Use of Computational Fluid Dynamics in optimization of natural smoke ventilation from a historical shopping mall – Case Study

Grzegorz Krajewski[1] **and Wojciech Węgrzyński**[2]

Building Research Institute (ITB), Fire Research Department
ul. Filtrowa 1, 00-611 Warszawa, Poland
[1] *e-mail: g.krajewski@itb.pl*
[2] *e-mail: w.wegrzynski@itb.pl*

Abstract

In this paper the Authors present a results of a complex case study, in which a natural smoke ventilation system was introduced into a historical mall "Hala Koszyki" located in the centre of Warsaw. As the building was protected by historical authorities, the only solution possible was to use a natural system – known for very low performance in façade applications. To maximize the performance, a Computational Wind Engineering exercise was performed, to find the most onerous wind attack angles, and optimize the performance of the system at these conditions. Once the wind influence was known, a transient analysis was performed that included the growth of the fire within the building, as well as a numerical evacuation study. The resulting system was immune to the wind effects, and provided safe evacuation to users of the building, even at difficult wind conditions.

Keywords: fire, smoke, CFD, natural ventilation, NSHEVS

1. Introduction

Smoke and Heat Ventilation systems (SHEVs) are a group of technical solutions used in buildings in order to ensure the required level of fire safety in the building in accordance with the Polish Building Law Act. Natural smoke ventilators combined into Natural Smoke and Heat Ventilation Exhaust system (NSHEVs) are the simplest, cheapest and yet still quite effective tool for the removal of smoke and hot combustion products out of the protected building. The principle of operation of these solutions is the difference of density between the surrounding air and hot smoke and gasses produced in the fire, that cause buoyant forces to act, which push the smoke out of protected volume. The NSHEV system can influence the safety of the building by:

- increasing the time available for people to evacuate from the building, so called Available Safe Evacuation Time (ASET), by reducing the threat posed by hot and toxic gasses produced in the fire;
- slowing down the fire growth by limiting the temperature of the smoke and thus reducing the radiation returned towards flammable materials in the building;
- improving safety of emergency operations in the building by the reducing both the amount and the temperature of the smoke inside of the building.

The concept of natural ventilation is presented on a case of historical mall in Warsaw, Fig. 1.

2. Natural ventilators

The performance of a single ventilator may be different than the performance of a complete system in a real building. To assess this difference, the authors performed a study [1] in which different types of NSHEV systems were investigated. Despite the fact all of investigated systems were designed following same set of rules, each system gave different results in similar fire and wind conditions. This proves, that individual assessment is necessary for complex cases, such as this presented for historical shopping mall.

The evaluation of NSHEV design in adverse wind conditions can be separated into three steps:

1. determination of wind coefficient at various important areas of the building and performing a risk analysis in order to choose worst case scenarios for the smoke and heat removal;
2. performing combined wind and fire analysis in the building to assess the performance of the system, for chosen fire and wind scenarios in order to estimate the Available Safe Egress Time;
3. performing evacuation modelling in order to asses the Required Safe Egress Time, and them comparison of these times.

The study should also consist of risk analysis to find appropriate fire design scenario, choice of physical models and sub-models, as well as a basic mesh sensitivity study. The latter can be very important, when due to the size of numerical domain, the mesh quality has to be adjusted to fit the available computational power, Figure 2.

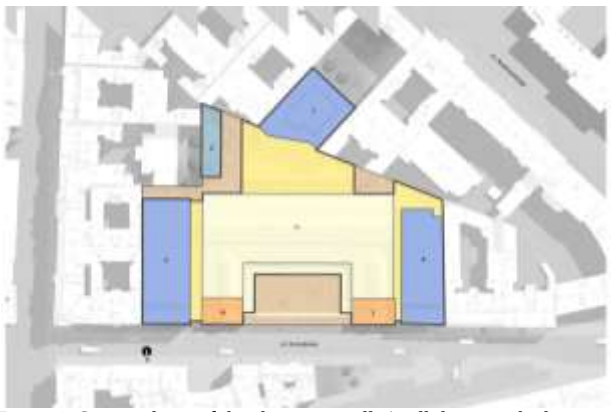

Figure 1. Surroundings of the shopping mall (mall distinguished in yellow)

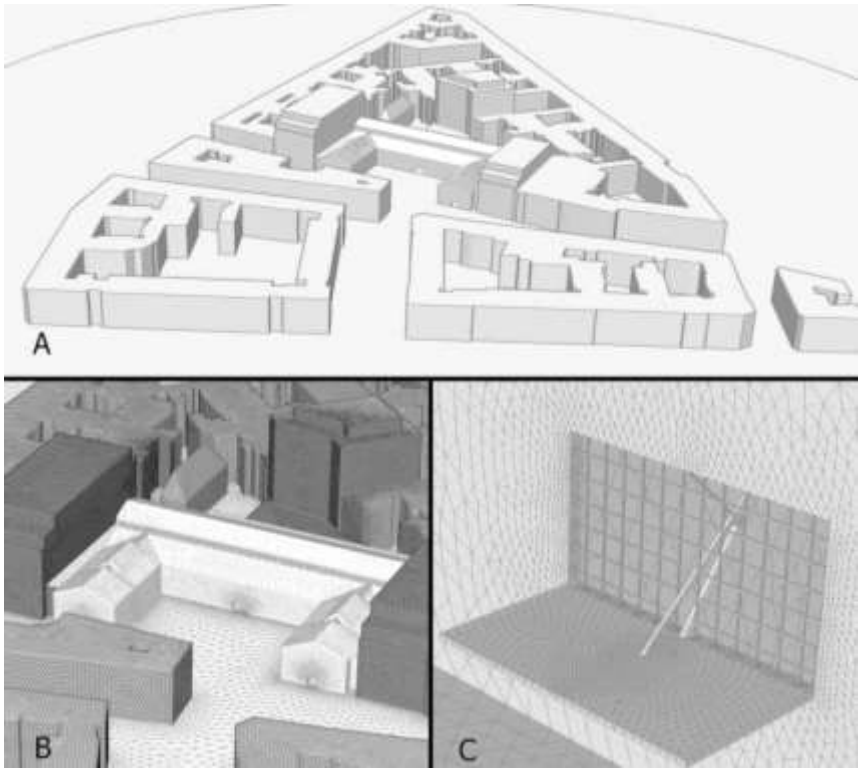

Figure 2. Overview of computational domain (A), mesh on the surroundings of the mall (B) and detailed model of a vertical natural ventilator (C) used as a reference for the mesh sensitivity analysis

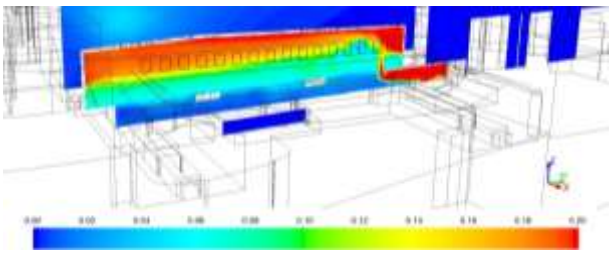

Figure 3. Results of CFD analysis – mass density of smoke in a cross section of the building in 10th minute of the analysis

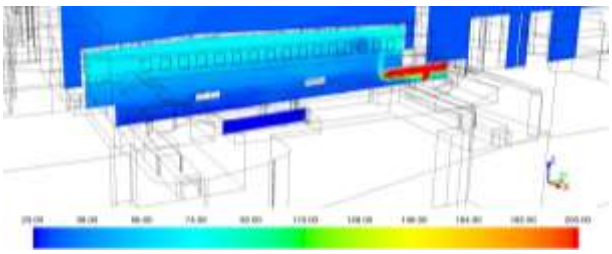

Figure 4. Results of CFD analysis – temperature of smoke in a cross section of the building in 10th minute of the analysis

3. Conclusions

In the paper the authors present a methodology for combined fire safety and CWE analysis used in order to evaluate the risk of fire for building occupants, illustrated by a practical application in a historical shopping mall. As performing wind and fire analysis, that has to be transient, for large amount of fire scenarios and multiple wind velocities or angles requires large computational power, authors present an approach of simplifying the amount of scenarios, by decoupling the analysis. First, a steady state wind analysis is performed, that leads to determination of the worst wind scenarios. Then, if justified by the risk analysis, these scenarios are used for transient smoke and heat spread modelling (Figure 3÷4), which allows estimation of how much time it takes for environmental conditions to exceed critical values. This time, called Available Safe Evacuation Time, is then compared with Required Safe Evacuation Time. If time required to leave the building is shorter than time in which fire will endanger the occupants, the building can be considered safe and the ventilation system functional. If required, the analysis can be further improved with risk analysis of fire growth, simulation of fire growth, evaluation of the influence of fixed extinguishing systems, or gaseous extinguishing systems

References

[1] Węgrzyński, W. and Krajewski, G. (2017) Influence of wind on natural smoke and heat exhaust system performance in fire conditions. *Journal of Wind Engineering & Industrial Aerodynamics* Pages 44-53, 2017..