FIRE BEHAVIOUR OF LARGE SCALE WOODEN ROOF STRUCTURES

Veronika Hofmann[1], Norman Werther[2], Stefan Winter[3]

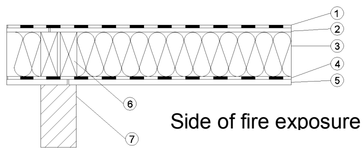
ABSTRACT: In a German research project the structural fire prevention for large scale wooden roof structures under parametric fire exposure was investigated. In this paper the effect of flame spread at exposed lining and inside the elements, the protection capacity of lining under natural fire exposure as well as measures to avoid glowing combustion inside the elements will be presented, to reach a sufficient level of fire safety for the plane elements, junctions, penetration areas and the entire structure. Based on these results a proposal for design strategies of wooden roof elements with enhanced fire safety for industrial buildings and special event buildings under consideration of structural measures will be provided.

KEYWORDS: timber, fire behaviour, large scale roof structures, glowing combustion, flame spread

1 INTRODUCTION

According to the German guideline for industrial buildings, like storage and production facilities and German standards, such as DIN 18234-2 [3], the use of timber and wood based products is limited for the non-loadbearing envelope structure like walls and roof elements. In addition for the construction of a wide span timber structure often a special permission by authorities is needed.

To achieve code compliance structural loadbearing elements have to be designed for a certain fire resistance, depending of building size and further active fire protection methods. This is also possible with structural timber elements. However the use of prefabricated timber frame wall and roof elements is currently not allowed, unless passing a specific fire test, if compartment size is excessing 2,000m² (=21,528foot²) for walls and 2,500m² (=26,909foot²) for the roof structures respectively. These elements have to show a limited contribution to flame spread at surface and inside the elements, no further glowing combustion after fire exposure and a specific fire resistance under natural fire conditions in accordance with the German test standard DIN 18234-1 [1].



(1) roof covering
(2) wood based panel
(3) cavity insulation
(4) air tightness membrane / vapour barrier
(5) wood based panel / gypsum plaster board
(6) timber frame element
(7) supporting timber structure

Figure 1: *example of timber frame element for large area roof system*

Within the scope of the German research project the behaviour and performance of timber frame elements for large scale roof systems have been examined in the case of fire. In this process the effect of flame spread at exposed lining and inside the elements, the protection capacity of lining under parametric fire exposure as well as measures to avoid smouldering fires inside the elements were analysed. The scope of the investigations is to reach sufficient level of fire safety for the plane elements, junctions, penetration areas and the entire structure.

[1] Veronika Hofmann, Research Associate, Chair for Timber Structures and Building Construction, Technische Universität München, Arcisstr. 21, Munich, Germany.
Email: veronika.hofmann@tum.de
[2] Norman Werther, Research Associate, Chair for Timber Structures and Building Construction, Technische Universität München, Arcisstr. 21, Munich, Germany.
Email: n.werther@tum.de
[3] Stefan Winter, Professor, Chair for Timber Structures and Building Construction, Technische Universität München, Arcisstr. 21, Munich, Germany.
Email: winter@tum.de

2 COMPARISON OF NATIONAL AND EUROPEAN REQUIREMENTS ON WIDE SPAN ROOF STRUCTURES

Comparing National und European requirements in respect to the fire protection of wooden roof structures the equality of the safety objectives becomes obvious.

The application of large scale wooden roof structures in accordance to their use in industrial buildings, entertainment and convention centres, shopping centres and storage buildings was investigated.
Thereby the requirements with regard to the construction depicted in Figure 1 were contrasted.
Thus differences of the requirements within Europe was identified and summarized.

In Austria, wooden roof elements have to be designed in a way that there is only a limited contribution to flame spread on the surface and inside the elements. Considering the fire behavior of the insulation placed in the cavity of the element, a special construction of the element is needed if the compartment size is excessing 1800 m². These requirements are comparable with the German regulation for industrial buildings.

With regard to the fire hazard and the fire class of buildings the reaction-to-fire classification for the lining and the cavity insulation as well as an encapsulation criterion is specified in Finland. In industrial buildings the reaction-to-fire classification of linings must be at least B-s1, d0 according to EN 13501-1 [10] (except D-s2, d2 for low fire hazard). This applies to fire class P1 buildings having elements with cavity insulation with a reaction-to-fire classification of A2-s1, d0. For fire class P2 buildings the lining must fulfil the K2 10 requirement (encapsulation criterion according to EN 13501-2 [11]), if the reaction-to-fire classification of the cavity insulation is not at least B-s1, d0.

In Switzerland roof elements containing combustible materials should not support the fire propagation on the roofing, and they should not be a risk for the neighborhood. Thus there is an area restriction of 2400 m^2 in single-story buildings and 1200 m^2 in multi-story buildings, if the lining is made of combustible material. Furthermore there are requirements for the reaction-to-fire classification and the thickness of the roof covering, as well as for the reaction-to-fire classification of the cavity insulation. In addition it is not allowed to have a blank cavity inside the element.
Using non-combustible lining in combination with non-combustible cavity insulation for the construction, there is no limitation for the compartment size.

Italy defines its requirements in accordance to the type and size of the fire load.

All requirements have the same fire safety objective in limiting fire spread on the roofing. Thus a limited contribution to flame spread on the surface and inside the elements should enable sufficient extinguishment by fire brigade.

3 PARAMETERS INFLUENCING THE FIRE EXPOSURE AND FLAME SPREAD

The fire behaviour of a construction is significant affected by the specific boundary conditions such as geometry and the type of occupancy. These conditions results in different fire load densities and ventilation conditions finally. The effect of boundary conditions and the distance between the roof and the fire causes different fire scenarios and temperatures for the exposed structure.
Assuming an effective fire service intervention the German standard DIN 18234 examines only the time of fire growth. In this fire stage sufficient oxygen for combustion is available and the fire is designated as fuel controlled.
However the maximum of the temperature on the exposed lining depends on the distance between the roof and the fire load. A diagram (see Figure 2) for the critical heat release rate as a function of the distance between the roof element and the fire was developed on the basis of the plume theory. By using this diagram critical fire loads, used in DIN 18234, and non-hazardous fire loads related to different distances between the roof and the fire were identified.

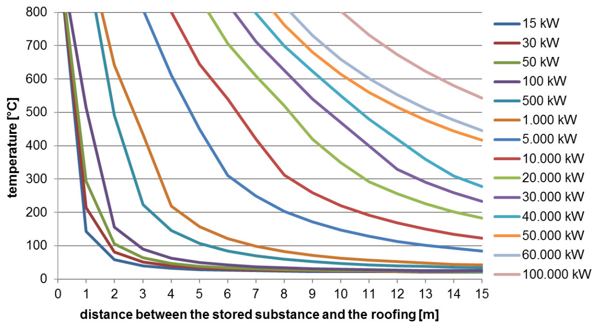


Figure 2: *influence of the distance between the roof and the fire source to the temperature on the exposed lining for different heat release rates*

Furthermore the influence of the exposed lining material, the effect of roof inclination, the compartment size and the concept of fire safety system must be considered in examinations to assess the flame spread and the fire exposure level.

4 PRELIMINARY SMALL SCALE FIRE TESTS

4.1 ROOF ELEMENTS

In these investigations protection capacity of the gypsum fiberboards linings and wood based panels were analysed. Further on the influence of mineral wool insulation and cellulose insulation on temperature formation, falling off time of linings and the risk of smoldering fires have been assessed.

4.1.1 Test setups

In a first part of the project small scale fire tests of 10 cavity insulated timber frame roof elements lined with fire retardant and non-combustible materials respectively have been conducted under natural fire exposure, based on the thermal conditions of DIN 18234-1. The used exposure level is depicted in Figure 3.

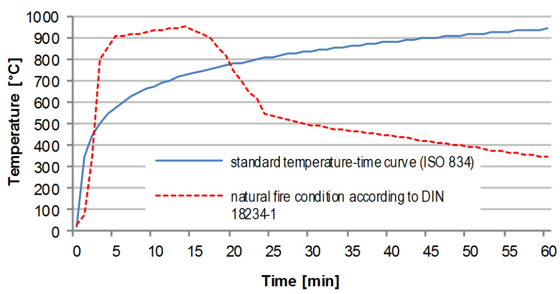


Figure 3: *Comparison of ISO 834 fire exposure and measurements taken from DIN 18234-1 fire test*

Hereby the temperature-time curve was produced by a diesel fuel burner.
Without any additional external loading the single-span roof element was embedded in the horizontal opening of the furnace (W x H =1450 mm x 1390 mm) as depicted in Figure 4. In all tests the specimens were exposed on room sided linings.

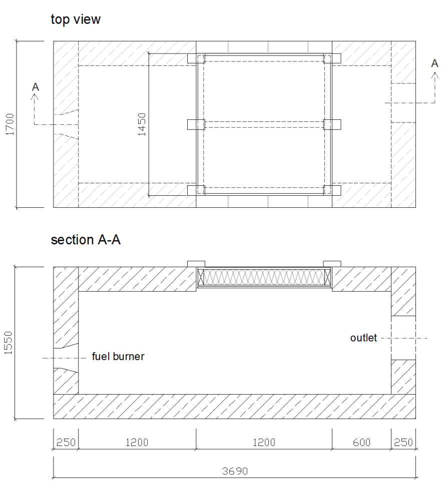


Figure 4: *position of the roof element on the furnace*

Timber members with a dimension of W x H = 80 mm x 160 mm were used as framing. In order to assess the influence of spacing between the timber joists to the failure time of the lining an additional joist was fixed inside the frame to create two cavities (see Figure 5).

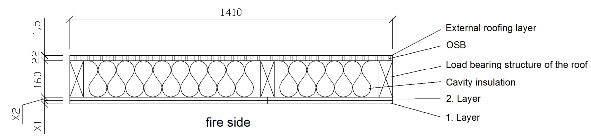


Figure 5: *sectional view of the roofing element in the small scale fire tests*

A 22 mm thick OSB was chosen for planking of the timber structure on the upper side of the element. In addition a waterproof roof covering was placed on the OSB.
According to the different construction outlined in Table 1 the cavities were filled with cellulose flakes, glass wool or rock wool.
The lining consisted of a different numbers of layers, different layer thickness and different combinations of OSB (=Oriented Strand Boards), gypsum fiberboards (GF-boards) and fire rated gypsum plasterboards (=GP-boards). The fixing of the lining was effected by screws with a bond length of 20 to 40 mm and a distance between the screws of 150 mm. Furthermore there was a butt joint between the lining boards, fixed on the timber frame underneath. In addition a vapor barrier was put between the lining and the cavity insulation.

Table 1: *Types of construction for the small scale fire tests*

	construction	left side (833 mm)	right side (517 mm)
V1	1.layer	40 mm OSB	40 mm OSB
	2.layer	-	-
	cavity insulation	glass wool	cellulose flakes
V2	1.layer	18 mm OSB	15 mm GP
	2.layer	-	10 mm GF
	cavity insulation	rock wool	cellulose flakes
V3	1.layer	15 mm GF	15 mm GF
	2.layer	-	-
	cavity insulation	glass wool	rock wool
V4	1.layer	18 mm GF	12,5 mm GF
	2.layer	-	10 mm OSB
	cavity insulation	glass wool	glass wool
V5	1.layer	15 mm GP	15 mm GP
	2.layer	10 mm GF	10 mm OSB
	cavity insulation	cellulose flakes	rock wool
		left side (675 mm)	right side (675 mm)
V6	1.layer	12,5 mm GF	12,5 mm GF
	2.layer	12,5 mm GF	12,5 mm GF
	cavity insulation	cellulose flakes	glass wool
V7	1.layer	15 mm GF	15 mm GF
	2.layer	15 mm GF	15 mm GF
	cavity insulation	cellulose flakes	cellulose flakes
V8	1.layer	18 mm GF	15 mm GF
	2.layer	12 mm OSB	10 mm OSB
	cavity insulation	glass wool	glass wool
V9	1.layer	12,5 mm GF	10 mm GF
	2.layer	15 mm GF	12,5 mm GF
	cavity insulation	cellulose flakes	cellulose flakes
V10	1.layer	18 mm OSB-SF	18 mm OSB-SF
	2.layer	-	-
	cavity insulation	glass wool	cellulose flakes

4.1.2 Experimental results

The interior linings consisting of OSBs and gypsum boards always led to the critical temperature, assumed with approx. 300°C (cf. [13]), being reached within the investigation period and consequently to the combustion of the OSBs and charring of the timber frame elements. Linings of gypsum fiberboards only fulfill the protective capacity starting from a thickness of 27.5 mm. When gypsum fiberboards were combined with fire rated gypsum plaster boards, a total thickness of approx. 25 mm (15 mm gypsum plasterboard + 10 mm gypsum fiberboard) was sufficient to protect the timber frame elements and the cellulose insulation from charring. Because of the fire propagation within the construction, the gypsum bonded boards such as gypsum fiber or gypsum plasterboards is preferable to the combination of OSBs and gypsum fiberboards.

Gypsum fiberboard and gypsum plasterboard have the same protective capacity up to a temperature of 500°C on the back side of the lining. After exceeding 500°C behind the lining, the gypsum fiberboard fails more quickly than the gypsum plasterboard.

The cracking in the gypsum boards started after 13 minutes by using 10 mm gypsum fiberboard. When using 12.5 mm gypsum fiberboard the cracking appeared after 16 minutes. At this time the temperature in the furnace was about 800°C. The cracking of 15 mm gypsum fiberboard and plasterboard was initiated in the phase of cooling down (after 20 minutes).

Furthermore the protective capacity of gypsum fiberboards, subjected to temperatures according to DIN 18234 was compared to the protective capacity of gypsum fiberboards subjected to standard temperature time curve according to ISO 834 [9] (depicted in Figure 6).

The comparison showed that significantly lower protection times for the gypsum boards could be achieved under parametric fire exposure than under standard temperature-time curve exposure.

The natural fire condition according to DIN 18234-1 generates a temperature of 300 °C significantly faster between the lining and the cavity insulation.

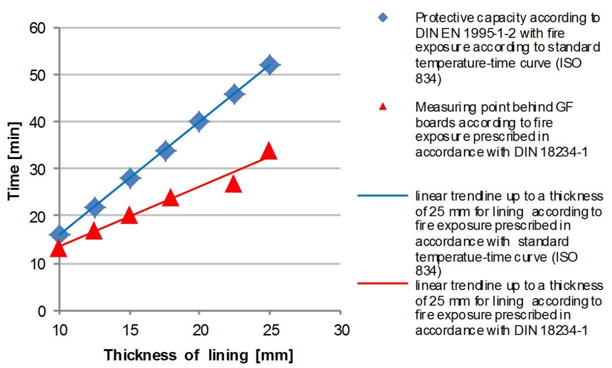


***Figure 6:** Comparison of the protective capacity of gypsum boards to DIN 18234-1 and the standard temperature-time curve: time to reach 300°C on the back side of the lining in reference to the fire exposure*

Rock wool and glass wool showed the same protection capacity, because they are protected by lining, which were falling down in the cooling phase of the fire exposure under temperature less than 600°C.

Comparing the fire exposure of the roof elements under natural fire conditions according to DIN 18234 and under conditions generated by the furnace made clear that the fire exposure of the element caused by the furnace is more powerful. The spacial fire exposure of the element could be a reason for this effect.

4.2 JOINTS AND CONNECTIONS

In these investigations the protection capacity of the joints between elements was analyzed.

4.2.1 Test setups

The use of conventional element joints (depicted in Figure 7) leads to fire penetration in the gap between the elements, which results in glowing combustion of the timber frame (see Figure 8).

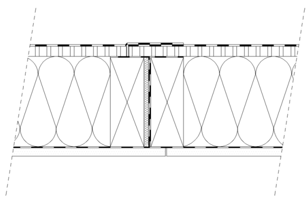


***Figure 7:** Conventional element joint*

***Figure 8:** production of smoke as a consequence of glowing combustion in the gap*

Thus practical joints were designed and analyzed avoiding fire penetration and glowing combustion within the construction.

Practical experience of fire resistance testing showed that failure of jointing is produced by the quality of its construction.

Therefore fire tests for joints in accordance to DIN 18234 - 1 were conducted.

Thereby four roof systems were analyzed. Each system consisted of two wooden roof elements (W x H = 0.89 m x 0.97 m/ element 1 and element 2) in a row. The heating of the test stand was generated by the ignition of 30 kg wood cribs.

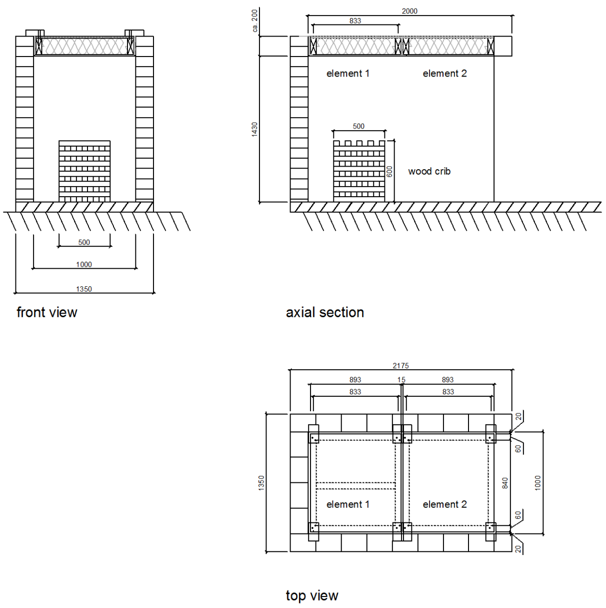


Figure 9: *test setup in according to DIN 18234-1, but shortened*

The position of the joint between the single-layer lining (gypsum board) can be seen in Figure 10. Underneath the joint a 10 mm gypsum fiber strip was added in order to avoid glowing combustion of the timber frame.

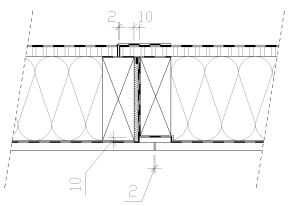


Figure 10: *jointing V I and V II*

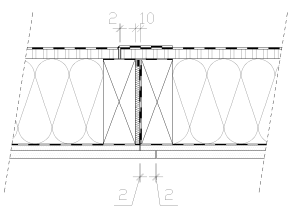


Figure 11: *jointing V III and V IV*

The joint between the gypsum boards of the two-layer linings can be seen in. Figure 11.
The gap between the elements was filled with rock wool in test V I, V II and V III and with glass wool in test V IV.

Thermocouples were fixed in the joints on the back side of the room sided lining and inside the construction, recording the temperature during the fire tests. The position of the thermocouples can be seen in Figure 12.

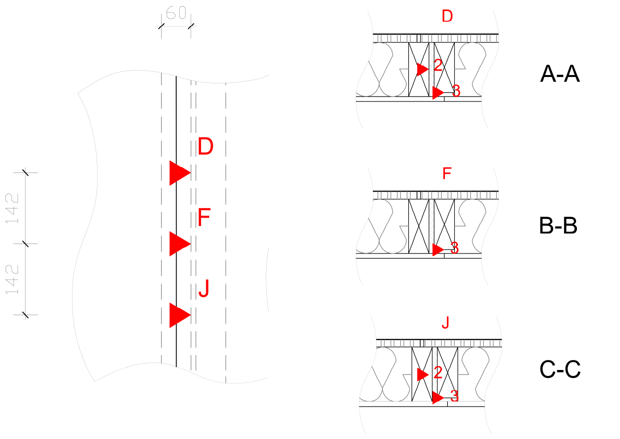


Figure 12: *position of thermocouples in the element joint between the roof elements*

4.2.2 Experimental results

By backing the joint of the linings with an additional gypsum fiberboard the designed joints showed a sufficient protective capacity. The construction avoided the ignition of the timber frame at the element joint.

A glowing combustion of the timber frame, produced by a lateral fire penetration, could not be observed.
Figure 13 illustrates that on the back side of the 10 mm gypsum strip a temperature of max. 110°C (D3, J3, F3) existed. A maximum temperature of 70°C was measured after 25 minutes on the half height of the timber frame (D2, J2).

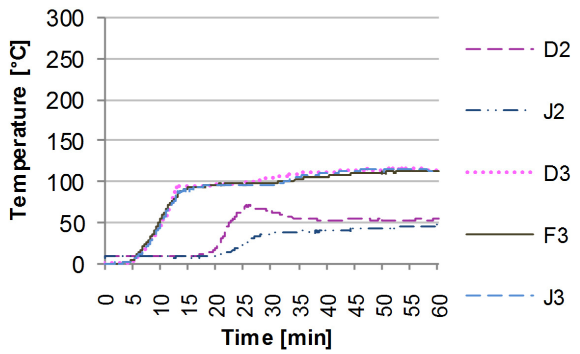


Figure 13: *temperature-time curve of thermocouples fixed in the jointing between the roof elements (Test I) (position of thermocouples referred to Figure 12)*

On the back side of the 10 mm gypsum board which was protected by 15 mm gypsum board facing the fire a temperature of max. 90°C existed.
The staggered joint between the gypsum boards resulted in temperatures of 80°C after 12 minutes on the half height of the timber frame.
Using 10 mm thick rock wool or 20 mm glass wool (compressed to 10 mm) showed no difference in protection capacity of the timber joint (cf. Figure 14).

VII VIV

Figure 14: *view of jointing area after deconstruction*

5 LARGE SCALE FIRE TESTS

5.1 ROOF ELEMENTS

5.1.1 Test setups

Based on the results of the preliminary small scale fire tests large scale fire tests have been conducted.
The dimension of the test stand was 8 m * 2 m in according to E DIN 18234-1 [2].

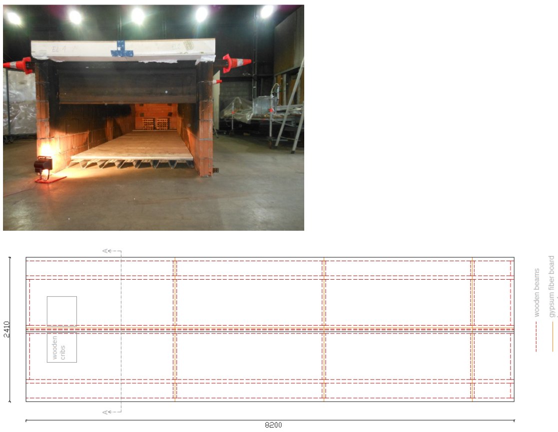


Figure 15*: test stand according to E DIN 18234-1 and a top view of the test specimen*

The heating of the fire test stand was effected by the ignition of 60 kg wood cribs.
The roof system consisted of two parallel oriented roof elements in order to proof the element joint between the elements.
The dimension of each roof element was W x H = 1.20 m x 8.2 m. The load carrying system consisted of timber frames. 18 mm thick OSB was chosen as the planking of the timber structure on the upper side of the element. In addition a waterproofing of the roof was placed on the OSB.
According to the construction in Table 2, the cavities were filled with cellulose flakes and glass wool.

The room sided lining consisted of gypsum fiberboards. In combination with the cavity insulation of glass wool, 15 mm gypsum fiberboard was taken as lining. A glass fiber mesh with a melting point of 1000°C was fixed on the timber frame to avoid the insulation falling down after failure of the gypsum boards.

Another testing setup included a room-sided 15 mm gypsum fiberboard and 10 mm gypsum fiberboard for the second layer to protect the cellulose insulation in the cavity.
The cladding was fixed by screws with a bond length of 20 to 40 mm and a distance between the screws of 100 mm

In a third testing the investigated construction consisted of glass wool in combination with 18 mm gypsum plasterboard. The better protective capacity of the thicker plasterboard avoids the failure of the cavity insulation, thus the glass fiber mesh was not applied.

Table 2: *summary of assessed setups*

	room sided lining	air tightness	fastening of insulation	cavity insulation	upper lining
V1	1.layer: 15 mm gypsum board	vapour barrier	glass fiber mesh	glas wool	18 mm OSB
V2	2.layer: 10 mm gypsum board 1.layer: 15 mm Fermacell firepanel	vapour barrier	-	cellulose flakes	18 mm OSB
V3	1.layer: 18 mm gypsum board	vapour barrier	-	glas wool	18 mm OSB

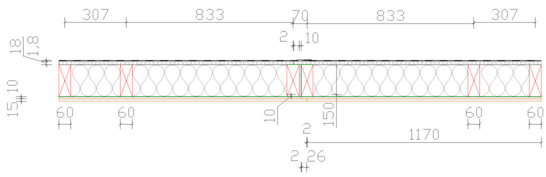


Figure 16: *example of the construction on the basis of test 2 (section A-A of Figure 15)*

5.1.2 Assessment values

The assessment of the test results was made in regard to the failure criteria.
The roof system has failed in accordance to DIN 18234-1, when on of the following events occur:

a) Occurring flames on the upper side of the roofing, no flame spread should excess an area of 0.25 m²;
b) Falling down of parts of the roof structure or collapse of the roof structure;
c) Flame spread on the surface of the roofing and the occurrence of a secondary fire on the front or back end of the roof system
d) Falling down of burning parts of the element (e.g. flaming droplets), that does not extinguish by itself during the falling down;
e) Flame spread on the room sided lining beyond the edge of the roof system;
f) No further glowing combustion within the construction after fire exposure.

5.1.3 Experimental Results

Two minutes after the ignition of the wood cribs, the flame touched the room sided lining of the elements.
From that time the present temperature on the room sided lining of the elements were 850°C for 20 minutes.
After caving-in the wood cribs the temperature declines to 150°C.
The cracking and falling down of the gypsum fiberboards started in the phase of cooling down (after 20 minutes).
The time of cracking and the falling down of pieces of the gypsum boards is depending on the type of the gypsum board, its thickness and its span length.

The temperatures on the room sided surface of the timber frame were recorded by an infrared camera. Temperatures less than 100°C were recorded before reconstructing the element.

No further glowing combustion of the timber frame after fire exposure was observed. This could be confirmed by falling temperatures recorded by thermocouples inside the element.

Flames touch the lining (2. minute)

Caving-in of wood cribs (25. minute)

Cracking of gypsum board (26. minute)

Falling down of parts of the gypsum board (ca. 35. minute)

***Figure 17:** fire progress using the example of test 1*

The damage pattern of the tested elements shows, that pieces of the gypsum fiberboards were fallen down, however only in the area of directly fire exposure.
After condensation of the bounded water the composition of the gypsum board is changing. Therefore the cracking of the board started in the phase of cooling down of the specimens. As a result the falling down of pieces of the gypsum board was initiated.
The Fermacell firepanelboard (used in V2) and the common gypsum fiberboard differ in their structure. Thus the change in the structure of the firepanelboard clearly reduced the crack formation.
The protective lining of the element in test 1 in using 15 mm gypsum fiberboard caused a temperature of more than 300°C on the back side. The timber frame behind the gypsum board was charred. A maximum depth of 7 cm was pyrolized in the area of the direct fire exposure.
The testing construction 2 with two layer lining showed a small area with collapsed firepanelboards (first layer) and one crack in the 10 mm gypsum fiberboard (second layer). The cellulose insulation within the construction changed its color from grey to brown exclusively in the area of the crack. The timber frame was charred only in the area of glowing combustion of the cellulose.
The remaining part of the timber frame was protected against pyrolization by the two layer gypsum board.

Test 3 shows a similar failure like test 1. The charring rate of the timber frame was less than in test 1 (charred depth 6 cm).

The glass wool insulation of test 1 and test 3 had changed its color in the area of fallen down gypsum boards.

The construction of test 1 and test 3 reached the required protective capacity in accordance to DIN 18234-1 for large scale wooden roof structures.
No failure criteria occurred during the test and within the 2 hour observation after the test.

The setup of test 2 showed a further glowing combustion of the cellulose insulation 3 hours after the ignition of the wood cribs.
The further glowing combustion resulted that the postulated protective capacity could not be achieved.
During the time of observation after the test, no smoke generation was identifiable within the construction.
In the future, using thicker gypsum boards in combination with cellulose insulation might be advisable to restrain the crack formation.

To improve the fire behavior of the tested constructions the spacing between the timber beams could be reduced, because a smaller span of the gypsum board has a beneficial effect for crack formation and time of falling down. Another positive effect to delay the falling down of the gypsum board is using thicker boards.

5.2 PENETRATIONS

5.2.1 Test setups

In a further test the fire behaviour of penetrations of service installation and dome lights have been conducted.
The dimension of the test stand according to DIN 18234-3 [4] is W x L x H = 3.60 m × 2.40 m × 2.40 m.
One of the four walls had an opening for a door with dimension of W x H = 2.00 m × 0.80 m.

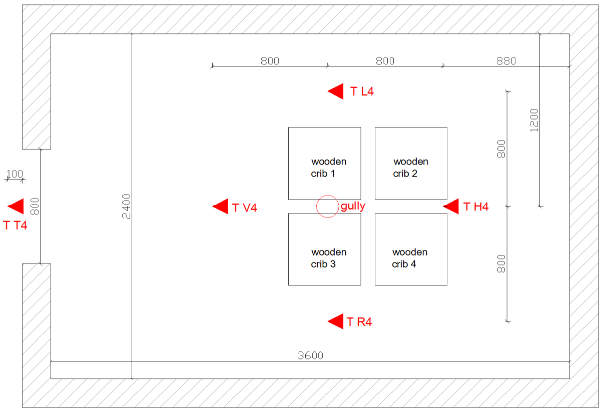


***Figure 18:** top view of test stand, including position of thermocouples*

The heating of the fire test room was effected by the ignition of 120 kg wood cribs.

With regard to the frequency of needed penetrations in the roofing, a test with an implemented gully was analyzed (see Figure 19).

Test stand with specimen

System for the assessed penetration

***Figure 19:** view of test stand and the penetration system*

The unstressed, single span roof element was put in the opening of the test stand as a horizontal closing.
The penetration in the middle of the element was framed by timber beams (W x H = 60 mm x 150 mm).
These timber frames were also protected by 15 mm gypsum fiberboard over the height, and by 10 mm gypsum fiberboard on its narrow side (see Figure 20). Furthermore the penetration was protected by two additional 18 mm gypsum fiberboards with a height of approx. 70 mm. These two boards were used to fix the fire protection collar on the room side of the roof element. The cavity between the gully and the penetration above the two 18 mm gypsum fiberboards was filled by glass wool.
The gully itself was completed by a pipe (Ø 150) on its bottom side. The standard setup of the construction correlated to test 1 of the large scale fire tests.

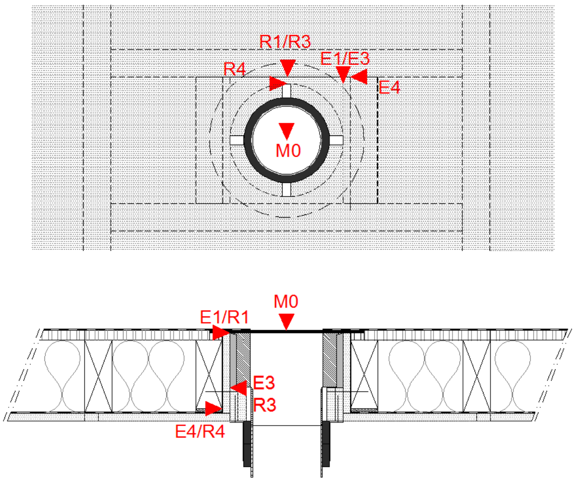


***Figure 20:** sealing system for gully penetration*

Other penetrations, used for skylight domes, were not investigated in this test series.

A suggestion of the design of other penetrations (e.g. used for dome lights) is given in a design catalogue (see [14]). In general the protection of the timber frame at the penetration (used for gully or dome light) should be designed in the same way independent of the type or size of the penetration (see Figure 21).

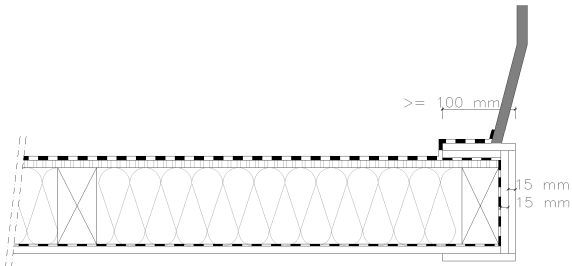


***Figure 21:** protection of the timber frame at the penetration*

5.2.2 Assessment criteria

In accordance to DIN 18234-3 the flame spread on the upper side of the element is the failure criterion for the test. The flames haven`t excessing a distance of 0.10 m away from base point of the penetration (cf. Figure 22). To asses this failure criterion, an observation period from beginning of the test up to 20 minutes after beginning is necessary.

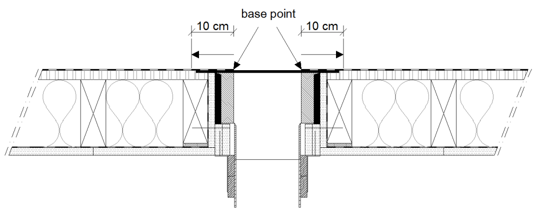


***Figure 22:** visualisation of the assessment value*

Avoiding flame spread on the element, some measures are needed to protect all penetrations and joints. Particularly the base point of a penetration may show a limited contribution to flame spread at the surface and inside the elements.

5.2.3 Experimental Results

The fire protection collar expanded seven minutes after starting the fire test and finished the inflammation through the gully. Thus no flame spread occurred on the surface of the roof element.

When assessing the specimens two hours after the test, no damage on the upper side of the element was visible. The removing of the waterproofing layer around the penetration showed that the OSB and the top side of the Gully were intact. The gypsum fiberboards fixed on the timber frame of the penetration were not damaged after removing the gully. There was no discoloration of the gypsum board noticeable inside the penetration. The timber frame protected by gypsum boards was absolutely undamaged.

The temperature-time-curve of the thermocouple M0 in the middle of the penetration confirmed that the fire protection collar foamed after 7 minutes and prohibited a further fire exposure of the penetration.

After activating the fire protection collar, the temperature (M0) dropped from over 700 to 80 degree.

On the bottom side of the timber frame (E4 und R4) the temperature rose after failure of the lining (23 minutes after starting the test) and reached a maximum of 180°C after 80 minutes. The low heating of the timber frame prevented the pyrolization of the timber element.

The points of measurement E3 and R3 behind the two 18 mm gypsum fiberboards and the E1 and R1 on the top of the penetration showed a maximum temperature of 100°C.

A short inflammation through the penetration without excessing the base point was detected. Nevertheless the test was passed in accordance to DIN 18234-3. In addition the foaming of the fire protection collar prevented further inflammation through the penetration and burning components dropping out of the gully.

According to DIN 18234-3 penetrations are classified by different sizes.

Small penetrations are needed for gullies and pipe culverts. Medium penetrations with dimensions of more than 0.3 m x 0.3 m or a diameter bigger than Ø 0.3 m are usually designed at skylight bases and used for domes. Thereby different materials could be used for skylight bases. They could be applied in different ways on the bearing construction and connected with the waterproofing layer. It has to be stated that different ways of construction necessitate special and conformed measures.

By using the standard construction for small and medium penetrations, a protection of the timber frame by two layers of gypsum board, each with 15 mm, and a simple staggered joint is suggested, resulting out of experience from some other fire tests.

Proposals for the protection of penetrations needing special measures are summarized in a detailing catalog [14].

6 DISCUSSION OF RESULTS

The small scale fire tests brought new fundamental knowledge in respect to the behaviour of materials and components of the timber frame elements under natural fire exposure.

Furthermore the thermal softening, the crack formation and a potential falling off of the lining and other components were determined. The protective capacity of each layer, the effect of flame spread at exposed lining and inside the elements and the risk of uncontrolled smouldering fire inside the element after the fire exposure were also investigated.

A study of parameters shows the protection time of the assessed cladding materials under parametric fire exposure. As criteria to determine the protection capacity of the lining the critical ignition temperature of 300°C (=572°F) for wood members was used. For elements insulated with cellulose the protection capacity of the lining was determined by using a critical temperature of 200°C (=392°F).

The large scale fire test showed the effect of a new designed jointing detail between two elements to avoid glowing combustion and uncontrolled smouldering fires for timber elements.

7 CONCLUSIONS

By using specific lining materials in combination with cavity insulation and under consideration of the developed jointing detail a large number of designs are applicable. These are summarised in a design catalogue for fire safe wooden roof elements [14].

Thus the desire of clients, architects and carpentries for practical application to renewable primary products comes true. This contributes to a wider use of timber and wood based products as well as of biogenic insulation material and the benefit of image.

ACKNOWLEDGEMENT

The authors would like to acknowledge the technicians at TU München for their help assembling the specimens, thank Wiehag GmbH, Grossmann Bau GmbH, Fermacell GmbH, Isofloc Wärmedämmtechnik GmbH, Knauf Insulation GmbH, Egger Holzwerkstoffe GmbH, Kronoply GmbH, WOLFIN Bautechnik GmbH, Promat GmbH, MOLL bauökologische Produkte GmbH and ESSMANN GmbH for providing the materials, and thank the Federal Ministry for Economics and Energy (BMWi) on behalf of the International Association for Technical Issues related to Wood Technical (iVTH) for funding this research project by the German Federation of Industrial Cooperative Research Associations (AiF).

REFERENCES

[1] DIN 18234-1: 2003-09 „Baulicher Brandschutz großflächiger Dächer – Brandschutz von unten - Teil 1: Begriffe, Anforderungen und Prüfungen; geschlossene Dachflächen

[2] E DIN 18234-1: 2007 „Baulicher Brandschutz großflächiger Dächer – Brandschutz von unten - Teil 1: Begriffe, Anforderungen und Prüfungen; geschlossene Dachflächen; Änderung 1

[3] DIN 18234-2: 2003-09 „Baulicher Brandschutz großflächiger Dächer – Brandschutz von unten - Teil 2: Verzeichnis von Dächern, welche die Anforderungen nach DIN 18234-1 erfüllen; geschlossene Dachflächen“

[4] DIN 18234-3: 2003-09 „Baulicher Brandschutz großflächiger Dächer – Brandschutz von unten - Teil 3: Begriffe, Anforderungen und Prüfungen; Durchdringungen, Anschlüsse und Abschlüsse von Dachflächen“

[5] DIN EN 1995-1-2: 2010-12 „Eurocode 5: Bemessung und Konstruktion von Holzbauten – Teil 1-2: Allgemeine Regeln – Tragwerksbemessung für den Brandfall“

[6] Österreichisches Institut für Bautechnik: OIB Richtlinie 2.1 Brandschutz bei Betriebs-bauten, Ausgabe Oktober 2011, , Oktober 2011

[7] Vereinigung Kantonaler Feuerversicherungen: Brandschutzrichtlinie, Verwendung brennbarer Baustoffe 13-03d, Bern 2003

[8] E2 National Building Code of Finland - Fire safety of production and warehouse buildings Guidelines 2005, Helsinki, März 2005

[9] ISO 834-1:1999-09 “Fire-resistance tests- elements of building construction-Part 1: “General requirements”

[10] EN 13501-1:2007: Fire classification of construction products and building elements-Part1: Classification using data from reaction to fire test“

[11] EN 13501-2:2007 “Fire classification of construction products and building elements-Part2: Classification using data from fire resistance tests, excluding ventilation services “

[12] Hosser, D.: Leitfaden Ingenieurmethoden des Brandschutzes, Technischer Bericht vfdb TB 04-01, 3., überarbeitete und ergänzte Auflage, Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Braunschweig 2013

[13] Schjerve, N.: Beiträge zur Entzündung und Brandausbreitung – Experimente, Modellierung, CFD- Simulationen , Wien, Juni 2012

[14] Hofmann, V.; Werther, N.: Brandverhalten großflächiger Holzdachelemente, Schlussbericht, München 2014