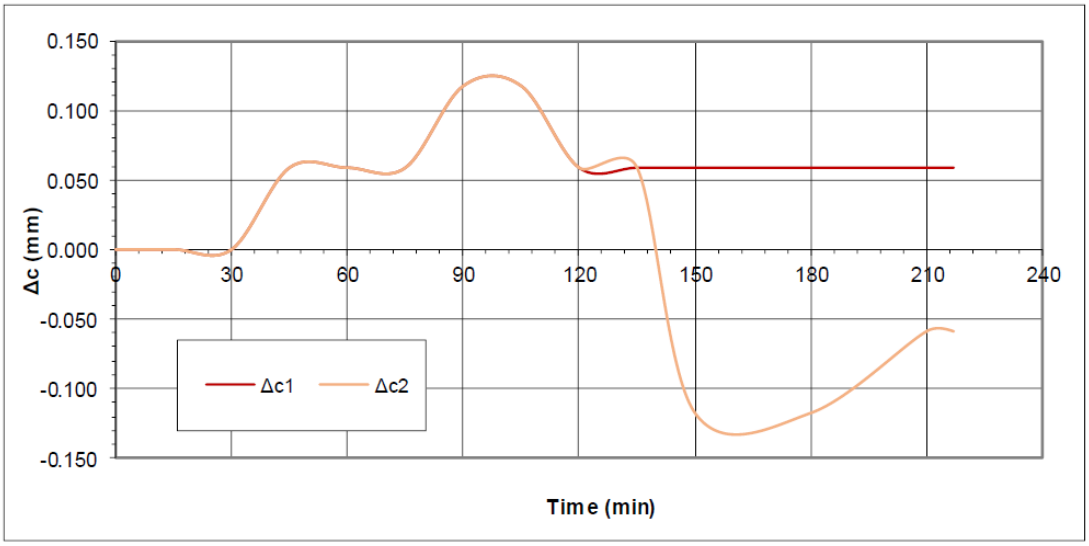
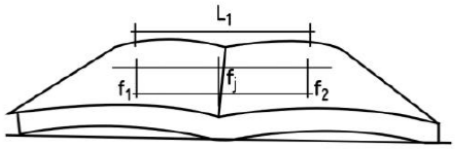


Figure 20: Displacement measurements Δc – horizontal installation 3 m × 3 m [9]

Measurement according to EN 15254-5, Annex B:



$$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm) Δf_1	Δf_2
0:00:00	0.000	0.000
0:05:00	0.002	0.005
0:10:00	0.002	0.005
0:15:00	0.002	0.004
0:30:00	0.003	0.004
0:45:00	0.002	0.004
1:00:00	0.002	0.005
1:15:00	0.001	0.004
1:30:00	0.001	0.004
1:45:00	0.001	0.004
2:00:00	0.000	0.003
2:15:00	0.000	0.002
2:30:00	-0.001	-0.001
2:45:00	-0.001	-0.005
3:00:00	-0.001	-0.011
3:15:00	0.000	-0.014
3:30:00	0.001	-0.017
3:36:00	0.001	-0.018

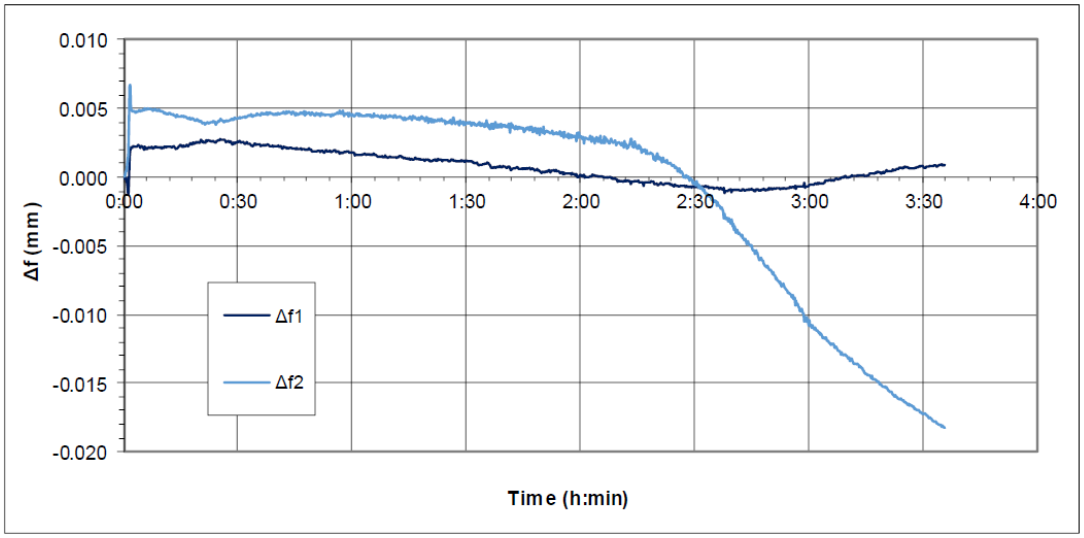


Figure 21: Displacement measurements Δf – horizontal installation 3 m × 3 m [9]

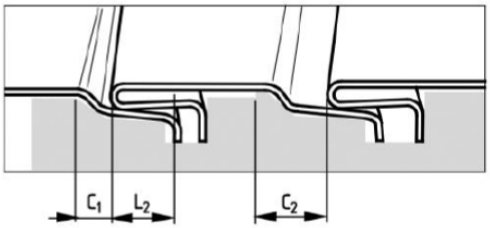
Results obtained:
During the test, flame and hot gas tightness was demonstrated for 216 minutes.
The horizontally spanning panels are EI 180 according to § 5.2.4 of EN 13501-2)

5.2 Results of large-scale tests

5.2.1 Test n°1: Vertical installation without intermediate beam

During the test, flame and hot gas tightness was demonstrated for 94 minutes.
Displacements Δc and Δf were measured over time (cf. Figure 22 and Figure 23 below).

Measurement according to EN 15254-5, Annex B:



$\Delta c = (c_2 - c_1)/L_2$

Figure B.2 — Calculation of Δc

L_2 = 17 mm
c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)			
	Δc_1	Δc_2	Δc_3	Δc_4
0	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000
45	0.000	0.059	0.059	0.059
60	0.000	0.059	0.118	0.059
75	0.059	0.059	0.176	0.059
90	0.176	0.176	0.176	0.059
107	0.235	0.353	0.176	0.059

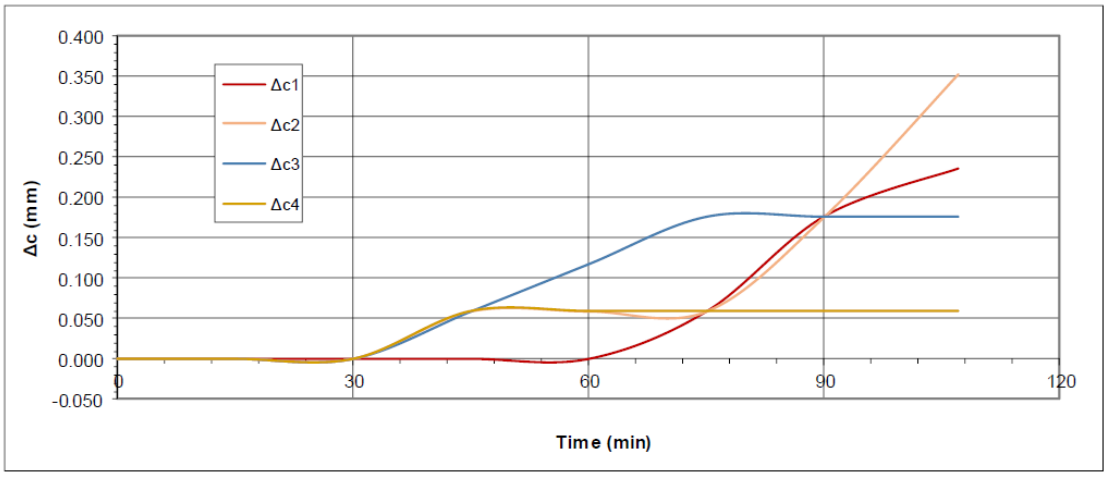
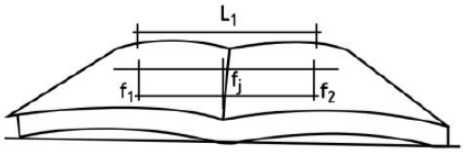


Figure 22: Displacement measurements Δc – vertical installation 6 m × 5 m [10]

Measurement according to EN 15254-5, Annex B:



$$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm)		
	Δf_1	Δf_2	Δf_3
0:00:00	0.000	0.000	0.000
0:05:00	0.002	0.002	-0.003
0:10:00	0.003	0.002	-0.003
0:15:00	0.001	0.002	-0.004
0:30:00	0.003	0.003	-0.003
0:45:00	0.006	0.005	-0.002
1:00:00	0.010	0.009	0.001
1:15:00	0.010	0.016	0.002
1:30:00	0.016	0.019	0.004
1:45:00	0.026	-0.009	0.008
1:47:20	0.024	-0.017	0.007

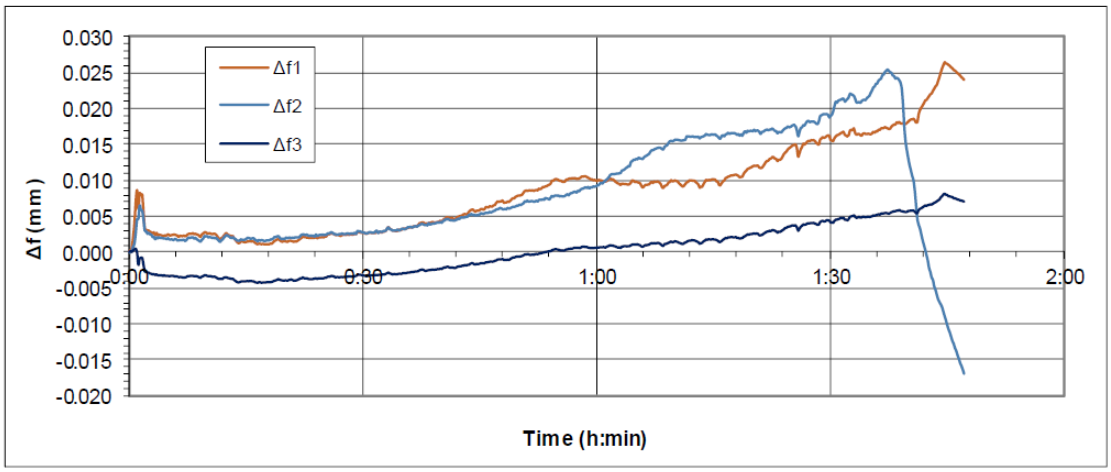


Figure 23: Displacement measurements Δf – vertical installation 6 m × 5 m [10]

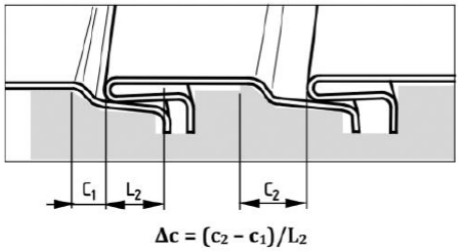
Results obtained:
During the test, flame and hot gas tightness was demonstrated for 94 minutes.
The vertically spanning panels are EI 90 according to § 5.2.4 of EN 13501-2).

5.2.2 Test n°2: Vertical installation with intermediate horizontal beam

During the test, flame and hot gas tightness was demonstrated for 141 minutes (integrity and radiation) and 104 minutes (insulation).

Displacements Δc and Δf were measured over time (cf. Figure 24 and Figure 25 below).

Measurement according to EN 15254-5, Annex B:



$\Delta c = (c_2 - c_1)/L_2$

Figure B.2 — Calculation of Δc

L_2 = 17 mm

c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)			
	Δc_1	Δc_2	Δc_3	Δc_4
0	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000
30	0.059	0.059	0.000	0.000
45	0.059	0.059	0.000	0.000
60	0.059	0.235	0.059	0.000
75	0.059	0.235	0.059	0.000
90	0.059	0.235	0.176	0.000
105	0.059	0.235	0.412	0.000
120	0.059	0.235	0.706	0.000
135	0.118	0.235	0.824	0.059
144	0.118	0.235	0.824	0.235

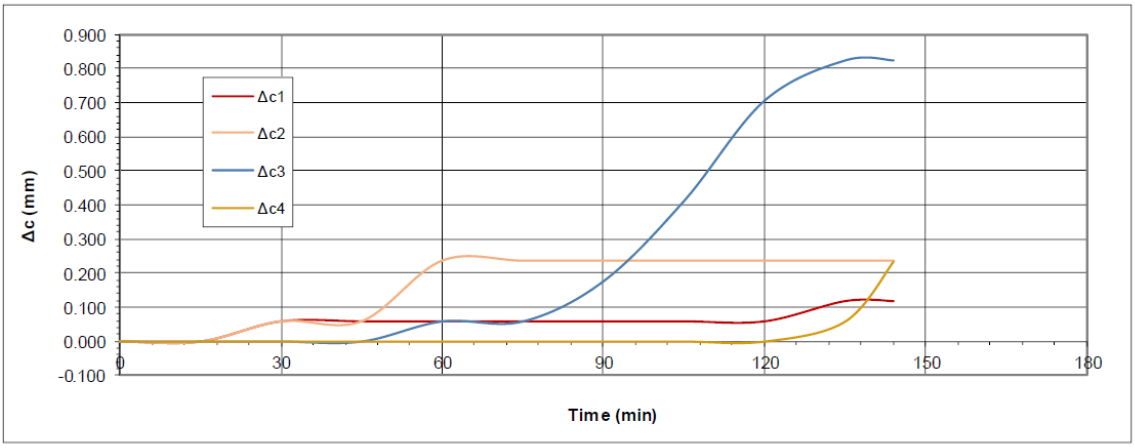
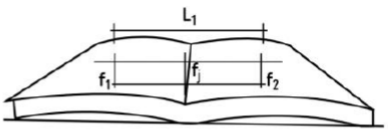


Figure 24: Displacement measurements ∆c – vertical installation 5.0 + 1.0 m × 5 m [12]

Measurement according to EN 15254-5, Annex B:



$$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm) Δf_1	Δf_2	Δf_3
0:00:00	0.000	0.000	0.000
0:05:00	0.003	0.002	0.000
0:10:00	0.003	0.001	0.000
0:15:00	0.003	0.000	-0.001
0:30:00	0.004	0.000	-0.001
0:45:00	0.004	-0.001	-0.001
1:00:00	0.004	-0.001	0.000
1:15:00	0.005	-0.007	0.004
1:30:00	0.005	-0.007	0.007
1:45:00	0.003	-0.006	0.024
2:00:00	0.004	-0.005	0.033
2:15:00	0.026	-0.008	0.022
2:24:20	0.035	-0.011	0.019

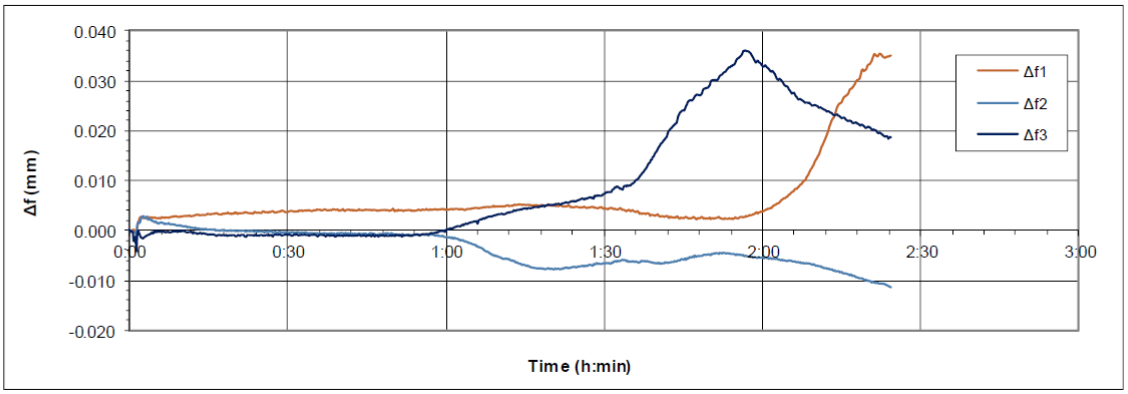


Figure 25: Displacement measurements Δf – vertical installation 5.0 + 1.0 m × 5 m [12]

Results obtained:

During the test, flame and hot gas tightness was demonstrated for 141 minutes and insulation 104 minutes.

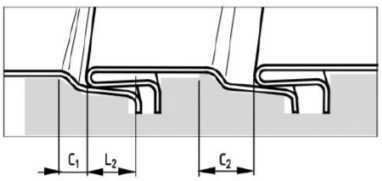
The vertically spanning panels are E 120 and EI 90 according to § 5.2.4 of EN 13501-2).

5.2.3 Test n°3: Horizontal installation without intermediate column

During the test, flame and hot gas tightness was demonstrated for 126 minutes.

Displacements Δc and Δf were measured over time (cf. Figure 26 and Figure 27 below).

Measurement according to EN 15254-5, Annex B:



$\Delta c = (c_2 - c_1)/L_2$

Figure B.2 — Calculation of Δc

L_2 = 17 mm

c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)				
	Δc_1	Δc_2	Δc_3	Δc_4	Δc_5
0	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.118
30	0.000	0.000	0.000	0.000	0.176
45	0.000	0.059	0.000	0.000	0.176
60	0.000	0.059	0.000	0.059	0.059
75	0.000	0.059	0.000	0.353	0.059
90	0.118	0.059	0.000	0.588	0.059
120	0.294	0.118	0.176	0.824	0.059
135	0.353	0.176	0.529	0.941	0.059
144	0.412	0.235	0.882	1.000	0.059

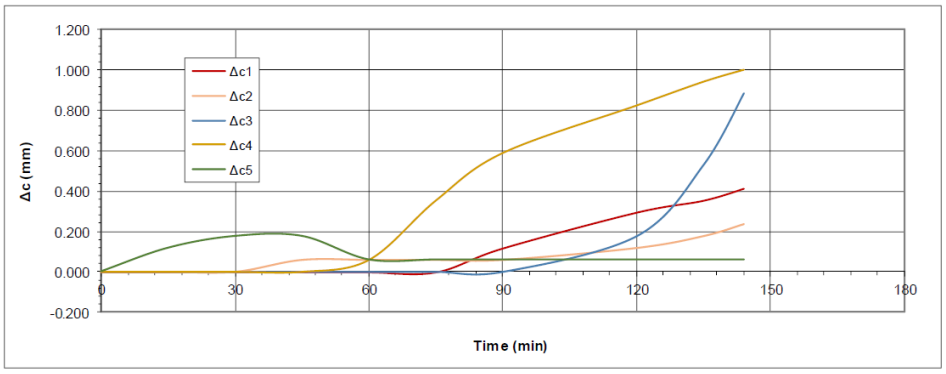
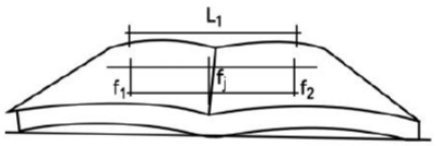


Figure 26: Displacement measurements Δc – horizontal installation 5 m × 6 m [11]

Measurement according to EN 15254-5, Annex B:



$$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm) Δf_1	Δf_2	Δf_3
0:00:00	0.000	0.000	0.000
0:05:00	0.001	0.000	0.002
0:10:00	0.001	0.001	0.002
0:15:00	0.001	0.000	0.002
0:30:00	-0.001	0.000	0.002
0:45:00	-0.004	-0.001	0.002
1:00:00	-0.006	-0.002	0.002
1:15:00	-0.010	-0.003	0.001
1:30:00	-0.014	-0.002	0.001
1:45:00	-0.022	-0.002	0.000
2:00:00	-0.032	0.007	0.000
2:15:00	-0.047	0.030	-0.001
2:24:00	-0.065	-0.009	-0.002

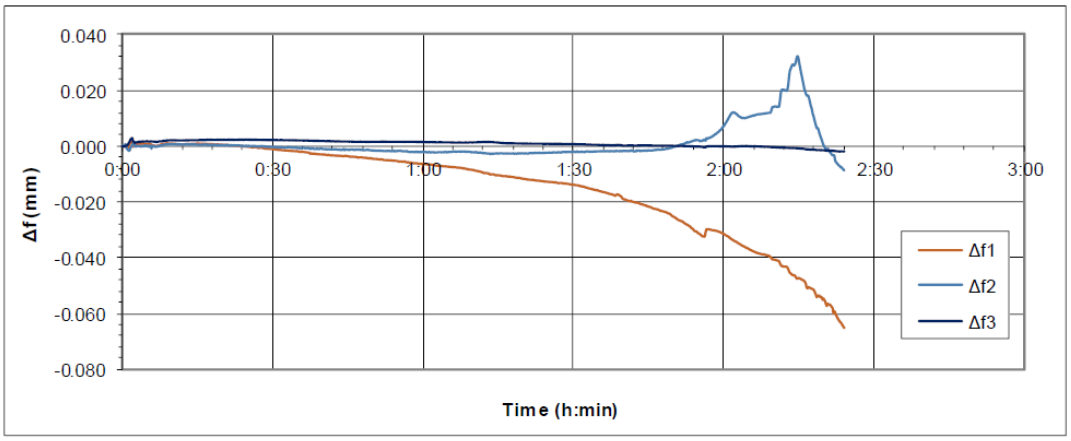


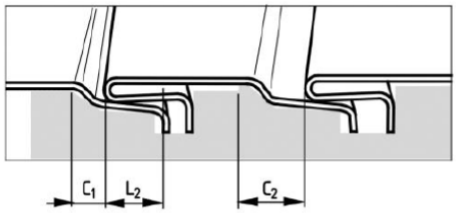
Figure 27: Displacement measurements Δf – horizontal installation 5 m × 6 m [11]

Results obtained
During the test, flame and hot gas tightness was demonstrated for 120 minutes.
The horizontally spanning panels are EI 120 according to § 5.2.4 of EN 13501-2).

5.2.4 Test n°4: Horizontal installation with intermediate vertical column

During the test, the insulation was satisfied for 122 minutes and 163 minutes for integrity. Displacements Δc and Δf were measured over time (cf. Figure 28 and Figure 29 below).

Measurement according to EN 15254-5, Annex B:



$\Delta c = (c_2 - c_1)/L_2$

Figure B.2 — Calculation of Δc

L_2 = 17 mm

c_0 = 2 mm (before the test)

Time (min)	Deflection difference (mm)				
	Δc_1	Δc_2	Δc_3	Δc_4	Δc_5
0	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.059
45	0.000	0.000	0.059	0.000	0.059
60	0.000	0.000	0.059	0.000	0.059
75	0.000	0.000	0.059	0.000	0.059
90	0.000	0.000	0.059	0.000	0.059
105	0.059	0.000	0.059	0.059	0.059
120	0.059	0.000	0.000	0.176	0.000
135	0.118	0.176	0.000	0.176	0.000
150	0.118	0.294	0.000	0.176	0.059
180	0.118	0.412	0.000	0.176	0.059

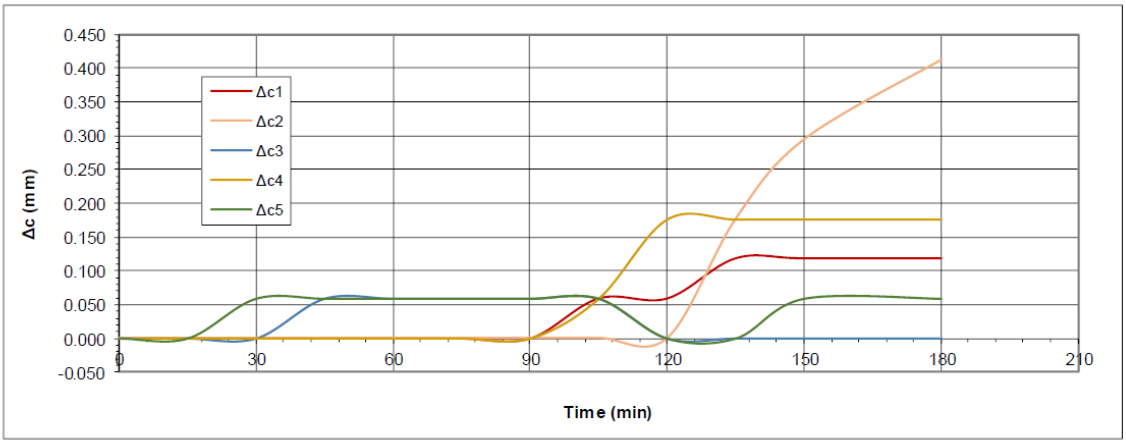
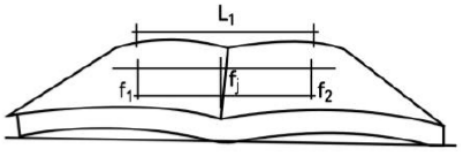


Figure 28: Displacement measurements Δc – horizontal installation 4.5 + 0.5 m × 6 m [13]

Measurement according to EN 15254-5, Annex B:



$$\Delta f = (f_j - 0{,}5x(f_1 + f_2))/L_1$$

Figure B.1 — Calculation of Δf in midspan section

L_1 = 1200 mm

Time (h:min:s)	Deflection difference (mm) Δf_1	Δf_2	Δf_3
0:00:00	0.000	0.000	0.000
0:05:00	0.002	0.005	0.004
0:10:00	0.002	0.005	0.005
0:15:00	0.002	0.005	0.005
0:30:00	0.001	0.004	0.005
0:45:00	0.001	0.003	0.005
1:00:00	0.000	0.003	0.004
1:15:00	0.000	0.004	0.006
1:30:00	0.001	0.005	0.009
1:45:00	0.000	0.005	0.015
2:00:00	-0.003	0.006	0.008
2:15:00	-0.017	0.003	-0.001
2:30:00	-0.026	0.009	-0.001
2:45:00	-0.033	0.015	0.006
3:00:00	-0.037	0.020	0.008

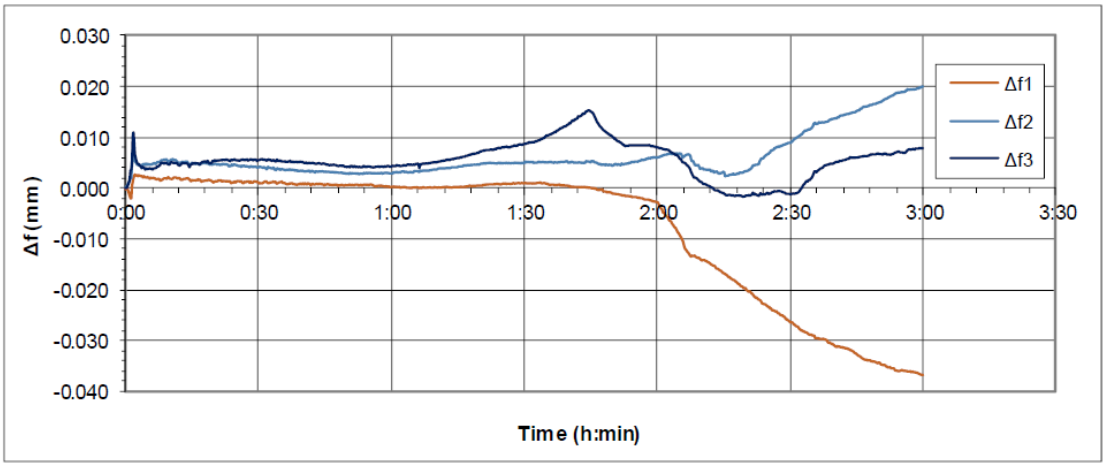


Figure 29: Displacement measurements ∆f – horizontal installation 4.5 + 0.5 m × 6 m [13]

Results
During the test, flame and hot gas tightness was demonstrated for 163 minutes.
The insulation criteria were satisfied for 122 minutes.
The horizontally spanning panels are EI 120 according to § 5.2.4 of EN 13501-2).

5.2.5 Synthesis of tests results

The synthesis of the results is given in the Table 5below:

Table 5: Overview of tests results on walls

Wall configuration		Test results	
Panel arrangement	**Wall sizes**	**Integrity**	**Insulation**
Horizontal	3 × 3 m	216	216
	5 × 6 m	126	126
	5 × 6 m (with intermediate steel column)	163	122
Vertical	3 × 3 m	198	198
	5 × 6 m	94	94
	5 × 6 m (with intermediate steel beam)	141	104

Remark:

It can be noted that the intermediate frame increases the wall performance by 37 minutes for panels spanning horizontally and by 47 minutes (integrity only) and 10 minutes in insulation for panels spanning vertically.

6 APPLICATION OF THE SCOPE EXTRAPOLATION RULES OF STANDARD 15254-5 (2018)

6.1 For vertical installation (based on 3 m × 3 m seamless test) with 6 m height (span) and 5 m width without intermediate beam (seamless)

a) Integrity and insulation

The target fire performance duration is 120 minutes.

During the 3 m × 3 m seamless vertical test, the EI performances were 198 minutes.

The minimum duration criterion of 10 minutes is met.

The time overrun is 78 minutes or (78/120) = 65%.

According to Table 4 of Article 5.3.1 of the EN 15254-5 standard:

As the test was carried out at 3 m with 78 minutes of exceedance or 35% of exceedance, the span extension is 7.5 m.

This means an EI 120 performance at 7.5 m in vertical installation can be achieved by applying the scope extension rules of standard 15254-5 (2018).

The large size test (did not validate this duration (94 minutes).

The result obtained during the large-scale test of a 6 m span (height) × 5 m width, without stitching is EI 90 minutes.

Conclusion

The scope extension rules, section 5.3.1 of the 15254-5 standard (2018), is therefore not verified for the panel tested in vertical position.

6.2 For horizontal installation (based on 3 m × 3 m seamless test) with 5 m span and 6 m height without vertical column

The target fire performance duration is 120 minutes.

During the 3 m × 3 m horizontally test, the EI performances were 216 minutes.

The minimum duration criterion of 10 minutes is met.

The duration overrun is (216-120) = 96 minutes or 96/120 = 80%.

According to Table 4 of Article 5.3.1 of the EN 15254-5 standard.

As the test was carried out at 3 m with 96 minutes of exceedance or 35% of exceedance, the span extension is 7.5 m.

This means an EI120 performance at 7.5 m in horizontal installation can be achieved by applying the scope extension rules of standard 15254-5 (2018).

The large size test, conducted on a span of 5 m × 6 m height, confirmed this, and validated the EI 120 with a 5 m span (126 minutes).

This was successful for 120 minutes (EI), but there was an integrity failure at the 127th minute (6 mm gap gauge on the second joint from the bottom) and at the 136th minute (sustained flame in half the height of the wall).

The scope extension rule, section 5.3.1 of standard 15254-5 (2018), is therefore verified for the 3 m => 5 m extension but it is clear that it is not possible to reach 7 m, so this EXAP rule does not work on the panel tested.

The result obtained during the large-scale test 5 m horizontally × 6 m vertically without stitching is 126 minutes.

At the 127th minute

At the 135th minute

Conclusion:

The scope extension rules, section 5.3.1 of standard 15254-5 (2018), are therefore not verified for the panel that is tested horizontally.

6.3 For horizontal installation (based on test 3 m × 3 m seamless test) with 4.5 m span and 6 m height with vertical column

The target fire performance duration is 120 minutes.

During the 3 m × 3 m horizontally test, the flame and hot gas tightness was 216 minutes for integrity and insulation.

The minimum duration criterion of 10 minutes is met.

The duration overrun is (216-120) = 96 minutes or 96/120 = 80%.

According to Table 4 of Article 5.3.1 of the EN 15254-5 standard.

As the test was carried out at 3 m with 96 minutes of exceedance or 35% of exceedance, the span extension is 7.5 m.

This means an EI120 performance at 7.5 m in horizontal installation can be achieved by applying the scope extension rules of standard 15254-5 (2018).

The large size test, conducted on a span of 4.5 m × 6 m height, confirmed this, and validated the EI 120 with a 5 m span (163 minutes for integrity and 122 for insulation).

This was successful for 120 minutes (EI), but there was an integrity failure at the 163rd minute and an insulation failure at the 122nd minute.

The scope extension rule, section 5.3.1 of standard 15254-5 (2018), is therefore verified for the 3 m => 5 m extension but it is clear that it is not possible to reach 7 m (because 122 minutes of insulation only), so this EXAP rule does not work on the panel tested.

At the 164th minutes

Conclusion

The scope extension rules, section 5.3.1 of standard 15254-5 (2018), are therefore not verified for the panel tested horizontally at minimum for the insulation criteria.

6.4 For vertical installation (based on test 3 m × 3 m seamless test) with 5.0 m span and 6 m height with horizontal frame

The target fire performance duration is 120 minutes.

During the 3 m × 3 m vertically test, the flame and hot gas tightness was 198 minutes for integrity and insulation.

The minimum duration criterion of 10 minutes is met.

The duration overrun is (198-120) = 78 minutes or 78/120 = 65%.

According to Table 4 of Article 5.3.1 of the EN 15254-5 standard.

As the test was carried out at 3 m with 198 minutes of exceedance or 65% of exceedance, the span extension is 7.5 m.

This means an EI120 performance at 7.5 m in horizontal installation can be achieved by applying the scope extension rules of standard 15254-5 (2018).

The large size test, conducted on a span of 5.0 m × 6 m height, confirmed this, and validated the EI 120 with a 5.0 m span (141 minutes for integrity and 104 for insulation).

The scope extension rule, section 5.3.1 of standard 15254-5 (2018), is therefore checked for the 3 m => 5 m extension but it is clear that it is not possible to reach 7 m (because 104 minutes of insulation only), so this EXAP rule does not work on the panel tested.

Integrity failure after 142 minutes

Conclusion

The scope extension rules, section 5.3.1 of standard 15254-5 (2018), are therefore not checked for the panel tested vertically at minimum for the insulation criteria.

7 APPLICATION OF THE SPAN EXTRAPOLATION RULES OF STANDARD 15254-5 (2007-2009-2013 EGOLF)

7.1 For vertical installation (based on 3 m × 3 m without stitching test)

The criteria in ∆c and ∆f of standard 15254-5 (2013) Annex B from the 3 m × 3 m test are as follows (no criteria in 2018 version):

1) Extensions are only allowed if Δc < 0,5;
2) If Δf < 0,01, the span may be increased up to 12 m with the same classification as the tested span;
3) If Δf > 0,06, the span may be increased up to 4 m with the same classification as the one tested in accordance with the direct application.
4) For values between 0.01 and 0.06, measurements to calculate Δf and Δc can be obtained by linear interpolation and will be taken throughout the test. During the span evaluation, measurements at the time of the resistance class will be used.

This implies that for the same panel, various spans can be allowed; to achieve this, the criterion ∆c should be followed.

The result obtained during the test at 3 m span × 3 m seamless is 198 minutes.

∆c at 120 minutes is equal to 0.059 / 0.176 so< 0.5 => so, span extension is possible,
Δf at 120 minutes is between –0.011 and 0.007 so < 0.1,
So, the span can be increase up to 12m with the same classification.

The test at 6 m vertically is at 94 min. So, clearly not possible to extend at 12m!

		Integrity	Insulation	Radiation
Vertical	3 horizontally × **3** m vertically	198	198	198
	5m horizontally × **6** m vertically	94	94	94
	5m horizontally × (**5.0** +1.0) m vertically (with intermediate steel)	141	104	141

Conclusion

The tested panel failed at 198 minutes in 3mx3m and at 94 mm in 5x6m, so, it is not possible to go at 12m. So, the ∆c Δf rule does not work.

7.2 For horizontal installation (based on 3 m × 3 m without stitching test)

The criteria in ∆c and ∆f of standard 15254-5 (2013) Annex B from the 3 m × 3 m test are as follows (no criteria in 2018 version):

1) Extensions are only allowed if Δc < 0,5;
2) If Δf < 0,01, the span may be increased up to 12 m with the same classification as the tested span;
3) If Δf > 0,06, the span may be increased up to 4 m with the same classification as the one tested in accordance with the direct application.
4) For values between 0.01 and 0.06, measurements to calculate Δf and Δc can be obtained by linear interpolation and will be taken throughout the test. During the span evaluation, measurements at the time of the resistance class will be used.

This implies that for the same panel, various spans can be allowed; to achieve this, the criterion ∆c should be followed.

The result obtained during the test with a span of 3 m × 3 m seamless is 216 minutes.

∆c at 120 minutes is equal to 0.059 so < 0.5 => so, span extension is possible,
Δf at 120 minutes is between 0 and 0.003, so < 0.1

So, the span can be increase up to 12m with the same classification.

The test at 5 m is at 126 minutes. So, clearly not possible to extend at 12m!

		Integrity	Insulation	Radiation
Horizontal	**3** m horizontally × 3 m vertically	216	216	216
	5 m horizontally × 6 m vertically	126	126	126
	(**4.5**+0.5) m horizontally × 6 m (with intermediate steel)	163	122	163

Conclusion

The tested panel failed at 216 minutes in 3mx3m and at 126 mm in 5x6m, so, it is not possible to go at 12m. So, the ∆c ∆f rule does not work.

8 APPLICATION OF THE SPAN EXTRAPOLATION RULES OF THE 15254-5 STANDARD FROM IFBS/DIBT/PPA EUROPE RULES

8.1 For vertical installation (based on 3 m × 3 m seamless test)

The criteria are defined in Table 6below:

Table 6: New extended application rule for vertical application proposed in the IFBS/DIBT/PPA project

Tested span length	Extrapolation
From 3 m to 6 m	-35 minutes by span meter

It was measured on the 3 m × 3 m test = 198 minutes:

4 m span => 198 - 35 =163 minutes
5 m span => 163 - 35 =128 minutes
6 m span => 128 – 35 = 93 minutes
On the large-scale test, it was measured: Without horizontal frame, Fishwall span test at 6 m => **94 minutes**

Conclusion
So, for the vertical span panels without horizontal frame, following the extended rules proposed by PPA Europe, a span of 1 minutes is validated for the panel with vertical span (but the result is very near). But the EI90 classification is obtained both in accordance with the PPA/IFBS/DIBT rules and the tests carried out for the Fishwall project.

8.2 Real test of 5.0 + 1.0 m vertically and 5 m horizontally with horizontal intermediate frame at 5.0 m

For integrity:

- It was measured on the test 3 m × 3 m = 198 minutes:
- 4 m of span => 198 - 35 = 163 minutes
- 5m of span => 163 - 35 = 128 minutes
- 6 m of span => 128 – 35 = 93 minutes
- For 5.0 m + 1.0 of span (height) × 5 m width the result is 141 minutes for integrity **with horizontal intermediate frame** without stitching.

For insulation:

- It was measured on the test 3 m × 3 m = 198 minutes:
- 4 m of span => 198 - 35 = 163 minutes
- 5m of span => 163 - 35 = 128 minutes
- 6 m of span => 128 – 35 = 93 minutes
- For 5.0 m + 1.0 of span (height) × 5 m width the result is 104 minutes for insulation **with horizontal intermediate frame** without stitching.

Conclusion
So, for vertical span panels, with horizontal frame, following the extended rules proposed by PPA Europe, a span is validated for integrity, but it is not validated for the 24 minutes insulation. Nevertheless, both results give EI90.

8.3 For horizontal installation (based on 3 m × 3 m without stitching test)

The criteria are defined in the Table 7 below:

Table 7: New extended application rule for horizontal application proposed in the IFBS/DIBT/PPA project

Tested span length	Extrapolation
From 3 m to 6 m	-20 minutes per metre of span
From 6 m to 7.5 m	-35 minutes per metre of span
From x meter to x +2 m$\leq 10\,m$	-35 minutes per metre of span

It was measured on the 3 m × 3 m horizontal test 216 minutes seamless:

- 4 m of span => 216 - 20 = 196 minutes
- 5 m of span => 196 - 20 = 176 minutes (almost 3 hours => for 126 measured (2 hours)
- 6 m of span => 176 - 20 = 156 minutes
- It was obtained 126 minutes measured Fishwall at 5 m => therefore, the PPA/IFBS/DIBT rules are not satisfied for the tested panel.

Conclusion

So, for horizontal span panels, without vertical frame, following the extended rules proposed by PPA Europe, a span of 50 minutes is not validated for the vertical span panel. However, the classification EI120 is obtained both following the PPA/IFBS/DIBT rules and the tests performed for the Fishwall project.

8.4 Real test of 4.5 + 0.5 m horizontally and 6 m vertically with vertical intermediate frame at 4.5 m

In the large-scale test, it was measured without stitching:

For 4.5 m of span, the with vertical intermediate frame without stitching: integrity = 163 minutes, isolation = 122 minutes.

It was measured on the test 3 m × 3 m = 216 minutes seamless:

For Integrity:

The rule should be -20 minutes per meter of span.

4 m of span => 216 - 20 = 196 minutes for (196 PPA/IFBS/DIBT)

4.5 m of span => (196+176)/2 = 186 minutes for PPA/IFBS/DIBT for (163 minutes tested) => not safe

5 m of span => 216-20-20 = 176 minutes

For 6 m of span => 216 – 20 – 20 - 20 = 156 minutes.

For Insulation:

The rule should be -20 minutes per meter of span.

4 m of span => 216 – 20 = 196 minutes for (196 PPA/IFBS/DIBT)

4.5 m of span => (153+90)/2 = 186 minutes for PPA/IFBS/DIBT (122 minutes tested) => not safe

5 m of span => 196 - 20 - 20 = 176 minutes

6 m of span => 176 - 20 = 156 minutes

Conclusion

Thus, for horizontally spanning panels, with vertical frame, the extended rules proposed by PPA Europe do not validate a span of 23 minutes for integrity and 64 minutes for insulation.

9 CONCLUSION

The objective of this report was:

- To study the state of the art in terms of extrapolation of the scope of sandwich panels with two steel facings and a mineral wool core according to the different versions of standards EN 1364 and EN 15254-5 on the one hand and compare them with the available tests carried out both in small dimensions (3mx3m) and large dimensions 5m by 6m in other parts;
- To analyze the current normative developments on the EN 15254-5 standard on the basis of IFBS/DIBT/PPAeurope research [15] in relation to this existing state of the art;
- To analyze the full-scale tests carried out as part of the FISHWALL project in view of the state of the art previously cited;
- To conclude whether the current version of EN 15254-5 is safe or not in one part and whether it is possible to establish extrapolation rules of safety scope in line with current normative developments.

It turns out that the only large-scale tests available are those appearing in the IFBS/DIBT/PPAeurope report [15], which confirms that the current EN 15254-5 standard is not safe in part and that the new rules of the range extrapolation proposed there seems much safer and representative of the behavior of large-sized panels from other parts. The new (confidential) draft standard EN 15254-5 takes this approach from.

Therefore, it was decided to verify the fundamental points above-mentioned, based on experimental results obtained from the standard fire tests performed on 5x6m walls in the scope of task 2.1 and the relevant test results for 3x3m walls provided by Euroclad group LTD, the results of which are given below.

The test results of the FISHWALL project are as follows:

		Integrity	**Insulation**
Horizontal	**3** m horizontally × 3 m vertically	216	216
	5 m horizontally × 6 m vertically	126	126
	(**4.5**+0.5) m horizontally × 6 m (with intermediate steel)	163	122
Vertical	3 horizontally × **3** m vertically	198	198
	5 horizontally × **6** m vertically	94	94
	5 horizontally × (**5.0**+1.0) m vertically (with intermediate steel)	141	104

About the extended application EN 15254+5 (2021)

The extended applications in accordance with EN 15254-5 (in application) are not safe for the tested panel, both horizontally and vertically.

About the ΔcΔf rule for the EN 15254-5 (2018 annex B)

The ΔcΔf rule does not work.

About the PPAS/IFBS/DIBT rules (proposed in 2021)

The testing of the PPA/IFBS/DIBT extended application rules are given below.

The PPA/IFBS/DIBT rules don't work too bad for panel spanning vertically only with a decrease of the performance for each meter added from the initial test.

	Without intermediate profile				With intermediate profile			
Span	**6 m**				**5.0 m**			
Panels spanning vertically	E tested FISHWALL	E (**) PPA/DIBT	I tested FISHWALL	I (**) PPA/DIBT	E tested FISHWALL	E (**) PPA/DIBT	I tested FISHWALL	I (**) PPA/DIBT
Duration in minutes	**94**	93	**94**	93	**141**	112	**104**	112
Possible classification	**90**	**90**	**90**	**90**	**120**	**90**	**90 (*)**	**90**
Span	**5m**				**4.5 m**			
Panels spanning horizontally	E tested FISHWALL	E (**) PPA/DIBT	I tested FISHWALL	I (**) PPA/DIBT	E tested FISHWALL	E (**) PPA/DIBT	I tested FISHWALL	I (**) PPA/DIBT
Duration in minutes	**126**	176	**126**	(*)	**163**	186	**122**	186
Possible classification	**120**	**120**	**120**	**120**	**120**	**120(*)**	**120**	**120(*)**

(*) If we lose the E level, we must be at the same level of E for the other classifications (I). It can't be higher than E according to EN 1363-1

(**) Obtained through the extrapolation rules of PPA/DIBT/IFBS on large scale tests compared with 3 m × 3 m, tested panels for a field of application of 6 m maximum with a possible loss of performance in front of a required level (here 120 minutes).

Remark 1

The rule for span between X and 10 m does not seem logical, how is it possible to maintain the same time reduction as for the span between 3 m and 7.5 m?

Tested span length	Extrapolation
From 3 m to 6 m	-20 minutes per span meter
From 6 m to 7.5 m	-35 minutes per span meter
From X meter to X + 2 m $\leq 10\,m$	-35 minutes per span meter

The extrapolation rules could be the following based on the draft Fishwall tests results.

Important remark

These draft rules must be checked with other tests results during the EXAP process of revision of EN 15254+5.

The PPA Europe rule seems difficult to apply for low performances.

The PPA/DIBT/IFBS proposal rules are acceptable if:

- The performance continues to decrease to the level of the possible lower classification of EN 13501-2 (60, 90, 120, 180) below the level obtained in the 3 m × 3 m tests after the reduction time rules defined below.

And:

- a safety gap of few minutes should be defined in connection with committee 15254-5 (same gap as EN 1364-1 or EN 1634-1).

And:

- The field of application of the extended rules is limited to 7.5 m maximum.

And:

- The PPA rule must not be applied for extensions which are already allowed in the EN 1364-1 standard.

And:

- There is no beam or column on the reference test.

And:

If we lose the E level, we must be at the same level of E for the other classifications **(I)** (Rules given by EN 1363-1 and EN 13501-2).

And the extrapolation rules are finally:

Horizontally:

Length of the tested span	Extrapolation
From 3 m to 6 m	-20 minutes per span meter with x minutes of safety
From 6 m to 7.5 m	-35 minutes per span meter with x minutes of safety

Vertically:

Length of the tested span	Extrapolation
From 3 m to 6 m	-35 minutes per span meter with x minutes of safety

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APPPENDIX A. APPLICATION EXAMPLES OF SPAN EXTENSIONS BASED ON THE 15254-5 STANDARD.

A.1. Example n° 1 - 3 m × 3 m vertical test – Direct application (Annex B, to standard EN 15254-5 of 2018)

The fire resistance tests result according to EN 1364-1 for a wall made of sandwich panels with two steel facings and a mineral wool core, installed vertically and measuring 3 m × 3 m, is integrity to flames and hot gases for 135 minutes.

The target fire resistance is EI 90 from the inside to the outside.

The time overrun compared to the target time of 120 minutes is 135-120 = 15 minutes.

The minimum 10 minutes criterion is therefore met.

This overrun represents 15/120 = 12.5% < 20% compared to the EI 120 classification.

Therefore, the criterion 13.3 direct application of EN 1364-1 applies. Only an extension of 1 m is possible.

Therefore, the classification report's scope is carried out by direct application according to the EN 1364-1 standard to 3 m + 1 m = 4 m.

Therefore, the criterion of non-exceedance of 10 m is satisfied.

Conclusion:

By direct application EI 120 4 m.

A.2. Example n° 2: 3 m × 3 m horizontal test – Extended application (Annex B to standard EN 15254-5 of 2018)

The fire resistance tests result according to EN 1364-1 for a wall made of sandwich panels with two steel facings and mineral wool core, installed vertically and measuring of 3 m × 3 m, is integrity to flames and hot gases for 135 minutes.

The target fire resistance is EI 90 from the inside to the outside.

The time overrun is 135-90 = 45 minutes.

The minimum 10 minutes criterion is therefore met.

This overrun represents 45/90 = 50% > 35% compared to the EI 90 classification.

Therefore, the criterion 5.3.1 2nd line, the extended application of EN 15254-5 standard applies, i.e., 7.5 m maximum span.

The criterion of not exceeding 10 m is fulfilled.

Table 4 - Extrapolation of tested span length from standard 15254-5 (2018)

Tested span length	Extrapolation
3 m	Up to 6 m if 20 % overrun, min 10 min
3 m	Up to 7,5 m if 35 % overrun, min 10 min
> 4 m	Up to tested length + 2 m if 20 % overrun, min 10 min

Conclusion:

By extended application EI 90 7.5 m.

A.3. Example n° 3: Extended application from a 6 m × 3 m horizontal installation test (Annex B to standard of 15254-5 of 2018) basing on overrun rules.

The fire resistance tests result according to the EN 1364-1standard for a wall made of sandwich panels with two steel claddings and a mineral wool core in a vertical installation of 6 m × 3 m is integrity to flames and hot gases for 125 minutes.

The target fire resistance is EI 90 from the inside to the outside.

The time overrun is 125-90 = 35 minutes.

The minimum 10 minutes criterion is therefore met.

This overrun represents 35/90 = 50% > 20 % compared to the EI 90 classification when tested over 4 m.

Therefore, criterion 5.3.1 3rd line, the extended application of EN 15254-5 applies, considering the initial tested width of 6 m.

This means a span of 6 m + 2 m = 8 m.

The criterion of not exceeding 10 m is met.

Table 4 - Extrapolation of tested span length from standard 15254-5 (2018)

Tested span length	**Extrapolation**
3 m	**Up to 6 m if 20 % overrun, min 10 min.**
3 m	**Up to 7,5 m if 35 % overrun, min 10 min.**
> 4 m	Up to tested length + 2 m if 20 % overrun, min 10 min

Conclusion:

By extended application EI90 8 m.

A.4. Example n°3. Extended application from one 6 m × 3 m horizontal installation test (Annex B to standard 15254-5 of 2013) basing on ΔcΔf rules.

The fire resistance test results following EN 1364-1 for a wall made of sandwich panels with two steel facings and a mineral wool core in a horizontal installation of 3 m × 3 m, seamless, the integrity to flames and hot gases is as follows:

Δc < 0.5 in all cases.

Δf = 0.005 for 60 minutes.

Δf = 0.01 for 90 minutes.

Δf = 0.03 for 120 minutes.

And integrity lost at 150 minutes.

The test was performed with a free vertical edge.

Furthermore, the scope extrapolation rules are set out in Annexe B of standard EN 15254-5 (2013):

1) If no seam is used in the assemblies, panel to panel during the reference test at the 3 m height, the following rules apply:
2) Extensions are allowed only if Δc < 0,5;
3) If Δf < 0,01, the span can be increased up to 12 m with the same classification as those tested;
4) If Δf > 0,06, the span can be increased up to 4 m with the same classification as the tested panel according to the direct application field;
5) Values between 0.01 and 0.06 can be obtained by linear interpolation. Measurements for the calculation of Δf and Δc shall be carried out throughout the entire test period. When assessing allowable spans, measurements at the appropriate fire class shall be used.

This means that for the same panel, various spans can be allowed for different classes. To do this, the criteria at Δc must be met;

The direct extension of EN 1364-1 from 3 m to 4 m, is implemented by a free vertical edge test.

For the EI 120 performance:

Δf = 0.03

Indeed, the rule of 3 by linear interpolation is as follows:

Δc = 0.01 => 12 m span.

Δc = 0.06 => 4 m span.

For a deviation of -0.05 relative to 0.06, there is a span extension of 8 m.

For a deviation of -0.03 compared to 0.06, there is a span extension of 4.8 m.
The final scope extension is therefore: 4 m + 4.8 m = 8.8 m

Conclusion:

By extended application EI120, 8.8 m.

For the EI 90 performance:

$\Delta f = 0.01$.
The result meets the extension criterion.
$\Delta c = 0.01$ => 12 m span

Conclusion:

By extended application EI90, 12 m.

APPPENDIX B. FLOW CHART FOR DIRECT APPLICATION ACCORDING TO THE EN 1364-1 STANDARD AND EXTENDED FOLLOWING THE EN 15254-5 STANDARD

B.1. Case where the initial test is a 3 m × 3 m in accordance with EN 1364-1 standard.

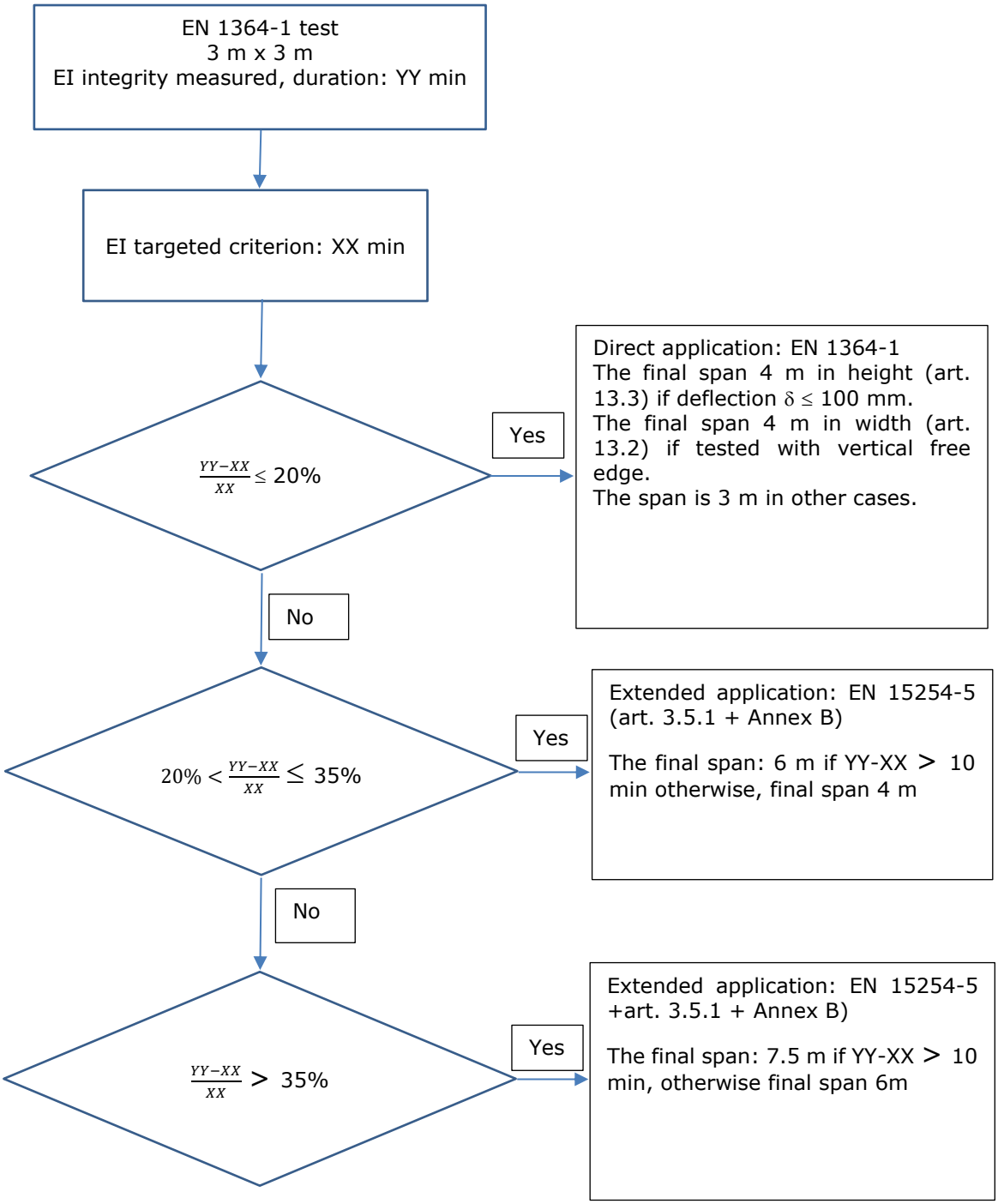


Figure B.1 – Flow chart for direct and extended applications when the initial tested span is 3 m

B.2. Case where the initial test is greater than 4m in accordance with the 1364-1 standard.

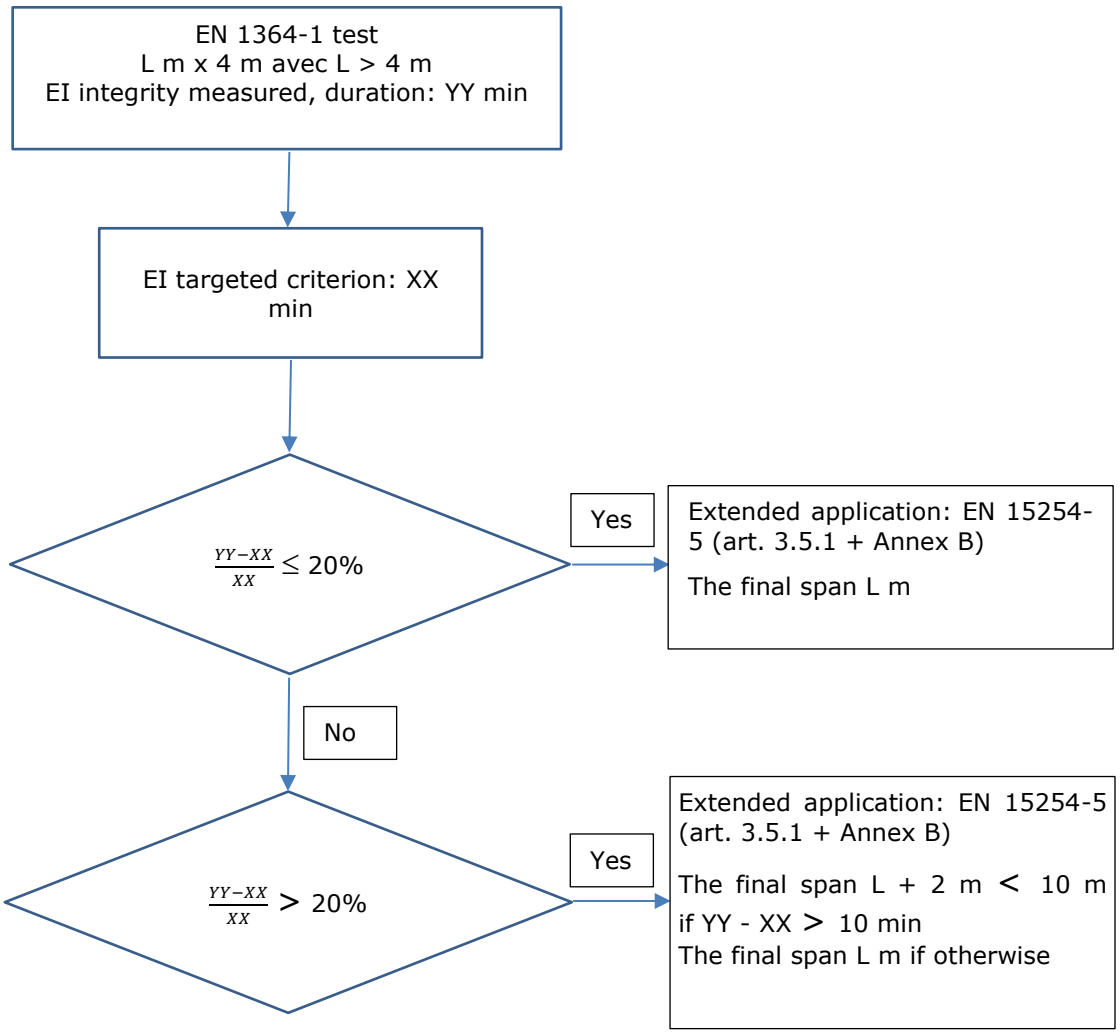


Figure B.2 - Flow chart of direct and extended application if the initial tested span is greater than 4 m

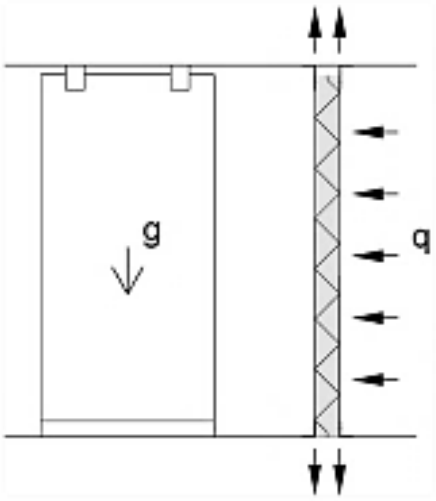
APPPENDIX C. DETERMINATION OF ACTING AND RESISTING FORCES OF SANDWICH PANEL ASSEMBLIES IN A FIRE SITUATION ACCORDING TO ANNEX B OF THE EN 15254-5 STANDARD

By vertical mounting orientation:

Forces are acting at one face, but both faces have to be designed for the same force as fire can be from each direction. Forces acting at the top of the panels:

Tensile forces: $F_{t,Ed} = L\ b\ (q+g)$

Shear forces: $F_{v,Ed} = (L\ b\ q)/2$



By horizontal mounting orientation:

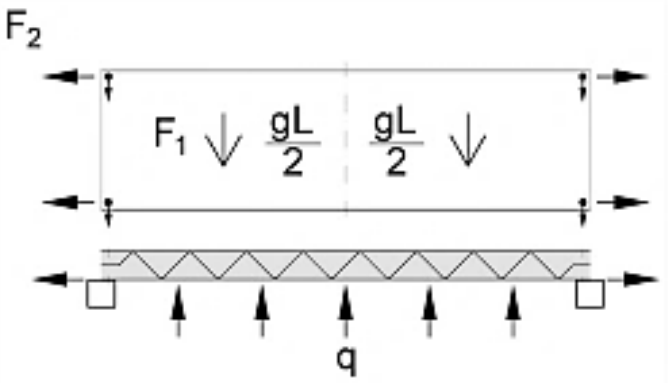
Forces are acting on the extreme fastener at the end of the panels:

Tensile: $F_{t,Ed} = (Lbq)/2$

Shear: $F_1 = (Lbq)/2$

$F_2 = Lb(q+gL/8b)$

$F_{v,Ed} = (F_1^2+F_2^2)^{1/2}$



In the equations above, q is air pressure in fire (0,3 kPa if nothing else specified), g own weight in kPa, L span in m, b panel width in m.

The number of fasteners needed is calculated as following for temperature on the fasteners as measured from the fire test:

$F_{v,Ed}/F_{v,Rd} + F_{t,Ed}/F_{t,Rd} \leq n\ k_{y,\theta}$

where

$F_{v,Rd}$ and $F_{t,Rd}$ = the design value for shear and tensile strength of the fastener in normal temperature;

$F_{v,Ed}$ and $F_{t,Ed}$ = the forces acting at the fasteners calculated from the formulae above;

n = the number of fasteners;

$k_{y,\theta}$ = the decrease on the yield strength of the used steel according to EN 1993-1-2 ($k_{y,\theta} = 1$ for steel temperature up to 400 °C, below 1 for steel temperature above 400 °C);

The material and load factors are set to 1,0 in the above equations.

Figure B.3 — Membrane (catenary) forces acting on the fasteners of a sandwich panels in case of fire