Adding toxicity characteristics to facade fire evaluation and testing

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Abstract. The amount and toxicity of smoke released during the burning of facade materials are generally not restricted. This greatly restricts the conditions of escape and also increases the risk of firefighting interventions. The author of the article considers it timely to include the quantitative and qualitative data of toxic gases in the scope of qualification performance criteria, the timing of their concentration, and the importance of their potential role in the dangers of the fire environments. The European methodology under development does not include examining this parameter.
Key words: *facade fire, smoke spread, risk, toxicity*

Problem statement

Not only the accidents recently happened (often resulted in death) are account for the importance of the control and regulation of fire spread on building façades with openings but also the changed building structures and building usage habits. Nowadays, not only the inflammable coatings and coating systems applied on the façades of buildings, but also solar panels and solar collectors can contribute to the spread of fire and may hinder the escape and escape conditions through heat and toxic gas and smoke formation. Even the construction of façade solutions of natural material (e.g. boarding) as well as façades planted with vegetation appears as a requirement.

The quantity and character of combustible materials and electronic devices accumulated in the building has also been changed: in case of flats (and offices) the time from the generation of fire until the full development of combustion phenomena reduced to a fraction of amount. The "natural" fire spread barriers, which are typical of our buildings erected in the past, are often unavailable due to lowered levels of elevation, increased size of doors and windows as well as spreading of flammable façade solutions.(Takács, 2007)

Following the flashover (phenomenon of bursting into flame) in the rooms the doors and windows with non-fireproof glazing break out and the inner fire flashes back to the façade. Depending on different parameters of the structural design of the façade the fire may spread over different paths as well as may strongly damage or moreover shatter the coverings and claddings applied around the opening. In certain cases the fire spread extremely fast on the façade, during which the building burst into flames and burned at the full height in minutes. (Nishio,2016)(White & Delichatsios, 2015)

The façade fires of the recent past that got a lot of publicity involved occasionally several dozens of fatalities. Especially dangerous are the high buildings, the façades provided with combustible heat insulation without air gap or the aerated façades designed with combustible composite coverings and claddings,(Jensen, 2013)(White & Delichatsios, 2015), and the incorrectly prepared façade insulation systems. (Bánky & Mezey, 2009)

The fire protection regulations for building engineering take into account by various stipulations that the possibilities of rescue and extinguishing are limited especially in case of high buildings.(Miskey 2013) (Morvai 2014)

The quantity and toxicity of the fume released during the combustion of the façade materials is generally not limited, although it also strongly restrains the conditions of survival and escape, as well as increases strongly the risk of firefighter interventions.(Urbán 2015)The deaths of the victims of the façade fires are more likely caused by the toxic fumes accumulating in the rooms than the direct flame effect(the ratio is about 80% in case of „general" building fires).

A significant part of the façade fires is caused by external causes (e.g.: trash bin fire), against which even the built-in extinguishers have proved to be ineffective, therefore these solutions cannot replace the implementation of façade designs with the required resistance.

The examination and evaluation of hazardous substances generating during the combustion of façade solutions and their spreading are completely outside the work of the new European Procedure Working Group. In this article, we examine the characteristics and possibilities for further development of the test procedure applied in Hungary according to MSZ 14800-6: 2009 standard. It is possible and necessary to deal with the physiological effects of the combustion of the façade materials despite that we have to calculate on almost infinite variation of toxic substances. Reasonable limits and thresholds are also necessary in this area, much more than before.

Briefdescription of the test procedureas per MSZ 14800-6:2009 Hungarian Standard (Móder et al. 2016)(MSZ 14800-6:2009) The test aims at determining the vertical and horizontal fire spread characteristics (fire-spread limit value Th) for coatings on building façades with openings, for coverings and claddings mounted with or without air-gap, for external thermal insulation systems (ETICSs). The test rig made of non-combustible materials is a three-storied building. The fire room is in downstairs, the second and third levels are observation levels. The main façade fields of the test building are unbuilt; their development method depends on the test model.

On the test model building the different façade solutions can be tested according to the actual development. The ETICSs and the ventilated cladding systems are tested on non-combustible porous concrete most often made with standard windows. The façade solutions with special openings can be tested mainly by transforming the infilling brickwork, so that the height of the solid wall section between the openings as well as the window built in the opening of the fire room meet the technical solution to be qualified. Prior to the test a wooden window with standard glazing, opening outwards is built in the opening infilling brickwork sized 1.2×1.2 m in front of the fire room.The test can be made in both indoors and outdoors, if the required environmental conditions are met (see pictures Nos. 1 and 2).

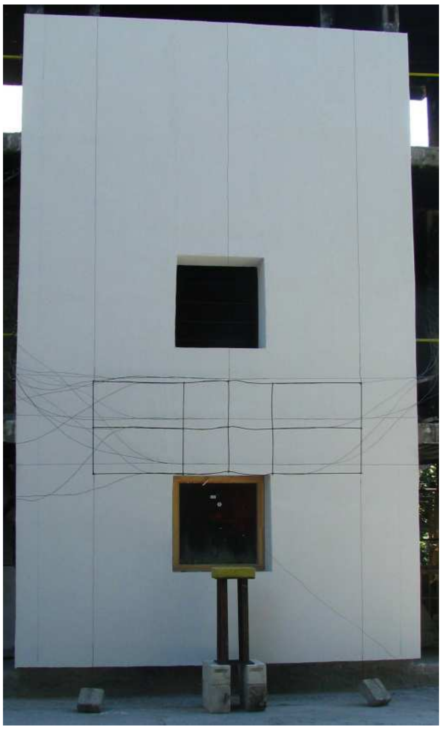

Figure 1.
Sample of ETICS on façade prepared for test to be made in the Fire Protection Testing Unit of ÉMI
(Source: ÉMI. Fire Protection Testing Unit)

Figure 2.
Test of ETICS on façade according to MSZ 14800-6:2009 standard.
(Source: ÉMI Fire Protection Testing Unit)

The test procedure simulates a fully-developed indoor fire and inspects the resulting fire-spread from the aspect of the level(s) above. The application of the standard "temperature-time" fire curve in the fire room as per ISO 834-1:1999 international standard means indisputably a stable starting point against the fire effects with a not realistic test background applied in other test procedures.

The specified fire exposure is ensured by lumber pile made of pine wood crib of 650 kg, compiled according to standard specifications, placed in the fire room. The air-dry pine roof battens have a nominal size of 25×50×1500 mm, as well as 25×50×2000 mm. The distance between the ribs placed discontinuously in the lumber pile is ~50 mm.

The thermal energy of ~3.25 MW released during the test represents the combustion of a fully furnished room (flat or office) and ensures the following fire curve (as per ISO 834-1:1999 standard) during the test (the standard test is scheduled to last up to 45 minutes):

$$T - T_0 = 345 \times \lg(8t + 1) \text{ [K]} \quad (1)$$

To ensure and regulate the conditions of burning, furthermore to ensure the uniform exposure to fire in case of different tests the wooden frame window of the fire room shall be opened in the 5th minute after ignition. The air supply of the fire room can as well as should be regulated by manually adjustable shutters. The standard specifies the tolerances of the fire curve that should be maintained during the test.

Temperature data collection is carried out at the following places:

– at 5 specified places in the fire room (T_{tt}),
– in front of the façade, in a distance of 10 and 50 cm from the façade plan at 9 – 9 places (T_{lz}),
– in the observation room, in a distance of 10 cm from the inner wall plane at 16 (T_{any}) by means of a measuring panel of 1.20 × 1.20 (m).

Additional thermocouples can be placed where higher temperature is expected.

PERFORMANCE CRITERIA AND CLASSIFICATION ACCORDING MSZ 14800-6:2009 The façade fire-spread limit value (T_h) of the façade coating, cladding and

ETICS means the length of time measured and specified in minutes when any of the following phenomena occurs:

- The damage caused by the surface combustion of the coating, cladding and heat insulating system spreads up to the upper plane of the breast-wall.
- The surface combustion of the façade coating, cladding and heat insulating system spreads from the side of the window opening in the fire zone in horizontal direction, in entire height of the model at places up to 1.50 m;
- The difference between the temperature (T_{lz}) measured in the flame zone coming out the fire room and the temperature (T_{any}) measured behind the window on the observation level is not higher than 300 K for longer than 2 minutes:

$$T_{lz} - T_{any} \leq 300 \text{ K} \quad (2)$$

- In case of burning or not burning falling droplets of cladding systems are heavier than 5 kg.

According to the standard the tested façade solutions can be categorized based on their performance generally as follows: „has no fire propagation limit value", $T_h \geq 15$ minutes, $T_h \geq 30$ minutes, $T_h \geq 45$ minutes. In several cases the National Fire Protection Code make claims on the façades with openings (in addition to further requirements) concerning the façade fire propagation limit value depending on the number of building levels and structural design. (OTSZ)

The MSZ 14800-6:2009 standard is advanced among the "competitive" national standards due to its special conditions (Smolka et al, 2013) (Yoshioka et al, 2012). These are as follows:

- Full-scale inspection, which directly connected to the fire exposure specified in the international and European standards, serving for determining the fire resistance performance of the building structures;
- Both openings can be inspected by means of realistic intersection design;
- Above the opening in fire room a fire effect close to the "external fire" curve can be experienced;
- Duration of the test fits well to the actual occurrences of fire;
- The status features of the protected space can be well tested;
- Clear, minute-based assessment method fitting to the European classification system;
- „Specific" façade solutions can also be tested.

The computer simulation of the phenomenon of the fire-spread on façade that cannot be described either with the classic combustion theory or with the characteristics of the fire class is still in initial stadium. It can be seen from the results until now that these simulation procedures can effectively be applied when selecting the test models and spreading the results. From the aspect of our study the most important test *condition* is that the status characteristics of the protected space and the toxic substances that can be generated can be studied under realistic conditions.

In the observation space, smoke and toxic gas analyzes, as well as supplementary temperature measurements not required by the standard, but which are very important to us, have been part of the domestic laboratory tests for a long time. From the introduction, ÉMI Non-profit Llc. carried out around 100 standard tests. The majority of the structures studied were façade heat insulation system, but there were also fitted, glued covers and claddings, and special structures.

The tests demonstrate very well the different and unique behaviors of different systems and types. Certain structural designs only provide appropriate performance with the precise design of the details, while other solutions are less sensitive to this. During façade inspections of constructions it has become apparent that the junctions of the insulating systems to be implemented are often made incorrectly. The coverings and claddings of combustible material and thermal insulation often produce very strong heat and smoke.

EFFECT OF SMOKE FROM FIRE EVENTS ON HUMANS (Heizler 2004) (Beda, Bukovics 2004) It is well-known that, depending on the composition, the smoke originating from fire events can have a number of unfavorable effects on humans. It is most conspicuous that during imperfect combustion a large amount of smoke is produced in a short time, their components (soot, flying ashes, liquid hydrocarbons, additional gaseous components) greatly limit the visual distance. The strong decline in visibility (under ~10 m) may also cause a sense of uncertainty or panic. Concerning the consequences, the composition of the gas may have more serious after maths. The three main effects of smoke are: throttle effect (causes asphyxiation), poisonous(toxic) effect and aggressive (caustic) effect.

The *suffocatives ubstances* are not toxic in themselves, but they extrude the oxygen from the air. When the oxygen concentration falls below 12%, oxygen deficiency occurs in the human body. This will cause permanent damage in a few minutes. Suffocative substances are i.e. the hydrogen (H_2), the methane (CH_4), the noble gases, the nitrogen (N_2) und the carbon dioxide (CO_2). The *toxic substances* damage the blood and the nervous system. They may get into the human body through there spiratory tracts and the skin. Such material is the carbon monoxide (CO), the hydrogen cyanide (HCN), dioxins and furans (PCDD, PCDF), the polychlorinated (PCB), the phosgene ($COCl_2$), the polycyclic aromatic hydrocarbons (PAK).

Table 1.

Typical physiological effects of toxic materials(Own editing)

Toxic material	Characteristic effect
CO	It inhibits oxygen delivery of blood. It accumulates in the blood as stable CO hemoglobin. The absorbed CO degrades slowly. The symptoms of CO intoxication depend on the concentration. Survivors of poisoning may suffer from neurological injury, epilepsy, Parkinson's disease.
HCN	It passes directly to the cells, where it blocks the oxygen use and may cause central respiratory paralysis.
Dioxins and furans	It causes skin and liver damage (half-life period is 5 to 10 years) long-term effects.
PCB	Prolonged exposure leads to hepatic and immune damage as well as spleen injuries
$COCl_2$	After several hours of latency it may cause pulmonary edema. High concentrations may lead to direct suffocation.
PAK	Carcinogenic and inheritance-altering. It hampers reproductive ability. Health damage will only be discovered after a long time.

The *aggressive (corrosive) toxics* irritate and image the mucous membranes of the airway; furthermore they destroy the lung tissues. In the 24 to 48 hours after inhalation of the gases pulmonary edema may develop.

Table 2.

Typical physiological effects of aggressive toxins (Own editing)

Aggressive (corrosive) toxics	Characteristic effect
Cl	It strongly irritates the airways, eyes and skin. After latency, it causes lung damage and cardiac damage.
NH_3	It attacks the eyes and upper respiratory tract (laryngocatarrh), as well as it may cause headache, coughing and sickness.
Formaldehyde	It attacks the eye's conjunctiva, the skin and the mycoderm of the upper respiratory tract. Coughing, tearing and drowsiness may appear. Heavy breathing in case of higher concentration.
$NO_{x,}$ most often NO_2	After 3 to 24 hours of latency it can be resulted in breathing difficulties and pulmonary edema
Acid fumes	ingesting respiratory and digestive organs

It is obvious from the above tables that the inhalation of the smoke developing from the combustion of different substances may result in extremely serious and complex consequences. The toxicity depends not only on the type of the burning substance but also on the relating combustion stage. In the different combustion stages (developing fire, full fire, extinguishing phase, and chilling phase) the combustion product of the same substance has different compositions. Depending on the concentration the smoke of every fire may be fatal.

The toxic effect should also be considered in spaces where there is no combustion, but smoke occurrence is possible. In case of smoke developed with flame-burning (this is characteristic also for façade fires), the application of the effective dose ratio (HDH) can be used to characterize the toxic hazard of the burning substance. The HDH is dimensionless number, which is the ratio of the dose actually suffered and the dose produced the tested effect (i.e. 50% death).

Table 3.

Conditions of survival according to domestic literature

Criterion	Limit	Limit with safety factor
Heat radiation on floor level (in protected space)	< 20 kW/m^2	< 10 kW/m^2
Oxygen concentration	> 12 tf%	> 14 tf%
CO_2concentration	< 6 tf%	< 5 tf%
CO concentration	<1400 ppm	<700 ppm
Height of the smokeless layer	> 1.5m	> 1.8m
Temperature of hot flue gas layer	< 600°C	< 300°C
Temperature of the lower gas layer	< 65°C	< 50°C

Table 4.

Conditions of survival according to foreign literature(Toxicology, Survival and Health Hazards of Combustion Products 2015)

Criterion	Survival criterion	
	Short-term exposure	Longer exposure
Heat radiation (kW/m^2)	4.0(< 3 minutes) 6.0 (< 1.5 minutes)	1.6 (10 <minutes) (without heavy clothing)
Air temperature (ºC)	140(5 minutes)	75-80(60 minutes)
CO_2concentration (ppm)	30000(3%)(15 minutes)	20000(2.0%)(30 minutes)
CO concentration (ppm)	1000(5 min)	500(30 min)
Oxygen content (%)	15(5-10 minutes)	17-18(60 minutes)
Hydrogen sulfide (ppm)	300(5 minutes)	200(30 minutes)
"C5" carbonic hydrogen	3000ppm(10 minutes)	N/A

MEASURING RESULTS ON OBSERVATION LEVEL OFFAÇADE MONITORING During the previous fire spread tests the certain characteristics of the condition of air were tested by a TESTO-type gauge on the observation level of the testing tower (on the level above the combustion chamber) in a height of 1.50 m above the floor line. The maximum characteristics of the condition of air measured on façade solutions of various types were strongly different:

Table 5.

Conditions of measured on the observation level of the testing tower. Examples of different façade solutions.

	CO_2 %	CO ppm	T [°C]
Mounted façade covering and cladding system, with rockwool thermal insulation, with steel plate cover	**~ 2,5**	**~ 1100**	**~ 100**
Mounted façade covering and cladding system, with glued, combustible paneling, with air gap, aluminium frame and rockwool insulation	**~ 4.5**	**~ 1800**	**~ 155**
Well-formed polystyrene based insulation system	**~ 6**	**~ 1000**	**~ 145**

In case of defective formed heat insulation system the CO concentration exceeded 3000 ppm.

Conclusions

The measurements performed in the observation space of the testing equipment according to MSZ 14800-6:2009 standard, at least according to the characteristics examined so far and in relation to them, deliver valuable information on the extent of the risk of the given façade solutions with openings in case of façade fire:

– The non-combustible systems with appropriate geometry have the smallest risk. The basic conditions of survival may exist even on the level directly above the fire (especially close to the floor and with closed windows);

– The heat insulation systems with properly selected flammable materials and careful junction design can be established at a*still acceptable* risk level for the parameters under consideration;

– Systems where the quick and direct burn of the combustible heat insulating foams and coverings may occur within the duration of the fire spread limit value, produce a quantity of toxic material so that the conditions of survival in the room on the level above the fire are in no way available.

Based on the above conclusions, an extension of measurements may be proposed in the context of further research. It seems advisable to perform parallel measurements at a height of several observations (0.5, 1.0 m, 1.5 m, 2.5 m) to get the temperature and concentration profiles known. It is also necessary to expand the examined parameters. Supported by parallel laboratory research, a complete exclusion of certain materials or solutions may be recommended for façade use.

The toxicity of façade solutions, at least in some components of the test method and the development of the corresponding minimum requirements could be forward-looking even at European and international level.

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