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Research paper

Numerical analysis of storey-to-storey fire spreading

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Abstract: The paper presents detailed comparisons for numerical simulations of fire development along the facade, with particular emphasis on the so-called "leap frog effect", for different variations of window opening sizes and storey heights. A total of 9 models were subjected to numerical analysis. The problem occurred in most of the analyzed models – i.e., the fire penetrated through the facade to the higher storey. It should be noted that the adopted hearth was identified by standard parameters, and materials on the facade were non-combustible – as a single-layer wall. In the case of real fires, the parameters of the release rate can also vary greatly, but the values are usually higher. It has been shown that the most dangerous situation is with small size windows, where the discharge of warm gases and flames, causes a fairly easy fire jump between floors. The leap frog effect can be limited by increasing windows and storey height – this changes the shape of the flames escaping from the interior of the building and limits the possibility of fire entering the storeys above. In addition, increasing the size of windows results in a reduction of fire power per unit window dimension [KW/m^2] at constant fire power (fuel-controlled fire), which is also of key importance for the fire to penetrate with the leap frog effect.

Keywords: fire, the leap-frog effect, façades, fire safety, large scale facade test, storey-to-storey fire spreading

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1. Introduction

Combustion is a chemical process in which particles undergo phase transitions and the generated energy is absorbed or expelled. A fire is an uncontrolled process of combustion of organic and inorganic materials in their intended place, spreading in an uncontrolled way. This process can be described by means of the combustion triangle representing the simultaneous occurrence of three factors. The first factor is heat, more precisely thermal energy – the principal factor starting a fire. Another factor is oxygen, in the presence of which oxidation can take place and the final factor is a fuel – materials capable of oxidation in the presence of an oxidizer in the form of a gas, a liquid or a solid. The combustion triangle together with the reactions involved is shown in Figure 1.

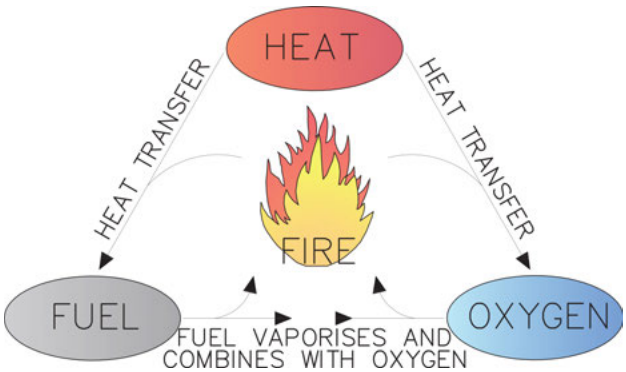


Fig. 1. Combustion triangle

Two basic types of fires are distinguished: fuel-controlled fires and oxygen-controlled fires. In the case of buildings, fuel-controlled fires, with characteristic flame combustion, usually occur. In the case of oxygen-controlled fires, flameless combustion occurs. During combustion the materials undergo volatilization. Figure 2 shows exemplary flame combustion.

Fires in a building can spread in various ways and are highly complex since there are many factors which can affect them. As part of this research the spreading of a fire on the façade was analyzed. In the case of such a fire there are many aspects and phenomena which have not been fully explored yet. For example, the materials involved, classified according to the materials fire classification [1], have a bearing on the way a fire develops. Another factor is the type of the external structure. In the case of ventilated façades, the air gap can cause the fire to spread due to the stack effect [2–6] which greatly increases the speed of fire development. Also the strength and direction of wind have a bearing on a fire. Flames can be forced into or drawn out of a room. If flames are drawn out of a room the fire can faster spread to higher storeys. Another important aspect is the outdoor temperature and air humidity. If the air humidity is high, the fire develops less rapidly and is easier to control because a considerable part of the fire's energy is absorbed by the humid air and by the

Fig. 2. Building's external wall cladding on fire in Address Downtown Dubai in 2015

processes transforming the water particles in the air into water vapour, which is similar to the action of water mist.

In the case of a fire in the façade, fire can spread from storey to storey by getting inside rooms through openings such windows, doors or utility ducts. Such a fire begins with the destruction of an obstacle, e.g. a windowpane. As a result, flames and hot gases can get outside the building. In this way high temperatures begin to act on the façade. If the fire is strong enough, the flames can reach the windows of the upper storey– this is usually the fault of the insufficient height of the spandrel wall. The high temperature of the windowpane on the storey above can destroy this windowpane, whereby flames can get inside the room, causing a fire in this room. The spreading of a fire on the façade from storey to storey is referred to as fire leapfrogging. This mechanism can be described as follows:

1. The fire inside a room in a building develops, flames move closer and closer to the windows and all the materials stored near them.
2. The windowpane is damaged by the flux of heat acting on it (convection).
3. Through the damaged windowpanes flames and hot gases get outside onto the façade.
4. The flames being in contact with the façade act on it and on the glazings on the upper storeys, damaging the windowpanes there and getting inside the rooms.

Figure 3 shows the mechanism of fire spreading on the façade from storey to storey.

This phenomenon can be investigated by studying full-scale façade models or numerical models. In most cases, numerical models are a good alternative to full-scale façade tests [7]. When investigating such phenomena it is worth validating the numerical model against a full-scale model. In most cases, the models yield similar results [8, 9].

There are many full-scale façade test standards [10–13] in the world. They are based on the spreading of fire from a recess/opening simulating window openings of a room in

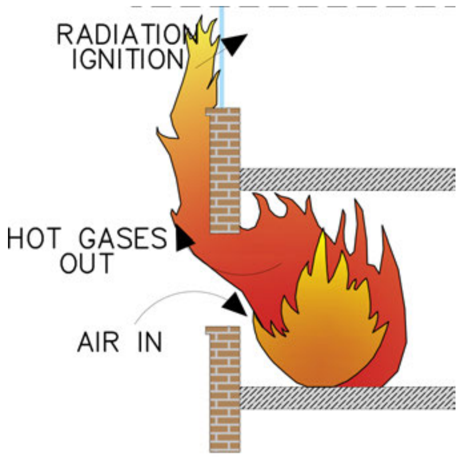


Fig. 3. Mechanism of fire spreading on the façade from storey to storey

the actual building. A fire source with prescribed parameters (peculiar for each standard) is located there. The flames getting out of the recess act on the external wall cladding and other elements of the wall. A comparison of the standards for full-scale façade models can be found in [14].

The next step in the development of the fire is the destruction of the windowpane and the flames getting outside through the opening, but this is not always followed by the spreading of the fire on the façade to the upper storeys. In the case of a typical fire in a room, after about five minutes of fire impact a tempered glass pane shatters into small pieces and falls down.

After the windowpane is destroyed greater amounts of oxygen flow into the storey being on fire, accelerating the development of the fire. The flames getting outside onto the façade usually cling to it. This is caused by the flow of air along the building. This flow of air acts as another stimulus extending the height to which the flames reach and to which the hot gases are transported. The shape of the flames which get outside and their possible clinging to the façade depend also on the shape and dimensions of the windows [15–17]. Heat exchange between the warmer air and gases and the colder air takes place. This phenomenon is called thermal radiation. The necessary condition is the lifting of the flames and the hot gases up to an appropriate height so that they come into direct contact with the window on the upper storey. This can happen if the fire becomes strong enough. Korrhoff in [18] specifies the fire power of 1.5 MW on the opening's exterior as the power needed to trigger the mechanism of storey-to-storey fire spreading.

The conclusions emerging from the above are as follows. Also the dimensions and shape of the windows are factors having a bearing on the fire spreading mechanism. However, because of the large number of the variables involved, without carrying out physical tests or numerical simulations it is very difficult to assess the possibility that this mechanism may occur.

An example of such a fire is presented in [18]. The whole façade was made of non-combustible materials. Figure 4 shows the actual development of the fire with storey-to-storey fire leapfrogging on the façade and the instants at which the critical stages occur.

Fig. 4. Development of actual fire acc. to [18]

It follows from the above that a fire can develop through the leapfrogging mechanism, but this does not always happen since it depends on the strength of the fire, the external conditions, the location of the fire and the shape of the windows. As of today, it seems practically impossible to eliminate this way of fire spreading. It is important, however, to take appropriate steps to limit this phenomenon. The present authors think that in this regard the knowledge in this field needs to be broadened. The aim of this research was to examine the possibilities of fire development for different storey heights and different overall dimensions of the windows. The knowledge about windows dimensions influence can give the possibility of proper building design in terms of increased fire safety of the building.

2. Numerical models of façade

In order to perform the analysis of the influence of the dimension of the windows and the height of the storey on the general conditions of the influence of the threat caused by the development of fire on the facade, numerical simulations of different dimensional variants of the facade were performed. Software has been used to perform the simulations. PyroSim uses solver Fire Dynamics Simulator (FDS). The software uses the Navier-Stokes equations. The turbulence behaviour is generated by the large-eddy simulation (LES). The software is dedicated to low-rate flows, with the emphasis on the transport of smoke and heat from fires. In the software, heat transfer via radiation is solved by means of the radiative transport equation for gases. The equation is solved using the finite volume method (FVM) [7].

Numerical models of tested facades were developed by adapting solutions from standards for the study of large scale façade model [14], including the shape of the tested facade model, assumptions on the course of the heat release rate (HRR) and the type of fire source. The adoption of such parameters allowed the unification of the studied cases and relating them to today's engineering knowledge of the risk of fire development.

The overall dimensions of the numerical model (including the atmosphere surfaces), are contained within a cuboid with the base dimensions 3400 mm × 3000 mm and the height of 7400 mm. The fire source is located in a room on the first above-ground storey. In this room there is an opening through which flames can get outside onto the façade's outer skin. An additional opening is located on the second above-ground storey. A cotton curtain, whose dimensions corresponded to the window opening in the façade model, was modelled in this opening. The model has two openings simulating open windows on the first and second above-ground storeys. Several model versions, differing in the height of the storeys and the size of the openings, were analysed. The window openings are located at the distance of 1150 mm from the floor topping level in the room. All the models were made alternatively to exemplary model 5, which present the dimensions, shape and individual materials. The differences between the different numerical models of the façades tested are shown in Table 1.

Table 1. Comparison of storey heights and opening sizes for particular models

Group no.	Model no.	Storey height	Opening dimensions (w. × h.)
Group 1	Model 1	2750 mm	1200 × 1200 mm
	Model 2	3250 mm	1200 × 1200 mm
	Model 3	3750 mm	1200 × 1200 mm
Group 2	Model 4	2750 mm	1500 × 1500 mm
	Model 5	3250 mm	1500 × 1500 mm
	Model 6	3750 mm	1500 × 1500 mm
Group 3	Model 7	2750 mm	1200 × 1350 (to the slab) mm
	Model 8	3250 mm	1200 × 1850 (to the slab) mm
	Model 9	3750 mm	1200 × 2350 (to the slab) mm

The fire source was adapted from façade testing standards BS 8414-1 [10] and EOTA No 761/PP/GRO/IMA/19/1133/11140 [12]. The fire source is equivalent to the HRR for a burning wood cribs. The wood cribs in full-scale models is represented by a stack of wood sticks. The HRR for the numerical model was assumed in accordance with the curve presented in BS 8414-1 [10]. The heat release rate curve for the adopted model is shown in Figure 6.

A cotton curtain, whose dimensions corresponded to the window opening in the façade model, was modelled in the window opening on the second storey. The HRR curve shown in Figure 7, determined for a cotton material (combustions of cotton shirts were carried out) was assumed for the curtain. The material specifications assumed acc. to [25] are as follows: density $\rho = 80$ kg/m^3, thermal conductivity $k = 0.06$ W/m·K and specific

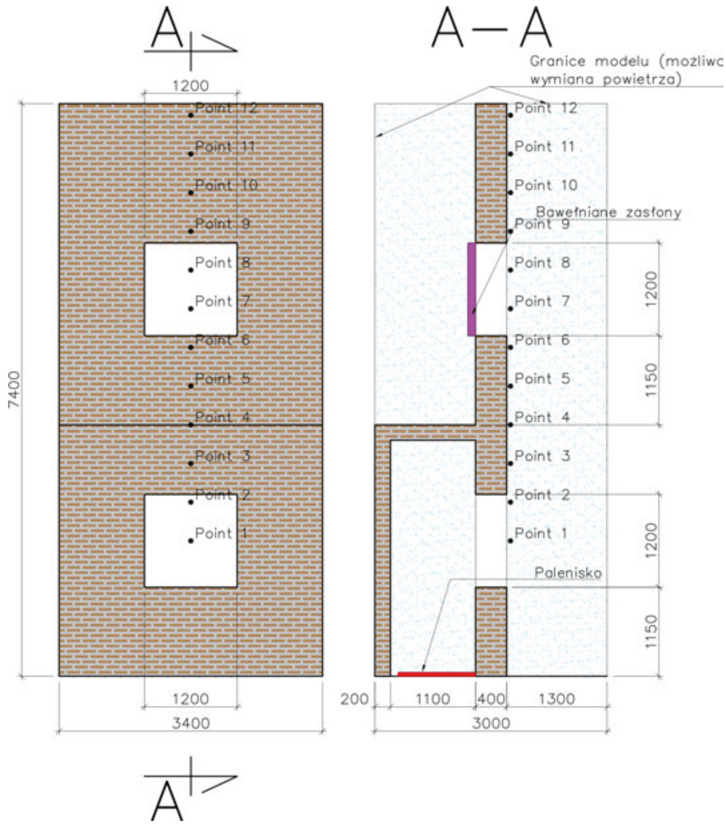


Fig. 5. Scheme and dimensions adopted for exemplary model

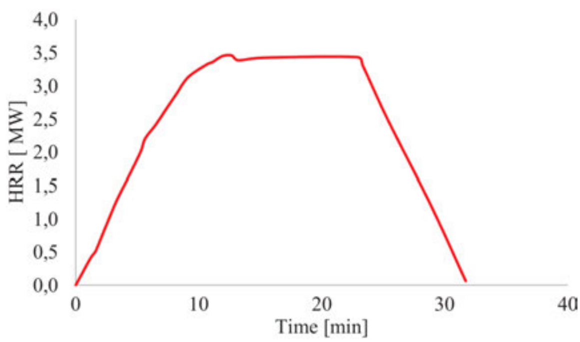


Fig. 6. Heat release rate adopted for numerical model in accordance with BS8414-1 [10]

heat c_p = 1300 J/kg·K. The ignition temperature – the minimum temperature causing the ignition of a dry material in air without the presence of a spark or flame – was assumed to be 510.15 K (237°C) [26].

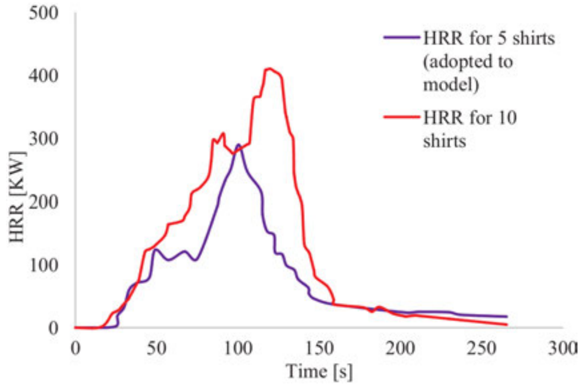


Fig. 7. Heat release rate for curtain [27]

The next step is the selection of an appropriate finite element mesh. Andersson [7] conducted real-world tests along with validating them with a numerical model based on the SP Fire standard 105. He verified the sensitivity of the finite element grid, assuming for this purpose the following grid dimensions: $50 \times 50 \times 50$ mm^3 and $100 \times 100 \times 100$ mm^3. No significant differences in the results between the different grid dimensions were found and the accuracy of the two grid variants in comparison with the physical model was sufficiently good. Also Degler et al. [28] used $100 \times 100 \times 100$ mm grids when numerically investigating the combustion of wood sticks with the standard HRR.

Instruction [29] presents an empirical formula $D^*/\delta x$ which allows checking the quality condition of the selected finite element mesh size. The use of such an empirical evaluation is due to the fact that FDS software is often used for small fires in relatively large spaces, and it is impractical to use a very dense mesh that captures detailed fire dynamics.

The formula for determining the mesh quality condition is presented below:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty \cdot c_p \cdot T_\infty \cdot \sqrt{g}} \right)^{\frac{2}{5}}, \tag{2.1}$$

where: $\rho_\infty = 550$ kg/m^3 – the ambient density of the burning material (a wood crib), $c_p = 1.76$ J/g·°C – the specific heat of the burning material (a wood crib), T_∞ – the temperature of the burning material, $g = 9.81$ m/s^2 – the gravitational acceleration, $\dot{Q}$ – the heat release rate, D^* – the characteristic fire diameter, which is a useful length scale incorporating the heat release rate of the fire.

Temperature T_∞ of 800°C was assumed after an analysis of various modellings of the standard fire source based on HRR [28]. The maximum HRR for the numerical models used, amounting to 3500 KW, was assumed as $\dot{Q}$.

$$D^* = \left(\frac{3.500 \cdot 10^6 \text{ kg} \cdot \text{m}^3/\text{s}^3}{550 \cdot 1000 \text{ g/m}^3 \cdot 1.76 \text{ Nm/g°C} \cdot 800\text{°C} \cdot \sqrt{9.81 \text{ m/s}^2}} \right)^{\frac{2}{5}} = 3.4 \tag{2.2}$$

In [30] the grid accuracy condition ensuring good agreement between the numerical model and the physical model was defined as $D^*/\delta_x \leq 13$. This condition was also used in [7], where a similar problem as the one in the present paper was examined.

$$\frac{D^*}{\delta_x} \leq 13 \tag{2.3}$$

The adopted $100 \times 100 \times 100$ mm grid is proper for the part of the model where burning, heat release and the flow of smoke and hot gases take place. In order to reduce the extensiveness of the numerical problem a $200 \times 200 \times 200$ mm grid was used in the places where the above phenomena did not occur. This grid satisfies the conditions specified in Instructions [29] and in study [7].

3. Results

The prepared facade models were numerically computed over a period of 33 min, such a time period was needed for the fire to develop, and for the fire to extinguish at the given HRR. The results obtained from such prepared numerical simulations allowed to analyze the course and trend of fire spread through the leap frog effect, assuming different variations of window openings dimensions and storey height.

Having verification in mind, temperature measurement points on the façade were assumed. The first point was located 350 mm above the window opening bottom (sill) on the second storey into which fire could get from the outside. The second measurement point was located at the upper slab level. The locations of the measurement points for model 1 are shown in Fig. 8. The measurement points in the other models were located alternatively to the ones in model 1.

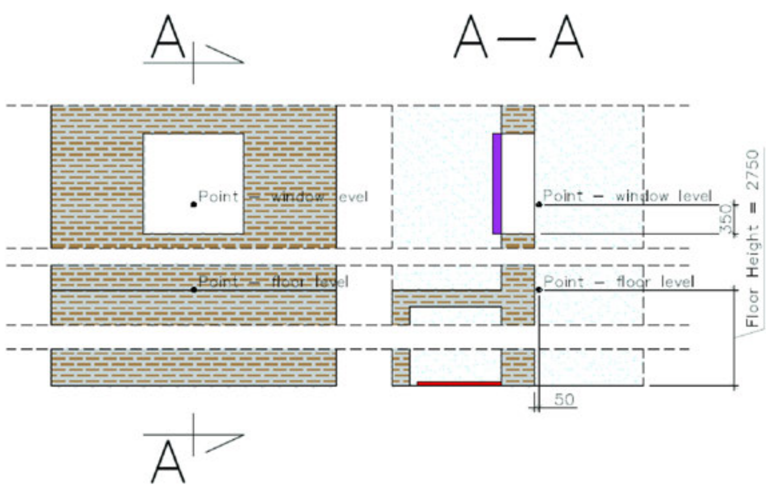


Fig. 8. Measurement points for model 1

Figure 9 shows temperature curves for the window opening level in the models belonging to group 1. The models in this group had 1200 × 1200 mm window openings. The particular models differed in their storey height, amounting to 2.75 m, 3.25 m and 3.75 m, respectively. In Figure 11 the sharp temperature jump in the measurement point indicates the instant when the cotton curtain ignited. The ignition of the cotton curtain differs between the particular models, but is very similar in terms of time, course and maximum values. The curtain ignites fastest in model 1 with the storey height of 2.75 m, i.e. within 378.6 s. In model 2 with the storey height of 3.25 m it ignites in 421.0 s and in model 3 with the storey height of 3.75 m in 414.0 s. An aberration here is the earlier (by about 7 seconds) ignition of the cotton curtain in the model with the storey height of 3.75 m (model 3) in comparison with the model with the lower storey height of 3.25 m (model 2). This indicates that under the particular model assumptions not only storey height, but also small window opening dimensions (1200 × 1200 mm) play a significant role in fire spreading.

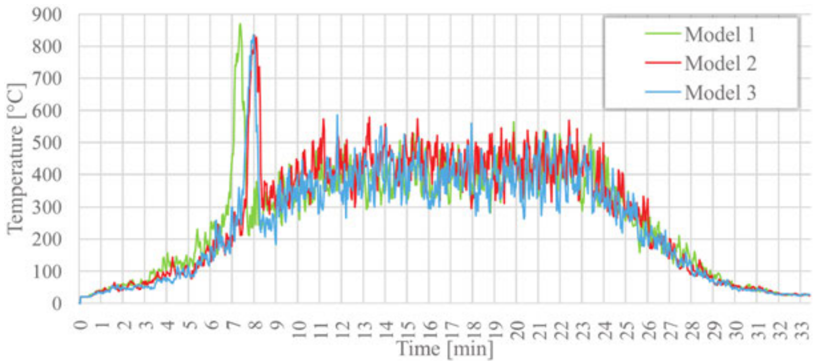


Fig. 9. Temperature curves for models in group 1 for measurement point located at window opening level

Figure 10 shows temperatures at the window level for numerical models in group 2, with 1400 × 1400 mm window openings. In comparison with the models with 1200 × 1200 mm window openings, one can already notice differences in the maximum temperature and in the temperature curve in relation to storey height between the individual models. This indicates a tendency for small window openings to strengthen the possible storey-to-storey fire spreading. In the case of group 2, it is apparent that the smaller the storey height, the quicker storey-to-storey fire spreading occurs. The cotton curtains ignite within 421.5 s, 517.7 s and 557.3 s for the height of 2.75 m, 3.25 m and 3.75 m, respectively. Also noticeable is a temperature difference at the maximum fire development (non-instantaneous curtain combustion) to the disadvantage of model 4. The models with larger storey height reach a higher temperature at the fire's peak.

Models 7, 8, 9 in group 3 had window openings 1200 mm wide and extending to the upper slab, reaching the height of respectively: 1350, 1850 and 2350 mm. The cotton curtains ignited only in model 7. This happened within 373.8 s from the start of the fire. The absence of ignition in models 8 and 9 was due to the fact that the temperature at

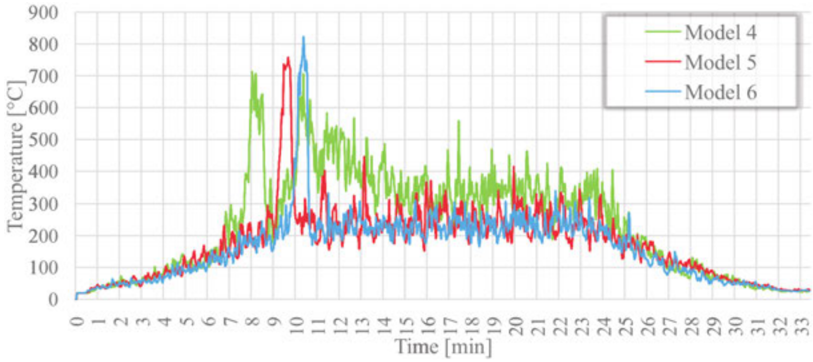


Fig. 10. Temperature curves for models in group 2 for measurement point located at window opening level

the window opening level was lower than the ignition temperature of the curtains (it did not reach even 200°C). In the case of the higher windows, the flames getting outside the window are more diffuse and do not cling to the façade. The temperature curves for models 3 are shown in Figure 11.

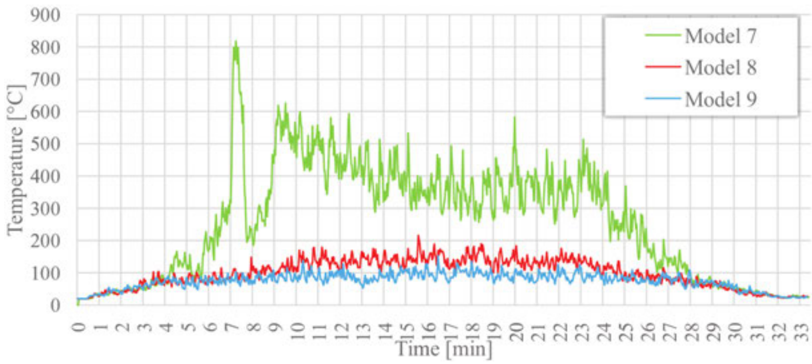
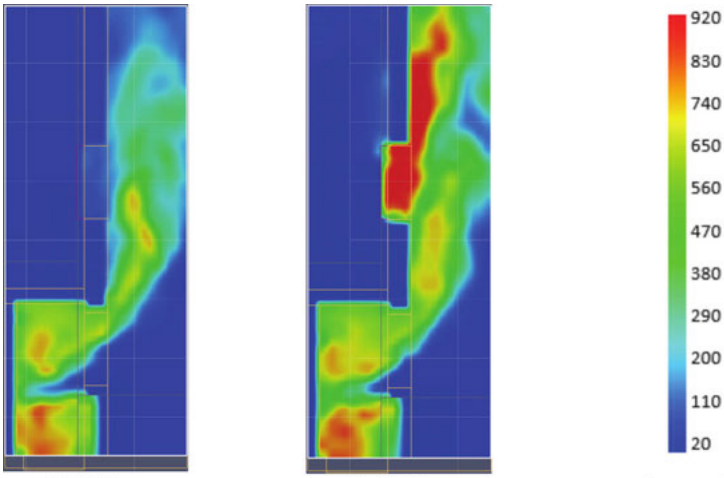


Fig. 11. Temperature curves for models in group 3 for measurement point located at window opening level

Figure 12a shows the developed fire, corresponding to the 350.8 s of the numerical simulation, for model 1. As on can see, the flames getting outside through the window opening rise along the façade – this tendency is typical of small window openings. The temperature at the window level above the storey reaches about 500°C, which is a temperature sufficient to destroy windowpanes. The developed fire after the ignition of the cotton curtain is shown in Figure 14b).

Figure 13 shows temperature curves at the upper slab level for the models in group 1, with 1200 × 1200 mm window openings. As in the case of the temperature curves for the window level, similar temperature values are observed for all the models. The conclusions



a) 350.8 s, b) 445.0 s, c) temp [°C]

Fig. 12. Development of fire over time for model 1

are similar as for Figure 9, but at an appropriately small fire surface. The effect of storey height on the possibility of occurrence of fire leapfrogging is of second importance.

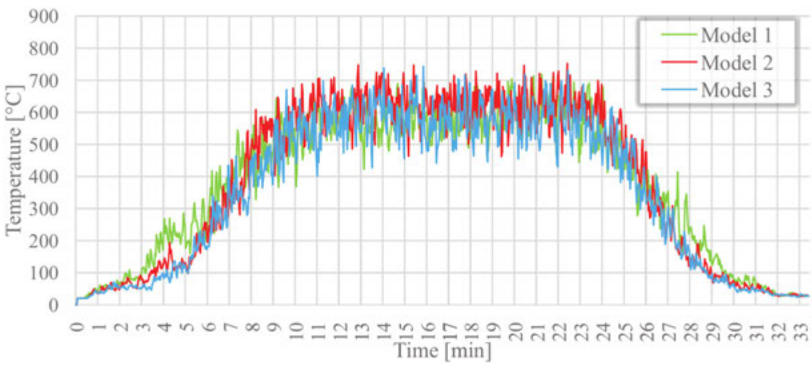


Fig. 13. Temperature curves for models in group 1 for measurement point located at upper slab level

In the case of group 2, with 1400×1400 mm window openings, the difference between model 4 and the other models becomes apparent. It reaches about 100°C in the developed fire, as shown in Figure 14. The temperature for the whole group 2 is significantly lower (by 100–200°C) than for group 1, depending on the considered model.

Figure 15 shows temperature curves for the models in group 3, having the largest windows. A considerably lower temperature in the measurement points for models 8 and 9 is noticeable. Due to the fact that the windows are so high the flames do not cling to the façade, but move away from it, as shown in Figure 16c). The developed shape of the flames in the fire in models 7 and 9 is shown in Figure 16.

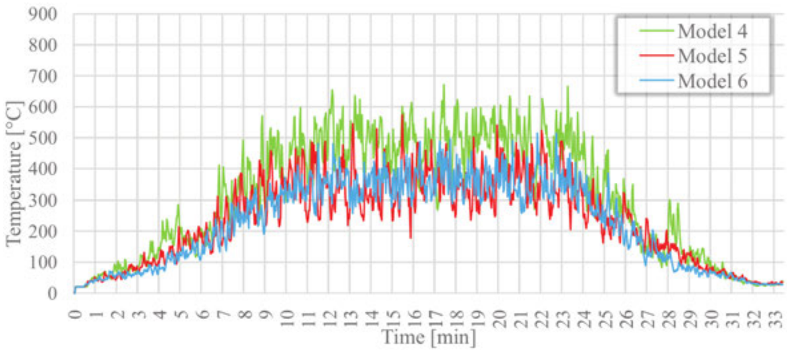


Fig. 14. Temperature curves for models in group 1 for measurement point located at upper slab level

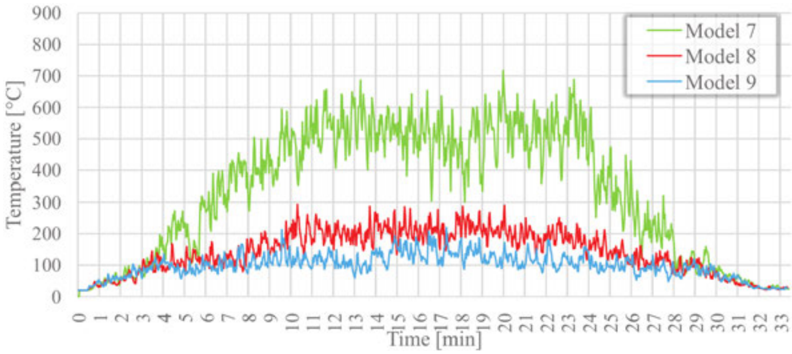


Fig. 15. Temperature curves for models in group 2 for measurement point located upper slab level

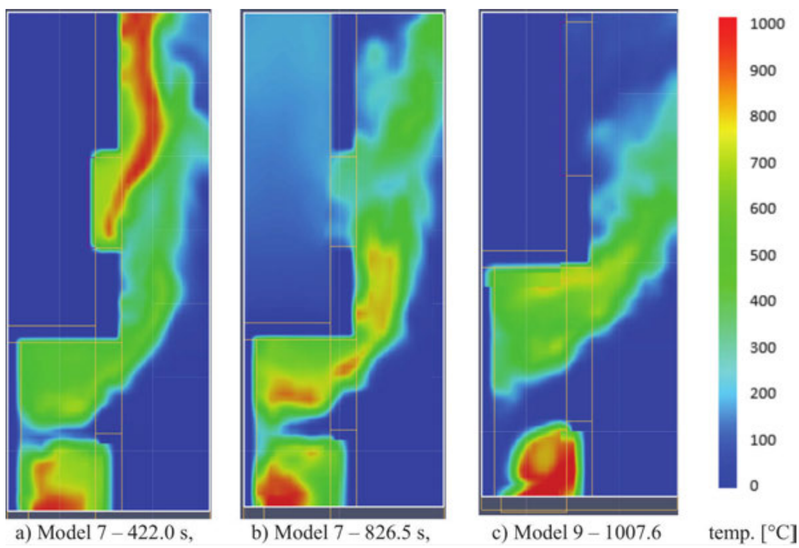


Fig. 16. Development of fire for model 7 and model 9

Figure 17 shows the average temperatures reached at the upper slab level during a fire and deviations from the average temperature. One can notice a high concentration and small deviation of temperature for the 1200 × 1200 mm window openings. In this case, at so small opening area, storey height has a smaller effect. In the case 1400 × 1400 mm window openings, the temperature deviates more from the average value. The temperature is considerably lower (by about 150°C) than the one for the 1200 × 1200 mm window openings. In the case of the model with windows 1200 mm wide and extending to the upper slab the average value is not reliable. A large deviation from the average is observed there.

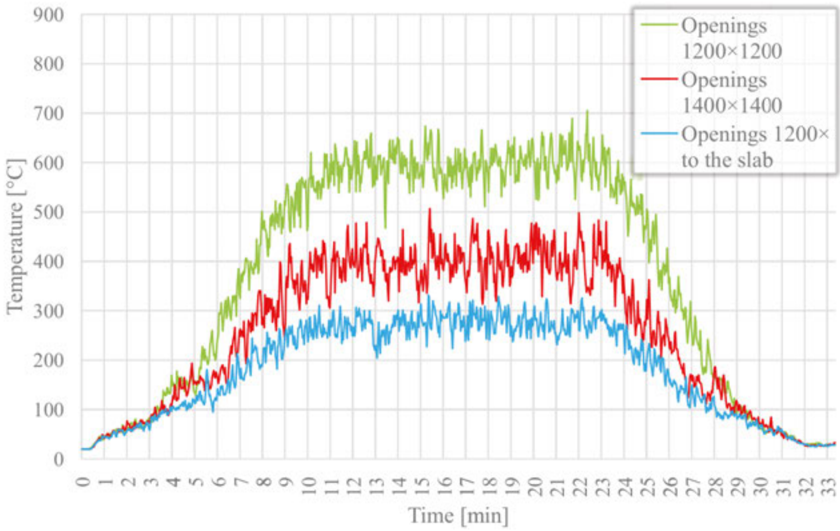


Fig. 17. Temperature curves for models in group 3 for measurement point located at window opening level

The averages for the 2.75 high stories significantly deviate from those for the other storey heights. The storey height of 2.75 makes the largest difference. Considering that the differences in temperature averages between the story height of 3.25 m and 3.75 m are minimal, one can conclude that the shape and dimensions of windows have a greater bearing on the occurrence of fire leapfrogging than storey height.

In addition, all models include measurement points measuring HRRPUV (heat release rate per unit volume) on the glass surface of the first storey where the fire source is modeled. In Figure 19 showing HRRPUV, it is noticeable that Models 8 and 9, where no fire transfer between floors occurred, significantly deviate in fire power per unit dimension [KW/m^2], the average value for these models is in the range of 15–20 KW, where for Models 1–7 it is over 35 KW. This leads to conclusions that the shape of windows is important from the point of view of the shape of flame plume and adhesion to the building, but additionally large window dimensions significantly reduce fire power per unit dimension [KW/m^2], which is also important aspect in the transmission of fire to the floors above.

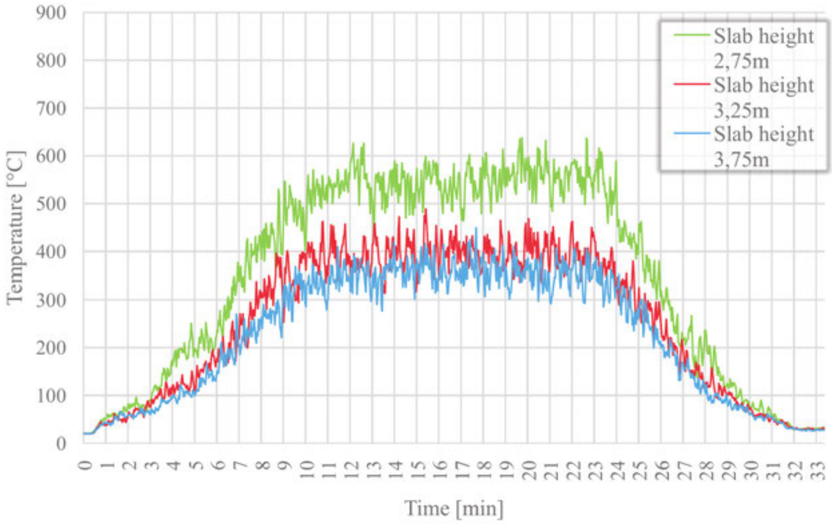


Fig. 18. Average temperatures versus storey height

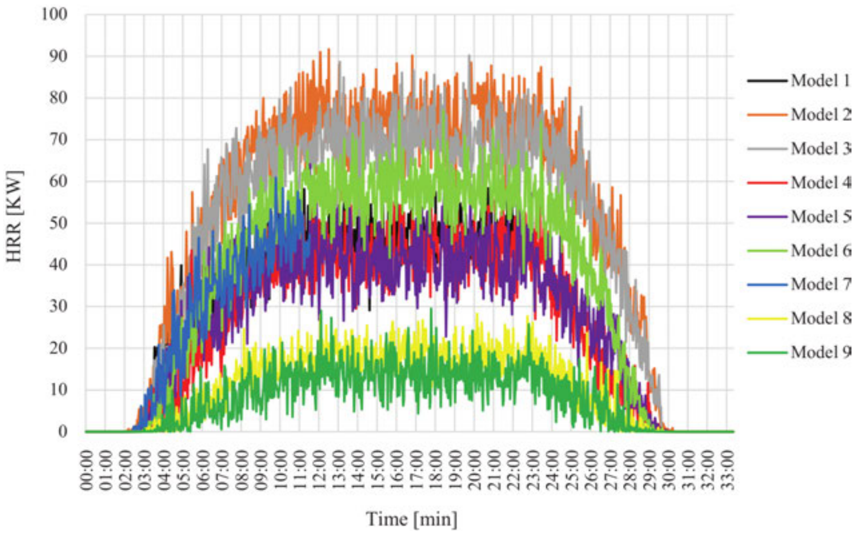


Fig. 19. HRR on the surface of the window opening from which the fire escapes

4. Conclusions

The paper presents detailed comparisons for numerical simulations of various dimensions of the facade in terms of fire risk, in particular the spread of fire between storeys along the facade (the so-called leap frog effect).

The problem of fire spread along the facade between storeys (the so-called leap frog effect), applies to most of the analyzed models, i.e. the fire transfers between successive storeys of the building. It should be noted that for the purpose of the simulation, a standard fire source in accordance with BS8414-1 [10] was assumed, emitting the appropriate HRR curve and a maximum power of 3500 KW, which values correspond to a crib placed in the vicinity of the window. In case of real fires, the maximum power may gain many times higher values due to, among others, elements of the room furnishing, e.g. closets, carpets, curtains etc.

The important finding is that the shape of the window is the most critical factor for fire leapfrogging. Different window opening dimension were considered in the analysis. In the case of the smallest (1200 × 1200 mm) window openings, the effect of storey height was marginal – the temperature curve was relatively constant for the different storey heights. In the case of the 1400 × 1400 mm window openings, differences in how the fire developed depending on the storey height (ranging from 2.75 m to 3.75 m) became apparent. The temperatures in the measurement points were by as much as 200°C higher in the case of the lower model. An analysis of the two groups of models varying in their window openings indicated that the risk of fire leapfrogging is greater in the case of relatively small window openings, and storey height only minimally contributes to its reduction.

In the case of group 3, with window openings 1200 mm wide and extending to the upper slab, the fire leapfrogging effect was reduced. Fire spreading occurred only in the model with the storey height of 2.75 m. In the case of models with the storey height of respectively 3.25 m and 3.37 m, fire did not get to the upper storey. The use of such solutions for windows in buildings, undoubtedly benefits the safety of the entire building in terms of possible fire development on the facade – changing the shape of the fire plume coming out of the storey, which is less adjacent to the wall.

Increasing window size with constant HRR for all models has a positive effect on reducing HRRPUV. Lower fire power per unit dimension [KW/m^2] for models with large window openings results in less probability of flame penetration to the storey above. It is worth to note here that for such fires in most cases we have flame combustion, controlled by fuel, so increasing the oxygen supply will not increase the fire power, and increased window size in later phase of fire will reduce the fire power per unit dimension [KW/m^2]. An important aspect that requires further analysis is to correlate the HRRPUV required for the flames to reach the upper storey in the future.

It should be noted that it seems that storey-to-storey fire spreading should occur quicker when the windows are large and higher, and certainly when they extend along the full height of the wall, as in the case of models in group 3, but this a deceptive conclusion to draw. The carried out numerical simulations show that such windows are safest as regards fire spreading through leapfrogging. Whereas, windows with a small surface area are very dangerous ones since they intensify fire leapfrogging due to the higher rates of flow of gases and smoke through such windows.

The results of numerical simulations also present a possible next step in improving safety in terms of fire development, presenting that it is reasonable for buildings – especially tall buildings, to perform such analyses at the design stage. It is possible that small changes in solutions at this early stage can bring huge benefits in case of fire outbreak and its development on the external facade.

In addition, it should be noted that a very good trend in the market of new investments is to make large glazing. Although the primary goal for investors is to satisfy and meet the expectations of customers, it is also possible that in an unconscious way they increase the safety of the building in terms of preventing the possible development of fire, especially through the leap frog effect.

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Analiza numeryczna rozprzestrzeniania się ognia pomiędzy kondygnacjami po elewacji

Słowa kluczowe: pożar, efekt "żabiego skoku", bezpieczeństwo pożarowe, modele wielkoskalowe elewacji, elewacje, rozprzestrzenianie się pożaru po elewacji

Streszczenie:

W artykule przedstawiono szczegółowe porównania dla symulacji numerycznych rozwoju pożaru po elewacji, z szczególnym uwzględnieniem tzw efekt "żabiego skoku", dla różnych wariacji rozmiarów otworów okienny i wysokości kondygnacji. Analizie numerycznej poddano łącznie 9 modeli. W większości analizowanych modeli problem ten wystąpił – tzn. ogień przedostał się po elewacji na wyższą kondygnację. Należy zauważyć iż przyjęte palenisko było zidentyfikowane o parametry normowe, a materiały na elewacji były niepalne – jako ściana jednowarstwowa. W przypadku pożarów rzeczywisty parametry szybkości uwalniania mogą być również bardzo zróżnicowane, lecz są to wartości zazwyczaj większe. Wykazano iż najniebezpieczniejsza sytuacja to niewielkie gabarytowo okna, w których to wyrzut ciepłych gazów i płomieni, powoduje dość łatwy przeskok pożaru pomiędzy

kondygnacjami. Efekt żabiego skoku, można ograniczyć poprzez zwiększanie okien, oraz wysokości kondygnacji – powoduje to zmianę kształtu wydostających się płomieni z wnętrza budynku, oraz ogranicza możliwość przedostawania się ognia na powyższe kondygnacje. Dodatkowo zwiększanie gabarytów okien powoduje zmniejszenie mocy pożaru na jednostkę wymiaru okna [KW/m2] przy stałej mocy pożaru (pożarze kontrolowanym przez paliwo), które to również ma kluczowe znaczenie przy przedostaniu się ognia przy efekcie żabiego skoku.

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