VALIDATION OF CFD SIMULATION MODEL OF FRENCH BALCONY FAÇADE FIRE TEST WITH PARAPET GLASS

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ABSTRACT

We have been carried out numerous CFD modelling of full-scale elevation fire propagation tests during the recent years. In Europe, there is no unified full-scale elevation fire propagation test so Hungary could maintain an own test standard using a full-scale façade model with windows. In this paper, following the validation of the CFD model of the Hungarian test method is introduced, we have modified our model with French balconies using certified building product called Pyroswiss® Parapet glass railing and finally the validation of the modified model is introduced.

INTRODUCTION

In Europe, in spite of unified fire testing standards, no uniform facade fire propagation test procedure exists. The issues of elevation fire propagation and its testing are more and more frequently addressed, especially as external thermal insulation composite systems (ETICS) with combustible core or at ventilated façade claddings. The necessity of testing has also been supported by recent fire disasters (e.g. the fire case of the London Grenfell Tower on June 14, 2017). As there is no applicable European standard for testing, the standard for testing MSZ 14800-6:2009 is in effect in Hungary [1], which is unique in Europe, as well as globally, involving full-scale fire propagation test performed on façades with windows. There are façade fire propagation tests applied in certain European member states as well, but those are usually performed on façades without openings, sometimes with a considerably smaller fire exposure.

French balconies are called those balcony doors on the façade that start on the floor level, but there is no balcony, in the conventional sense, attached to them, at most there may be a narrow step-out shoulder. The Hungarian testing method is suitable for elevation fire propagation testing of French balcony configurations, but, with the exception of one test with already expired validity, there are currently no elevation fire propagation test results available in respect of French balconies in accordance with the Hungarian testing standard. The purpose of our research presented in this paper is to verify that a French balcony equipped with glass with E -ef 120 resistance-to-fire performance verified by accredited laboratory test, and classified E30 according to testing based on the standard ÖNORM B 3800-8:2013 [2] can also be suitable for preventing elevation fire propagation for as long as 120 minutes, both between stories of the building and in the line of horizontal fire compartment border, by fully meeting the requirements determined in the technical documentation. In this research, in addition to analyzing accredited laboratory testing data being available, we also verified the compliance of the configuration by numerical fire simulation, which we built up in CFD simulation environment, by modeling the testing standard MSZ 14800-6:2009, but applied it to the case of French balcony configuration.

THE HUNGARIAN FULL-SCALE ELEVATION FIRE PROPAGATION TEST METHOD

The purpose of facade test on fire propagation in Hungary is to determine vertical and horizontal fire propagation characteristics (fire propagation limit value, T_h) for façade claddings, coatings and external thermal insulation composite systems, furthermore, in case of building façades with openings, to determine criteria for fire propagation barriers in respect of non-compliant façade solutions. The testing equipment is a three-storey construction. In front of the ground floor (fire chamber) room and on the lower two stories wall structures are built, which are identical with the reception wall structure applied in the field of application of the system being tested (in a general case: brick wall or aerated concrete wall with plaster), in which façade openings of a size of 1.20 × 1.20 m will be formed on both levels. On the fire chamber level, in the vertical axis line of the wall structure, a wooden window opening outwards (due to reasons of the testing technique applied), with nominal size of 1.20 × 1.20 m, with double layered heat insulated glass with layer thickness of 4-16-4 mm will be built in, which will be opened in the 5th minute of the test. The side walls and the slabs do not have any openings; on the back façade ventilation channels enabling the regulation of the flow of air into the fire chamber, with door and shutters can be found (see Figures 1 and 2).

The test is performed in the open air, so it can be performed in case of the following meteorological conditions: the temperature of ambient air before the test can be 20 ± 10 °C, the velocity of wind can be 1 m/s at most. Tests shall not be started in rain, or if it is expected to be raining during the period of time of the test. Fire impact for the test will be produced by burning a stack made of 650 kg of pine wood that is air dry (humidity content: 12 m% ± 2 m%). The base area of the timber stack is 1.50 x 2.00 m, it is 1.00 m high and composed of roof battens with a cross section of 25 × 50 mm, placed at distances equal to the width of one element from each other. The first row of the stack is at a distance of 0.50 m from the internal plane of the main façade wall. The wood bonfire is set alight using 10 kg of diesel oil on 1 kg of wood chips, with a simple source of ignition (match). Following ignition, with the windows of the fire chamber closed, the opening and closing of the door on the back wall of the fire chamber room and movable shutters that can be controlled manually or with a machine, is controlled in a way that fire can be developed and the average rise of temperature should follow the temperature-time curve according to the standard ISO 834 [3] with not more than 10% of difference during the test:

$$T_g = T_0 + 345 \times \log_{10} (8\,t + 1)\ [\mathrm{K}]$$

where:

T_g the average temperature measured in the fire chamber [°C];
T_0 the temperature of the fire chamber at the starting time of the test [°C];
t the period elapsed since the ignition of fire [min].

Figure 1-2: Facade test on fire propagation seen from the front and from the back, the side of air supply openings

After the test, the monitored building structure can be given an elevation fire propagation limit value of 15, 30 or 45 minutes. The criteria in point 4.6.1 of the Hungarian facade test standard on fire propagation, in case of the fulfillment of any one of these, the test must be interrupted, and the tested system shall be assigned the classification of the so far attained limit value; are the followings:

- *the damage caused by surface burning of the façade coating, cover, heat insulation system reaches the upper level of the parapet wall*;
- *the propagation of surface burning of the façade coating, cover, heat insulation system reaches 1.50 m horizontally from the side window opening of the fire chamber at any place in the full height of the model*;
- *the difference between the temperature (T_{lz}) measured at given points in the flame zone exiting the fire chamber to be taken into consideration for evaluation and the temperature (T_{any}) arising (measured in projection) in the window opening on the observation level shall not exceed 300 K for a period of more than 2 minutes;*
- *in case of coating systems, falling off in mass or in a dangerous extent of any element (falling off of pieces of a weight exceeding 5 kg).*

It can be stated that the Hungarian elevation fire propagation testing method is among the most reliable ones even on an international scale, and it even gives a more relevant picture on the behavior of certain external thermal insulation composite systems especially with combustible core or façade claddings with air gap in a fire case than many other test methods. However, we shall also mention the disadvantages of the Hungarian testing method:

- The test is slow and expensive; the sample façade has to be built up in front of the testing equipment, by respecting drying and other technology related times; the test is performed in the open air, so it can be performed only in case of limited weather conditions, so not more than 15 to 20 tests can be performed with one equipment in one season.
- The test results generally enable a strongly limited application. Although the testing method itself would be suitable for testing façade configurations with a wide variety of geometries, still tests are only performed for vertical façades with window openings at 130 cm from each other. This is good because test results can be compared, but it is unfavorable from the point of view of architectural diversity.

- In addition to the above, using the Hungarian elevation fire propagation limit value test method, we cannot currently model an exposure to fire longer than 45 minutes, as the quantity of heat resulting from the 650 kg of wooden stack, stipulated by the standard, will start to decrease after 45 minutes.

Due to the above, alternative methods have to be searched for extending the tests, where great role may be given to modeling by CFD simulation.

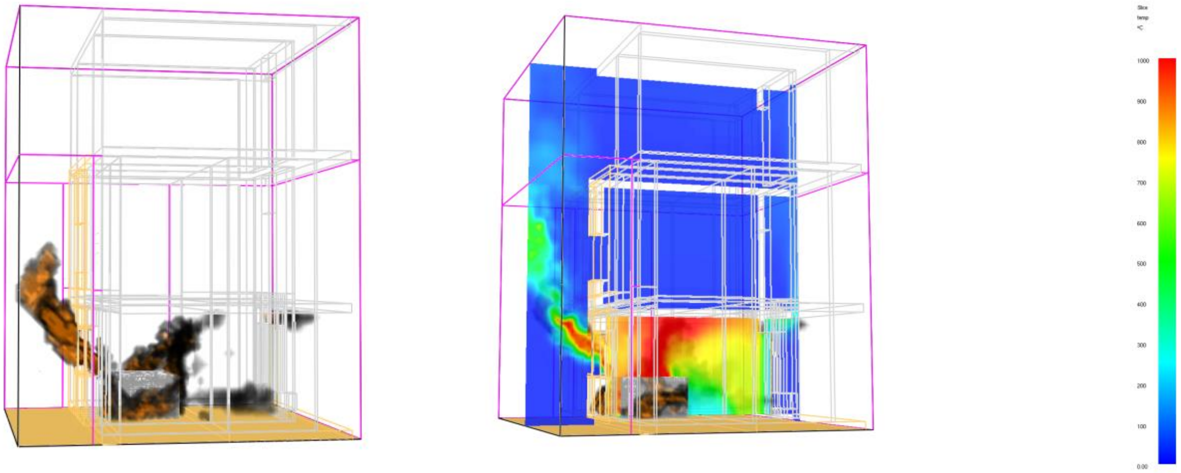
CFD SIMULATION AND VALIDATION OF THE FAÇADE FIRE PROPAGATION TEST ACCORDING TO MSZ 14800-6:2009

For the purpose of extendability of full-scale facade fire propagation test results, we prepared the standard test equipment in FDS/PyroSim fire simulation environment. Using the results of an already performed test of a given external thermal insulation composite system, the proper operation of the model can be verified and validated. As it has been already established by Simo Hostikka and Gelb Bystkov [4], modeling of full-scale fire tests does not substitute testing, it has a double role:

- in case of new developments, it can be used in preparation for testing;
- in case of a façade coating or façade heat insulating system already having test results, it can provide information on whether the system is suitable with geometrical conditions that are different than the tested configuration (e.g. shoulders, divisions, back-drawn building parts, etc.).

Our goal was to develop a simulation method that is suitable for examining different geometrical situations in addition to, and supplementing the elevation fire propagation test performed for a given building product, so, after validation of the model, for verification of the compliance of French balcony configuration, being subject of the test by modeling.

The elevation fire propagation testing in CFD simulation environment complies, in respect of all of its parameters, with the technical parameters determined in the standard. The scale of the cell grid that determines the simulation in its basic parameters is made up of 10x10x10 cm cells in the general parts of the model, while in parts that are critical from the point of view of the test, it is much more refined, having partly 5.0x5.0x5.0 cm and partly 2.5x2.5x2.5 cm cells. This is important, as due to the finer cell division, we get more precise temperature values at the critical positions. The ignition source is a 10x10x10 cell with a performance of 500 kW/m^2, dying out after 120 seconds. Fire exposure is ensured by a 650 kg stack of spruce wood composed of 10x10 cm slats 1.50 m and 2.00 m long [135 kW/m^2; 275 °C ignition temperature; ρ=430 kg/m^3]. The pouring of 10 liters of diesel fuel according to the standard was modeled by 10 pcs of dispersed 10x10x10 cm blocks with material set to diesel fuel. The placement of the stack, i.e. the test fire is in the position determined by the standard.



Figures 3 - 4. The shape of the plume in the 567th second, and temperature field test in the 1513th second. The plume leaving through the window gets separated from the façade plane, just as in real testing, then adheres back above the window of the fire chamber, in accordance with the Coanda effect.

The temperature formed in the fire chamber corresponds to the temperature-time exposure curve for closed spaces referred in ISO 834 with a difference of ±10% permitted by the test standard (Figure 5). In the standard test, the temperature starts to decrease from the 30th minute, as the bonfire of wood ensuring the fire load is being consumed, which effect is left out of consideration, so our temperature results follow further the temperature-time exposure curve for closed spaces referred in ISO 834.

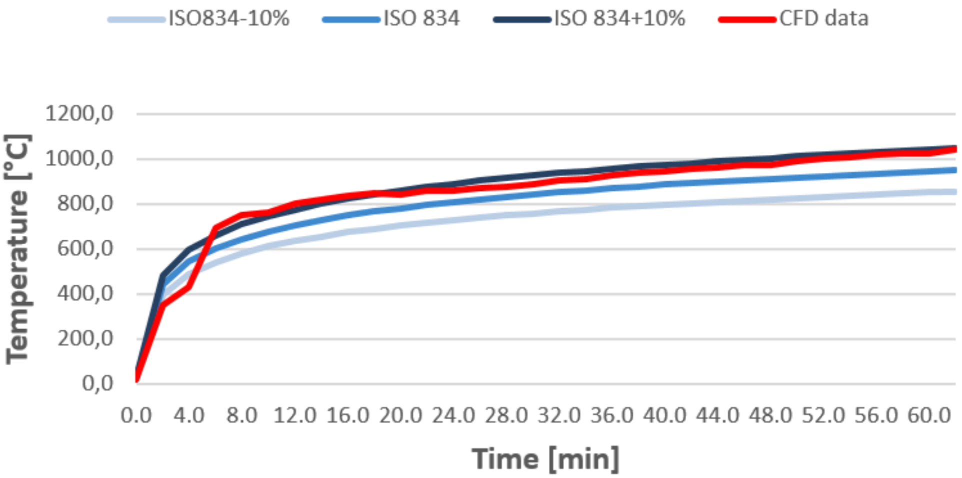


Figure 5: Temperature data of the fire chamber from our CFD façade fire test simulation, compared with the ISO 834 temperature-time curve

With the above, we verified that our elevation fire propagation test simulation model corresponds to full-scale fire testing [5].

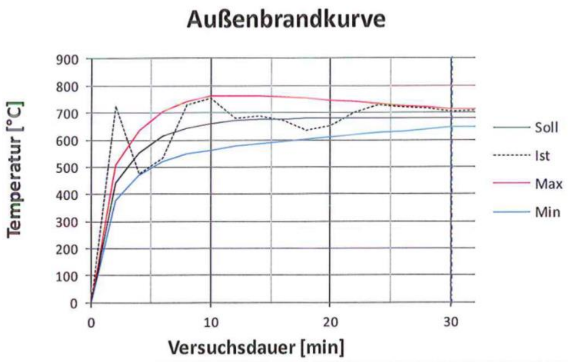
VALIDATION OF CFD SIMULATION OF FAÇADE FIRE SPREAD WITH FRENCH BALCONY CONFIGURATION

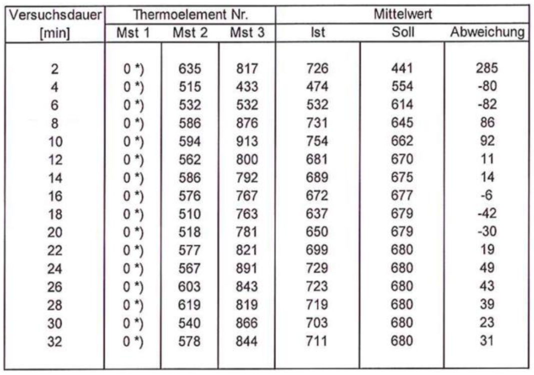
In spite of the fact that many various configurations can be tested in the facade fire propagation test equipment used in Hungary, a great number of experiences exists only with façade configurations with a vertical distance of 130 cm between the window heading and the window parapet above it, as tests are typically performed in such a configuration. In addition, currently there are no applicable glased fire-safe railings for French balconies with EI resistance-to-fire performance characteristics available on the market.

The selected subject of our validation method is the SGG Pyroswiss® glass railing is products of VETROTECH Saint-Gobain Central & Eastern Europe, Siegfried-Marcus-Str. 1, 4403 Steyr. The modes and numbers of performance certificates at our dipsosition are as follows:

- Masgistratsabteilung 39 VFA – Labors für Bautechnik: laboratory report (Laborbericht) No. VFA 2014-0244.01 on the resistance of Vetrotech Saint-Gobain International AG Pyroswiss® Parapet VSG 66.2 French balcony glass railing against flame flash-over for 30 minutes according to the standard ÖNORM B3800-8:2013 – March 20, 2014 [6]
- Masgistratsabteilung 39 VFA – Labors für Bautechnik: Declaration of opinion (Stellungnahme) No. K 2014-0320 on the basis of the laboratory report No. VFA 2014-0244.0, on the appropriate structural configuration of Pyroswiss® Parapet VSG 66.2 French balcony railings – November 6, 2014 [7]
- IBS – Institut für Brandschutztechnik und Sicherheitsforschung test report No. 11070403-a on E-ef 120 minutes fire resistance of Vetrotech Saint-Gobain International AG Pyroswiss® Plus type 6 mm thick glass – October 18, 2011 [8]

The two-layered 66.2 Pyroswiss® Parapet glass has test result according to the standard ÖNORM B3800-8:2013, which was developed in Austria especially for testing the resistance-to-fire of French balcony parapet glasses against elevation fire propagation. In the test, a separating wall is built in front of the standard vertical test furnace, with a gap on its lower part, and the fire exposure exits in front of the furnace through this gap. The tested French balcony railing is built in above the lower gap. In front of the test equipment, a deflector wall is built, which forces the flames to direct upwards, thereby modeling the vertical flow which is formed in case of a fire in front of a façade. The distance of the deflector wall is set in a way that the average of the measurement points above the horizontal gap in front of the furnace should correspond to the values of the external fire exposure curve.





Versuchsdauer [min]	Thermoelement Nr.			Mittelwert		
	Mst 1	Mst 2	Mst 3	Ist	Soll	Abweichung
2	0 *)	635	817	726	441	285
4	0 *)	515	433	474	554	-80
6	0 *)	532	532	532	614	-82
8	0 *)	586	876	731	645	86
10	0 *)	594	913	754	662	92
12	0 *)	562	800	681	670	11
14	0 *)	586	792	689	675	14
16	0 *)	576	767	672	677	-6
18	0 *)	510	763	637	679	-42
20	0 *)	518	781	650	679	-30
22	0 *)	577	821	699	680	19
24	0 *)	567	891	729	680	49
26	0 *)	603	843	723	680	43
28	0 *)	619	819	719	680	39
30	0 *)	540	866	703	680	23
32	0 *)	578	844	711	680	31

Figures 6-7. Temperature-time curves of the Pyroswiss Parapet glass test measured above the opening of the test equipment, according to ÖNORM B3800-8:2013, on the basis of the test report MA 39 – VFA 2014-0244.01, corresponding to the E-ef external fire exposure curve

The double, laminated Pyroswiss® Parapet glass, with a thickness of 12.76 mm (66.2) and size of 2200*1100 mm in accordance with the standard ÖNORM B 3800-8:2013 [3], used in the test model as a parapet glass fixed to an aluminum-timber composite balcony door, has an E30 fire resistance limit value according to the test protocol MA 39 – VFA 2014-0244.01, without thermal insulation, tested for integrity, so-called external fire impact temperature-time exposure (ef – external fire). In addition, the single-layer 6 mm Pyroswiss® glass has a test result of E-ef 120 according to the test report IBS 11070403-a, tested only for integrity, without thermal insulation performance, so-called external fire temperature-time exposure (ef – external fire).

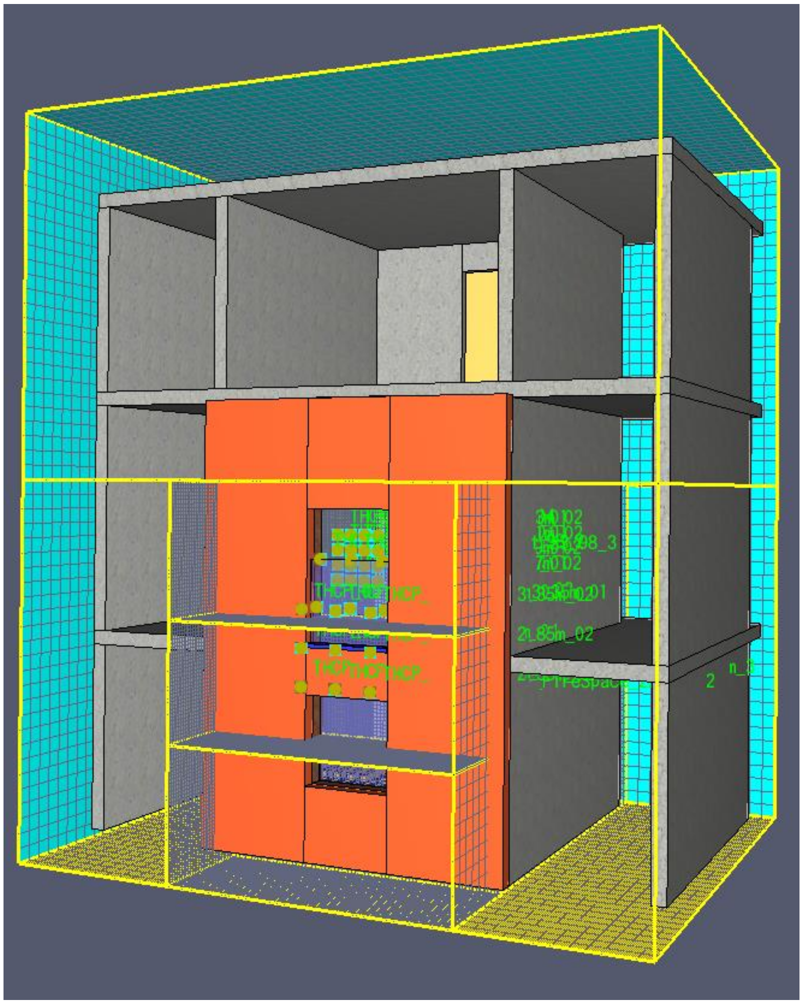


Figure 8. The picture of the CFD test model according to MSZ 14800-6:2009, but transformed according to ÖNORM B3800-8:2013 in FDS/PyroSim environment

Our goal was to find out whether the glass structure provides appropriate protection against elevation fire propagation in spite of having an E – ef performance characteristic and not EI. We transformed our CFD model into a model convenient for testing French balconies, the basis of which is thus the test method according to the standard MSZ 14800-9:2006, however, with the transformation of the observation area, it includes a French balcony in accordance with the test model described in the standard ÖNORM B3800-8:2013. On the CFD model of the test equipment according to the standard MSZ 14800-6:2009, we made the following modifications (see Figure 8):

- we transformed the observation space window into a French balcony in a way that its heading is identical to the window heading of the test equipment according to the standard MSZ 14800-6:2009, however, at the place of the window parapet according to the standard there is a French balcony glass parapet as described in the test model according to the standard ÖNORM B3800-8:2013,

- on the upper edge of the glass parapet, we placed temperature sensor stamps according to the standard ÖNORM B3800-8:2013 (on both sides and in the middle),
- in the fire chamber, burning has been set in a way to comply with the value of the temperature-time exposure curve according to ISO 834 ±10 % for 120 minutes instead of 45 minutes.

In our modified elevation fire propagation test model, we placed virtual temperature sensor instruments according to the standard ÖNORM B3800-8:2013 on the top of the parapet glass, at both sides and in the middle. On Figure 21, it can be seen well that the average temperature does not exceed 140 °C, and the increase of temperature, with a starting temperature of 20 °C, is 100-120 K, so it complies with the temperature difference peak values measured on the upper edge of the parapet wall in the test MA 39 – VFA 2014-0244.01 (see Figure 21), without considering curve No. 3, showing the temperature exposure of the glass railing fixed along the polystyrene thermal insulation, which is not relevant in our case. The permitted difference of temperature according to the standard ÖNORM B3800-8:013 is 250 K, and the measured data are much lower – not only within the 45-minute period of the elevation fire propagation limit value, but also for 90 or 120 minutes. In case of standard risk class KK according to the Hungarian regulation, the requirement value for fire barrier walls is (R)EI 90, in case of standard risk class MK, it is (R)EI 120, and according to our interpretation, the parapet glass is part of the elevation fire propagation barrier.

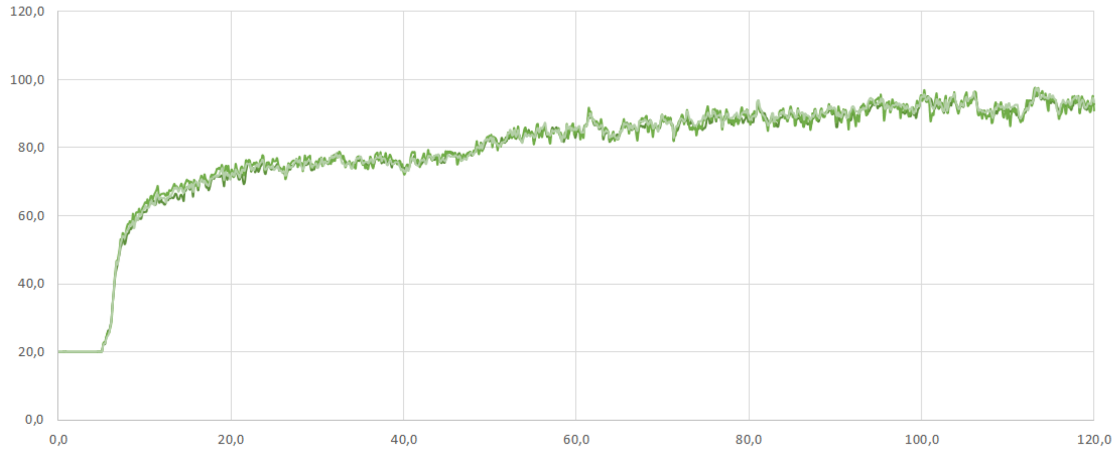


Figure 9. Curves of thermocouples inside the glass railing, at a height of +3.35 m copied on top of each other. It can be well seen that the average temperature does not exceed 90 °C, and with a starting temperature of 20 °C, the increase of temperature does not exceed 40-70 K over the whole test period of 120 minutes.

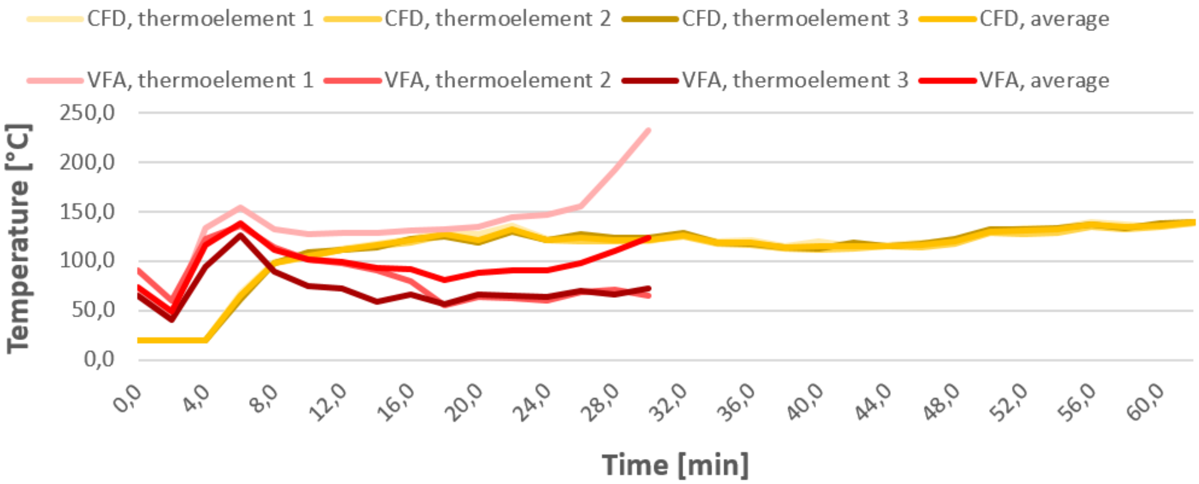


Figure 10. Temperature data measured on the upper edge of the parapet glass in test MA 39 – VFA 2014-0244.01 compared to our simulation results (see the temperature measurement points on Figure 15)

In knowledge of the simulation results, we can establish the followings:

- The Pyroswiss® glass in the test MA 39 – VFA 2014-0244.01 has a test result with 120 minutes external resistance-to-fire performance (E-ef 120) (test report IBS 11070403-a). The test No. IBS 11070403-a providing the result of E-ef 120 fire resistance was performed in accordance with standards EN 1363-1:1999, EN 1363-2:1999 and EN 1364-1:1999 with linear fixing.
- Testing according to the standard ÖNORM B 3800-8:2013 is also based on the external temperature-time exposure curve (ef – external fire). One of the most important findings of our study is that during elevation fire propagation tests performed in accordance with the Hungarian standard MSZ 14800-6:2009 temperature data measured on the façade between the fire chamber opening and the observation area opening, in the topmost temperature measurement line are close to the temperature-time exposure curve and similar, close to the E-ef curve (values around 680°C, see Figures 6-7).
- On the basis of the test reports MA 39 – VFA 2014-0244.01 and IBS 11070403-a, the criteria in point 4.6.1 of the Hungarian standard MSZ 14800-6:2009 for facade test on fire propagation are met in the following way:
  a. *damage caused by surface burning of the façade coating, cover, heat insulation system extends up to the upper plane of the parapet wall:* this point is not applicable, as there is no combustible material;
  b. *the propagation of surface burning of the façade coating, cladding external composite thermal insulation system reaches 1.50 m horizontally from the side window opening of the fire chamber at any place in the full height of the model* – this point is not applicable, as there is no combustible material;
  c. *the difference between the temperature (T_{lz}) measured at given points in the flame zone exiting the fire chamber to be taken into consideration for evaluation and the temperature (T_{any}) arising (measured in projection) in the window opening on the observation level shall not exceed 300 K for a period of more than 2 minutes:*
  According to Figure 10, during the test MA 39 – VFA 2014-0244.01 of Pyroswiss® parapet glass, the difference of temperature compared to the beginning of test did not increase beyond 200 (250) K at any point on the upper edge of the glass surface. The evaluation criteria of the standard ÖNORM B 3800-8:2013 are different in this respect from the boundary condition in point c) of the standard MSZ 14800-6:2009, but the objectives of both tests are the same: to verify that the temperature in the observation space (testing space) increases above the ignition temperature of combustible materials during the duration of

the test. Remark: according to Figure 10, curve VFA No. 2 and 3 were measured on one side of the sample, connected to a system with mineral fiber core, while curve No. 1 was measured on a glass railing connected to an external thermal insulation composite system with polystyrene core. This is the reason for the spectacular difference in temperatures from the 15th minute.

d. *in case of façade cladding systems, falling off in mass or in a dangerous extent of any element (falling off of pieces of a weight exceeding 5 kg):* detachment or falling off of parts happened neither in case of the parapet glass test MA 39 – VFA 2014-0244.01 nor in the test IBS 11070403-a.

In the test IBS 11070403-a, Pyroswiss® glass was tested in a single layer with 6 mm thickness, receiving a classification of E120 (ef). In the test MA 39 – VFA 2014-0244.01, the parapet glass was a two-layered Pyroswiss® glass. As this is the typical application for French balconies due to safety reasons, this latter version is proposed also from fire safety aspects.

SUMMARY

In the first section of our research, we built up the CFD model of the Hungarian facade test on fire propagation equipment and performed the validation of our model on the basis of the results of former tests. Following this, we used our model for testing the compliance against elevation fire propagation of a specified construction product, the Pyroswiss® Parapet VSG 66.2 fireproof glass French balcony railing, extending the possibility of application of Austrian test results. In our study we verified that CFD simulation is a suitable method for extending previous full-scale fire tests, with the following requirements:

- the technical solution to be actually applied (in our case the type, fixing, vertical and horizontal dimensions of the French balcony railing and the solution for connecting structures) shall comply to the configuration figuring in the laboratory test result protocol, any deviation can be permitted only in favor of safety (e.g. fixing of the French balcony parapet railing to the façade wall structure with appropriate fire resistance limit value, with continuous connection on both sides, instead of fixing it to the door),
- the simulation cannot substitute for the first type testing of a building product (exernal thermal insulation composite system, façade cladding with air gap, French balcony railing, etc.), it can only support the compliance of a façade with different configuration than the test model in certain cases.

Further possibilities of research with the method detailed in this paper:

- extending the elevation fire propagation test results of façade coating with air gap,
- studying fire propagation between floors of a building within atria,
- studying protection methods against fire propagation between façade surfaces belonging to different fire sections, with an angle smaller than 120 degrees with each other, both outside of the building, and within atria.

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