# Fire Performance of Timber Structures under Natural Fire Conditions

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## ABSTRACT

In recent years the use of wood as a building material has become popular, especially for dwellings. One of the preconditions for its use is adequate fire safety. Technical measures, especially sprinkler and smoke detection systems, well equipped fire brigades and a better knowledge in the area of structural fire design of timber structures allow the use of timber in a wider field of application. Full scale tests on wooden modular hotels were performed under natural fire conditions to look at the efficiency of different fire safety concepts. In a first series the efficiency of technical measures, especially fast response sprinkler systems, was studied. The second series showed the possibility and limits of structural fire safety measures. Special attention was given to the influence of combustible room surfaces on fire growth and fire spread inside and outside the room. The tests enlarged the experimental data for validation of natural fire simulations (temperatures, fire spread etc.) and for verifying the methods for the fire resistance calculation of wood constructions.

**KEYWORDS:** fire performance, timber structures, tests under natural fire conditions, performance based design, efficiency of sprinkler systems

## NOMENCLATURE LISTING

$A_v$ area of the window opening (m$^2$)
$A_t$ total area of the boundary surfaces (m$^2$)
$h_{eq}$ height of the window opening (m)
$H_u$ net heat of combustion (MJ/kg)
$M$ weight of combustible materials (kg)
$O$ opening factor (m$^{1/2}$)
$Q_{fi}$ fire load (MJ)
$q_{fi}$ fire load density calculated over the room floor area (MJ/m$^2$)

## INTRODUCTION

The choice of building materials may markedly influence building fire safety. The mechanical and thermal properties of building materials change at elevated temperatures. This change of material properties has an important influence on the structural behavior in case of fire. Combustible building materials like timber burn at their surfaces, release energy and thus contribute to fire propagation and the development of smoke in case of fire. Prescriptive fire regulations often restrict the use of timber. However, in the last couple of years, many countries have started to introduce performance based fire

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regulations or liberalized the use of timber for buildings [1]. These regulations open the way for new applications, particularly for an extended use of timber structures in multi-storey buildings. In taking advantage of the new possibilities it is essential to verify that fire safety of timber buildings is not lower than of buildings made of other materials.

A large research project on the fire behavior of timber structures is currently being carried out in Switzerland [2]. The research project aims at supplying basic data and information on the safe use of timber in multi-storey buildings. Further novel performance based design concepts for multi-storey timber buildings are under development based on extensive element and full scale testing as well as a large statistical data base on fires in timber and concrete/brick buildings [3]. This paper presents the main results of full scale tests on wooden modular hotels performed under natural fire conditions. The objectives of the experimental tests were to verify the efficiency of different fire safety concepts for multi-storey timber buildings and to expose any weaknesses in the fire safety of the modular hotels. The test results permitted the development of hotels of modular construction in wood, which were proposed for the last national Swiss exposition. Compared to conventional structures the wooden modular hotels presented many advantages (ecological, low-cost and prefabricated structures, to be reused and recycled at the end of the exposition).

## TESTING PROGRAMME

The experiments on wooden modular hotels consisted of element testing under ISO-fire exposure [4] as well as full scale tests under natural fire conditions. The fire tests on elements were performed in the vertical furnace (3 x 3 m) at the Swiss Federal Laboratories for Material Testing and Research (EMPA) in Dübendorf and permitted to study the fire behavior of four different light timber frame wall assemblies. The wall assemblies were exposed to the standard fire until the integrity criterion or the thermal insulation criterion failed. The results of these fire tests formed the basis for the construction of the hotel modules and have been already documented in detail [5].

Table 1. Overview of the full scale tests performed under natural fire conditions.

| Fire test | Safety concept | Fire type | Modules | Window opening | Room linings |
|---|---|---|---|---|---|
| BE bb g | technical (sprinkler) | pre-flashover fire | H1 | closed | combustible |
| BE bb o I | technical (sprinkler) | pre-flashover fire | H1 | opened | combustible |
| BE bb o II | technical (sprinkler) | pre-flashover fire | H1 | opened | combustible |
| BÜ nbb | structural | post-flashover fire | lower: G1<br>upper: H2 | opened<br>closed | non combustible<br>combustible |
| BÜ bb | structural | post-flashover fire | lower: H1<br>upper: H2 | opened<br>closed | combustible<br>combustible |
| BÜ nbb demo | structural | post-flashover fire | lower: G2<br>upper: H2 | opened<br>closed | non combustible<br>combustible |

The full scale tests on wooden hotel modules under natural fire conditions were performed on the testing field of the fire brigades near Zurich. In a first series (series BE), the efficiency of technical measures, especially fast response of automatic fire detection systems and sprinkler systems, was studied. After ignition of a mattress, it was observed whether the fire could spread on further goods or even on the room surface, before technical measures could control the fire. The second series (series BÜ) of full scale tests looked at the possibility and limits of structural fire safety measures. For these tests, the sprinkler system was turned off and the window was opened so that the fire was able to grow very quickly based on the large air supply. Special attention was given to the fire propagation across the facade and the influence of combustible surfaces on the fire intensity. Further the importance of structural detailing on the fire resistance of the structure was analyzed in detail. Table 1 gives an overview of the full scale tests performed under natural fire conditions.

## DESCRIPTION OF THE HOTEL MODULES

Four hotel modules (H1, H2, G1 and G2) were manufactured in shop as light timber frame construction and transported by means of trucks to the testing location. The dimensions of the modules were: length 6.6 m; width 3.1 m; and height 2.8 m. The long walls did not have any openings. On the other hand, the short walls had a door on one side, and a window opening made of standard double glass on the opposite side (see Fig. 1). During the tests, the door remained always closed. The size of the window opening was 1.5 m x 1.7 m (width x height). These dimensions correspond to an opening factor $O = A_v \cdot \sqrt{h_{eq}} / A_t \approx 0.041\,m^{1/2}$, where $A_v$ and $h_{eq}$ are the area and height of the window opening, respectively, and $A_t$ is the total area of the boundary surfaces (ceiling, floor and walls including the window opening).

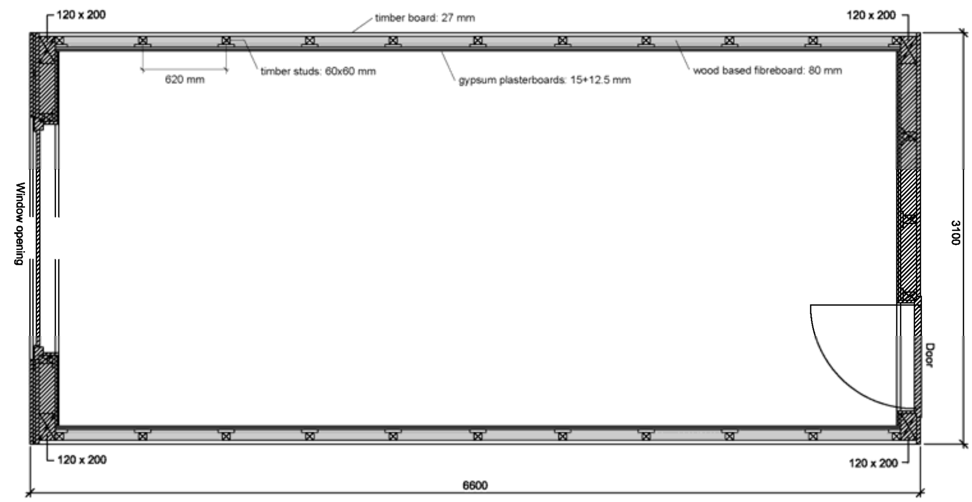


Fig. 1. Schematic plan of the hotel module G2 made of light timber frame assemblies.

The modules were identical in its basic construction and dimensions, differed however in the choice of the interior room linings of walls and ceiling. For the modules H1 and H2 combustible wood panels (oriented strand boards, OSB) were used. On the other hand, the linings of the modules G1 and G2 consisted of one or two layers of non combustible gypsum plasterboards. The combustible floor made of timber boards (modules H1, H2 and G1) or timber hollow core elements (module G2) was covered by a thin layer of linoleum. Table 2 gives the details of the materials and their thicknesses used for the construction of the four modules. The materials were selected not only based on a fire point of view, but rather had to satisfy also different requirements regarding building physics, economics, ecology, etc.

Table 2. Details of the materials and their thicknesses used for the construction of the four modules (single layers are given from the interior to the exterior of the room).

| Module | Modules H1, H2 | Module G1 | Module G2 |
|---|---|---|---|
| Floor | linoleum: 3 mm<br>timber board: 19 mm<br>wood based fibreboard: 140 mm<br>timber board: 35 mm | linoleum: 3 mm<br>timber board: 19 mm<br>wood based fibreboard: 140 mm<br>timber board: 35 mm | linoleum: 3 mm<br>hollow core elements: 195 mm<br>(filled with rock wool batts) |
| Walls | OSB: 18 mm<br>wood based fibreboard: 80 mm<br>timber board: 35 mm | gypsum plasterboard: 18 mm<br>wood based fibreboard: 80 mm<br>timber board: 35 mm | gypsum plasterboard: 15+12.5 mm<br>wood based fibreboard: 80 mm<br>timber board: 27 mm |
| Wall with door | OSB: 18 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm | gypsum plasterboard: 18 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm | gypsum plasterboard: 15+12.5 mm<br>wood based fibreboard: 120 mm<br>timber board: 27 mm |
| Wall with window | OSB: 18 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm<br>ventilation gap: 20 mm<br>timber board: 19 mm | gypsum plasterboard: 18 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm<br>ventilation gap: 20 mm<br>timber board: 19 mm | gypsum plasterboard: 15+12.5 mm<br>wood based fibreboard: 120 mm<br>timber board: 27 mm<br>ventilation gap: 20 mm<br>timber board: 19 mm |
| Ceiling | timber board: 19 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm | gypsum plasterboard: 18 mm<br>wood based fibreboard: 120 mm<br>timber board: 35 mm | gypsum plasterboard: 2x15+12.5<br>rock wool batts: 120 mm<br>timber board: 27 mm |
| Floor framing | timber joists: 60x140 mm<br>spacing: 620 mm | timber joists: 60x140 mm<br>spacing: 620 mm | timber floor made of hollow core elements: 195x195 mm |
| Walls framing | timber studs: 60x60 mm<br>spacing: 620 mm | timber studs: 60x60 mm<br>spacing: 620 mm | timber studs: 60x60 mm<br>spacing: 620 mm |
| Ceiling framing | timber joists: 60x100 mm<br>spacing: 620 mm | timber joists: 60x100 mm<br>spacing: 620 mm | timber joists: 60x100 mm<br>spacing: 410 mm |

The light timber frame construction of the walls was built with sawn timber studs, for the floors and ceilings sawn timber joists were used (see Table 2). The timber framing (studs and joists) as well as the timber boards were made of spruce. As insulating batts, Pavatherm boards based on 100% wood fibres or rock wool batts were placed in the cavities of the light timber frame assemblies. Table 3 gives manufacturer, combustibility and density of the materials used for the construction of the hotel modules.

Table 3. Overview of the material properties.

| Material | Manufacturer | Combustibility | Density |
|---|---|---|---|
| Timber boards | - | combustible | 380-440 kg/m$^3$ |
| OSB | Kronospan AG, Menznau (CH) | combustible | ca. 600 kg/m$^3$ |
| Wood-based fibreboards (Pavatherm) | Pavatex AG, Kleindöttigen (CH) | combustible | ca. 150 kg/m$^3$ |
| Rock wool batts | Flumroc AG, Flums (CH) | non combustible | ca. 32 kg/m$^3$ |
| Gypsum plasterboards (Fermacell) | Fels-Werke GmbH, Münsingen (CH) | non combustible | ca. 1010 kg/m$^3$ |

## SPRINKLER AND FIRE DETECTION SYSTEMS

All modules were equipped with an automatic fire detection system (FDS) with four different sensors as well as two sprinkler systems. The first one was attached on the ceiling, the second one on a wall. The activating temperature of the ceiling sprinkler was 57°C or 68°C and that of the wall sprinkler 68°C. Each sprinkler system was equipped with an independent water supply so that the behavior of both systems could be examined independently. Moreover for the second series BÜ of full scale tests with sprinkler system turned off, it was possible to fill the water pipes with compressed air, in order to assess the activating temperature of the sprinkler systems without using water.

## MEASUREMENTS

During the tests, the temperature at more than 100 locations was measured and recorded with thermocouples of chromel-alumel, type K. The thermocouples were located on the room surface as well as within the wall, ceiling and floor elements. At the windows, the glass temperature was measured on the internal and external surface of the window. The room temperature was measured at distances of 50, 600, 1100 and 2000 mm from the ceiling at two locations.

The total weight of the modular construction was measured by four load cells placed at the base of the construction. The gas concentrations of oxygen, CO and $CO_2$ were recorded with a gas measuring instrument. All tests were documented by video cameras and photos, as well as test protocols. Three immobile video cameras recorded the module front, the side view and the module interior. Further observations of the tests were recorded by mobile video cameras. A professional video team generated a video documentation of the full scale tests. For the tests BÜ nbb and BÜ bb, also infrared pictures of the module front were recorded.

## FIRE LOAD AND FIRE IGNITION

In building fires, the contents (movable fire load) as well as combustible construction materials contribute to the total fire load. In a hotel room, the contents consist mostly of beds, tables, cabinets, electronic apparatus, etc. Each module was equipped with a typical mattress (1.6 x 2.0 m) made of foam material (see Fig. 2 left). As additional movable fire load, 11 wooden pallets were located in the module (see Fig. 2 right). The mattress was ignited with four dl n-heptane.

Fig. 2. Movable fire load consisting of a mattress (left) and wooden pallets (right).

Tables 4 and 5 give the movable fire load as well as the additional fire load due to the combustible construction materials for the fire tests BÜ. For the calculation of the fire load, a net heat of combustion $H_u$ of 17.5 MJ/kg for wood as suggested in EN 1991-1-2 [6] was assumed. For the calculation of the additional fire load due to combustible construction materials, only the combustible linings (OSB for the walls and timber boards for the ceiling and the floor) have been considered. However, after the linings began falling down, the wood based fibreboards placed behind the linings also contributed to the fire load.

Table 4. Movable fire load for the fire tests BÜ.

| Fire test | BÜ nbb | | BÜ bb | | BÜ nbb demo | |
|---|---|---|---|---|---|---|
| | M [kg] | $Q_{fi}$ [MJ] | M [kg] | $Q_{fi}$ [MJ] | M [kg] | $Q_{fi}$ [MJ] |
| Mattress: $H_u$ = 24 MJ/kg | 24.9 | 597.6 | 20.8 | 499.2 | 21.7 | 520.8 |
| Mattress cover: $H_u$ = 18 MJ/kg | 1.7 | 30.6 | 1.7 | 30.6 | 1.7 | 30.6 |
| Wood pallets: $H_u$ = 17.5 MJ/kg | 230.7 | 4037.3 | 209.9 | 3673.3 | 238.2 | 4168.5 |
| n-heptane: $H_u$ = 44 MJ/kg | 0.4 | 17.6 | 0.4 | 17.6 | 0.4 | 17.6 |
| Total movable fire load | 4683 MJ | | 4221 MJ | | 4738 MJ | |
| Total movable fire load density[a] | 234 MJ/m$^2$ | | 211 MJ/m$^2$ | | 237 MJ/m$^2$ | |

[a]fire load density calculated over 20 m$^2$ floor area

Table 5. Additional fire load due to combustible construction materials.

| Fire test | BÜ nbb | | BÜ bb | | BÜ nbb demo | |
|---|---|---|---|---|---|---|
| | M [kg] | $Q_{fi}$ [MJ] | M [kg] | $Q_{fi}$ [MJ] | M [kg] | $Q_{fi}$ [MJ] |
| Walls: OSB ($H_u$ = 17.5 MJ/kg) | - | - | 440 | 7700 | - | - |
| Ceiling: wood ($H_u$ = 17.5 MJ/kg) | - | - | 148 | 2590 | - | - |
| Floor: wood ($H_u$ = 17.5 MJ/kg) | 148 | 2590 | 148 | 2590 | 148 | 2590 |
| Total additional fire load | 2590 MJ | | 12'880 MJ | | 2590 MJ | |
| Total additional fire load density[a] | 129 MJ/m$^2$ | | 644 MJ/m$^2$ | | 129 MJ/m$^2$ | |

[a]fire load density calculated over 20 m$^2$ floor area

The total fire load density (calculated over the floor area) for the modules with non combustible wall and ceiling linings varied between 363 and 366 MJ/m$^2$, for the module with combustible wall and ceiling linings the total fire load density was approximately 855 MJ/m$^2$. Table E.4 in EN 1991-1-2 [6] gives for hotel rooms an average fire load density of 310 MJ/m$^2$.

## RESULTS OF PRE-FLASHOVER FIRE TESTS (SERIES BE)

The first series BE of full scale tests was performed with activated detection and sprinkler systems. Each test was performed using the module H1 (see Table 1). Table 6 gives an overview of the most relevant results of these fire tests. The tests showed that the sprinkler system was able to control the fire quickly even though the mattress was ignited from below. In all experiments, the measured activating time of the sprinkler systems varied between two and three minutes after fire ignition. No significant differences were observed between the sprinkler system on the ceiling and the system on the wall. Further the tests showed that the ventilation conditions (window opened or closed) did not substantially influence the activation of the sprinklers.

The automatic fire detection system (FDS) had four detection algorithms with different sensitivity (FDS 1, 2, 3 and 4). All detection algorithms discovered the fire within two minutes, i.e., about one minute quicker than the sprinkler systems. Further it was noted that all fire detectors activated before the mattress ignited, whereas all sprinklers activated after the mattress ignited.

Table 6. Main results of the fire tests BE with activated sprinkler system.

| Fire test | Time of mattress ignition [min] | Sprinkler on the ceiling $\Theta_a$ [°C][a] $t_a$ [min][b] | Sprinkler on the wall $\Theta_a$ [°C][a] $t_a$ [min][b] | Fire detection systems (FDS) Measured detecting time [min] | | | |
|---|---|---|---|---|---|---|---|
| | | | | FDS 1 | FDS 2 | FDS 3 | FDS 4 |
| BE bb g | ca. 01’50” | 57°C 2’45” | 68°C (air) - | 00’21” | 00’33” | 01’02” | 01’27” |
| BE bb o I | ca. 02’00” | 68°C 03’03” | 68°C (air) - | 00’30” | 00’33” | 01’15” | 01’46” |
| BE bb o II | ca. 01’20” | 57°C (air) 02’01” | 68°C 02’15” | 00’33” | 00’36” | 00’50” | 01’19” |

[a]$\Theta_a$: activating temperature of sprinkler
[b]$t_a$: measured activating time of sprinkler

Figure 3 shows the temperatures measured on the ceiling for the first fire test (BE bb g). In all experiments, at the time of the sprinkler activation the room temperatures measured at different locations varied between 50°C and 200°C. Because flashover occurs only at higher temperatures, the combustible room linings during the early stage of the fire development had no influence on the activation of the sprinkler systems.

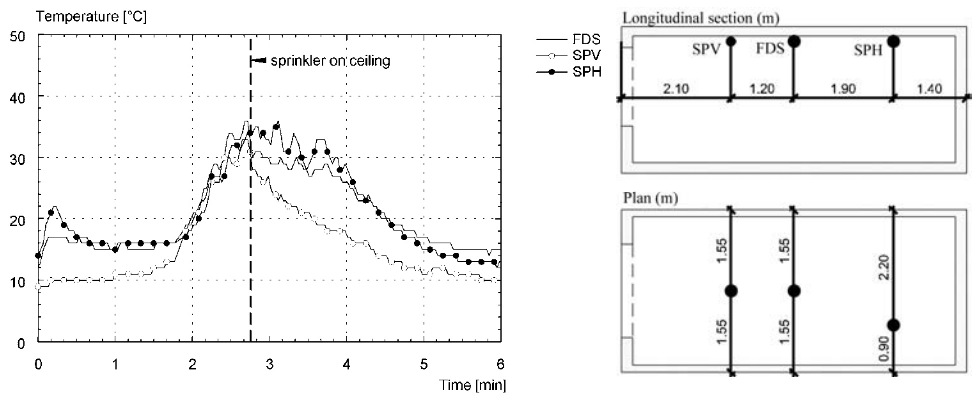


Fig. 3. Room temperatures measured on the ceiling for the first fire test (BE bb g).

In all experiments, the sprinkler system was able to extinguish the fire before the fire could spread on further goods or even on the combustible room surfaces. On the other hand, for the second series of tests with deactivated sprinkler systems, flashover occurred only a few minutes after the theoretical activation of the sprinkler systems. Figure 4 shows the damage on the mattress as well as on the wall and the floor. It can be seen, that because of the fast activation of the sprinkler system, the damages were very small. Even the mattress was not completely burned up. The tests have confirmed that with fast response sprinkler systems the influence of a combustible structure on the fire safety was compensated and the fire safety objectives can be fulfilled by any type of construction. Despite fast fire development, the structure was undamaged because the sprinkler system extinguished the fire in an early stage.

Fig. 4. Damages on the mattress (left) and on the wall and the floor (right).

## RESULTS OF POST-FLASHOVER FIRE TESTS (SERIES BÜ)

The second series of full scale tests was performed with deactivated sprinkler systems. Each test was performed using two modules, i.e., one module was placed above another module (in Tables 1 and 7 the modules used are indicated as “lower” and “upper”). Table 7 gives an overview of the most relevant results of these fire tests.

Table 7. Main results of the fire tests BÜ with sprinkler system turned off.

| **Fire test** | | **BÜ nbb** | | **BÜ bb** | | **BÜ demo** | |
|---|---|---|---|---|---|---|---|
| Modules | | lower: G1 | upper: H2 | lower: H1 | upper: H2 | lower: G2 | upper: H2 |
| Window | | opened | closed | opened | closed | opened | closed |
| Ignition time of mattress | | ca.01’30” | — | ca.01’40” | — | ca.01’40” | — |
| Flashover | | ca.06’00” | — | 04’27” | — | 06’58” | — |
| Failure time of exterior window glass of upper module | | n.u. | 13’57” | n.u. | 06’09” | n.u. | 14’25” |
| Failure time of interior window glass of upper module | | n.u. | 42’35” | n.u. | 07’28” | n.u. | 40’16” |
| Sprinkler on the ceiling | $\Theta_a$ | 68°C (air) | 68°C | 68°C (air) | 68°C | 68°C (air) | 68°C (air) |
| | $t_a$ | 02’15” | 42’40” | 03’20” | — | 02’35” | 42’30” |
| Sprinkler on the wall | $\Theta_a$ | 68°C (air) | 68°C | 68°C (air) | 68°C | 68°C (air) | 68°C (air) |
| | $t_a$ | 02’20” | 42’41” | 03’27” | 07’30” | 02’44” | 41’21” |
| Fire detection systems (FDS) | FDS 1 | 00’25” | 15’10” | 01’10” | 06’54” | not used | 18’37” |
| | FDS 2 | 00’29” | 15’31” | 01’10” | 07’00” | | 19’26” |
| | FDS 3 | 00’59” | 19’54” | 01’17” | 07’16” | | 20’33” |
| | FDS 4 | 01’26” | 31’27” | 01’50” | 07’30” | | 28’48” |

[a]$\Theta_a$: activating temperature of sprinkler
[b]$t_a$: measured activating time of sprinkler
[c]n.u.: window not used in the lower module

After fire ignition, in all experiments fire grew very rapidly and the temperatures rose within a few minutes to flashover. For the module with combustible wall and ceiling linings flashover occurred after about 4 minutes. For the modules with non combustible wall and ceiling linings flashover occurred between ca. 6 and 7 minutes. A series of full scale fire tests has been recently performed by VTT using different timber compartments with and without protection of the wood structure by gypsum plasterboard [7]. In these experiments, flashover occurred between 4 and 6 minutes, confirming the results of the fire tests on modular hotels.

The influence of combustible linings was clearly observed after flashover occurred. For the module with combustible wall and ceiling linings the external burning out the window was much more severe than for the modules with non combustible wall and ceiling linings (see Fig. 5). The temperatures measured with the infrared camera on the facade confirmed the visual observation (see Fig. 6).

Fig. 5. Fire development 7 minutes after fire ignition; left: lower module with combustible linings (fire test BÜ bb), right: lower module with non combustible linings (fire test BÜ nbb).

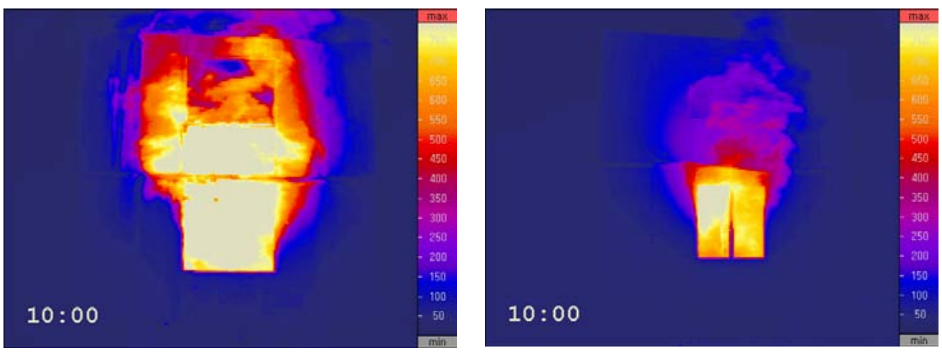


Fig. 6. Temperatures measured on the facade 10 minutes after fire ignition; left: lower module with combustible linings (fire test BÜ bb), right: lower module with non combustible linings (fire test BÜ nbb).

The tests with non combustible linings also showed that the 250 mm protruding ledge made of 1 mm thick steel sheet and placed on the facade between the lower and the upper module (see Fig. 5) was able to delay the fire spread over the facade and to limit the damages at the facade. In these tests, the interior glass of the upper window failed only after about 40 and 42 minutes. In the case of the test with combustible linings the heat flux from the flames emerging from the window opening on the facade was much higher and therefore fire spread could not be significantly delayed by the ledge. In this test, the interior glass of the window of the upper module failed already about 7 minutes after fire ignition.

Figure 7 shows the temperatures measured at different heights on the interior as well as the exterior glass of the upper module for the fire test BÜ nbb. When the exterior glass failed, the maximum and minimum glass temperatures were 200°C and 100°C, respectively. On the interior glass, a first crack was observed after 34 minutes. At that time, the maximum and minimum glass temperatures were 230°C and 70°C, respectively. Similar results were observed also in the other tests. In the test BÜ nbb demo, the exterior glass collapsed with maximum and minimum glass temperatures of 220°C and 80°C, respectively.

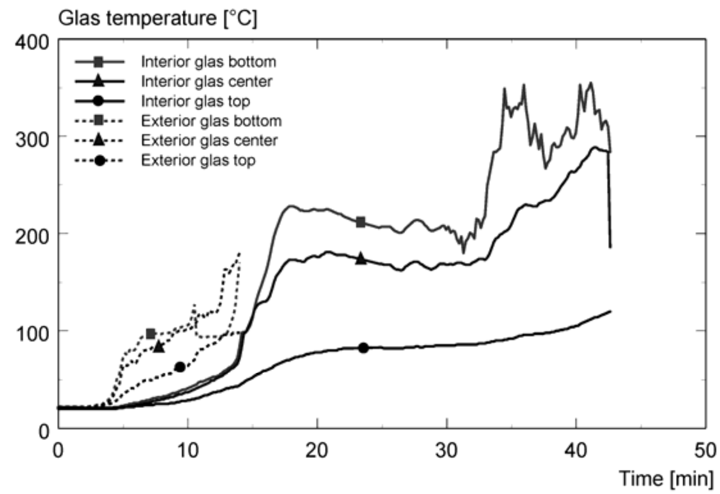


Fig. 7. Temperatures measured at different heights (bottom, center and top) on the interior as well as the exterior glass of the upper module for the fire test BÜ nbb.

Figure 8 shows the room temperatures measured on the ceiling in the front as well as in the rear of the module. It can be seen, that due to the limited amount of oxygen the temperature in the rear of the module was lower than in the front close to the opening window. Further, no significant differences were observed in the temperature curves for the module with and without combustible wall and ceiling linings. This confirms that only a part of the pyrolysis gases released by the combustible wall and ceiling linings burnt inside the room. The unburnt gases flowed out of the window opening, causing intense combustion outside the module where oxygen was available in large quantities. Similar results have been also obtained in [7].

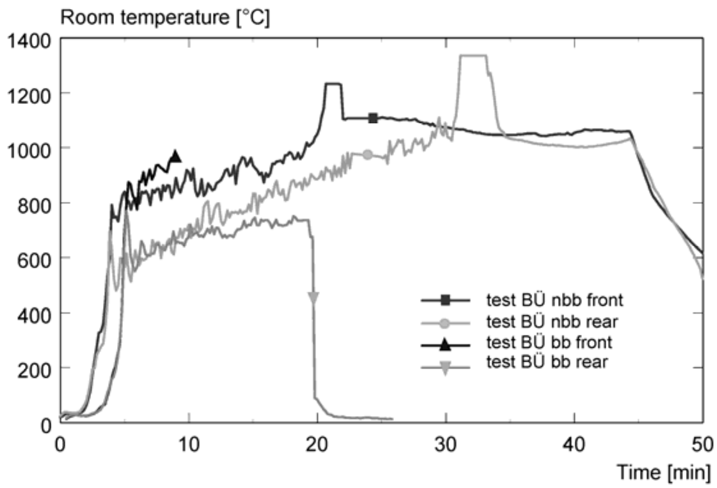


Fig. 8. Room temperatures measured on the ceiling in the front as well as in the rear of the lower module for the fire test BÜ nbb and BÜ bb.

The temperature development in the module was simulated using two different softwares (BSBG and OZone). Figure 9 shows the comparison between simulations and results of the test BÜ nbb. Figure 9 also reports the ISO standard fire curve. It can be seen, that the temperatures measured in the fire compartment were higher than in case of the ISO standard fire curve. Further, a good agreement between test results and simulations with Ozone and modified BSBG was observed during the first half hour of the fire test. After that time, the simulations predicted a reduction of the temperature in the module, which was not observed. A possible reason is that after about 30 minutes the lining made of one layer gypsum plasterboard begun falling down, so that the wood based fibreboards placed behind the gypsum plasterboard started burning and contributed to the fire load.

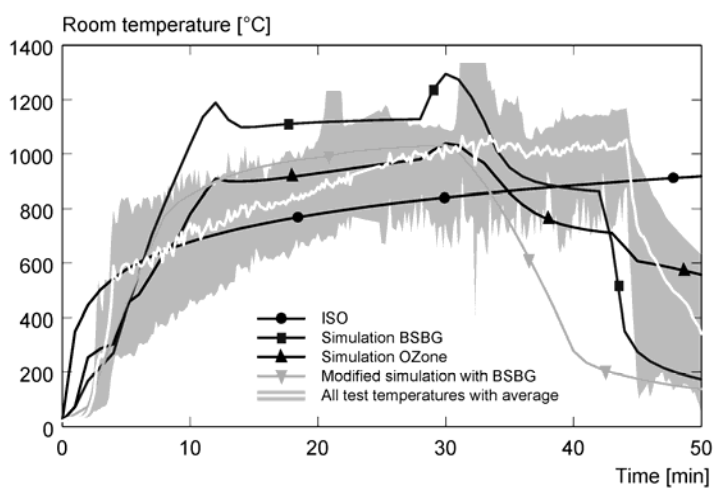


Fig. 9. Comparison between simulations and results of the test BÜ nbb.

## CONCLUSIONS

Full scale tests on wooden modular hotels were performed under natural fire conditions to look at the efficiency of different fire safety concepts. In a first series the efficiency of technical measures, especially fast response sprinkler systems, was studied. The second series showed the possibility and limits of structural fire safety measures. Special attention was given to the influence of combustible room surfaces on fire growth and fire spread inside and outside the room.

The tests have confirmed that with fast response sprinkler systems the influence of combustible construction on the fire safety was compensated and the fire safety objectives can be fulfilled by any type of construction. Despite the development of a fast fire the structure was undamaged because the sprinkler system extinguished the fire in an early stage. Even the damage on the furniture was small. With pure structural measures it is possible to limit the fire spread to one room even for timber structures. In one test a complete burn out of the room without fire propagation to other rooms was achieved. In the room above the fire compartment no elevated temperatures were measured and even the smoke concentration was at normal level until the breaking of the windows. However combustible surfaces may lead to an increased burning rate and therefore increased external burning and risk of fire propagation over the facade. However combustible surfaces like wooden linings can be also found in non combustible buildings.

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