NUMERICAL SIMULATION OF FIRE SPREAD IN TERMINAL 2 OF BELGRADE AIRPORT

by

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Original scientific paper
UDC: 519.876.5:614.841.41
BIBLID: 0354-9836, *11* (2007), 2, 251-258

This paper concern the results of software fire spread process prototype in terminal 2 of Belgrade airport using computational fluid dynamics. Numerical simulation of fire for the most critical fire scenario has been performed, primarily obtaining the space and time distribution of: velocity, pressure, temperature, and smoke concentration, assuming that HVAC systems have been switched off and all doors on the evacuation ways have been opened, just as the fire started. Also, two simulations have been compared of the smoke ventilation and not ventilation for the same scenario. Within the framework of the results presentation, isosurfaces of constant temperature (100 ºC) and smoke concentration (4000 ppm) are presented, based on the numerical simulation. Progression of these surfaces along the terminal 2 coincides to the experimental and experience evidence, forming the plume zone just above the fireplace, and spreading in the zone of underground ceiling and stairwell openings.

Key words: *fire spreading simulation, computational fluid dynamics*

Introduction

During the airport terminal fire in Düsseldorf, Germany, in April of 1996, 17 people died, 70 others were injured, and hundreds were trapped in toxic smoke. With millions of pounds of damage, this was one of the worst airport catastrophes worldwide.

Increasingly the fire protection concerns at airports are being addressed using computational fluid dynamics and most of these studies have been based on the prescriptive recommendations on design of an airport terminal building given by appropriate standards (BS 5588-0). Although, the prescriptive approach provides adequate technical solutions to most of the questions regarding the fire safety in buildings, a new fire engineering approach [1] is more holistic, performance based, and provides more fundamental and economical solution. Whilst the protection of life is the main objective of the fire safety regulations, the financial impact of fire on a business as a result of direct property damage or lost production might also be important considerations. The recently adopted standard [1] introduces so called Qualitative Design Review (QDR), a structured technique that allows project engineers to address all fire safety issues by identifying the worst case scenario. The new standard requires a comparative study to be carried out to assess the potential impact of system failures, *i. e.* it has been recognised that it is difficult to establish the level of fire safety in absolute terms.

The international airport in Belgrade (Serbia) was opened in 1927. As a constant traffic increase demanded significant airport enlargement, the new passenger terminal was built in 1960's. Apart of the so called "non-functional" components, such as concession areas, rest rooms, communication systems, none of the elements providing services directly related to a passenger have not been refurbished since. As expected from the airport terminal built more than three decades ago, there are three clearly subdivided area within the building: (a) processing facilities (process passenger and their baggage), (b) holding facilities (areas in which passenger wait for some events such as passport control), and (c) flow facilities (passengers use them to move between processing and holding facilities). However, today the Belgrade airport aims to maintain a high level of service, offering more space to catering and retail businesses, enhancing thermal comfort and improving safety procedures in passenger terminals. As the new standard imposes "objectives" rather than "solutions", the QDR enables project engineers to identify and incorporate necessary changes in architectural design of building while maintaining the specific level of fire safety.

This study, conducted as a part of the refurbishment project of Terminal 2 of Belgrade Airport, compares the effect of introducing the new mechanical ventilation system on fire spread in the terminal building of Belgrade airport with the situation prior to refurbishment, by following the principles given in the new "performance based" standard. Of particular interest was data monitored on the escaping route, at the head height. This data was used to assess the safety of escaping passengers.

Problem description

The number of possible fire scenarios in the case of an airport terminal is almost indefinite and it is not feasible to assess the effect of all of them. The modelled fire scenarios include the following factors: (a) occupant characteristics, (b) design fire, and (c) fire location.

Occupant characteristics. Variations in evacuation response time are related to occupant familiarity of building, position of occupants in building, occupant alertness, and occupant mobility. Detailed analysis of escape behaviour in fires and layout of the terminal building lead to conclusion that the international arrivals located at the underground level would present the most critical area regarding fire safety, as most of passengers would not be familiar with the building. In addition, passengers' movement is limited before passing passport control and reclaimed baggage would block escape routes.

Fire location. In a life safety analysis, a fire located adjacent to the widest exit route generally represents the worst case scenario as it will mean that the exit would not be available for escape [1]. Furthermore, as the location of the fire within the terminal building influences the time required by the fire services to begin to fight the fire once they have arrived on site, the special attention was paid locating the design fire. The international baggage claim area of the terminal building, located at the underground level, was selected for design fire location. Figure 1 shows the layout and geometry of the design fire location.

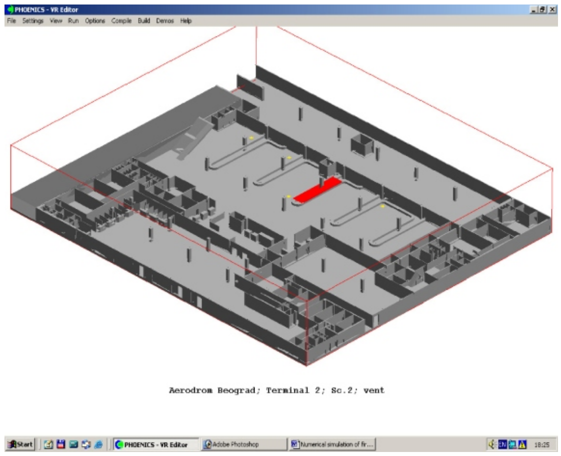

Figure 1. The layout and geometry of the design fire location (color image see on our web site)

The initial design fire area of 42.4 m^2 corresponds with the actual size of the conveyer belts currently used at the airport. Mass release rate of fire of 0.6 kg/s for combustible content of cotton, leather, wool, cellulose, and rubber was assumed.

Design fire. Most of the fires can be characterized by the following phases [2]: incipient phase (slow initial growth phase characterized by smoldering), growth phase (fire propagation period), fully developed phase (steady burning rate), decay phase (the period of declining fire severity), and the extinction (no release of energy). In order to model the worst case fire scenario this study assumes no incipient phase and very short growth phase of 10 seconds in which heat release of fire linearly reaches 500 kW/m^2. As the objective of this study was to evaluate the ability of the occupants to escape from the fire the remaining decay phase was not considered. The modeling results presented in this study take into account the first 5 minutes of the growth and fully developed fire only.

In a fire model with the RNG k-ε turbulence model, the air flow induced by the fire has been predicted by solving the general transport equation for the mean flow variables, Φ, in the well known form:

$$\frac{\partial}{\partial t}(\rho_{\mathrm{a}}\Phi) \quad \frac{\partial}{\partial x_{\mathrm{j}}}(\rho_{a} U_{\mathrm{j}}\Phi) \quad \frac{\partial}{\partial x_{\mathrm{j}}} \; \Gamma_{\Phi} \frac{\partial \Phi}{\partial x_{\mathrm{j}}} \qquad S_{\Phi} \tag{1}$$

There are eight equations in the form of eq. (1) with Φ includes air velocity components U, V, W, temperature T, turbulent kinetic energy k, and dissipation of turbulent kinetic energy ε, smoke mass concentration Y_{S}. ρ_{a} is the air density, S_{Φ} is the source term, and Γ_{F} is the total transport coefficient in the equation for flow variable Φ. Equations (1) are coupled by the mass continuity equation. The fire is taken as a volumetric heat source appeared in the source term of the conservation equation for temperature as well as radiation heat transfer contribution. Buoyancy force due to temperature variations were taken into account using Boussinesque approximation in momentum equation for the vertical velocity component. Summarized mathematical model of fire spreading is given in tab. 1.

Non uniform Cartesian grid was applied with total number of cells in exceedance of 500.000. Number of time steps was set to 60 for 300 seconds simulation. The simulation was performed using a general CFD code, PHOENICS 3.5.

Table 1. Summarized mathematical model of fire spreading

Φ	Γ_Φ	S_Φ
1	0	0
U_i	v_{ef}	$\frac{\partial P}{\partial x_i} + \beta g_i \rho_a (T - T_0)\delta_{ij}$
T	a_{ef}	$\dot{q}_{fire} \quad \dot{q}_{rad}$
Y_S	D_{ef}	$\dot{m}_{smoke}$
k	$\mu + \frac{\mu_t}{\sigma_k}$	$\rho_a(G + F - \varepsilon)$
ε	$\mu + \frac{\mu_t}{\sigma_\varepsilon}$	$\rho_a \frac{\varepsilon}{k} C_{\varepsilon 1}G + C_{\varepsilon 3}F - C_{\varepsilon 2}\varepsilon - \alpha\varepsilon)$
$G \quad v_t \frac{\partial U_i}{\partial x_k} \quad \frac{\partial U_k}{\partial x_i} \frac{\partial U_i}{\partial x_k}; \quad F \quad \beta g_i \overline{\theta u_i}; \quad v_t \quad a_t \quad \frac{C_\mu k^2}{\varepsilon}$		
$\alpha \quad C_\mu \eta^3 \frac{\frac{1 \quad \eta}{\eta_0}}{1 \quad \beta\eta^3}; \quad \eta \quad \frac{Sk}{\varepsilon}, \quad S \quad \sqrt{2S_{ij}S_{ij}}$		
$S_{ij} \quad \frac{1}{2} \frac{\partial U_i}{\partial x_j} \quad \frac{\partial U_i}{\partial x_i}; \quad \overline{\theta u_i} \quad a_t \frac{\partial T}{\partial x_i}\delta_{ij}$		
$\sigma_k, \sigma_\varepsilon, C_{\varepsilon 1}, C_{\varepsilon 2}, C_\mu, \eta_0, \beta$ = 0.7194, 0.7194, 1.42, 1.68, 0.0845, 4.38, 0.012, respectively		

Results discussion

The numerical simulations of different fire scenarios within the terminal building were performed assuming failure and normal working conditions of the ventilation system. All doors along the evacuation routes were opened when fire started. Based on the simulation, both temperature (100 °C) and smoke concentration (4000 ppm) isosurfaces were derived. Progression of these isosurfaces coincides with the similar experimental studies [3] forming the plume zone just above the location where fire initially started and spreading towards the stairwell openings and the underground ceiling. To evaluate the risk of smoke concentration on the escape route, a numerical probe was located approximately 32 metres away from the design fire location at the height of 1.75 m (fig. 2).

Figure 3 compares temperatures at the 1.75 m height, assuming both (a) not ventilated case of the terminal prior to the refurbishment and (b) ventilated case with the mechanical smoke protection ventilation system in place. Significant differences are apparent as the fire protection wall has been added during the QDR stage of the project. It can be observed that the introduction of both measures provides a tenable environment for passengers and staff to enable their safe escape from the building. Moreover, by limiting the area of fire spread for a few hours, it is believed that these measures have assisted in property protection, and more importantly have enabled the entry and subsequent operations of fire fighters. Note that the significant increase in temperature has not been occurred along the newly designed escape route (see fig. 3a, numerical red pen probe). As similar patterns were obtained in the case of smoke concentration they have not been presented. Because of its buoyancy the smoke rises from the fire. Initially the buoyancy is low and the smoke follows the ambient air currents present before the fire occurred but as its heat release increases, its buoyancy increases and begins to dominate air currents in the enclosure. Progression of these isosurfaces coincides with the similar experimental studies forming the plume zone just above the location where fire initially started and spreading towards the stairwell openings and the underground ceiling.

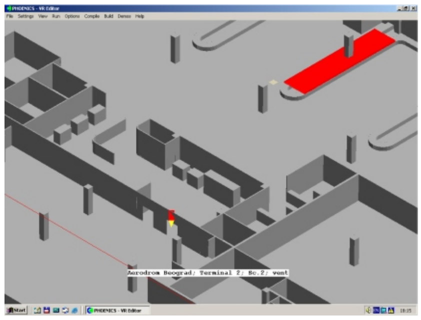

Figure 2. Location of a numerical probe within the international arrivals area

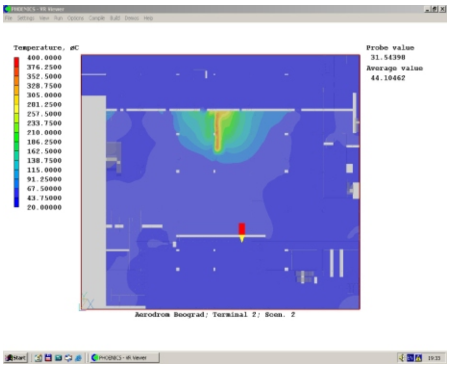

Figure 3a. Temperature distribution prior to refurbishment

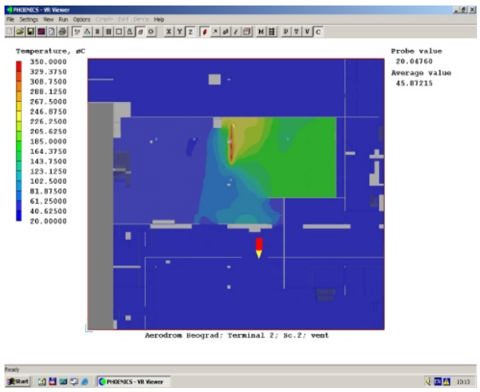

Figure 3b. Temperature distribution with mechanical smoke protection ventilation system in place

Figures 4 and 5 compare temperatures and smoke concentrations simulated in both cases (a) prior to refurbishment (not ventilated case) and (b) after refurbishment (ventilated case) and recorded by numerical probe located in the exit area (see fig. 2). Based on the "not ventilated" simulation, the substantial increase in both temperature and smoke concentration occur approximately after 260 seconds. Assuming a passenger escaping speed of 0.6 m/s, the passenger presentation time (interval between the time at which a warning of a fire is given and the time at which a person reaches a place of safety assuming walking speed is unrestricted) from the international baggage arrival area would be an estimated 53 seconds.

Note, that this "optimistic" time is calculated disregarding distribution of passengers with in the area, ignoring disability of passengers to orient in the space that they are not familiar with and find exits, disregarding passengers reluctance to enter heavily

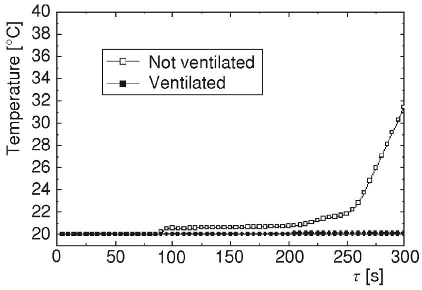

Figure 4. Comparison of temperatures on the escape route (recorded by numerical probe) for both not ventilated and ventilated case

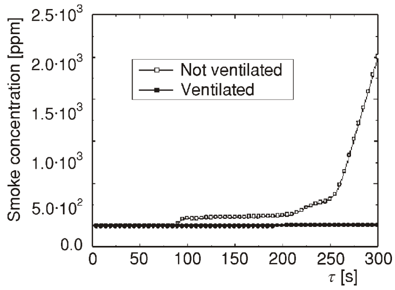

Figure 5. Comparison of smoke concentrations on the escape route (recorded by numerical probe) for both not ventilated and ventilated case

smoke-logged escape routes, and finally assuming tolerable levels of all radiant, convected and conducted heat [4]. The total evacuation time calculated [5] assuming a case where the area was sparsely populated with a population density of less than one third of the design population is approximately 80 seconds. In a case where the fire affected area contains the maximum design population, the total evacuation time well exceeds 120 seconds. This is not acceptable as temperatures above 120 °C, simulated after 100 seconds, may cause skin pain and burns. In the "ventilated" case (which includes the newly suggested fire protection wall) the fire engineering tenability criteria are completely satisfied, meaning that a minimum clear layer height of 2.5 m above the floor and a maximum upper layer temperature of 200 °C.

Figure 6 and 7 show the critical 100 °C isosurfaces in both cases "ventilated" and "not ventilated". With mechanical ventilation in place both temperature and smoke concentration would reach the critical values after 300 seconds only at the location where fire initially started, *i. e*. the international baggage arrivals area (fig. 6). Although the smoke penetration through the stairwell openings in this case would not be critical during the first five minutes of fire, the additional stairwell pressurization systems were recom-

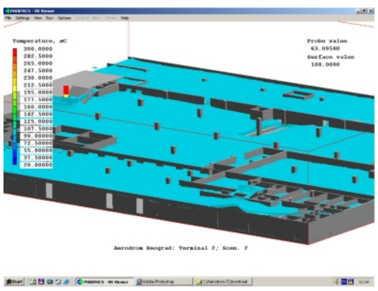

Figure 6. The 100 °C isosurfaces after 300 seconds simulated for the "not ventilated" case

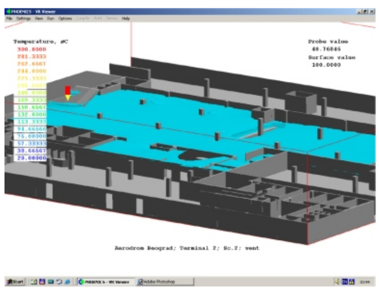

Figure 7. The 100 °C isosurfaces after 300 seconds simulated for the "ventilated" case

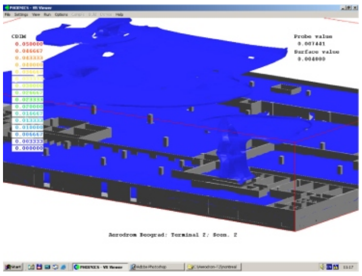

Figure 8. The 4000 ppm smoke isosurfaces after 300 seconds simulated for the "not ventilated" case

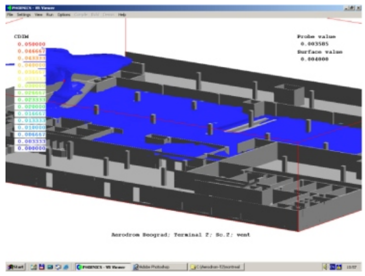

Figure 9. The 4000 ppm smoke isosurfaces after 300 seconds simulated for the "ventilated" case

mended in order to prevent smoke penetration to the ground level enabling all passengers and terminal staff to evacuate the terminal promptly. The situation is significantly worse for "not ventilated" case. During the period of simulation the underground ceiling zone is fully covered by the temperature front of 100 °C (fig. 7). At the same time the smoke concentration front of 4000 ppm fully covers the underground ceiling area significantly penetrating the ground floor of the terminal building through the stairwell openings between the ground and the first floor (figs. 8 and 9). The stairwell openings between the ground and the first floor are affected as well.

Conclusions

The recently adopted standard on application of fire safety engineering principles to the design of buildings [6] introduces so called Qualitative Design Review (QDR), a structured technique that allows project engineers to address all fire safety issues by identifying the worst case scenario. As the new standard imposes "objectives" rather than "solutions", the QDR enables project engineers to identify and incorporate necessary changes in architectural design of building while maintaining the specific level of fire safety. Using these principles, apart of the mechanical smoke protection ventilation, the new fire safety wall was introduced in the international baggage arrival area early in the design process

Based on the simulation, both temperature (100 °C) and smoke concentration (4000 ppm) isosurfaces have been derived. Progression of these isosurfaces coincides with the similar experimental studies forming the plume zone just above the location where fire initially started and spreading towards the stairwell openings and the underground ceiling. In the case with no ventilation the temperature front has 2 minutes time delay to the smoke concentration front of 4000 ppm. Unlike of temperature, which reaches 100 °C during the first five minutes at the underground ceiling level only, the smoke penetrates throughout the stairwell openings towards both first floor and underground level of the terminal.

However, with mechanical ventilation in place both temperature and smoke concentration would reach the critical values only at the location where fire initially started. Although the smoke penetration through the stairwell openings in this case would not be critical during the first five minutes of fire, the additional stairwell pressurization systems were recommended in order to prevent smoke penetration to the ground level enabling vast majority of passengers and terminal staff to evacuate the terminal promptly.

Although the standard has not been enforced yet in most of European countries (as in the case presented in this study), it is believed that this standard, recently adopted in the UK, on application of fire safety engineering principles to the design of buildings [6, 7] provides a flexible approach to design using performance related objectives rather that prescriptive solutions. Although this "freedom" in the design stage of a project encourages innovation, it also carries an additional liability not just for project engineers, but for members of different approval bodies working on the project if the assumption made during the project were not based on well documented evidence.

References

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Paper submitted: November 1, 2006
Paper revised: December 10, 2006
Paper accepted: December 12, 2006