Influence of material of boundary condition on temperature and visibility

Luciano Nigro, Andrea Ferrari, Elisabetta Filippo
H.A.E Srl – Jensen Hughes EU Alliance
Via Vincenzo Monti, 52 Rho (Mi), ITALY

Executive summary
The differences in the results in terms of temperatures and visibility achievable in a dominium modeled by FDS are investigated when the physical properties of the boundaries of the dominium are varied.
Several runs of fire modeling are carried out, varying the physical properties of the boundaries of the dominium, with constant all other parameters, to get an idea of the sensitivity of the achievable results to the input physical parameters.
The results of the analysis show that it is important to know the characteristics of the boundaries of the dominium differentiating an adiabatic dominium from a dominium where a certain heat transfer is taken into account. The effects of the variations in the boundary materials are affecting the temperature much more than the visibility. The exact knowledge of the physical properties of the boundary materials is however less important for the final results of the calculations.

INTRODUCTION
It is commonly accepted the performance based design process to be structured in 9 main steps accounting for the *SFPE Engineering Guide to Performance-Based Fire Protection*:
- Defining project scope,
- Identifying goals,
- Defining objectives,
- Developing performance criteria,
- Developing fire scenarios,
- Developing trial designs,
- Quantifying design fire curves,
- Evaluating trial designs,
- Documenting design process.

Within this framework, the prediction of burning behavior in buildings is the step to which a lot of efforts are paid with the consideration that as more precise the quantitative analysis can be as better will be the performance-based fire safety design.
The HRR curve or CO and Soot production yield are the main parameters used to define the fire behavior, but an accurate fire model also requires a definition of material finishes as a boundary condition of the computational domain. In a new building project, the type and/or the characteristics of materials that will be used to actually “make” the building are often not defined at the time when the performance based analysis is conducted. For this reason, it is important to understand how the boundary conditions influence the results of the quantitative analysis great attention to the temperature and the visibility that are the main values investigated by the model.
In a finite element model, the gas temperature is computed at the center of the grid cell. At a boundary cell, the gas temperature at the face of the cell that falls at the boundary interface is also estimated. The wall temperature and the temperature of gas cells depend on the density of the wall, which is calculated by the equation of state.

The most commonly used finite element computational software nowadays is FDS; since its first launching in 2000, FDS has been implements with a lot of additional tools and model features, making it one of the best package for fire simulation currently available to the Fire Engineers worldwide.

The wall heat transfer in FDS, for thermally thick boundaries, takes into account both radiative as well as convective heat fluxes. The boundary condition on the front surface of a solid boundary obstruction is:

\[-k \frac{\partial T}{\partial x} (0,t) = \dot{q}^c + \dot{q}^r\]

The convective heat flux is the maximum between convective and the temperature gradient:

\[\dot{q}^c = \max \left[ C|\Delta T|^\frac{1}{3} \frac{k}{L} 0.0037 \text{Re} \frac{4}{5} \text{Pr} \frac{7}{5} \right]\]

The calculation of temperature depends on the density and species mass fractions.

- \(C\), an empirical coefficient for natural convention, is equal to 1.52 for a horizontal plane and 1.31 for a vertical plane,
- \(\Delta T\) the temperature difference between the wall cell and the neighboring gas cell,
- \(k\) is the thermal conductivity of the gas,
- \(L\) is the characteristic length related to the size of the physical obstruction,
- \(\text{Re}\), Reynolds number, based on the local characteristic length scale \(L\).

The radiative heat flux is the sum of incoming and outgoing components:

\[\dot{q}^r = \dot{q}^r_{\text{in}} - \dot{q}^r_{\text{out}} = \varepsilon \left( \dot{q}^r_{\text{inc}} - \sigma T_w^4 \right)\]

Where:
- \(\dot{q}^r_{\text{inc}}\) is the incident radiation,
- \(\sigma\) is the Stefan Boltzmann constant and
- \(T_w\) is the surface temperature.
- \(\varepsilon\) - the emissivity - is a material property of the surface.

As fire is characterized by non-homogeneous temperature distribution, the incident radiation heat flux should ideally include contribution from nearby flames, hot gases, and surfaces for which the incident radiation may be written as the sum of the contribution from all the radiating sources.

The purpose of this study is to examine which characteristics of material finishes are important in the evaluation of temperature and visibility and to which extent.

In order to achieve such result, a series of simulations are carried on with two different material finishes, calculating the temperatures and the visibility varying the characteristics of the
boundary walls only. Glass and concrete and with five different type of concretes, are used. These materials are considered to characterize the ceiling of a room, that normally is the most important portion of the boundaries; the floor and all the walls in the domain are considered as adiabatic surfaces for the aim of the study.

**FIRE SCENARIO**

The compartment used for the simulation fire experiment is 18.8 m wide, 13.2 m long and about 6.4 m high. The walls of the compartment are 0.4 m wide and thermal insulated, the floor is adiabatic and 14 squared beams (0.4 m side) support the ceiling of the compartment.

The ceiling of the compartment has been assumed to be a pitched roof: the lowest is 5 m high; the maximum elevation is 6.6 m high.

The openings to the external ambient are on two opposite sides of the compartment. Each opening is 1.2 m wide and 2.2 m high.

The trials are done using FDS version 6.3.2, a computational fluid dynamics modelling software based on a grid system, where walls, ceiling etc. are put in as obstructions. The doors are described as an open boundary, and heat transfer boundary conditions with appropriate thermal properties are applied on the room boundaries.

The grid used in the model has cells size equal to 20 cm in x, y and z-directions. The size of the grid is calculated on the basis of the characteristic diameter of the fire.

A number of different grid sizes were tested at the beginning of the study, varying the cell sizes, but the results showed that a grid size smaller than 20 cm per side had little improvement in comparison to the results obtained with a mesh with cell sizes equal to 20 cm in all directions.

The fire is in the center of a quarter of the compartment; four fire heat release rates are examined: 0.5 – 1 – 2 – 9 MW. The HRR of the fire is kept constant over a period of time because the purpose of the study is to evaluate the variation of temperatures in the compartment during the steady state of the fire scenario.

The fires with a heat release rate 0.5 – 1 – 2 correspond to three different scenarios that can be set in a compartment as the one indicated; the last heat release rate is the heat rate that is reached at the flashover in a compartment as that examined.

The fire is a pool fire, its area is based on the characteristic diameter, the value of heat release rate for unit area is calculated on the maximum value of heat release rate.

A material like Polyurethane (CH$_{1.7}$O$_{0.3}$N$_{0.08}$) is used for the pool fire, while the smoke yield and CO yield are assumed to be 0.07 kg$_{soot}$/kg$_{fuel}$ and 0.04 kg$_{CO}$/kg$_{fuel}$, respectively.
The duration of each test run is about 15 minute.

**PARAMETERS**

The definition of the boundary material is made only for the ceiling. The walls and the floor are assumed to be adiabatic obstruction which implies that they do not mix up with the external ambient.

Glass and concrete are the example materials of boundary condition used in the simulation trials. The characteristics of two materials that are taken under consideration are: density, thermal conductivity, and specific heat.

A first set of simulations are carried out with glass as ceiling material with the following characteristics:

Glass: density 3100 kg/m$^3$, specific heat 0.84 kJ/kg °K, transmittance 1.6 W/m$^2$ °K;

A second set of simulations are made with concrete with the following characteristics:

Concrete: density 2000 kg/m$^3$, specific heat 0.88 kJ/kg °K, transmittance 14.28 W/m$^2$ °K.

The scenarios with the definition of boundary conditions are compared to two basic cases. In the first basic case all materials of the boundary are adiabatic; in these conditions the whole heat is kept inside the domain because there is no heat transfer with the external ambient.

The second basic case has all material of boundary adiabatic but there are openings at the ceiling, 1.0 m wide and 4.4 m long. The openings on the ceiling may be the permanent openings, casually open windows, natural smoke and heat exhaust ventilators, or even a glass window that crash because of the temperature after a few minutes.

<table>
<thead>
<tr>
<th>Fire</th>
<th>Boundary Condition</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 MW</td>
<td>Adiabatic</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td>Adiabatic and Openings</td>
<td>A4</td>
</tr>
<tr>
<td>1.0 MW</td>
<td>Adiabatic</td>
<td>B1</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>B2</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>B3</td>
</tr>
<tr>
<td></td>
<td>Adiabatic and Openings</td>
<td>B4</td>
</tr>
<tr>
<td>2.0 MW</td>
<td>Adiabatic</td>
<td>C1</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>C2</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td>Adiabatic and Openings</td>
<td>C4</td>
</tr>
<tr>
<td>9.0 MW</td>
<td>Adiabatic</td>
<td>D1</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>D2</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>D3</td>
</tr>
<tr>
<td></td>
<td>Adiabatic and Openings</td>
<td>D4</td>
</tr>
</tbody>
</table>

*Figure 1: Fire and boundary condition of each scenarios*
In the above table the letters account for the HRR, with A, B, C and D representing the HRR of 0.5, 1, 2 and 9 MW respectively; the numbers account for the boundary conditions with 1, 2, 3 and 4 representing the adiabatic, glass, concrete and adiabatic + openings respectively.

The comparison to evaluate the variation of temperature is done comparing the temperature of the gas of the scenario with the definition of materials for the boundary condition in all fire scenarios. In this way, the change in temperature, when the characteristics of a material of boundary condition are altered, is compared in different types of fire.

For each fire, four scenarios are analysed, with the different boundary conditions. The comparison is done on the variation of material and the variation of the fire size.

The second set of simulation are done to evaluate the influence of density of the material of the boundary condition on the temperature. Concrete with different density and specific heat is used to define the ceiling; the transmittance is equal to 14.28 W/m² °K for each type of concrete modifying the thickness of the ceiling elements.

<table>
<thead>
<tr>
<th>Denomination</th>
<th>Density [kg/m³]</th>
<th>Specific heat [J/kg°K]</th>
<th>Thickness [mm]</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Concrete</td>
<td>1600</td>
<td>1200</td>
<td>56</td>
<td>Conc-1</td>
</tr>
<tr>
<td>Siliceous Concrete</td>
<td>2400</td>
<td>1200</td>
<td>119</td>
<td>Conc-2</td>
</tr>
<tr>
<td>Vibrated Concrete</td>
<td>2000</td>
<td>880</td>
<td>140</td>
<td>Conc-3</td>
</tr>
<tr>
<td>Calcareous Concrete</td>
<td>2300</td>
<td>913</td>
<td>105</td>
<td>Conc-4</td>
</tr>
<tr>
<td>Cell Concrete</td>
<td>1300</td>
<td>1200</td>
<td>45</td>
<td>Conc-5</td>
</tr>
</tbody>
</table>

Figure 2: Type of concrete used in the second set of simulations

RESULTS

Changing the boundary condition produces significant variations in the gas temperatures of the smoke layer; The variations in the visibility proved to be negligible, for the sake of the current study. For this reason the temperature only is the observed parameter.

The gas temperature is measured at the center of each grid cell. The mean cell gas temperature is derived from the density and species mass fraction via the equation of state:

\[
T_{ijk} = \frac{p_m}{\rho_{ijk} R \sum_{\alpha=0}^{N_s} (Z_{\alpha,ijk} / W_{\alpha})}
\]

Where: \( p_m \) is the pressure field within the \( m \)th zone,
\( \rho_{ijk} \) is the density,
\( R \) is the characteristic gas constant,
\( Z_{\alpha,ijk} \) is the mass fraction of species \( \alpha \).

The variation of the gas temperature of the smoke layer is measured using two different detectors. Ceiling gas temperature is measured using detectors of temperature called thermocouple. These thermocouples are arranged 10 cm below the ceiling, in four different point of measure: on the vertical of the fire seat [T-03],
three [T-04], six [T-02] and ten [T-01] meter from the fire. The positions of the points of measure of gas temperature are shown in Figure 3.

Another detector is used to calculate the gas temperature. The name of this detector is slice. Normally, FDS averages slice file data at cell corners. For example, gas temperatures are computed at cell centers, but they are linearly interpolated to cell corners.

The figure no. 3 shows the position of the thermocouple in the fire domain; the red triangle is the fire location.

Figure 3: Position of temperature measurement point

Figure 4: Position of slice
Figure 4 shows the slice position in the domain; as mentioned the slices are is used to describe the temperature profiles in the domain at a specific time.

**Scenarios A1-A2-A3-A4 – Fire 0.5 MW**

The Figure 5 shows the gas temperature at 500 second, during the steady state, with fire equal to 0.5 MW.

![Figure 5: Gas temperature - Fire size 0.5 MW](image)

The graphs in Figure 6 show the variation of the gas temperature over a period of time at all points of measure.

![Figure 6: Gas temperature over a period of time- Fire size 0.5 MW](image)
The values of gas temperature with adiabatic ceiling are the highest. The maximum value is about 110°C, in correspondence of the fire seat. Also, as expected, the value of gas temperature at 10 m from the fire seat is lower than the values of temperature in other point of measure. However, the values of the temperatures at 10 m from the fire shows the largest variation when the characteristics of the ceiling are varied. The variation of value of gas temperature is significant when the ceiling has opening; instead, the variation of gas temperature between the scenario A2 and the scenario A3 is about 6%.

Table 1 includes the mean of gas temperature (expressed in °C) at the four point of measure in all scenarios (A1-A2-A3-A4).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario A1</th>
<th>Scenario A2</th>
<th>Scenario A3</th>
<th>Scenario A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-01</td>
<td>96.6</td>
<td>82.4</td>
<td>76.5</td>
<td>54.5</td>
</tr>
<tr>
<td>T-02</td>
<td>99.8</td>
<td>87.6</td>
<td>81.7</td>
<td>56.9</td>
</tr>
<tr>
<td>T-03</td>
<td>112.1</td>
<td>104.9</td>
<td>102.1</td>
<td>63.4</td>
</tr>
<tr>
<td>T-04</td>
<td>101.8</td>
<td>91.6</td>
<td>86.8</td>
<td>53.1</td>
</tr>
</tbody>
</table>

Scenarios B1-B2-B3-B4 – Fire 1.0 MW

The results of scenarios B1-B2-B3-B4, with fire equal to 1.0 MW, are similar to results of scenarios A1-A2-A3-A4. The temperature of smoke layer is the higher in the scenario B1, because the ceiling is adiabatic. The gas temperature, at 500 seconds, of four scenarios are shown in the Figure 7.

The variation of gas temperature depends on the change of ceiling material. The maximum value is about 180°C, when the ceiling is adiabatic.
The variation of gas temperature between the scenario B2 and B3 is very low. It is possible to note the variation of the value in graphs in Figure 8 that show the gas temperature measured at the points T-01, T-02, T-03 and T-04.

![Temperature graphs](image)

**Figure 8: Gas temperature over a period of time - Fire size 1.0 MW**

The point of measure T-03, in correspondence of the fire seat, records the highest value of gas temperature. The variation of value of gas temperature is significant when the ceiling has opening; instead, the variation of gas temperature between the scenario A2 and the scenario A3 is about 8%.

Table 2 includes the mean of gas temperature (expressed in °C) at the four point of measure in all scenarios (B1-B2-B3-B4).

<table>
<thead>
<tr>
<th></th>
<th>Scenario B1</th>
<th>Scenario B2</th>
<th>Scenario B3</th>
<th>Scenario B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-01</td>
<td>148.2</td>
<td>122.7</td>
<td>111.3</td>
<td>76.9</td>
</tr>
<tr>
<td>T-02</td>
<td>153.1</td>
<td>131.4</td>
<td>121.3</td>
<td>81.1</td>
</tr>
<tr>
<td>T-03</td>
<td>177.0</td>
<td>164.5</td>
<td>160.5</td>
<td>91.7</td>
</tr>
<tr>
<td>T-04</td>
<td>155.7</td>
<td>138.4</td>
<td>129.5</td>
<td>74.9</td>
</tr>
</tbody>
</table>

**Scenarios C1-C2-C3-C4 – Fire 2.0 MW**

The temperature of smoke layer is shown in Figure 9. The variation of the gas temperature is significant in all scenario. It is possible to note that the layer of smoke is the greatest when the ceiling is adiabatic and the maximum value is 280°C. Moreover, the variation of gas temperature between the scenario with glass ceiling, C2, and the scenario with concrete ceiling, C3, is
significant. In the scenario C2, the mean temperature of gas near the ceiling is about 215°C and in the scenario C3, the material of ceiling is concrete, the mean temperature is about 200°C.

![Image showing gas temperature distribution](image)

**Figure 9: Gas temperature - Fire 2.0 MW**

The value of gas temperature in all point of measure is shown in the graphs in Figure 10. The highest gas temperature is recorded in the scenario A1, when the ceiling is adiabatic; the smallest value of gas temperature is equal to 120°C, when the ceiling has the openings.

The point of measure T-03 records the highest gas temperature because is on the vertical of fire seat.

The variation of gas temperature between the scenario C2 and scenario C3 is about 9%.
Table 3 includes the mean of gas temperature (expressed in °C) at the four point of measure in all scenarios (C1-C2-C3-C4).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Temperature T-01</th>
<th>Temperature T-02</th>
<th>Temperature T-03</th>
<th>Temperature T-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>227.7</td>
<td>189.3</td>
<td>170</td>
<td>115.7</td>
</tr>
<tr>
<td>C2</td>
<td>236.3</td>
<td>203.9</td>
<td>182.8</td>
<td>122.1</td>
</tr>
<tr>
<td>C3</td>
<td>281.7</td>
<td>263.6</td>
<td>249.5</td>
<td>139.7</td>
</tr>
<tr>
<td>C4</td>
<td>241.7</td>
<td>216</td>
<td>198.7</td>
<td>111.8</td>
</tr>
</tbody>
</table>

**Scenarios D1-D2-D3-D4 – Fire 9.0 MW**

The scenarios D are the scenario of flash over: the fire has a heat release rate equal to 9.0 MW. The gas temperatures are shown in Figure 11. In the scenario D1 the smoke layer is the greatest and with the highest value. The mean value of gas temperature is about 800°C. The change of ceiling material produce a different layer of smoke, the variation of gas temperature is significant between the scenario with glass ceiling, B2, the mean of gas temperature is about 640°C, and the scenario with concrete ceiling, B3, the mean of gas temperature is about 530°C.
The variation of gas temperature over a period of simulation time is shown in the graphs of Figure 12. In these graphs, it is possible to note the difference of temperature in all scenarios. The point of measure T-03 records the highest temperature, and the variation of gas temperature is significant only in the scenario with the opening. Instead, the other points of measure record gas temperature that defers in all scenarios. The variation of gas temperature between the scenario D2 and scenario D3 is about 20%. Table 4 includes the mean of gas temperature (expressed in °C) at the four point of measure in all scenarios (D1-D2-D3-D4).
### Table 4: Mean temperature of gas – Scenarios D – Fire 9.0 MW

<table>
<thead>
<tr>
<th></th>
<th>Scenario D1</th>
<th>Scenario D2</th>
<th>Scenario D3</th>
<th>Scenario D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-01</td>
<td>573.0</td>
<td>495.8</td>
<td>375.3</td>
<td>308.2</td>
</tr>
<tr>
<td>T-02</td>
<td>632.1</td>
<td>570.4</td>
<td>448.1</td>
<td>329.1</td>
</tr>
<tr>
<td>T-03</td>
<td>874.5</td>
<td>855.5</td>
<td>796.4</td>
<td>449.2</td>
</tr>
<tr>
<td>T-04</td>
<td>674.9</td>
<td>643.5</td>
<td>541.4</td>
<td>291.9</td>
</tr>
</tbody>
</table>

It should be noted that the glass ceiling calculation in this case, and partly in the previous case, is more theoretic that real, because the possibility of a glass ceiling to resist with temperatures exceeding 200 °C is limited, unless a fire resistance glass is adopted.

**Scenarios Conc-1 – Conc-2 – Conc-3 – Conc-4 – Conc-5**

The second set of simulation evaluate the variation of gas temperature when the density of the material of boundary condition changes.

In all scenarios the HRR of the fire and the transmittance of the material of the ceiling are constant, equal to 2.0 MW and 14.28 W/m² °K, respectively.

Figure 13 shows the temperature of smoke layer. The variation of the gas temperature is not significant, in all of scenarios the mean of gas temperature is about 250°C. Only in scenario Conc-5 it is possible to note that the layer of smoke is the greater.
The variation of the gas temperature over the period of simulation is shown in Figure 14. In all of the graphs, the difference of gas temperature is not significant. The point of measure T-03 records the highest temperature, about 250°C. In the scenario Conc-5, the gas temperature is the highest but the variation with respect to other scenarios is about 20%.
Figure 14: Gas temperature over a period of time- Fire size 2.0 MW – Concrete transmittance 14.28 W/m² °K

Table 5 includes the mean of gas temperature (expressed in °C) at the four point of measure in all scenarios (Conc-1, Conc-2, Conc-3, Conc-4, conc-5).

Table 5: Mean temperature of gas – Fire 2.0 MW– Concrete transmittance 14.28 W/m² °K

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario Conc-1</th>
<th>Scenario Conc-2</th>
<th>Scenario Conc-3</th>
<th>Scenario Conc-4</th>
<th>Scenario Conc-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-01</td>
<td>170.9</td>
<td>165.2</td>
<td>167</td>
<td>167.3</td>
<td>195.2</td>
</tr>
<tr>
<td>T-02</td>
<td>186.2</td>
<td>182.7</td>
<td>182.9</td>
<td>183.5</td>
<td>210.0</td>
</tr>
<tr>
<td>T-03</td>
<td>250.9</td>
<td>250.4</td>
<td>250</td>
<td>251</td>
<td>268.1</td>
</tr>
<tr>
<td>T-04</td>
<td>201.4</td>
<td>198.3</td>
<td>198.7</td>
<td>199.2</td>
<td>220.9</td>
</tr>
</tbody>
</table>

UNCERTAINTY ANALYSIS

The analysis, to evaluate the variation of gas temperature, are done with FDS 6.3. This program is a product of an international collaborative effort led by the National Institute of Standards and Technology (NIST) and VTT Technical Research Centre of Finland.

FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed (Ma < 0.3), thermally driven flow with an emphasis on smoke and heat transport from fires.

Numerical techniques used to solve the governing equations within a model can be a source of error in the predicted results. Validation efforts have moved beyond just transport issues to consider fire growth, flame spread, suppression, sprinkler/detector activation, and other fire-
specific phenomena. Verification and Validation of the model are discussed in the FDS Verification and Validation Guides.

The temperature estimates fall in a range between 2.5% and 7.5%.

The HGL temperature rise is proportional to the HRR raised to the two-thirds power. The uncertainty in the HRR of the validation experiments was estimated to be 7.5%. Increase in the HRR should lead to a 5% increase in the HGL temperature.

Table 4.1 in §4.3.3 of FDS Validation Guide summarizes the estimated uncertainties of the major output quantities.

CONCLUSION

This study is carried out to investigate the variation of gas temperature when the materials of boundary condition change.

The analysis includes modelling of ceiling materials as glass and concrete with various value of density, specific heat and transmittance.

The results show how the characterization of material finishes influence the gas temperature. The variation of gas temperature value is more significant when the heat release rate of the fire is greater.

The adiabatic condition for the ceiling is conservative, but it is important to define the boundary conditions, in particular the materials of which shell or outer walls are constituted, not to neglect the thermal exchange with the external environment.

The detailed characterization of the material has little influence; it was observed in fact that the main temperatures of the scenarios with glass ceiling are not so much different when compared to the main temperature of the scenarios with concrete ceiling.

Instead, it is very important to know if there are openings within the domain or during the evolution of the fire scenario, because the temperature of smoke layer changes dramatically when the internal domain and external environment are connected.

References

[1]. SFPE Engineering Guide to Performance-Based Fire Protection, National Fire Protection Association, Quincy, MA (2006);