INTERSECTII
INTERSECTIONS
http://www.intersections.ro

Benchmark Analysis between a Two-Zone Fire Model and a CFD Fire Model

Zeno-Cosmin Grigoraș, Mihaela Ibănescu
Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University, Iasi, 700050, Romania

Summary

This paper presents the benchmark analysis between a two-zone fire model and a CFD (Computational Fluid Dynamics) fire model.

A fire from a conference room is modelled using CFAST and FDS computer software. Both computer programs use advanced fire models based on energetic equilibrium.

The HRR (Heat Release Rate) curve is modelled according to the European legislation.

The aim of this benchmark analysis is to compare the temperatures computed by different fire models.

KEYWORDS: two-zone fire model, CFD fire model, FDS (Fire Dynamics Simulator), CFAST (Consolidated Model of Fire and Smoke Transport), fire safety engineering.

1. INTRODUCTION

The computer programs are tools that offer the possibility of "numerical experiments" in "virtual laboratories" at lower cost (compared to "physical experiments" in "testing laboratories") and with the credibility of the obtained results within the limits of the engineering acceptability [1].

The fire safety engineering approach uses complex mathematical models that describe the fire development.

This paper is based on a benchmark analysis between two different fire models: a two-zone fire model and a CFD (Computational Fire Dynamics) fire model. Both models use the energetic equilibrium to describe the fire development.

This study is performed in a conference hall located at the Faculty of Civil Engineering and Building Service from Iasi, Romania. The geometry of the analysed space is presented in Figure 1, and the interior of the considered space is presented in Figure 2 and Figure 3.

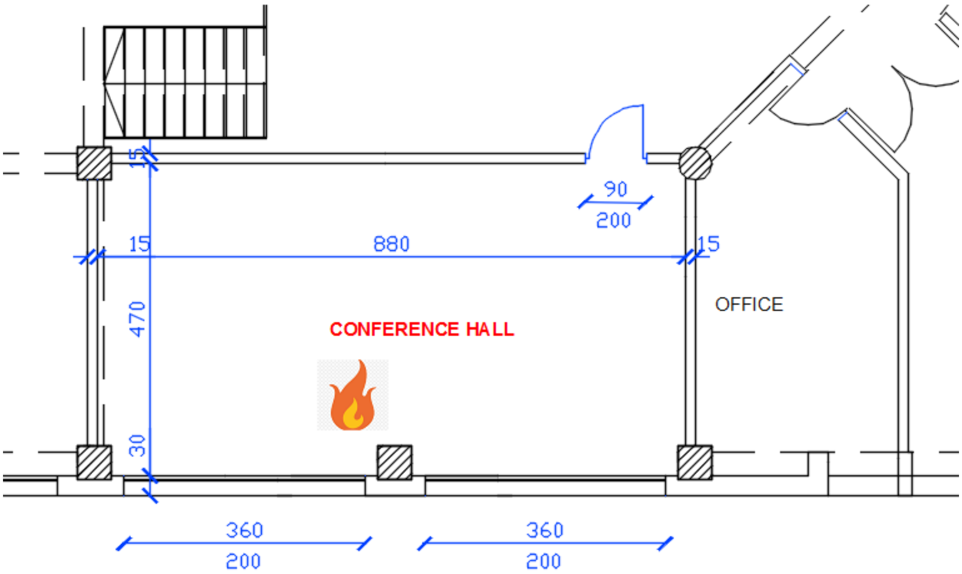

Figure 1. The geometry of the analyzed space – conference hall

Figure 2. The interior of the conference hall

Figure 3. The interior of the conference hall

The walls of the analysed space are made of 15 cm brick; the upper and lower slabs are made of 15 cm of reinforcing concrete, 15 cm in thickness. The main combustible material is wood.

2. FIRE DEVELOPMENT AND COMBUSTION MODELING

The fire load density was considered in compliance with the European codes [2,3] 420 MJ/m^2, corresponding to office type spaces. The fire development was modelled by considering different scientific works [4], in addition to Eurocodes. The Heat Release Rate (HRR) curve is shown in Figure 4: one stage fire development fire (growth stage) with a peak HRR of 456 kW at 202 seconds.

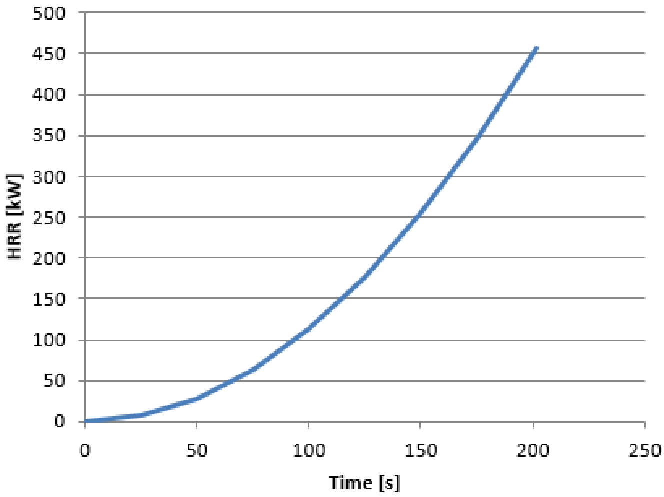

Figure 4. The geometry of the analysed space – conference hall

For this case study, the burning reaction of wood was simulated according to [4]. The combustion model involves the existence of a single fuel that is composed primarily of C, H, O and N that react with oxygen in one mixing-controlled step to form H2O, CO2, CO and soot [4]. The fuel properties are described in Table 1.

Table 1. The fuel properties

User input data	Value
Carbon atoms	1
Hydrogen atoms	1.7
Oxygen atoms	0.72
Nitrogen atoms	0.001
Heat of combustion [kJ/kg]	17500
The fraction of fuel mass converted into CO	0.004
The fraction of fuel mass converted into smoke particles	0.015

Another important aspect considered during the performed simulations is the thermal transfer to walls and slabs. The considered thermal properties are presented in Table 2.

Table 2. Thermal properties of walls and slabs

User input data	Unit	Walls	Slabs	User input data	Unit	Walls	Slabs
Material	-	brick	concreate	Specific Heat	kJ/(kg·K)	0.87	0.84
Thickness	cm	15	15	Conductivity	W/(m·K)	1.16	1.74
Density	kg/m^3	2000	2500	Emissivity	-	0.94	0.95

3. FIRE MODELS

The scientific understanding of fires has created the possibility of treating them as phenomena and subsequently, led to the engineering approach to fire safety. This field uses scientific and engineering principles for and controlling the burning process involved in fires and the structural effects in fire situations, as well.

3.1. Two-zone fire model

The scientific literature [5] defines the zone models in the assumption of uniform distribution of temperature in the fire compartment. The two-zone fire models assume the existence of two layers: an upper layer consisting of hot gases and a lower layer consisting of cooler gases. Both layer temperatures vary in time.

For the current case study, CFAST (Consolidated Model of Fire and Smoke Transport) software was used. CFAST is a two-zone fire model used to calculate the evolving distribution of smoke, fire gases and temperature throughout compartments of a building during a fire [6].

3.2. CFD fire model

The most advanced computational models describing the fire development are the CFD models. Based on numerical analysis of fluid dynamics, CFD fire models provide a high degree of credibility.

A 3D mesh is used for solving the mathematical equations describing the spread of smoke and hot gases together with the heat transfer for each mesh cell [7].

Conceptually, CFD fire models represent an extension of the two-zone fire models.

For the current case study, FDS (Fire Dynamics Simulator) software was used. FDS is a CFD model of fire-driven fluid flow. 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 [8].

ISSN 1582-3024

4. NUMERICAL SIMULATIONS

For both fire models, the input data consist of: analysed space geometry (for FDS a 40x40x40 cm mesh was used), thermal properties of the walls and slabs, HRR curve, fuel properties and the simulation time.

For the current case study, the two-zone model is presented in Figure 5 and the CFD model is presented in Figure 6.

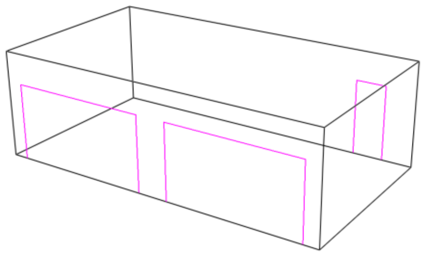

Figure 5. Two-zone model for the analysed space

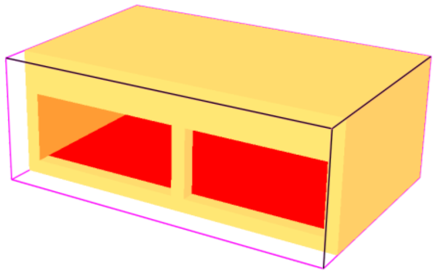

Figure 6. CFD model for the analysed space

5. RESULTS

According to the numerical analysis, Figure 7 and Figure 8 present the maximum temperature inside the analyzed space.

For the two-zone fire model, CFAST computed a maximum temperature of 45 ^{o}C.

For the CFD fire model, FDS computed a maximum temperature of 65 ^{o}C.

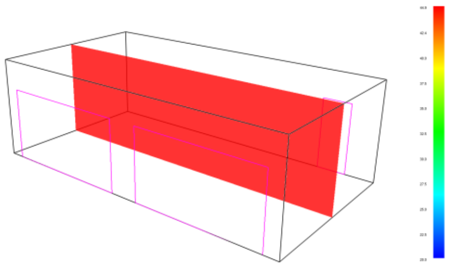

Figure 7. Two-zone model for the analysed space

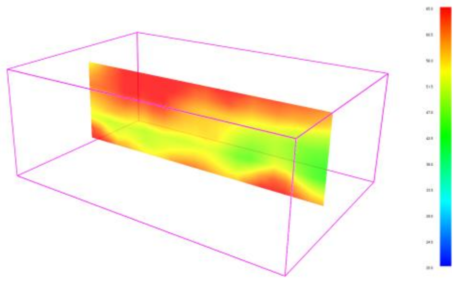

Figure 8. CFD model for the analysed space

6. CONCLUSION

For the considered fire scenario: peak HRR (456 kW), total burning time (202 s) and maximum temperature of the interior space (45°C and 65°C), it can be concluded that the fire has a low effect on the building structural elements.

It can be also concluded that the temperature difference, representing 20 °C, lies within the limits of engineering acceptability.

The temperature computed by CFD fire model is closer to the reality, but the two-zone fire model can be used for a quick simulation. In the case of a two-zone fire model, it is much easier to define the input data and the computational time is shorter.

ACKNOWLEDGEMENTS

The authors are grateful to Thunderhead Engineering Consultants Inc. USA for providing the free educational license for PyroSim (graphical user interface for FDS).

References

1. Diaconu-Sotropa D., *Ingineria securității la incendiu în construcții - suport de curs, (http:// http://server.ce.tuiasi.ro/~ddiaconu/)* Accessed: 12-01-2015 (in Romanian).
2. ****, Actions on Structures. Part 1-2: General Actions – Actions on Structures Exposed to Fire. Annex E: Fire Load Densities. Eurocode 1, EN 1991-1-2 Annex E.*
3. Grigoraș Z.C., Diaconu-Șotropa D., *Definirea focului de calcul conform SR EN 1991-1-2 Anexa E*, Revista Asociației Inginerilor Constructori Proiectanți de Structuri - AICPS REVIEW 1-2/2014 (2014) 150-155 (in Romanian).
4. DiNenno, P., Drydale D., Beyler C., Douglas Walton W., Custer R., Hall J., Watts J., *SFPE Handbook of Fire Protection Engineering*, Third Ed., Published by the National Fire Protection Association Massachusetts, USA, 2002.
5. Zaharia R., *Calculul structurilor la acțiunea focului. Partea I-a: Eurocoduri – Note de curs*, (http://www.ct.upt.ro/users/RaulZaharia/Curs_foc.pdf) Accesed: 12-01-2015 (in Romanian).
6. Peacock R., Reneke P., Forney G., *CFAST – Consolidated Model Fire Growth and Smoke Transport (Version 7) Volume 2: User's Guide*, National Institute of Standards and Technology, 2006.
7. Yeoh G. H., Yeun K. K., *Computational Fluid Dynamics in Fire Engineering – Theory, Modelling and Practice*, Butterworth-Heinemann, Elservier Science and Technology, USA, 2009. McGrattan K., Hostikka S., McDermott R., Floyd J., Weinschenk C., Overholt K., *Fire Dynamics Simulator User's Guide*, NIST Special Publication 1019, Sixth Edition, National Institute of Standards and Technology, 2017.
8. McGrattan K., McDermott R., Weinschenk C., Hostikka S., Floyd J., *Fire Dynamics Simulator – User's Guide*, National Institute of Standards and Technology Special Publication 1019, USA, 2017.