COST Action FP1404
Fire Safe Use of Bio-Based Building Products

FACADES WORKSHOP

Fire Safe Use of Bio-Based Building Products for Façades – Challenges and Limitations, Detailing and Testing

Book of Abstracts

9th – 10th November 2017
Barcelona, Spain

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School of Building Construction of Barcelona EPSEB
Polytechnic University of Catalonia UPC

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Book of abstracts of the Facades Workshop "Fire Safe Use of Bio-Based Building Products for Facades - Challenges and Limitations, Detailing and Testing". An event of the COST Action FP 1404 Fire Safe Use of Bio-Based Building Products intented for fire safety engineers, structural engineers, material scientists, fire service, authorities and industry representatives.

Editors: María Pilar Giraldo Forero
Ana María Lacasta Palacio

Organisers: The workshop is jointly organized by ETH Zurich, Research Institute of Sweden, Polytechnic University of Catalonia UPC, Forest Sciences Center of Catalonia CTFC and the Catalan Institute of Wood INCAFUST with the support of COST Action.

ISBN: 978-84-9880-685-4

DL B 26312-2017

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About the cover photo

Barcelona Biomedical Research Park

The BBRP was completed in 2006. The building project was carried out by a team of two prestigious architects: Manel Brullet and Albert de Pineda. It is located at Barcelona's sea front and has unic interior and exterior design. It is a very interesting example of the use of wood as material for facades, with a total surface of more than 8.000 m^2 of battens made of red cedar.

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Foreword

The Façade Workshop "Fire Safe Use of Bio-Based Building Products for Façades - Challenges and Limitations, Detailing and Testing" of the COST Action FP1404 "Fire Safe Use of Bio-Based Building Products" is one of the main activities in the third year of the lifetime of the Action.

The workshop addresses a very important topic, one which is coming under increased scrutiny as a consequence of a number of incidents which have occurred in the past few years. Some of these incidents have highlighted the potential for façades to provide a mechanism for rapid fire spread, contributing to devastating consequences of an event. As seems to have been the case in the Grenfell Tower tragedy in London on June this year, the choice of materials used in façade's may contribute to the fire development.

The workshop comprises twelve keynote speeches of experts sharing their experience and knowledge; providing a platform to discuss topics such as:

- Testing in the past and in the future
- Certification,
- Experience in different countries,
- Durability of Fire Retardant treatments,
- Building Regulations,
- Firefighting experiences and methods for combustible façades and
- Best practice.

We, the experts and members of COST FP1404 hope that the scientific content presented at the Workshop will contribute to a better understanding of the addressed topics and will help to strengthen the ever-growing network in the Fire Safe use of Bio-Based Building Products.

Joachim Schmid, chair of COST FP1404

David Lange, co-organizer of the Workshop

Ana María Lacasta and María Pilar Giraldo, organizer and host of the Workshop

Keynote

Presentations

How to regulate bio-based materials and products in facades

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Keywords: facades, bio-based products, regulations, protective structures, reaction to fire.

Background – More stringent energy efficiency requirements for buildings have increased insulation layer thicknesses and use of combustible insulation materials in external walls. Other changes during the last decades have included the following: Use of bio-based claddings have increased, new construction products have entered to the market and new structural and architectural solutions have been developed.

In regulations restrictions for use of combustible materials may be used or when such materials and products are allowed, minimum requirements for protection and for reaction to fire performance can be defined. Façade related regulations usually consider both flashover fires from windows or other openings and fires outside the building (see Figure 1).

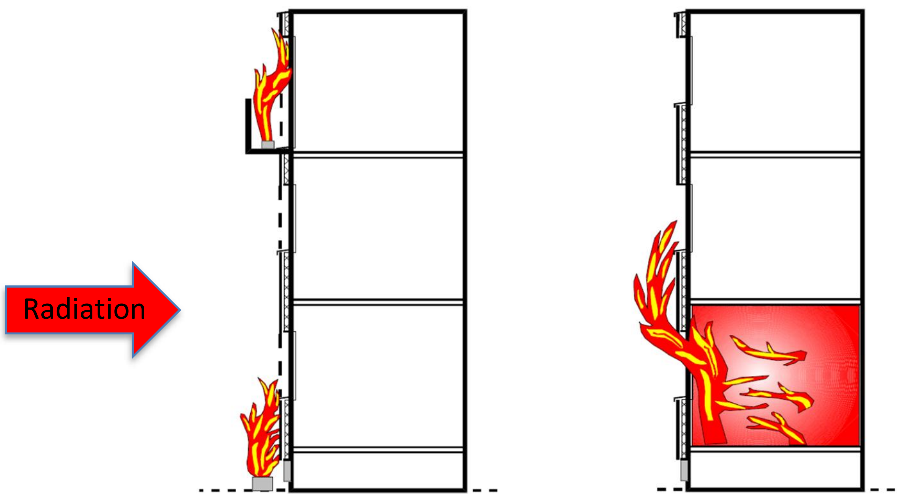

Figure 1. Typical fire scenarios for facades: Fire in a building located next to the façade, fire outside the building in front of the façade or fire inside the building with a flashover [1].

Possible ways of façade fire spread are at least the following:

- Fire spreading on cladding surface
- Fire spreading in ventilation cavity
- Fire spreading in thermal insulation
- Fire spreading to cavities of roof/attic

If no prevention is applied, fire may spread to other fire compartments or to neighbouring building. This is the main hazard that fire regulations are aiming to get under control.

Prevention of fires spreading on cladding surface – Reaction to fire class requirements can be used to regulate acceptable claddings. The class required may depend e.g. on the height of the building, use of the building or distance to neighbouring buildings. In many countries D-s2, d2 class claddings (e.g. wood) is allowed in low rise or medium rise buildings [2]. For high rise buildings the reaction to fire requirement is usually A2-s1, d0. Reasons for this are safety of evacuation and extinguishing of higher facades which will take more time and may come impossible.

Prevention of fires spreading in ventilation cavity – Reaction to fire classes may be used also to regulate acceptable fire properties for the surfaces of ventilation cavities. In addition, there may be requirements for fire protection ability (K class coverings in the inner surface of ventilation cavity), or for preventing fire spreading in the cavity (firestops).

Prevention of fires spreading to thermal insulation – For regulatory purposes protection of combustible thermal insulation products within external walls can be defined in relation to the fire exposures of concern. The assumed external fire exposure may be based on large flames from a window (flashover fire) or fire outside building (in case of sprinklered building). Similarly, protection is needed also to the internal side of the insulation. Main principles of protection of insulation products in external walls are given Figure 2 [3]. It is to be noted that the protection requirements are applicable also to edges of all windows and doors (including possible openings to ventilation gaps) as well as penetrations. Fire stops may be required in the insulation layer depending on fire performance of the insulation.

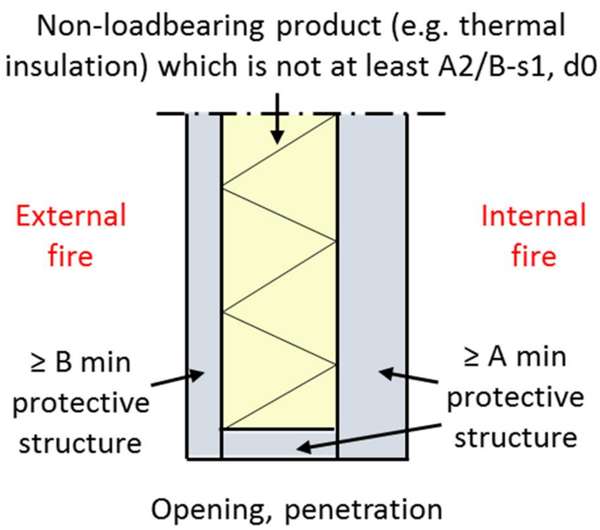

Figure 2. Protection against internal and external fire.

Prevention of fires spreading to cavities in roof/attic – Facade fires do not only endanger spaces behind the external wall, but also above, if these fires can spread to roof or attic cavities. Thus, preventive means may be required e.g. in the form of fire separation (see Figure 3).

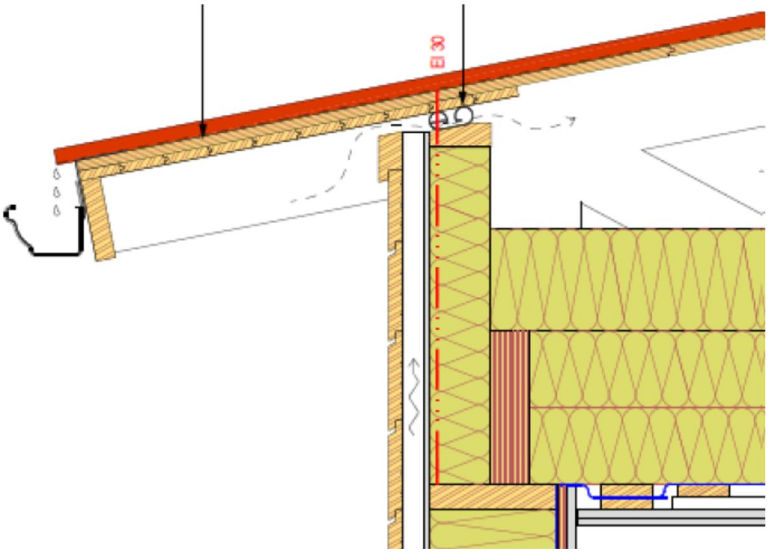

Figure 3. Example of method to prevent facade fire spreading to roof cavity.

Verification of fire performance of facades – Concerning regulations following options can be considered to show required fire performance of facades:

A. Application of a set of existing European test methods to control the different modes of fire spread
   - Reaction to fire (A1 … F classes)
   - Fire protection ability (K classes)
   - Fire-separating function (EI classes)
   - Load bearing structures (R classes)
   - Calculation methods (e.g. Eurocode)
B. Large-scale facade testing – need for harmonized European method
   - Capable of differentiating performance levels according to national needs
   - Need for extended application rules
C. Case by case assessment using performance based fire safety design.

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Fire safety of facades: basic principles, Belgian regulation and solutions for timber frame facades

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Keywords: timber facade, fire propagation, reaction to fire, fire resistance, fire regulation, details.

In the light of the recent façade fire that took place in high-rise buildings, and more particularly the tragic events of June 2017 in London, the BBRI has taken the initiative to draft a document concerning the fire safety of high-rise buildings in Belgium [1]. This publication gives an overview of the current and future Belgian regulatory and normative framework, especially with regard to fire spread within the facades. It also details the main facade systems (for instance timber facades) and highlights the key points which must be considered when designing and installing these systems.

Fire spread via the facades mainly occurs in one of the following three manners.

1. **Fire spread via the surface of the facade cladding**: to slow down this type of spreading, one generally needs to take measures relating to the reaction to fire of the facade cladding
2. **Fire spread from one compartment to another** (from floor to floor, for example): either internally, via the junction between the floor and the facade element or externally, when the flames are coming out of the facade by passing, for example, through glazed elements that are not fire-resistant. To remedy this type of spreading, it is necessary to ensure the fire resistance of the junction (between the floor and the facade) and that of the facade element at floor level
3. **Fire spread within the facade system** via combustible components (e.g. exposed insulation), the ventilated air cavity located behind the cladding (chimney effect), ... One can reduce this risk by using, amongst others, non-combustible or low-combustible elements, by protection the combustible element (panels with K_2 10 or K_2 30 protection classes), by interrupting the combustible insulation layers, the ventilated air cavity, ...

The measures that need to be taken according to the Belgian regulation to reduce these risks are detailed in the publication.

A research project concerning optimization of the performances (thermal insulation, air-tightness, acoustical insulation and fire-behaviour) of timber facades led to the development of new solutions for wooden claddings with class D-s3,d1 in end-use conditions (requirement for low-rise buildings in Belgium). It is important to stipulate that the requirements apply to façade claddings in their final application conditions, i.e. including the possible impact of underlying layers of materials and their method of fixing. The facade cladding on which the reaction-to-fire requirement applies cannot therefore be considered individually, but as it is executed on site (fig. 1).

a) b)

Figure 1: a) The reaction-to-fire requirement for a facade cladding applies to the cladding in end-use conditions b) Fire-reaction test on a timber cladding (SBI-test EN 13823 [2])

The research project led also to the development of E 60 fire-resistant timber frame facades that are positioned against a concrete floor. The performed fire-resistance tests according to the standards EN 1363-1 and 1364-4 [3] and some of the solutions are presented in the presentation. A first configuration has been developed without fire resistance panels. In this configuration, the panels are optional both on the inside and on the outside to ensure fire resistance. They shall be selected according to other considerations, notably their acoustic, hygrothermal and/or aesthetic properties.

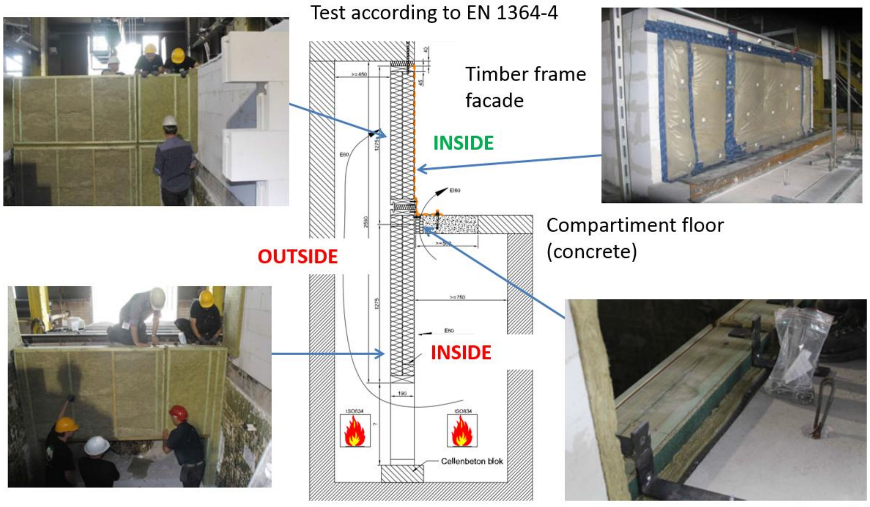

Figure 2: Fire-resistant test on timber frame façade and junction between concrete floor and timber facade (EN 1364-4)

This solution has been completed with a series of other configurations for timber facade elements with an E 60 fire resistance (see illustration on fig. 2). The latter are made up of specific inner and outer panels surrounding an insulation material (rock wool, glass wool or cellulose). Some configurations include rectangular timber studs, others I-shape wood joists (more commonly known as I-joists). One must ensure that these solutions are implemented while respecting all parameters, in accordance with the tests conducted (type and thickness of inside/outside panels, type of insulation, type and section of timber elements, type of sealing, ...).

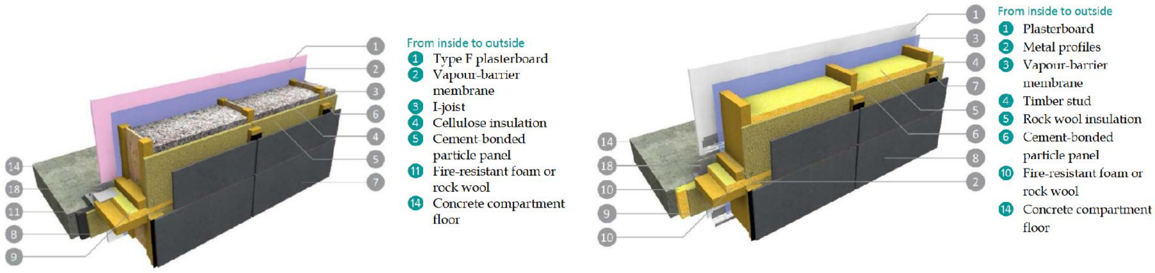

Figure 2.: Examples of details of timber façade E 60 and junction EI 60 with a concrete floor

Acknowledgments

This publication was drafted within the framework of the Standards Service Antenna 'Fire Prevention' financed by the Belgian Federal Public Service Economy, SMEs, Middle Classes and Energy.

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Fire safety of facades in Norway - Building regulations and experience from large scale fire tests

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Keywords: fire safety, facades, combustible insulation, building regulations, fire extinguishment.

Introduction - The Norwegian building regulations are performance based. There are two ways to fulfil the fire safety requirements: by using the solutions recognised as pre-accepted in the guidelines to the regulations or by application of an analysis following a fire safety engineering approach. The last version of the building regulations with guidelines was issued in July 2017[1,2].

For buildings where the consequences of a fire are assumed to be large, the guidelines restrict the application of combustible materials in facade systems. The use of combustible insulation is of a special concern and is treated explicitly in the guidelines to the regulations.

This paper presents the fire safety requirements for facades in Norway, and also test results from two recent research projects where fire safety of facade constructions was a topic. In the first project sandwich panels with combustible insulation were tested in a large scale fire. In the second project fire extinguishing in a ventilated, uninsulated wooden facade system was studied.

Fire safety requirements to facades in Norwegian building regulations - The requirements to fire characteristics of products and materials are stated as follows in section 11-9 (unauthorised translation):

> *(1) Structures shall be designed and constructed to ensure the probability of fires occurring, developing and spreading is minimal. The use of the structures and time necessary for escape and rescue shall be taken into account.*
> *(2) Products and materials shall not have characteristics that make an unacceptable contribution to the development of a fire. Weight shall be given to the possibility of ignition, speed of heat transfer, smoke production, development of burning drops and time to flashover*

The guidelines explain the safety level more detailed for facade systems with combustible insulation for exterior walls – i.e. the combination of exterior cladding and insulation. Combustible insulation is not pre-accepted in buildings where the consequences of a fire may be large (e.g. buildings with 5 or more floors, hospitals etc.). Facade systems shall be tested and approved according to *SP FIRE 105: Large scale testing of facade systems (1994)* [3]. This is a large scale fire test where the vertical specimen of the facade system is tested on a substrate having fire properties equal to or worse than the substrate to be used in the end use application. The fire source in this test is a tray of 60L heptane, and the specimen is exposed to the flames for 16-18 minutes. This test is required in Sweden, Denmark and Norway. A photo from a facade test according to SP FIRE 105 is shown in Figure 1.

Figure 1 SP FIRE 105 test of façade system. Photo: RISE Safety, Sweden.

For exterior surfaces that are not a part of a system involving combustible insulation products, the Euroclass system is used. The required classification is either D-s3,d0 or B-s3,d0, dependent on the fire safety classification of the building.

Large scale fire test of facade systems with combustible materials - RISE Fire Research has performed several projects considering the fire safety of combustible insulation for the authorities over the years. Results from a recent project on this topic were reported in 2013 and 2014 [3,4]. In the main project large scale tests of façade elements with polyisocyanurate (PIR) and polyurethane (PUR) insulation were performed in connection with a full scale fire in a single family house built in the 1950's. The burning of the house was initiated by the local fire service to arrange an exercise in smoke diving and extinguishing techniques. We were allowed to use this opportunity to perform ad-hoc fire tests in our project.

One of the purposes of our tests was to observe differences in temperature development when the following products were mounted on a substrate of 50 mm mineral wool:

1. Steel faced sandwich panel with PUR insulation, total thickness 100mm.
2. Surface laminated PIR sandwich panel covered with 19 mm wood panel cladding of spruce with an air gap of 45 mm between the wood panel and the sandwich panel.
3. 19 mm wood panel cladding of spruce with an air gap of 45 mm between the panel and the mineral wool insulation.

The fire source consisted of a garbage bin of PVC filled with a polyurethane mattress that was ignited by a burning block of 4 layers of 10x10 asphalt boards soaked with 1.5dL of heptane.

After all the "controlled" facade tests with garbage bins as fire sources were completed the house was allowed to burn down without any attempts of extinguishment. The three test setups are shown in Figure 2 together with photos from the tests.

It was observed that none of the sandwichpanels were more easily ignited than the uninsulated wood cladding. It was, however, observed that the rear side of the sandwichpanel with surface laminate was ignited. This indicates that protection of the insulation is important on both sides of the panel and also on the lower edge of the panel. During the burn down of the house the sandwichpanel with steel sheet covering had the least damage of the three facade systems.

Figure 2 **Upper left**: Test 1 - steel faced sandwich panel with PUR insulation. **Upper centre**: Test 2 - surface laminated PIR sandwich panel covered with 19 mm wood panel cladding of spruce with an air gap of 45 mm between the wood panel and the sandwich panel. **Upper right**: Test 3 - 19 mm wood panel cladding of spruce. **Lower left**: Test 2 and Test 1 after flame exposure. **Lower right**: All façade test specimen during total burn down of the house.

The tests in this project must be considered as indicative since we had to adjust the conduction of the tests according to the fire service's exercises. However, we are of the opinion that the observations and measurements in the tests gave information and experience that may be important when considering the fire safety of facade systems including combustible materials.

Extinguishing fires in ventilated wooden facades - Wooden facades are quite common in Norway, and are found both on older and modern buildings. A facade of wood requires ventilation to prevent damage by moisture and this means that there are gaps and voids behind the wood panels. In a project performed by RISE Fire Research in 2015-2017 different extinguishing techniques and systems were used to extinguish fires in voids and cavities in a model house built of wood, see Figure 3 [5,6]. In the test series with fire behind the outer wood panelling, use of the cutting extinguisher and CAFS (Compressed Air Foam System) were compared with conventional extinguishing with water combined with the use of a chain saw to open up the construction. An IR camera was used for detecting hot areas behind the panel in all tests, but to a different degree. All the three methods extinguished the fire, but there were some differences with regard to consumption of water and the extinguishing time, as shown in Table 1.

The conclusions from these tests were that all the three methods showed good effect on extinguishing the fire in the wooden facade, and all required quite short time to put out the fire. However, the differences in the amounts of water applied were considerable, with CAFS being the system using the smallest amounts.

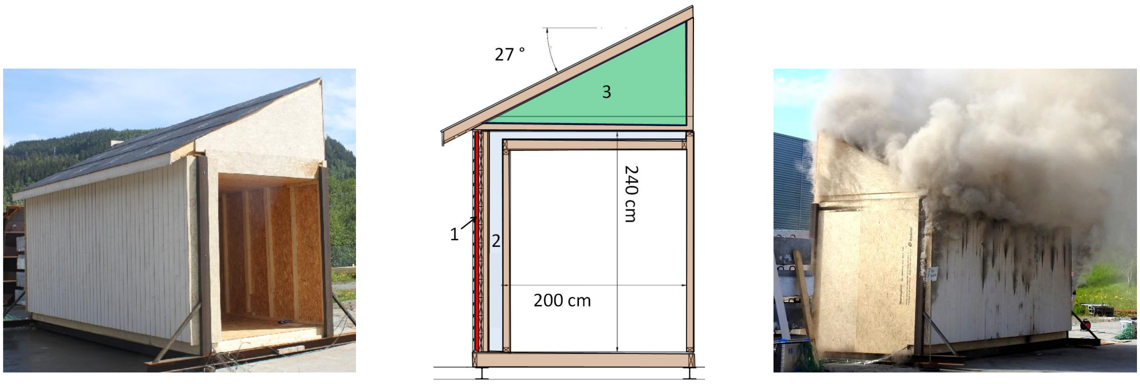

Figure 3 Left: The model house used for testing of extinguishing systems. Centre: The cavity number 1 is directly behind the exterior wood panel. Right: The fire development approximately 6 minutes after ignition in the cavity behind the wood panel [6].

Table 1 Results from extinguishing fire in a wooden façade [ref].

Extinguishing system	Extinguishing time [mm:ss]	Water applied [L]
CAFS, extensive use of IR camera	03:53	Ca. 40
Cutting extinguisher, some use of IR camera	02:32	Ca. 135
Water/chain saw, little use of IR camera	04:10	Ca. 220

Final remarks - The results presented here may be used as a background for further studies of fire behavior of facade systems. It has been shown that sandwich panel façade systems with combustible insulation may have fire properties comparable to – or even better than - traditional wooden ventilated facades. This should be studied more thoroughly through large scale testing. The extinguishing tests have shown that different extinguishing systems can be effective for extinguishing fires in ventilated wooden facades, but that the amount of water required for extinguishment can vary considerably. This may be important input to the fire services' planning and training regarding facade fires.

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Safety Aspects of Façade Fires: Novel Risks and Challenges Posed by High-Rise Buildings

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Keywords: façade fires, high-rise buildings, fire engineering design, large-scale testing.

Scope and objectives – A large number of recent high-profile fire incidents has demonstrated that façade fires in high-rise buildings may have devastating effects, incurring significant life and property losses. The introduction of combustible insulation materials, which provide a mechanism for rapid external vertical fire spreading, has gradually increased the impact of façade fires. In the case of high-rise buildings, façade fire risks are further intensified, due to the adverse impact of certain characteristics, such as large quantities of insulation materials used, prolonged occupant evacuation time, increased effects of external winds and difficult access for the fire-fighting personnel. An overview of the main characteristics of façade fires in high-rise buildings, characteristic incidents, past research activities and relevant legislative requirements is presented, aiming to provide a collective view on the topic of façade fires in high-rise buildings.

Façade fires in high-rise buildings – Façade fires may be initiated by either an internal fire source, e.g. an under-ventilated compartment fire where flames are ejected through an open window, or an external fire source, e.g. a fire originating from an adjacent building or a ground-level item, such as a waste container. It is evident that hazards related to façade fires are considerably increased when some components of the facade wall assembly are combustible. For instance, due to the ever-stricter requirements for building energy performance, there is a growing trend of installing thermal insulation materials on building facades; these materials are occasionally flammable (e.g. polymer-based). In terms of fire safety, high-rise buildings may differ from conventional lower height buildings in the following aspects: higher fire load, possibility for substantial vertical (upward) fire spreading, longer occupant evacuation times and increased impact of natural forces (e.g. stack effect, external winds) that affect fire and smoke movement [1]. Also, in the case of very tall buildings, facade fires may be very difficult to be tackled from the outside, since the fire may not be accessible to fire-fighting appliances.

Characteristic high-profile incidents – A series of recent high-profile large-scale fire incidents has demonstrated the potential devastating effects that façade fires may have, especially in the case of high-rise buildings equipped with combustible façade materials. It is well established that vertical fire spread from floor to floor and over the façade can have catastrophic results. Past fire incidents have demonstrated the danger of rapid and extensive fire spread over the length of the façade, either externally or internally through the insulation cavity. Even if there are no combustible components on the facade, the fire may spread in a leap-frogging fashion. Characteristic images of certain indicative high-rise building fire incidents, where significant vertical (floor-to-floor) fire spreading has been observed are depicted in Figure 1. In many cases, the fire extended to a large number of floors above the level it has originated, occasionally even spreading along the entire height of the building. It becomes evident that, due to the large number of occupants in high-rise buildings, such incidents may result in a high number of casualties.

***Figure 1**: Images of characteristic high-rise façade fire incidents, exhibiting significant vertical fire spreading; (from left to right) Windsor Tower (2005), Shanghai residential (2010), Grenfell tower (2017), Beijing TV cultural centre (2009).*

Physical mechanisms of fire spreading in façade fires – When a façade fire is established at the exterior wall of a building, the fire spreading rate can be significantly enhanced, by means of different physical mechanisms, the most important of which are the following [2]: Vertical fire spreading to the storeys above via radiative heat transfer through openings, fire spreading through the external surface of the façade assembly, if combustible materials are present, flame spreading within an internal vertical air cavity (e.g. ventilated façade), initiation of secondary external fires to lower levels, due to falling burning debris or downward fire spread.

Past research activities – Façade fires are characterised by the development of a rather complex turbulent, reactive, multi-component and multiphase flow-field, both inside and outside the fire compartment, the characteristics of which are affected by a large number of parameters, such as fuel type, fire load distribution, compartment geometry, opening geometry, façade geometry, façade materials, external wind etc. A large variety of interacting physical phenomena, such as heat transfer by conduction, convection and radiation, turbulent flow, combustion and pyrolysis chemical kinetics and temperature-dependent material properties, are involved in a typical façade fire, further complicating any effort to acquire an in-depth understanding of the physical mechanisms involved. As a result, research efforts focusing on façade fires had been rather scarce in the past; only during the last few decades have they started to appear more frequently in the open literature. Performing a large-scale compartment-façade fire test is a rather challenging and costly task; as a result, well documented large-scale façade fire experimental data sets are quite scarce [3-6]. A large number of intermediate-scale compartment-façade-fire tests has been performed by the Fire Engineering Unit at the National Technical University of Athens, aiming to determine the effects of fire load and opening geometry on the main geometrical and thermal characteristics of façade fires [7-9]. Based on the experimentally determined observations, a number of numerical correlations, capable of describing the main geometrical (e.g. flame length, width, projection) and thermal (e.g. centreline temperature, heat flux on the façade) characteristics of façade fires, has been developed [10-11].

Legislative requirements - A series of fire behaviour requirements related to external wall assemblies are commonly prescribed in regulations and building codes around the world. In most cases, prescriptive requirements focus on the following key issues: reaction to fire requirements for facade assemblies and materials, fire barrier requirements, horizontal separation distances of buildings and vertical separation distances of openings between successive storeys and requirements for sprinkler protection [2]. However, the majority of current building fire safety protection codes worldwide are lacking specific methodologies to evaluate the risks associated with façade fires. For instance, the Eurocode design guidelines, used across the European Union, do not specifically address risks associated with façade fires. From a regulatory standpoint, it is necessary to quantify the fire performance of combustible and incombustible facade claddings and exterior wall systems. Classification of façade systems and materials is commonly performed by means of standard large-scale façade fire tests; various such tests are in use around the world, exhibiting large variations in test geometry, fire source, specimen support details, severity of exposure and acceptance criteria. However, performance-based design approaches are gradually starting to be implemented worldwide, allowing the use of more cost-effective design solutions.

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Contribution of fire barriers in preventing fire spread across façades – experimental testing performed by University of Zagreb

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Keywords: fire safety of façades, fire barriers, large-scale testing, ETICS systems.

Scope and objectives – To satisfy the requirements set for reducing energy consumption in buildings, the thickness of the insulation layers in façade systems has increased at least twofold, with a tendency of further increase. The insulation layers can be made of either inorganic non-combustible materials or organic combustible ones. In case of fire, application of combustible insulation materials in façade systems increases the risk of fire spread vertically across façade and to adjacent buildings. Due to special fire safety problems related to high-rise buildings (i.e. risk associated with vertical spread across façades, prolonged evacuation, rescue not possible from outside, etc.), in most European countries, only non-combustible materials for façade application are used. For the lower buildings, e.g. with height from 11 to 22 m, the use of combustible materials in façade systems is allowed in Republic of Croatia, but if interrupted with fire barriers [1]. A fire barrier represents a non-combustible material used to break up continuous combustible construction to delay fire spread from its one side to the other. Hereafter, results of large scale fire testing performed on EPS (expanded polystyrene) based ETICS (*External Thermal Insulation Contact Systems*) specimens with and without fire barriers are shown. In the absence of a harmonized EU standard for large scale façade fire testing, fire performance of ETICS system in presented tests was assessed according to standard BS 8414-1 [2].

Experimental testing set-up – Test specimens were L-shaped, 8 m high, with main test wall (main face), 2.6 m long, and return wall (wing), 1.5 m long. The L-shape of the specimen represents an internal corner of a building.

Composition of test specimens and their classification according to the reaction to fire properties, as declared by the manufacturer, is shown in Table 1. The only difference between test specimens was 20 cm high horizontal fire barrier made of non-combustible material (stone wool – SW) that was installed as lintel protection above the combustion chamber (representing opening) of test specimen denoted with TS_2 (Fig. 1a).

Table 1. Description of test specimens

Test specimen	Thermal insulation material and thickness	Render	Fixing method	Reaction to fire class – HRN EN 13501-1[3]
TS_1	Expanded polystyrene (EPS) – 150 mm	Basic render reinforced with glass fibre mesh and final organic (acrylic) render – 5 mm	Adhesive and mechanical fixing	B-s2, d0
TS_2	Expanded polystyrene (EPS) – 150 mm + fire barrier 200 mm high; directly above combustion chamber			B-s2, d0 (A2-s1, d0 barrier)

The specimens of the same compositions were tested twice to assess repeatability of testing in outdoor conditions and comparability of obtained results.

a)

b)

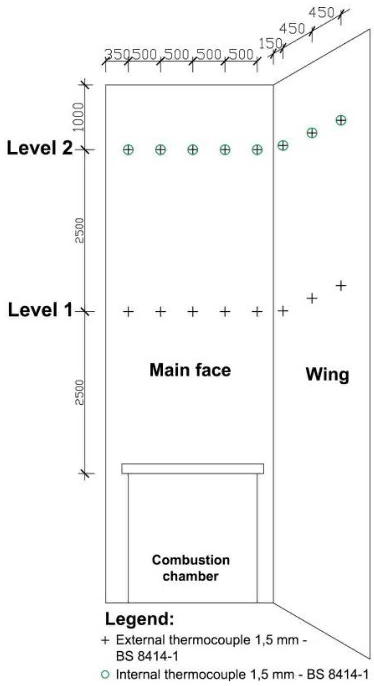
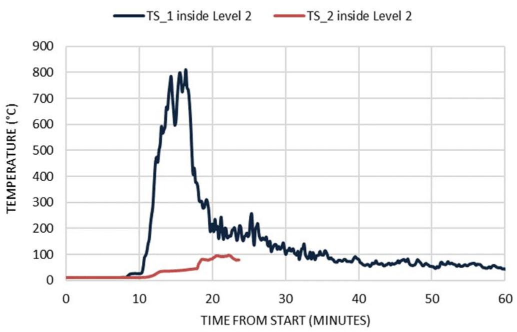


Fig.1. a) dimensions of fire barrier installed above combustion chamber of test specimen TS_2, b) position scheme of thermocouples embedded in both specimens, TS_1 and TS_2

Developed temperature profiles - To monitor evolution of temperatures during testing, external thermocouples were embedded on the main face of the façade and on the wing, both at Level 1 (2.5 m from combustion chamber) and Level 2 (5 m from combustion chamber) in accordance with BS 8414-1. Internal thermocouples were embedded at Level 2, on the main face of the façade and on the wing (Fig. 1b).

Analysis of average temperatures, developed during both tests within thermal insulation layer, shows that test specimen TS_2 has considerably lower temperatures compared to test specimen TS_1. Obviously, fire barrier has limited the fire development within the insulation material in test specimen TS_2 where, at Level 2, the temperatures remained below or around 100°C. The adverse effect occurred in specimen TS_1, i.e. the thermal insulation in this specimen was caught by fire where temperature peak rose above 700°C (Fig. 2).



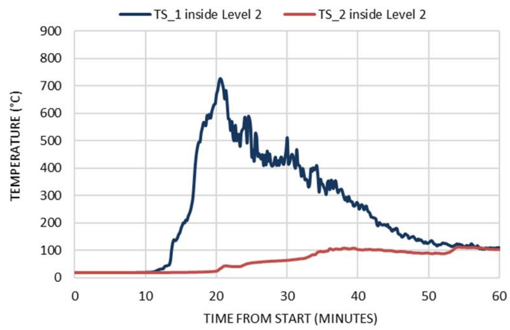


Fig.2. Average temperature within thermal insulation layer at Level 2 on main façade a) first testing, b) second testing

Visual appearances - More than 60 minutes from the start, firefighters hosed down fire sources for all test specimens for safety reasons. Figs. 3-8 present the pattern of behaviour of two façade systems during second testing. As it can be seen from figures, only the glass fibre mesh and finishing render was left of test specimen TS_1, while the entire thermal insulation burned up in less than 40 min after the start of fire. At test specimen TS_2, once the fire propagated over the fire barrier above the combustion chamber, the thermal insulation started to melt and burning droplets were released and felt around the specimen. The thermal insulation melted only partially at this test specimen.

Fig. 3. Start of the test

Fig. 4. 9 min from the start

Fig. 5. 19 min from the start

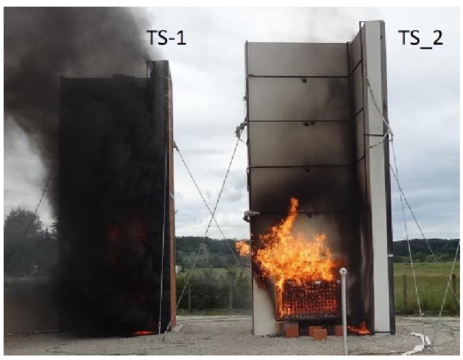


Fig.6. 28 min from the start

Fig. 7. 37 min from the start

Fig. 8. 57 min from the start

Effectiveness of fire barriers - Non-combustible stone wool fire barriers if positioned above the window opening can delay the fire spread of EPS ETICS in case of a fully developed fire impinging on the façade. Therefore, in systems like the ones tested, a non-combustible fire barrier can possibly be used as passive fire protection. The fact that the system with the fire barrier allowed considerable fire spread, although later in the test, shows that the safety margin of these types of systems are limited. They should therefore not be used on buildings such as high rise buildings and buildings where occupants need additional time to escape such as hospitals, kindergarden and nursing homes.

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Development of a reduced-scale testing methodology for façades in fire

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Summary

Sustainability is a major driving factor in modern building and has resulted in a number of innovative solutions. These designs increasingly challenge the conventional fire safety strategy which was developed throughout the 20th century. A key staple in this strategy is that fire should never spread externally over multiple floors, and doing so violates a significant portion of the assumptions and mitigation strategies. Modern façades nonetheless increasingly include the use of flammable materials and/or the introduction of ventilated cavities. Current test methods are expensive, time consuming and deliver little knowledge on the actual performance of a system. This research is focused on developing a reduced-scale combined experimental and modelling development tool to aid in products reaching the market both efficiently and safely.

Introduction

New regulations within the last decades have changed the way in which buildings are being designed. Stringent energy requirements require increasingly efficient insulation, and the simultaneous drive towards sustainability has resulted in a number of highly innovative solutions. Modern façades are gradually starting to contain flammable materials despite the lack in understanding of external flame spread and its impact on a building. One of the fundamental assumptions of the classic fire safety strategy is that there will be no external vertical flame spread and to change this requires a serious rethink of the entire design of a building [1].

In this current work, the initial focus has been on ETICS (External Thermal Insulation Composite Systems). These systems have insulation such as expanded or extruded polystyrene (EPS or XPS) or stone wool mounted on the existing substrate of a building, and are then protected by a thin layer of cement-based render. EPS has very poor flammability characteristics [2] and thus its usage is often restricted in buildings. As an example in Denmark, one way in which ETICS with EPS can be used in the façades of small buildings is by passing the Swedish SP 105 test [3]. There are many different full-scale test methods across Europe but they share many of the same qualities. Each typically involves large-scales (>5.5m height) and deliver little to no quantitative knowledge on the fire performance of the façade. Running tests is both expensive and time consuming, and this is a particular problem for small- and medium-sized companies who cannot afford to fail tests. Façade testing represents a difficult area in fire safety engineering due to the dependence on whole product behaviour as opposed to simple material-level fire behaviour [4]. Factors such as window and corner detailing, joints, fixing methods and cavities all provide additional fire engineering challenges.

Outline of methodology

A tool is being developed to help reduce the time and cost for manufacturers to bring a product to market [5]. The concept is that initially a manufacturer will test a product using a full-scale method which is relevant for their certification needs. In future this will most likely be the harmonised

European method currently under discussion. Typically, a manufacturer then has a wide range of other products with minor variations that they also wish to be able to retail and thus also require certification. Under normal circumstances this would require an extra test for every variation unless the authorities allow an alternate route. The aim of this tool is to perform a series of experiments ranging from micro- to intermediate-scale to determine key properties which are then input into a model and scaled up. This will give a prediction on whether the product variations are likely to pass or fail. In some cases, authorities may be willing to accept this as a performance-based solution if they are sufficiently convinced and depending on the specific country's regulations. Otherwise, full-scale tests can be run only on the products which are predicted to pass.

This methodology is reliant on the identification of the relevant failure criteria. For ETICS, this is hypothesised to be based on the melting of the insulation eventually leading to loss of the render. This then enables upward flame spreading to propagate. The rate of loss of insulation is based on the fire exposure for a given test method and can therefore also be used with an exposure as specified by a designer as part of a performance-based design. Detailing may play a larger role in the failure for other construction types.

Future development

Ventilated and bio-based façades are two popular modern solutions for the exterior design of a building. In the former case, the presence of a cavity results in significantly more complex fire dynamics that is substantially more difficult to predict. For the latter, there is currently a lack of understanding in the fire performance of bio-based materials and constructions. There is however relevant knowledge based on existing research in wildland fires, particularly at the wildland-urban interface. The ignitability of wildland fuels is strongly influenced by the moisture content [6,7] and additionally has more complicated effects due to seasonal variations [8]. Wildland fires with dead fuels on the ground do not readily propagate when the moisture content exceeds 10–40%, yet in crown fires propagation occurs with moisture contents as high as 70–135% [8] on a dry weight basis.

Demonstration façade fire tests [9] have been performed using a reduced-scale version of the SP 105 [3] method, broadly half-size. The goal of the tests was not scientific and was instead to inform various stakeholders including architects, engineers, building approvers, contractors and manufacturers. Results from a green (or living) façade system suggested that presence of moisture impeded ignition and was sufficient to prevent self-sustained flame propagation. Systems with cellulosic-based recycled paper insulation did not have ignition of the inside layer due to the penetration time through the protective layer being too long. However, in existing façade fire tests the durations are relatively short, e.g. 20 mins, compared to the incidence time of smouldering fires which can last hours or days [10]. This will require a new approach to properly evaluate the fire risk associated with these types of systems. The risks associated with bio-based insulation materials have already been a particular focus for investigation of smouldering [11,12] and other efforts have been made to provide a quantified approach to designing protective layers for insulation [13].

Acknowledgements

The first and second authors gratefully acknowledge the support of the Danish Innovation Fund (Innovationsfonden). Façade fire tests were financed by InnoBYG as part of a spireprojekt.

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Fire retardant treated wood facades – application of the new European durability standard

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Keywords: long term fire performance, reaction to fire, weathering, wooden facades.

Scope and objectives – Wooden facades are becoming more attractive to architects and builders when higher buildings in timber structure are becoming increasingly used worldwide. But wooden facades may not fulfil the fire requirements in national building codes and fire retardant treatments may be an option. However, the improved fire performance of the virgin fire retardant treated wood products may degrade over time, especially in outdoor applications due to climate strains as rain and UV exposure. The long term durability needs therefor to be addressed.

Durability of fire retardant treated wood products – Principles and methods - Requirements on durability of the fire performance are not mentioned explicitly in most building codes, probably partly caused by unawareness of the problem, but may also be due to the lack of procedures.

A European system with classes for Durability of Reaction to Fire performance (DRF) has been developed (EN 16755), see Table 1. The system is based on a technical specification (CEN/TS 15912) and North American systems (ASTM D 2898, ASTM 3201). It consists of a classification system for the properties over time of fire retardant treated wood and suitable test procedures.

Table 1. *Requirements for DRF classes of FRT wood products according to EN 16755.*

DRF class		Existing fire requirements	Additional performance requirements at different end use of fire-retardant wood products	
	Intended use	Reaction to fire class, initial	Hygroscopic properties	Reaction to fire performance after weather exposure
INT 1	Interior, dry applications	Relevant fire class	-	-
	Interior, humid applications	Relevant fire class	- Moisture content < 28 % - No exudation of liquid - Minimum visible salt with no increase at surface	-
EXT	Exterior applications	Relevant fire class	- Moisture content < 28 % - No exudation of liquid - Minimum visible salt with no increase at surface	Maintained reaction to fire performance [x]

x) Further details are given in EN 16577.

The initial fire class shall be verified according to relevant norms. Maintained reaction to fire performance after weather exposure shall be verified acc. to ISO 5660 or other relevant fire tests.

a)

b)

Figure 1. Weathering of FRT wood panels a) Natural field weathering with panels exposed both vertically (90º) and at 45º slope outside Stockholm, Sweden; b) Accelerated ageing according to EN 16577 (with box open).

Figure 2. Wooden facades are visible in the final building and may be used for all loadbearing systems. Strandparken building in Sundbyberg, Sweden.

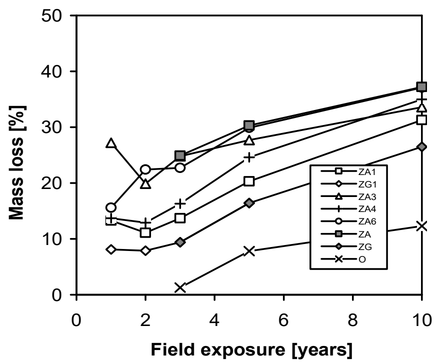

Figure 3. Mass loss during natural weathering of wood treated with different fire retardants and of untreated wood (X) up to ten years. Numbers 1-6 denote different surface coatings [4].

Background – Research shows that the excellent reaction to fire performance of virgin fire retardant treated wood products may degrade over time, especially at outdoor applications [2,3]. Recent experiments have confirmed that the fire performance may be maintained after weathering, if the retention levels are high enough, but several products loose most of their improved reaction to fire properties during weathering [4]. The mass loss during weathering may be used as an indicator of the maintained reaction to fire performance over time, see Figure 3. Paint systems contribute considerably to the weather protection at exterior applications.

Recommendations - Requirements on the long term durability of the fire performance of fire retardant treated wood products should be included in product specifications, certification documents and in the national building regulations in order to support the use of reliable wood products. It is especially important for wood products intended for exterior use. New fire retardant wood products with improved long term durability and more experience with correlation of natural field testing and accelerated ageing methods need to be developed.

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Fire safety of High Rise Buildings in Serbia

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Keywords: high rise residential buildings, fire safety, facades.

Scope and objectives – The fire safety of high rise residential buildings is the subject of research for the last five years at Department for Civil Engineering and Geodesy (FTS-UNS). This paper presents the basic information about the investigated building stock, survey methodology and fire safety criteria applied in the first phase of the research. In recent years, installation of an additional layer of thermal insulation on facades is the most usual renewal activity in Serbia, which initiates the need for more detailed fire safety analysis of facades. The objective is to present to the other participants of COST Action FP1404 our areas of interest and initiate future research partnership within Action FP1404.

Modernism in architecture promoted the high-rise residential tower as the optimal residential form for modern city. However, although the tradition of building of residential low and medium height forms was partially continued – freestanding high-rise buildings – towers and large dwelling blocks represent the residential symbol in the city of today. Thus, residential towers are the significant part of the urban inheritance and dwelling fond, and also the topic of our research. The fire safety issue has been considered as one of the priorities in buildings' maintains and renewals processes.

Fire safety issue was defined as one of the core structural aspects in European scientific research program COST C16 on existing residential buildings [1]. Presence of the fire safety problem was evidenced in seven countries (out of 15 which participated in research program) and it is ranged from low to medium [2]. Research program included residential urban buildings completed after 1950 and most of them are high raised, made of concrete, built in industrial way, as well as the buildings in scope of this study.

Research work was done on high rise residential tower shaped buildings in Novi Sad city area and resulted with data-base includes 64 items (Table 1). According to Serbian actual legislation [3], the high-rise building is defined as "a building greater than 30m in height, where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest story". In fact - it mostly includes buildings with 10 or more floors. The most of residential towers were built in the period of intensive residential building (1960-1990), with no detailed regulations on fire protection, until 1984. Even then, prescriptive rules were simplified, and often uniform solution was proposed resulting in the univocal rules, focused on the simplest solutions that were then extrapolated to larger models. Great part of the problem is lack of maintaining [4] and updating fire protection measures in buildings, even it was obligatory action by low.

In the observed city area - Novi Sad, all surveyed buildings (64) were built in concrete: most of them (38) by using industrial building technology “IMS” building system: precast prestressed elements, skeleton structure (labeled as IMS in Table 1). The rest of them (26) were built in classical way of building technology, reinforced concrete, and skeleton structure (labeled as RC in Table 1). Among 64 identified high-rise residential towers, 26 of them represent characteristic groups of built structures – building types (Table 1, Figure 1 - 2). Surveyed buildings consist of 4.469 apartments with approximately 14.000 tenants. One representative sample of each group was further examined in detail, for common characteristics related to building type: load bearing structure type, floor plans, building materials, façade shaping, staircases and elevators, smoke evacuation, fire compartments and fire escapes. All buildings were inspected for actual state of fire alarm systems and house fire hydrants, access roads and evacuation routes. State of the fire safety, based on data base statistics, indicates main topics for actions.

Table 1: High-rise residential towers in Novi Sad

Type	Number of buildings in group	Constr uction type	Stories	Apartment s /building	Tenants /building	Apartmen ts/b. group	Approx. Tenants /b.grou p
1	1	RC	Cellar + GF +10	70	215	70	215
2	4	RC	Cellar + GF +18	72	247	288	988
3	2	RC	Cellar + GF +14	84	252	168	504
4	3	RC	Cellar + GF +18	124	430	372	1116
5	3	IMS	Cellar + GF +14	56	223	168	669
6	3	IMS	G+17	68	246	204	738
7	3	IMS	Cellar + GF +17	64	256	192	768
8	3	RC	Cellar + GF +10	48	192	144	576
9	2	IMS	GF+14+Atic	60	214	120	428
10	1	IMS	Gf+16	108	342	216	342
11	3	RC	Cellar + GF +10	82	248	246	744
12	1	IMS	Cellar + GF +13	65	234	65	234
13	3	RC	Cellar + GF +17	68	262	204	786
14	3	IMS	GF+13	75	222	225	666
15	2	IMS	GF+14	98	308	196	616
16	2	IMS	GF+11	66	201	132	402
17	3	IMS	Cellar + GF +9	40	135	120	405
18	3	IMS	Cellar + GF +13	61	192	183	576
19	1	IMS	Cellar + GF +15+Atic	91	315	91	315
20	2	IMS	Cellar + GF +16	96	327	192	654
21	2	RC	Cellar + GF +14	60	220	120	440
22	1	RC	Cellar + GF +11	30	118	30	118
23	6	IMS	Cellar + GF +13	52	198	312	1188
24	3	IMS	Cellar + GF +16	93	338	279	837
25	2	RC	Cellar + GF +10	44	132	88	264
26	1	RC	Cellar + GF +10	44	124	44	124
	64					4.469	14.044

The change from traditional practice that simply follows the prescriptive code requirements to those that are based on fire safety analysis to obtain the required level of fire safety for the occupants is ongoing process in Serbia. The fire safety protocol is obligatory according to the actual Fire safety low (2009) in building exploitation phase. Fire protection Elaborate and Fire protection Main Design Plan are obligatory in design phase and, additionally, installation of automatic fire detection and alarm systems in new high-rise residential buildings. Moving towards the more flexible performance-based codes, allows flexibility in fire safety designs as long as the designs can provide the required level of fire safety to the occupants [5].

Figure 1 – High-rise residential buildings Type 13

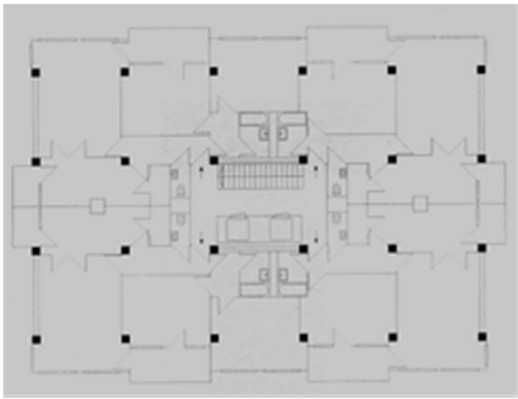

Figure 2 – High rise residential building Type 5 - Floor plan

Fire safety survey and evaluation of built structures was performed to provide valid information for defining the actual state of buildings' fire safety based on criteria analysis originated from actual legislation. Fire safety Low and other national legislations in Serbia are describing many demands that should be applied in urban, architectural and structural design of high-rise buildings. Some of them are of great significance for life saving issue and providing safe evacuation, so they are grouped and formulated as list of building's fire safety criteria in these research processes:

1. Industrial and residential areas should be located at proper distance, as well as residential buildings themselves (at least ½ of higher structure);

2. Access roads should be planned in a way and wide enough to provide movement of fire engines (only forward);

3. Access road has to lead to the plateau for fire-fighting intervention, which provides access to building's entrances/openings (windows);

4. Load-bearing building's structure has to stay stable in fire for 1,5 hours;

5. Building should be divided into fire compartments 500-1500m2 plan area, with separating membranes -walls - fire proof 90, each compartment has its own fire escape, with escape route no longer than 30m, doors in fire compartment's walls also has to be 1,5 hours fire proofed;

6. It is not allowed to connect the cellar to upper floors of building;

7. The building exit door should open to outside and at least 2,30m height; width depends upon number of residents;

8. Machine rooms (boiler room, transformer station, booster pump) should be separated fire compartments (90 minutes fire resistance);

9. At least one fire safe staircase, accessible from each floor, with fire-proof door and door self-closers;

10. Fire escape / fire stair – secondary staircase, made of metal or concrete;

11. Dimensions and shape of façade elements designed in a way to avoid the fire spread (at least 1m between the openings of two floors);

12. Route of evacuation should be with proper signalization and emergency light (60 minutes operating, with its own power supply);

13. Elevator shafts should be separated from staircase because they can contribute to the spread of smoke and fire, and automatically shut down in emergencies.

14. Wet standpipes should have hose cabinets on each floor (house fire hydrants). These hose cabinets contain 1” fire hose with a nozzle. In case of a fire, tenants can open the hose cabinet, pull out the hose and then open the valve allowing water to flow through the hose. Thus, this type of system requires water provided and pressurized up to each hose cabinet at all times. Buildings can either use county water pressure, or have some type of pressure booster, such as a pump;

15. Fire alarm system, as active fire protection system, that detects fire or the effects of fire, (heat detectors, smoke detectors, manual pull stations/manual call points) should be installed and functional, and as a result provides one or more of the following: notifies the occupants, notifies persons in the surrounding area, summons the fire service, and controls all the fire alarm components in a building. Fire alarm systems can include alarm initiating devices, alarm notification appliances, control units, fire safety control devices, annunciators, power supplies, and wiring.

The listed criteria, for their significant importance related to life saving issue, are main criteria in fire safety building analysis. Additionally, there are more technical standards regarding heating, ventilation, water and electrical supplying system, but they are not the subject of this survey. Most of them are difficult to investigate during field observation.

Fire safety evaluation of built structures was performed to provide valid information for defining the actual state of buildings’ fire safety based on criteria analysis originated from actual legislation. The findings of a survey were unsatisfactory: not one, out of 64 analyzed buildings, fulfilled fire safety requirements. Not one building is situated at safe distance from another one, and there is no fire compartmentation in any of the buildings or fume excavation in staircases. There is no Evacuation plan or exit signalization in any of those buildings and only 14 building plans contain fire stairs. Fire and fume spreading is easy possible, and tenants’ lives are seriously jeopardized, in all the buildings.

Those findings led to conclusion that there is, first of all, necessary to provide safe escape in case of fire. In the buildings with no fire stair, solution for upgrading the second stair case should be considered and existing fire stairs should be additionally investigated, because certain doubts occurred about its functionality in case of fire. Further investigation led to conclusion that the issue of life safety in case of fire is on critical level. Aiming to achieve a satisfactory level of fire protection, e.g. life safety, safety of people, material goods and environmental protection, it is necessary to review the conditions and perform comparative analyses of obtained results and actual demands of fire safety.

Every building is unique for its structure, situation, building materials, floor layouts so the fire risk assessment based on fire scenario event tree method provides to assess different combinations and detailed information about success or failure of proposed protection measures, as well as comparison of different combinations.

Sustainability has become the main driver in the built environment during recent decades, with energy efficiency becoming the foremost design criteria and appropriately quantified. By contrast, the approach taken for fire safety is much simplistic, relying on a series of prescriptions based on material classification and "pass–fail" criteria defined in standard fire tests [6].

Installation of an additional layer of thermal insulation on facades became the most usual renewal activity in Serbia in the recent years. However, the selection of materials with satisfactory thermal, but poor reaction-to-fire performance, can contribute to realization of fire hazard with catastrophic consequences – what already happened in a similar high-rise building in other countries. Contemporary facades are being designed with the aim to give visual identity and quality to the building, but apart from aesthetic criteria, facade should provide thermal and acoustic insulation, should be waterproof and should prevent the fire spread.

Materials used for production of thermal insulation can be organic or mineral. These materials contain a large amount of air which enables low thermal conductivity. Organic origin materials have a lower heat resistance and are more sensitive to climatic conditions. Classification of thermal insulation materials in use in Serbia, based on the origin of raw materials, is given in Figure 3. The properties of thermal insulation materials usually used for facades in Serbia have been compared [7-9] and are summarised in Table 2.

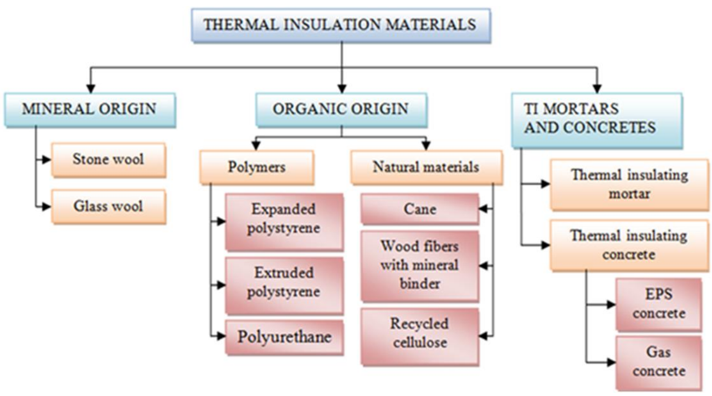

Figure 3. Classification of thermal insulation materials based on the raw materials origin

Table 2 - Properties of thermal insulation materials most often in use on facades in Serbia

Thermal insulation material	Thermal conductivity λ[W/mK]	Density ρ [kg/m3]	Reaction to Fire Euroclass	Melting temperature	Ignition temperature	Combustion products
Expanded polystyrene-EPS	**0.028-0.041**	**10-50**	**E-F**	**100°C**	**350-370°C**	**CO, CO2, H2O, soot**
Extruded polystyrene-XPS	**0.025-0.035**	**20 - 80**	**E-F**	**100°C**	**350-370°C**	**CO, CO2, H2O, soot**
Stone wool-SW	**0.033 - 0.045**	**22-180**	**A1-A2**	**1000°C**	**-**	**-**
Glass wool-GW	**0.030 - 0.045**	**10-130**	**A1-A2**	**700°C**	**-**	**-**

In high rise buildings it is allowed to use only insulation classified as A1-A2 on facades.

The presentation "Possibilities and conditions for use of bio-based thermal insulation materials in buildings: Prescriptive solutions – SERBIA" is available at COST FP1404 website – Poznan meeting, and provides detail information about Technical rule on Fire Safety of External Building Walls.

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Performance of ventilated-facade system under fire conditions: an experimental investigation comparing alternative building techniques

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Keywords: façade fire, large-scale experiment, ventilated-façade system.

Scope and objectives – The ventilated façade (VF) system is a double-wall construction, comprising an external lightweight cladding panel and the building's façade, which is used to increase the indoor comfort level in buildings. Literature reports on VF systems focus mainly on investigating their behavior in terms of energy consumption reduction and recently there has been an effort to document the regulatory requirements and specification of use across Europe [1]. Scarce reports can be found in the literature concerning the fire behaviour and hazards associated with such wall assemblies [2,3]. However, during a fire event, VF systems may contribute to fire spreading on the facade, representing a significant risk to the upper floors of a building, especially in the case of externally venting flames. Preventing fire spread in the air cavity is crucial. The use of fire stops may prevent fire spread through the air cavity but currently there is a lack of test standards to support selection of appropriate fire stops. In this context, the main scope of this work is to investigate the underlying phenomena affecting fire behaviour characteristics of the VF system, by means of large-scale compartment-façade fire testing.

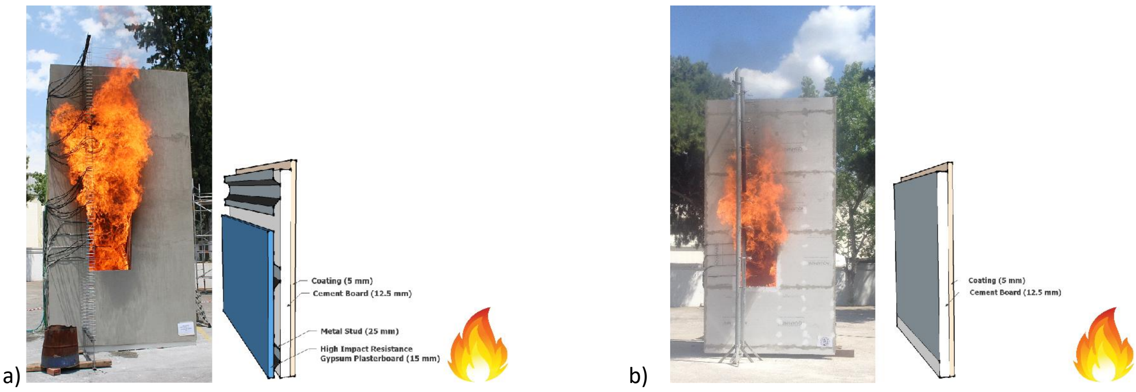

Figure 1. Fire test configuration and experimental setup a) VF system; b) PF wall configuration.

Large scale experimental setup – Aiming to investigate the fire behaviour of the VF concept two large-scale natural fire test were performed at the premises of Greek Firefighting Academy (Figure 2) [4]. Figure 1 presents a schematic drawing of the large-scale compartment-façade experimental apparatuses for the VF system and Plain Façade (PF) wall configuration. Emphasis has been given on the estimation of the thermal characteristics of the fire compartment and subsequent Externally Venting Flames (EVF), as these are the main physical parameters affecting the heat exposure of the VF façade system.

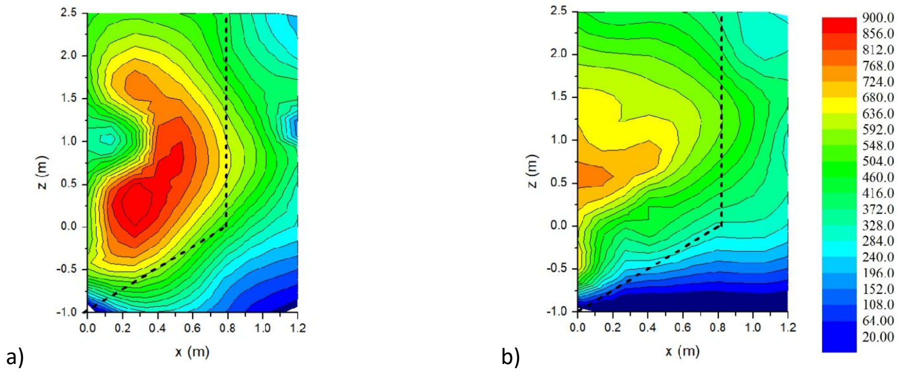

Figure 2. Temperature contours at the centreline plane perpendicular to the façade a) VF system; b) PF wall configuration.

Experimental investigation – Although emphasis was given on EVF characteristics, the importance of the compartment thermal conditions was also investigated. Towards this end, an extensive set of sensors is installed both inside and outside the test compartments, aiming to record the temporal variation of several important physical parameters such as: fuel consumption rate, temperatures at the interior and exterior (Figure 2) of the fire compartment, opening flow velocities, façade temperature (Figure 3) and heat flux, flame shape and dimensions. Experimental results suggest that the VF system proved to sufficiently sustain the 900s fire exposure.

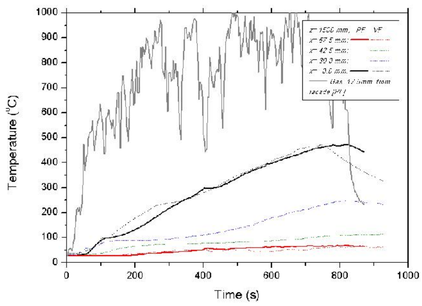

Figure 3. Temperature measurements at the various interfaces of the PF and VF systems at a height of 150 cm above the window lintel.

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Wood products as linings, floorings and claddings

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Keywords: FireInTimber guideline, test facade, type of facades.

This work is a draft from 2009 for the technical guideline for Europe Fire safety in timber buildings written by Birgit Östman.

4. 1 Reaction to fire classification in end use conditions

4.2 Improved reaction to fire performance

4.3 Facades

Structural fire protection is a fundamental requirement to facades as the outer surface of external walls of multi-storey buildings (independent of the used material). The goal is to prevent uncontrolled fire spread on the surface of the external wall for a required period.

Additionally, structural fire protection is essential to the various combustible facade specifications. Thus, timber and wood based products can be used without reducing the aspired security level.

However, there is so far no European harmonised solution on the fire performance of facades. Different solutions are applied in different countries.

4.3.1 Principles for fire safety of facades

The spread of a fire on the facade of a building generally is influenced by character, intensity and location of the initial fire.

Principally, the facade can be exposed to the following three fire scenarios:

- Scenario A: fire of a building located next to the facade
- Scenario B: fire outside the building in front of the facade
- Scenario C: fire inside the building in a room next to the exterior wall with at least one opening in the façade

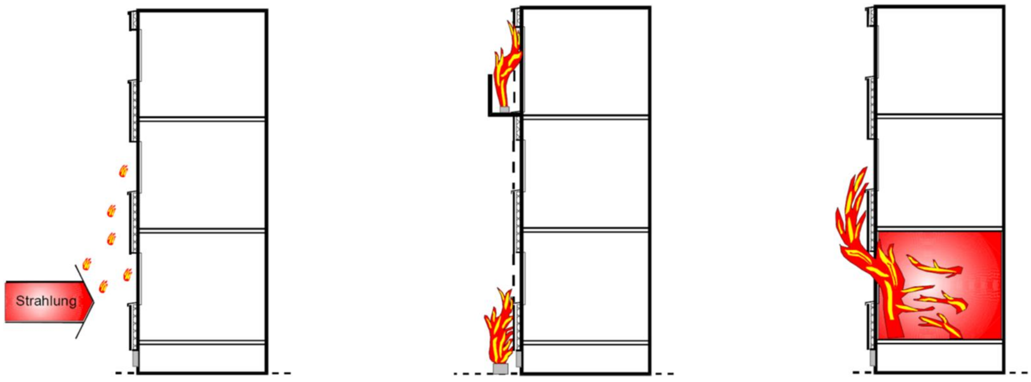


Figure 4.6. Fire scenario on exterior walls (source: Lignum Dokumentation Brandschutz)

Several fire tests have shown that the scenario with fire inside the building has the worst effect on the facade. This scenario causes the highest release of energy in front of the facade surface.

Comparing scenario B with C, conservative values for testing and evaluation of facades can be determined:

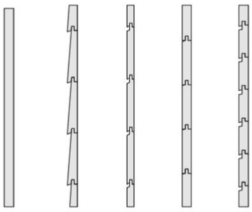
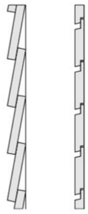
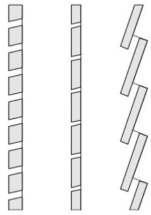
- release of energy in front of the facade — 1 – 1,5 MW
- average extend of flames — 2,5 – 3,0 m (max. 6,0 m)
- total time of thermal exposure — 15 – 20 minutes
- total time of exposure to blazing fire — 10 – 15 minutes

Real fires and fire tests show that all parts of a facade react to direct flame impact in the area of the plume dependent on their flammability. Windows or openings in the facade in this area without any performance in terms of fire protection are weak spots whether or not open or closed.

Basically, the behaviour of facades under fire load is dependent

- on the type and architectural features of the facade (facade with recessed ribbon glazing, perforated facade, angled facade),
- on the type and alignment of the cladding
- on the substructure including the rear ventilation opening

<u>Note that these are qualitative simplified results. Effect of ventilation gap is missing here!</u>

Parameters of influence	influence to fire behaviour		
	best	good	critical
Type of facade			
Type of cladding			

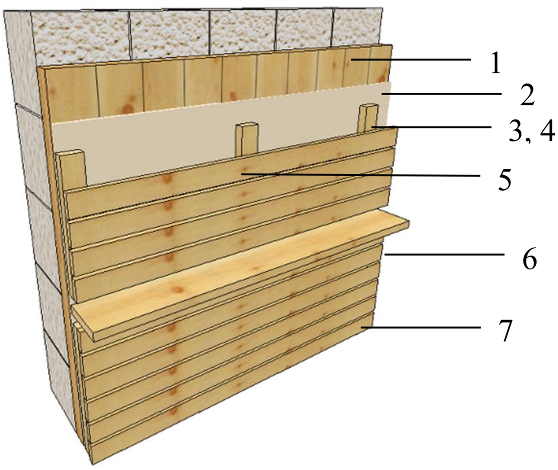
<u>Figure 4.7</u>. Examples for influence parameters to the fire behaviour of multi-storey facades (source: Lignum Dokumentation Brandschutz)

4.3.2 Experiments and research

Some data from German studies are available. <u>(does not really fit in a handbook, should we shorten and/or add some further studies from other countries?)</u>

<u>Large Scale Tests</u>

Wooden facade systems as described in <u>Figure 4.8</u> are applied to the facade test facility. In more than thirty tests many different types of timber and derived timber surfaces were combined with several fire barrier constructions made of rust-proof steel sheet or timber panels.



1. wall of test rig (240 mm lime-sand brick)
2. X-lam timber board (60 mm)
3. gypsum fibre board (15 mm)
4. optionally moisture protection foil
5. lathing, substructure
6. horizontal fire barrier between storeys
7. horizontal cladding

<u>Figure: 4.8</u>. Example of test specimen

The arrangement of the test setup and the test procedure follows the knowledge of the calibration tests and the German preStandard prDIN 4102-20 “Besonderer Nachweis für das Brandverhalten von Außenwandbekleidungen” (Special test of fire behaviour of claddings for external walls). The test facade is arranged on a 240 mm thick lime-sand brick wall. To provide an easy erection of the different test setups, the wall is covered with additional layers: a 60 mm massive 3-layer X-lam timber board and a 15 mm gypsum fibre board.

An opening at the bottom is to simulate a window. The flames from a wooden crib located in the opening attack the cladding of the facade. A crib of 50 kg is used as fire load, simulating the fire load in front of the facade after flash-over. Temperature measurements are carried out at the surface and in the rear ventilation layer. The test and observation time lasts normally 20 minutes.

<u>Tested facade constructions and surfaces</u>

During two and a half years a total of 33 different fire tests have been tested at the facade test rig in Leipzig (Germany).

In this time, several types of surfaces (open spaced cladding, tongue and groove profile, weatherboarding and various types of derived timber boards) with horizontal or vertical arrangement were combined with common substructures.

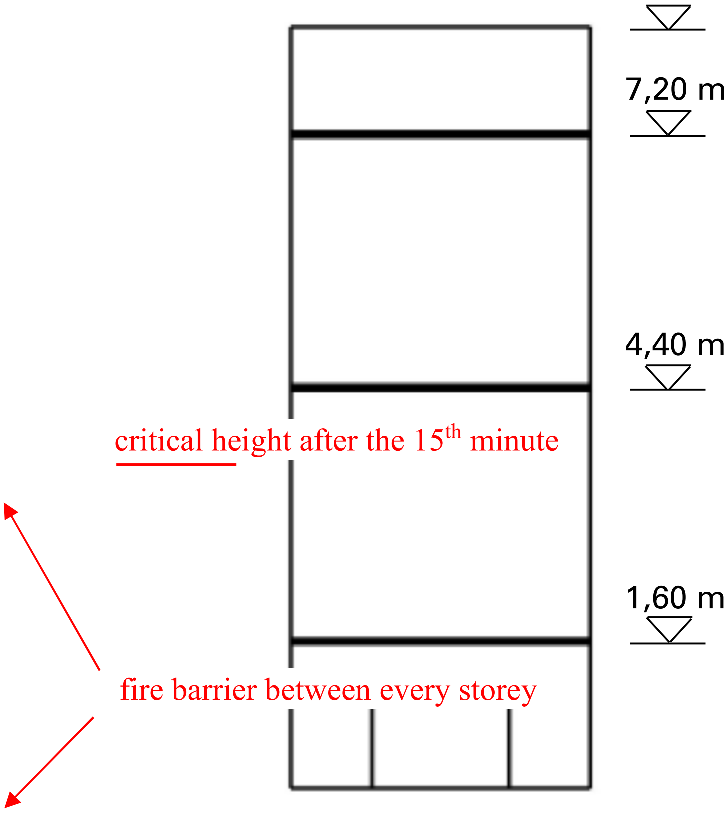
In all, these tests covered a wide range of typically used constructions for timber buildings. The tests for the Swiss research program are finished, but further research projects with other types of facades, like e.g. external thermal insulation composite systems (ETICS) will follow. Thus, the knowledge and source data pool is constantly growing.

<u>Figure 4.9</u>. Test rig with X-lam layer and concrete window frame

<u>Figure 4.10</u>. Wooden crib as fire load

<u>Figure 4.11</u>. Fully equipped test rig, ready to test

Figure 4.12. Fire after 15 minutes with burning surface limited to next floor



Full scale tests (concrete pier and panel construction building, Merkers, Germany)

Full scale tests were made on a building in Germany. The building was a concrete prefabricated slab construction. Before the fire tests were started, the building was fully covered with a timber surface and on the front side with a wooden balcony. The four storey building had a length of 40.2 m, width of 10.0 m and height of 14.5 m.

In total, six full scale fire tests were carried out. The tests can be classified by the type of the facade and the additional measures into three categories:

The first three fire scenarios were carried out to 27 mm thick three-layer solid timber board facade with a 20 mm projecting steel sheet fire barrier. The tests were splitted in a vandal fire in front of the facade with a 100 kg wooden crib and a single room fire (>600 MJ/m²) and a double room fire (>800 MJ/m²).

Fourth and fifth scenario were accordingly started as a room fire (>800 MJ/m²) shown in fig.8. The facade surfaces on both experiments were arranged with 20 mm tongue and groove profiles, but in the last test the rear-ventilation involved the full building height and no fire barrier was arranged between the storeys.

The sixth test was a simulation of a fire on a balcony exclusively made of timber. Therefore, a 150 kg wooden crib was ignited on the balcony located on the first floor. The facade beside the balcony had a horizontal fire barrier on each storey.

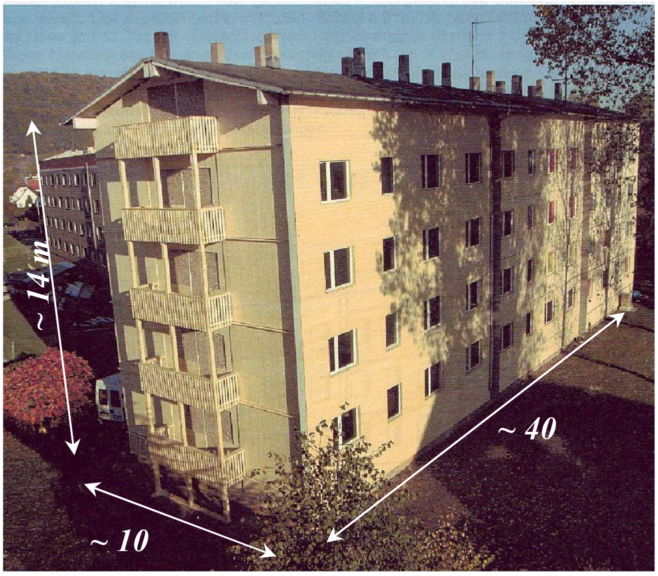


Figure 4.13. Testing object fully covered with timber

Figure 4.14. Fire in a room next to the exterior wall

4.2.1 Technical and constructional bases

The following conclusions regarding constructions by timber or derived timber materials can be drawn from the German fire tests accomplished:

- Non-load-bearing cladding for external walls ventilated at rear react in real fire scenarios (using a practice-oriented set up) noticeably better than expected from the experimental results of small fire tests.
- The self protection effect of timber through carbonization of the surface is inhibiting a rapid vertical fire spread. A significant lateral fire spread is not found or found only to a very limited and acceptable degree.
- Already by simple structural measures, fire spread in the rear ventilated area is controllable.
- In particular cases, the flammability of timber cladding systems for external walls is dependent on the influence of various parameters which if the worst comes to the worst can interfere with each other.
- Problems by fire fighting with water were not noticed in the full scale tests. As well, no extensive drop off of parts of the construction of the exterior wall endangering persons was noticed.
- A flammable exterior insulation can accelerate the fire spread.
- The tested standard coatings have no significant effect on the flammability of the cladding of the exterior wall.

In consideration of the defined protection goals and the test results described above, the following scheme for the conception of a construction catalogue for facades could be elaborated:

Fig. 4.15: type of façade (e.g. ribbon glazing)

Classification of facade type

The different types and configurations of facades can be categorized by their characters of fire spread and behaviour.

Parts of buildings can be classified by different categories in the catalogue.

Using the facade category, a specification of the facade construction according table 1 is possible.

Table 4.7. Determination of necessary fire precautions and assemblies

facade surface			**rear-ventilation**	**barrier every storey**			
synonym	Type of cladding	orientation	depth	≥ 200 mm	≥ 100 mm	≥ 50 mm	≥ 20 mm
derived timber boards		horizontal / vertical	≤ 50 mm				
			≤ 100 mm				
form-locking boarding groove and tongue profil		horizontal / vertical	≤ 50 mm				
			≤ 100 mm				
other force-fitted profiles and boardings		horizontal	≤ 50 mm				
			≤ 100 mm			O.K.	
		vertical	≤ 50 mm				
			≤ 100 mm				
open spaced boardings battens board on board weatherboarding …		horizontal	≤ 50 mm				
		vertical	≤ 50 mm				
			≤ 100 mm				

<u>How would be a 20- 25 mm rear ventilation gap (which is used in practice) be interpreted in the table above? What kind of barrier would be needed? Is it equal in performance with gaps until 50 mm?</u>

4.3 European conclusions

<u>European conclusions are needed and may be based on a Swiss research project in which a general protection goal was defined together with the authorities:</u>

In case of a fire on the outer surface of a building, the extension of the fire to more than two storeys above the initial fire shall not be possible before selective fire fighting.

This protection goal implicates the following requirements:

- By using timber or derived timber products for claddings meaning adding fire load to enclosing walls, the defined protection goal is not to be failed or disregarded.
- Claddings for external walls are only to be used for buildings up to a height which can be reached by selected fire –fighting from outside the building. Additionally, the application of such claddings is limited to buildings of classification 5 (h < 22 m; turntable-ladder vehicle h < 24 m).

- Within a defined time, the fire may not expand beyond an accepted area. Taking into account the results of the tests, a lateral (horizontal) extension is as well without additional measures sufficiently limited (factor horizontal versus vertical fire spread in timber an derived timber products circa 1:10).

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EN 13823 Reaction to fire test for building products (SBI test)

ISO 9705-1 Fire tests – Full scale room test for surface products

<u>Chapter 4.3</u>

DS/ISO 13875-1 Reaction to fire tests for facades – Intermediate-scale tests

DS/ISO 13875-2 Reaction to fire tests for facades – Large-scale tests

prDIN 4102-20 Besonderer Nachweis für das Brandverhalten von Außenwandbekleidungen

Swiss research reports (internal reports, unpublished) (http://www.lignum.ch)

Lignum Dokumentation Brandschutz: 7.1 Außenwände, Konstruktion und Bekleidung (http://www.lignum.ch)

Fire behaviour of wooden façades – State of the art in France

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Keywords: wooden façade, experimental research, fire spread, numerical modelling.

Scope and objectives – The thermal performances of buildings, as a mean to decrease the energy consumption in the construction sector, increased significantly these last years. Different designs of facades were recently developed to cope with the energy efficiency of buildings. One of them is the use of wooden façade. These facades are more and more proposed by the architects and the designers, in order to decrease the heat losses of buildings as well as for their low environmental impact. Furthermore, the greater interest to use ecological products was followed by the development of wooden facades integrating bio-sourced products such as straw, wood fiber, absorbent cotton of cellulose etc... Nevertheless, the development of these types of facades can lead to a high risk of fire spread via the facade and consequently can put in danger the life of the people located in the building if not taken into account in the early stage of the design.

The objective of the present paper is to briefly present to the other participants of the COST Action FP1404 the state of the art of fire safety of wooden facades complying with the French regulation based on experimental and numerical works carried out during these last five years at CSTB. We wish to share this experience and to establish future research partnerships in this field.

Small scale tests of wooden facades - The fire tests of reduced specimens were carried out using a modified SBI setup with a thermal load fixed to 85 kW. The dimensions of tested specimens were: width 1000 mm and high 1500 mm. These tests allowed to study the influence of different parameters such as:

- the thickness and geometry of the wooden claddings,
- the orientation of the wooden cladding (horizontal or vertical),
- the wood species, the geometry and nature (steel, FR wood) of the cavities barriers,
- the use of fire stop,
- the type of the screen located in the back of the claddings.

Full scale tests of wooden façades - The full scale tests based on the LEPIR2 facility started in 2012 [1]. This research allowed to identfy the most important parameters which influence the fire spread on a wooden facade and to define the configurations that are deemed to satisfy the fire safety criteria required by French regulation. The first stage of research has been finalized by the publication of national guideline [2] related to wooden facades. This guideline has been endorsed by the French public authorities in February 2017. The figures 1 and 2 represent respectively a drawing of a typical wooden facade tested at spandrel level and a full scale fire test picture. In order to add other configurations and to optimize the guideline, two more full scale wooden façade have been carried out recently in 2017 [3] and two other tests will be realized in 2018.

Modelling of fire spread via a façade - This research has been realized in the frame of a PhD work [4]. It is composed of two parts based on experimental and numerical studies. In the frame of the experimental research, eight medium scale tests with numerous measurement points were carried out [5]. The experimental set-up is described in the figure 3. The main purpose of these tests is to get some information on fire spread along a combustible façade in order to assess the ability of numerical codes to simulate flame propagation. Furthermore, in the frame of this PhD work, three full scale façade fire tests have been carried out in Sweden according to the SP Fire 105 method [6]. The first one concerned an inert cladding, the second was a plywood cladding fixed directly without void on the inert façade wall and the third one was a plywood cladding fixed over the inert façade with a fully ventilated cavity behind the cladding. The objective of fire tests was to study the vertical spread of fire via these three different façade configurations.

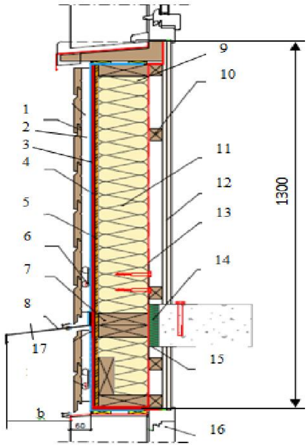

Figure 1: Vertical cut at the spandrel level.

Figure 2: Real scale fire test of a wooden façade.

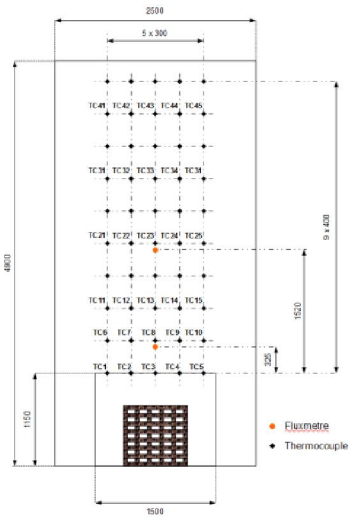

Figure 3: Front vu of experimental setup.

Figure 4: Medium scale fire test of a wooden façade.

References

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