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PREDICTION OF THE EFFECT OF BREAKING WINDOWS IN A DOUBLE SKIN FAÇADE AS A RESULT OF FIRE

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ABSTRACT

It is necessary for fire safety that in case of a flash-over situation, the windows in the outer skin would break very fast and before the windows in the inner façade would break, so that the model of Law is valid in which case the NEN 6068 could be applied. The wind blows towards the building for a worst-case situation. Computational Fluid Dynamics (2D) is used for calculating convective heat transfers assuming a specific heat source for the fire. WINFIRE is used for the predicting of radiation. Due to convection and radiation the temperature in the windows would rise and the window will eventually break. As a result we predicted that the obstructed outer skin would break within 10 seconds and a non-obstructing flashover situation will be left. Hence, the NEN 6068 can be applied.

INTRODUCTION

In the Netherlands the NEN 6068 (2001) is a fire safety regulation to predict if fire spread to other rooms or floors will be possible for a given geometry of the building. It is based on the model of Law (1981). This model assumes a flashover situation (steady state) and with this model it is possible to predict the heat flux of the flame and the window. The NEN 6068 states that fire spread to another room or floor will not be possible within 30 minutes if the heat flux at the surrounding windows is less than 15 KW. It further states implicitly that the flashover outside the building is not obstructed in any way. In case of a double skin façade the outer skin is an obstruction and therefore the NEN 6068 is not appropriate to use, because the model of Law is not valid. The NEN 6068 models a steady state situation and therefore does not take into account that the outer skin will be warmed up by the fire and eventually will break. If it can be predicted that the outer skin will break rapidly then there is no obstruction left and the model of Law will be valid again and the NEN 6068 could be used. The whole purpose of this exercise is to predict when the windows in the outer skin will break.

SITUATION DOUBLE SKIN FAÇADE

In figure 1 the double skin façade situation is described. A fire starts on the bottom floor. Eventually there will be a flashover. Vertical spread will possibly occur by flames breaking out of the room.

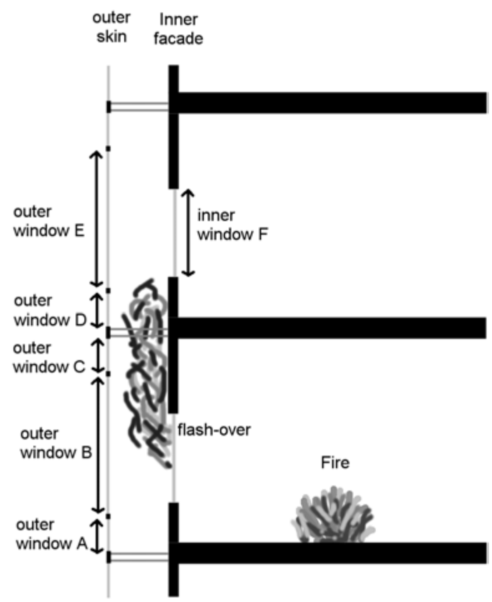

Figure 1: Double skin façade. In case of flashover, the outer windows B, C, D and E are obstructing the flame geometry. Window A is not obstructing the flame and can be neglected.

The windows B, C, D, and E in the outer skin are obstructing the flame and therefore the NEN 6068 cannot be applied. Note, that window A is not obstructing the flame and can be neglected.

SIMULATION

overview

NEN 6068 gives an indication of the temperatures in the room, which depends on the geometry of the room and the windows, just before flashover. In case of the double skin façade, the temperature in the room will be around 1400 K at that time. The time of the flashover is the starting point for the CFD simulation.
The tricky part of the simulation is that the geometry is changing when a window in the outer skin breaks. We can not use a steady state model, but need to use a transient model. For the simulation we used CFX which makes it possible to simulate changing geometry in combination of a transient time model. However, at that time, using the changing geometry model, it was impossible to use the radiation sub model. Radiation cannot be neglected in this situation. For the radiation we used our "in house" program WINFIRE, see e.g. Jakobs (1997). The CFD convective simulation gives us the shape of the flame at every time step. This shape is used as an input for WINFIRE, which then computes the radiation for every time step. The results of the convective and radiation heat at the outer window façade are used for calculating the heat transfer in a spreadsheet. This gives us the temperature rise in the outer window façade. When the temperature reaches the point that the window will break, the geometry will change. In figure 2 is given the flow diagram, which is used for our simulation.

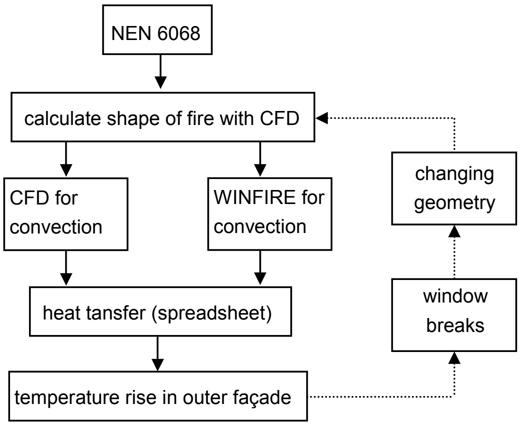

Figure 2: flow diagram of the simulation

CFD

The NEN 6068 is based on Law's model in which the shape of the flame is defined as is shown in figure 3.

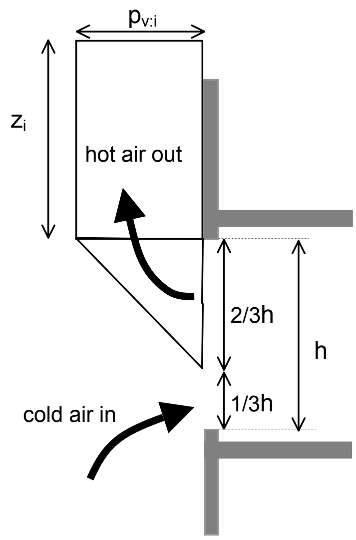

Figure 3: shape of flame according to the NEN 6068 (no obstructions)

As shown in figure 3, 1/3 of the window is used to let cold air in. The flames are pouring out of 2/3 of the window. The geometry of the room and the windows determine the burning rate, which in this case is 8.3 kg wood/s, which is equivalent to 47.3 kg/s air (fire and smoke). See e.g. Drysdale (1994). The temperature of the room for this geometry is 1383 K.
The geometry of the window, the temperature of 1383 K and the hot air (47.3 kg/s) are the input parameters for the inert CFD-simulation. The inner room is not modeled in CFD. To reduce calculation time the CFD-model is made 2D, which is shown in figure 4. Only the part within the thick black lines is modeled in CFD. The heat exchange to the right and the left is neglected.

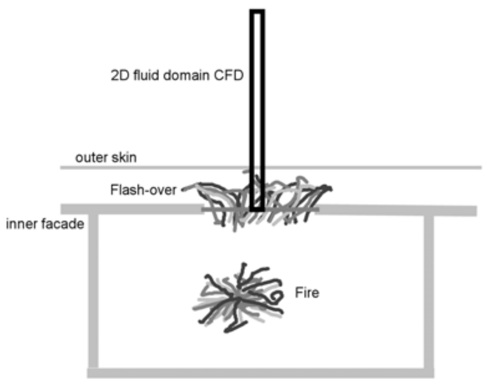

Figure 4: the 2D fluid domain region used for CFD.

The transient situation is calculated with the standard k-ε model. See e.g. Versteeg (1995). To ensure that flame will more or less stay between the inner and outer façade, a wind blowing towards the building is modeled with a wind velocity of 1 m/s at 10 m height. The wind profile can be described as:

$$u_h = u_{10} \frac{\log\left(\frac{h}{z_0}\right)}{\log\left(\frac{10}{z_0}\right)} \quad (1)$$

with:
h = the height
u_h = the wind velocity at height h [m/s]
z_0 = the roughness coefficient
See e.g. Wieringa (1983). In this situation the roughness coefficient is 0.3, which is in between open terrain and urban terrain.

radiation

The radiation from the flame is determined by the hot volume of the flame using the formula:

$$\phi_x = \frac{\sigma\varepsilon_r}{\pi} \int_A \frac{\cos\varphi_1 \cos\varphi_2}{r} \left(1 - e^{-kl}\right) dA \quad (2)$$

with ϕ_x is the heat flux at point x from area A with a thickness of l at a distance r. σ is the Stefan-Boltzman constant. k is the extinction coefficient (0.3 m^{-1}). ε_r is the emissiecoefficient of the flame body. The angles φ_1 and φ_2 are shown in figure 5 and are used to determine the configuration factor. For these calculations the program WINFIRE is used. For every time step the shape of the flame is calculated with CFD and with formula 2 the radiation is calculated.

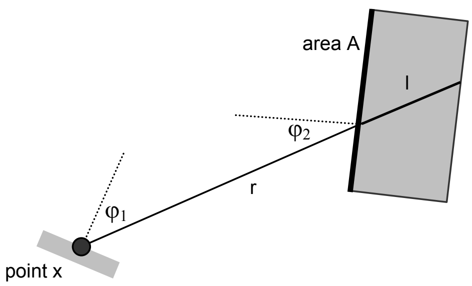

Figure 5: the configuration factor which is determined by φ_1 and φ_2.

temperature in glass

After calculation of the heat flux (convection and radiation) to the outer window, the temperature rise in the outer window has to be determined. We could not do this with a solid fluid domain in CFD, because the radiation was not calculated within CFD. The heat flux to the window can be described with the next formula at a time t:

$$q_{tot}(t) = \varepsilon q_r(t) + q_c(t) \quad (3)$$

with:
$q_{tot}(t)$ the total heat that is absorbed by the window
ε the absorption coefficient of the window
$q_r(t)$ the heat flux from radiation (determined with formula 2)
$q_c(t)$ the heat flux from convection (determined with CFD)
The heat flux from convection can be described with:

$$q_c(t) = \left[T_i(t) - T_g(t)\right]\frac{\lambda}{\delta} \quad (4)$$

where T_i is the temperature at the inner side of the outer façade, T_g is the temperature in the glass, λ is the heat conduction coefficient for glass (0.8 W m^{-1} K^{-1}) and δ is the thickness of the glass (0.006 m). The warming up of the glass can be described with the following formula:

$$\Delta T_w(t) = \frac{q_{tot}(t)}{\delta\rho C} \quad (5)$$

where ΔT_w is the temperature rise in the glass window caused by the heat flux $q_{tot}(t)$ at time t, ρ is the density of glass (2500 kg/m^3) and C is the heat capacity of glass (840 J kg^{-1} K^{-1}). Note that in this transient situation δ and ΔT_w are not constant but are a function of the position in the glass. This is shown in figure 6. The dotted line is the situation for a steady state situation, and the solid line is the transient situation at time step t, when $T_i(t)$ is rising in temperature.

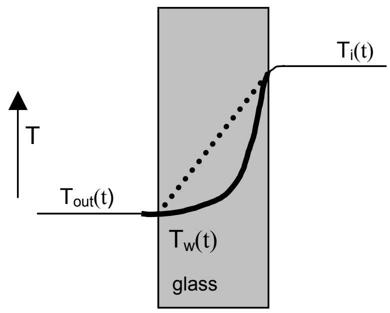

Figure 6: Profile of the temperature in the glass for steady state situation (dotted line) and transient situation (solid line).

We now assume that approximately only half of the glass will warm up. Hence, the effective thickness of the glass is only δ/2. The temperature rise $\Delta T_w(t)$ can now be described as:

$$\Delta T_w(t) = \frac{2q_{tot}(t)}{\delta\rho C} \quad (6)$$

If we want to know the temperature rise in a period Δt we can describe this with:

$$\Delta T_w(t) = \int_{\Delta t} \frac{2q_{tot}(t)}{\delta\rho C}\, dt \qquad (7)$$

If Δt is infinite small, $q_{tot}(t)$ will not change much in time and we can write formula 7 as

$$\Delta T_w(t) = \frac{2q_{tot}(t)\Delta t}{\delta\rho C} \qquad (8)$$

breaking of glass

The temperature difference that is needed to break the glass is not exactly known. There are a lot of uncertainties. It depends on the quality of the glass and it also depends on the temperature differences in the 3 directions in the glass. We neglect temperature differences in the directions of the thickness of the glass. It is assumed that the temperature of the glass will rise much quicker than the temperature in the window frame. We assume that the temperature of the window frame will stay constant (outside temperature) and that this will create a temperature difference. If this temperature in the glass rises up to a difference of 70 K with the window frame, the window will break.

Note that the heating of the glass in this model is an approximation. There exist models to predict the heating of the glass more accurate. Considering the uncertainties at which temperature the glass will break, a more accurate model for the heating of the glass will not lead to a more accurate solution as a whole.

RESULTS

In figure 7-10 are shown a few snapshots of the results of the CFD-model.

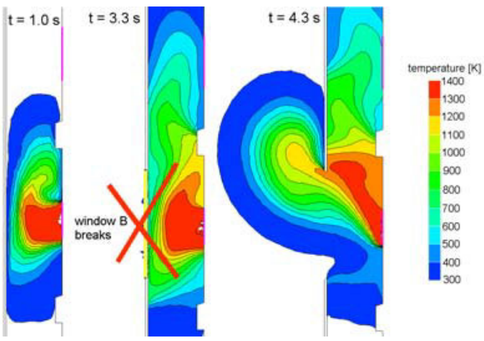

Figure 7: results of CFD-model, snapshots at t = 1.0 s, t= 3.3 s and t= 4.3 s. Note that window B breaks at t = 3.3 s.

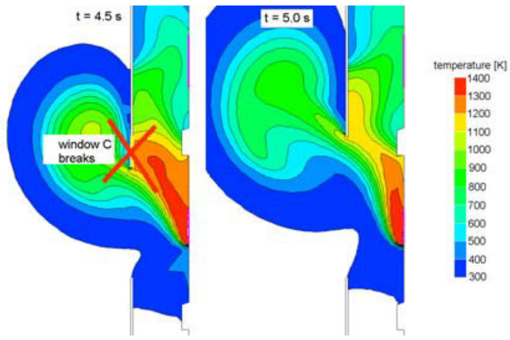

Figure 8: results of CFD-model, snapshots at t = 4.5 s and t= 5.0 s. Note that window C breaks at t = 4.5 s.

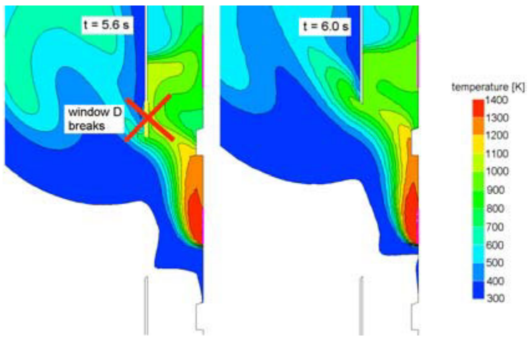

Figure 9: results of CFD-model, snapshots at t = 5.6 s and t= 6.0 s. Note that window D breaks at t = 5.6 s.

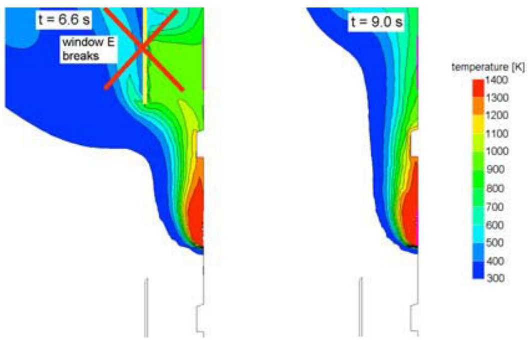

Figure 10: results of CFD-model, snapshots at t = 6.6 s and t= 9.0 s. Note that window E breaks at t = 6.6 s.

As can be seen in figure 7-10 all windows B, C and D are broken within 10 seconds and all obstructions for the flame are gone. Hence NEN 6068 can be applied. Note that window A will break at t = 7.5 s, but will not influence the shape and the temperature of the flame much.

In figure 11 is given the temperature rise of the windows A, B, C, D and E.

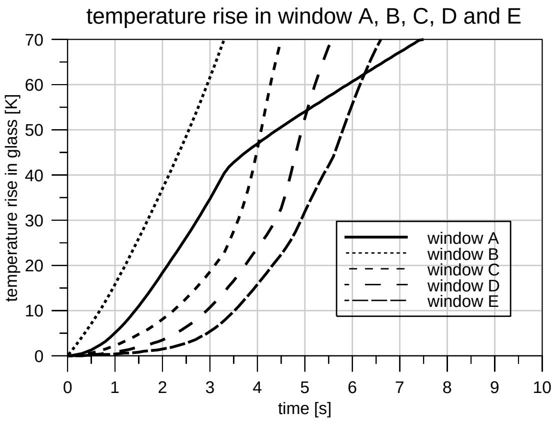

Figure 11: temperature rise in glass for window A, B, C, D and E.

Figure 11 shows that at 7.5 seconds all windows are broken. Note that the temperature in window A rises steeply until the first window (window B) breaks. At that moment a lot of hot air is going outwards and upwards and will not be near window A. Hence the temperature will rise more slowly afterwards. For the other windows the temperature rise will go faster after 3.3 seconds.

CONCLUSIONS

With a computational fluid dynamics model (CFX) and a radiation model (WINFIRE) it is possible to predict the temperature rise of the windows in the double skin façade. This simulation shows that in a very short time (within 10 seconds) the outer skin façade will be broken away and there will be no obstructions left to influence the shape and temperature of the flame. Hence, after less than 10 seconds the model of Law is valid. This means that the NEN 6068 can be applied to predict vertical fire spread to the next floor above.

The simulation shows that with a wind velocity of 1 m/s at 10 m height, the hottest part of the flame will stay within the outer skin for a worst case situation.

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