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PAPER FACTORY FIRE SAFETY ENGINEERING

Ruggero Poletto and Jordy Di Pierno

CFD FEA SERVICE SRL
Via Borgo Grande 19
37044 Cologna Veneta – VR - ITALY
e-mail: ruggero.poletto@cfdfeaservice.it

FSE PROGETTI srl
Via Ferruccio Parri, 931
47522 Cesena - FC - ITALY
e-mail: jordy@fseprogetti.it

ABSTRACT

The high fire risk of a paper factory site in Lucca – Italy – required the use of FSE, Fire Safety Engineering, to define the best safety procedure in case of fire. The case considered the combined presence of fire and paper, with the high level of emissions and the toxicity of the combustion products and the possibility of explosions due to the presence of paper dust coming from the production process.
The present paper considers the study from two separate point of views: the first one is the FSE Fire Safety Engineering approach where the safety levels required by Italian DM 03.08.2015 had to be satisfied and the latter is the computing power and scalability of FSE approaches defined earlier.

PROJECT AND FSE APPROACH DEFINITION

The Italian regulation DM 03.08.2015 defines ten different strategies a fire engineer needs to assess in order to complete a fire design of a structure. For each of these strategies the designer can apply the FSE – Fire Safety Engineering approach where the standard approach is not possible. In the design of a fire safety system of a paper factory placed in Lucca – Italy, the standard approach was not possible in the following strategies:

- S2 – *Fire resistance*: the fire engineers need to guarantee the fire resistance of the structures of the building for the time required by the occupants to safety escape
- S3 – *Compartments*: definition of the separation distance
- S4 – *Exodus*: time required to reach a safe location for the occupants before the fire and the smoke creates adverse condition

The building consisted of two blocks of buildings, named respectively Block A and Block B. Block A is made of two buildings and two canopies for a total surface of 10.000 m^2, while Block B consists of 5 buildings for a total of 6.000 m^2. In both blocks the storage consisted of paper and cardboards reels for a total maximum height of 7.25 m.

As far as the occupants are concerned, since the project refers to a working place, only occupants with a level of familiarity of the building in a wakefulness state are considered. The density of the occupants is of five people in block A with a training of medium level to the fire risk.

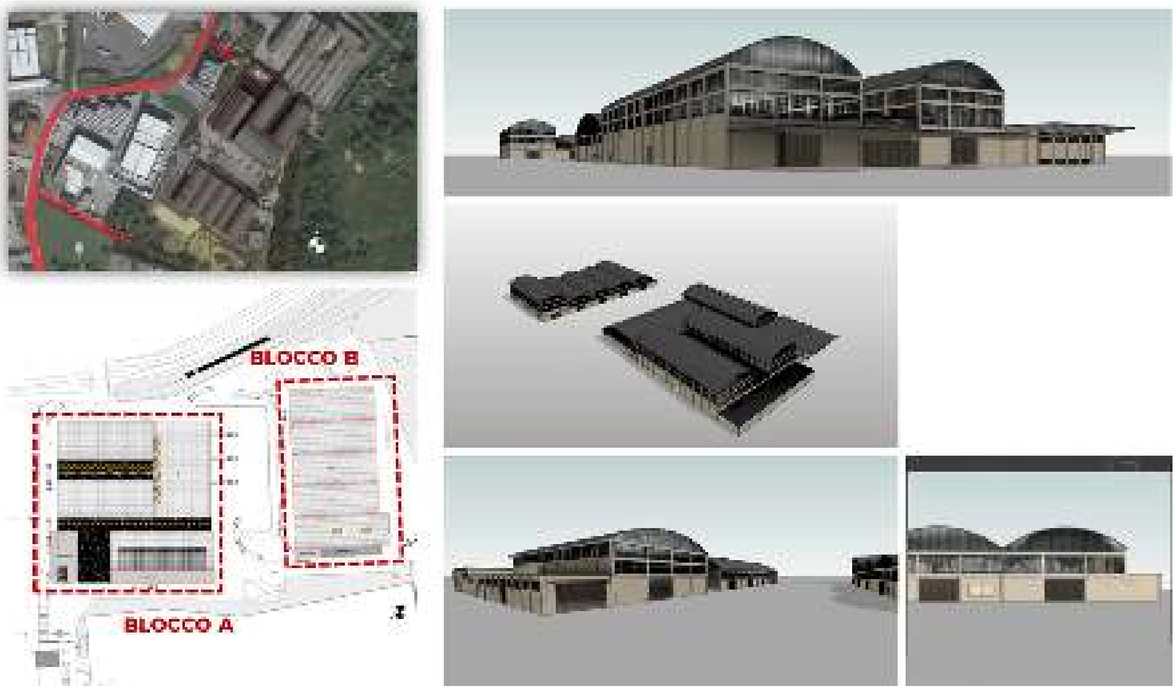

Figure 1: Geometry of the paper factory designed using Pyrsosim.

FSE SOLUTION

As specified before, the Italian DM 03.08.2015 defines two possible solutions for the three approaches mentioned in the previous chapter:

Table 1: Assessment of standard solution and FSE solution in the three approaches where DM 03.08.2015 standard approach could not be applied.

STRATEGIES	STANDARD SOLUTION	FSE SOLUTION
S2 – Fire resistance	Given the risk level III the solution obtained is a class 240. High costs involved due to a level of protection of the structures and/or to the presence of an active fire protection system.	• Definition of the fire natural curves • Analysis of the thermal time transient variation including second order effects
S3 – Compartments	Separation distance with other buildings is not satisfied	Check of radiating flow and smoke temperature flow reached by nearby buildings in the fire scenarios
S4 – Exodus	Exodus path lengths longer than the ones prescribed in the regulations	Definition of performance threshold for life

S2 – FIRE RESISTANCE

The presence of two different types of structures: steel and concrete. Steel structure suffer of a very low thermal inertia and of a very high conduction heat transfer coefficient. For this, when analyzing the thermal transient variation, it is important to consider efforts generated by second order effects

due to the presence of structure constraints which prevent the whole system to adjust to thermal expansion.
On the other hands, the presence of concrete structure where a high thermal inertia is presence with a low level of heat transport generates high thermal gradients within the very same building element.

S3 – COMPARMENTS

As per the DM 03.08.2015 a threshold value of E = 12.6 kW/m^2 is considered. The goal of the FSE analysis is the evaluation of this radiative heat transfer to nearby building and the demonstration that this threshold is not reached anywhere.

S4 – EXODUS

For the exodus situation, the M.3 chapter of DM 03.08.2015 defines four different thresholds to be verified to avoid the incapability of the occupants to reach a safe place independently. These four thresholds are:

1. Visibility 10 m at Z = 1.8 m from ground
2. Temperature 60 °C at Z = 1.8 m from ground
3. Radiation 2.5 kW/m^2 at Z = 1.8 m from ground
4. FED/FEC = 0.1

The total time the buildings satisfies these four thresholds defines the ASET which needs to be compared with the RSET – the total time required by the occupants to reach a safe place.

FIRE SCENARIOS DEFINITION

The definition of the fire scenarios to be considered has been limited to two:

- **Scenario 3**. This scenario has been chosen as the most dangerous given its central position with respect to the roof beam and for the proximity to US4 – emergency way out. This scenario has then been used to evaluate S2 and S4.
- **Scenario 4**. This scenario is the riskier in terms of compartments as it is at the center of the warehouse and it propagates quickly reaching the peak radiating power.

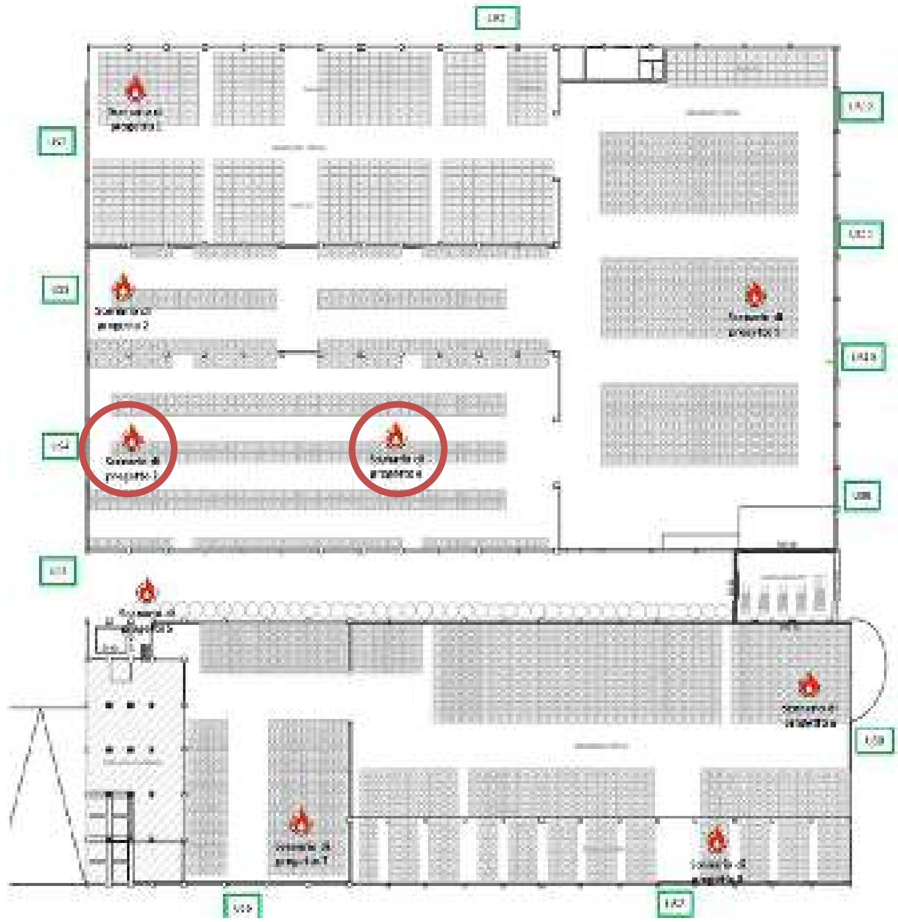

Figure 3: Position of all the fire scenarios considered.

RESULTS OF THE FSE – FIRE SAFETY ENGINEERING

Figure 1: Representation of the BIM model generated which defines the FSE analysis (BIM made with Revit and imported in Pyrosim to define the CFD geometry).

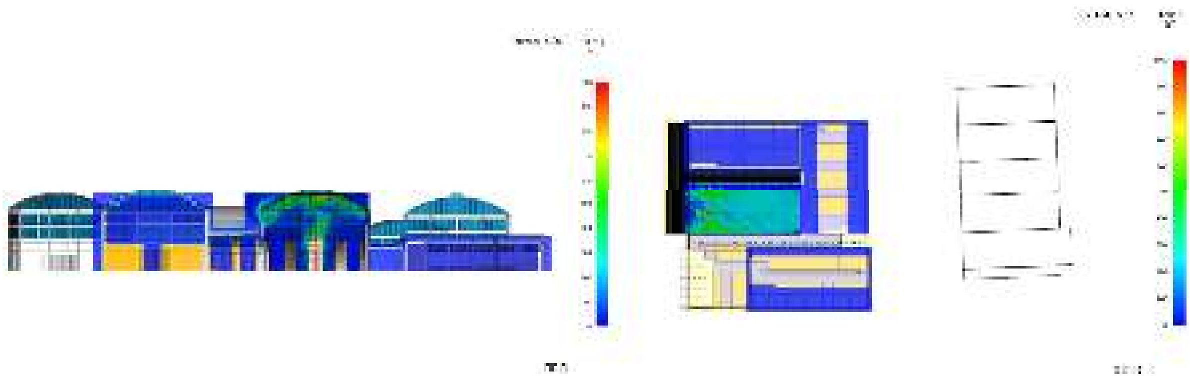

Figure 1: Temperature slices of Block A Scenario 3 with smoke stratification visible under the roof.

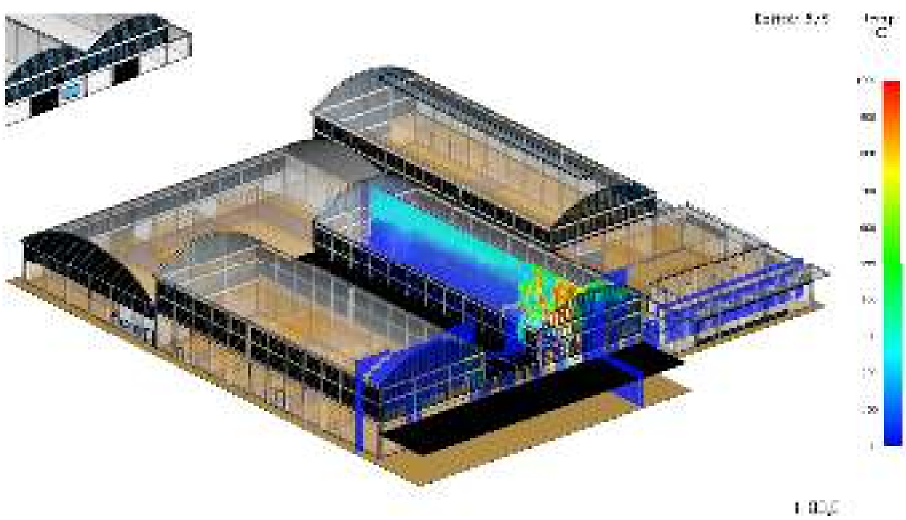

Figure 1: 3D representation of the temperature slice in Block A scenario 3.

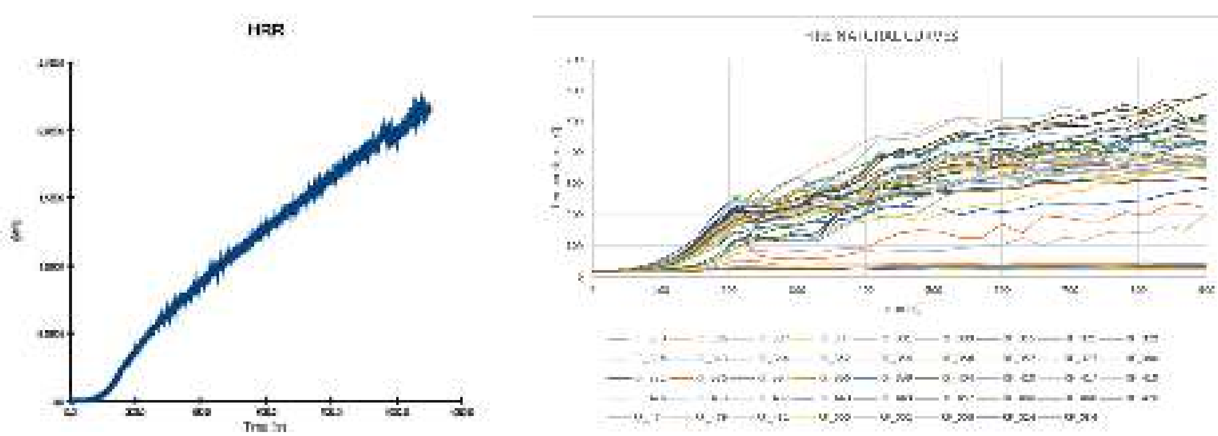

Figure 1: HRR and natural curves of FIRE. HRR increasing continuously in time because of propagation from one pallet to the nearby ones.

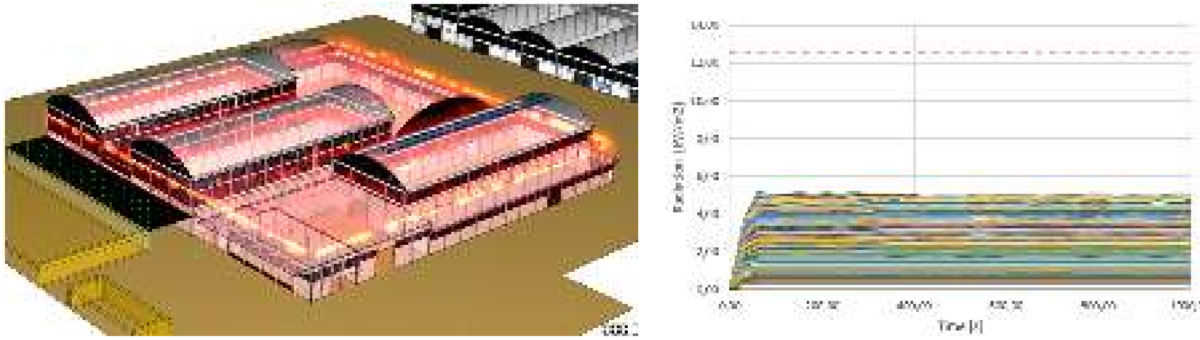

Figure 1: Generalized fire distribution in the Block A building. Definition of the separation distance depending on the radiative heat transfer obtained on probes located outside of the building in the direction of the nearby structures.

Figure 1: ASET verification of the four monitored parameters: ASET to verify corresponds to RSET obtained from Pathfinder with a margin of 100% of RSET. All four monitors must be below the thresholds until the ASET time is reached.

FDS SCALABILITY

Scalability test has been conducted to evaluate the platform for cloudHPC provided on the cloud (https://cloudhpc.cloud). The platform provides 2nd Gen AMD EPYC™ ROME Processors 3.1GHz with several configuration of RAM and vCPU (from 1vCPU to 224vCPU). Given the most recent version of FDS (6.7.9) which can use independently Multicore approach with OpenMPI and Multithread approach it was possible to evaluate the scalability using both approaches and a combination of the two.

The test has been conducted of two different cases: one on the Block A and a second on the Block B. Overall the meshes for Block A consisted of 2,866,928 cells while on Block B the mesh size is 2,249,448 cells. In both cases, the cell number refers to the total number of cells, without distinction between fluid or obstruction cells as defined by FDS.

Every case is executed on a core number which ranges from 4 to 16 and with a thread number of 1 to 4 threads per each core. Consequently, the two cases have been adapted to balance the workload among the core variation by splitting the meshes ad using the MPI_PROCESS parameter to equilibrate as much as possible the cells number among the cores used.

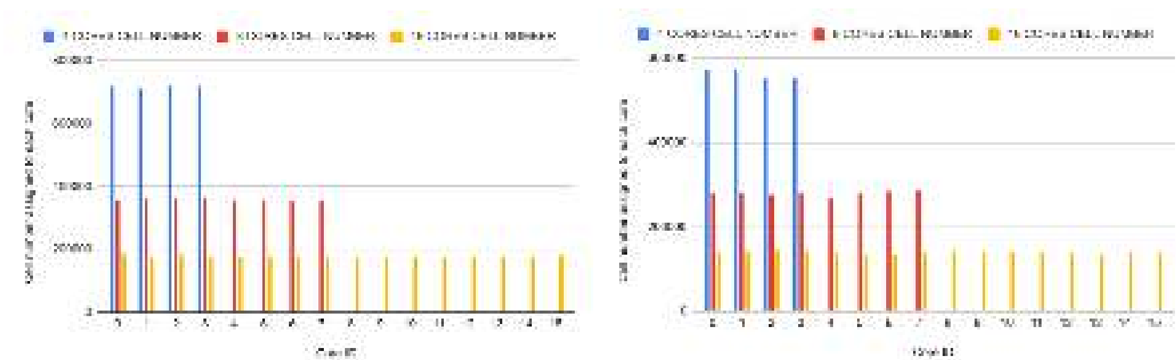

Figure 1: Definitions of the number of cells assigned to each core in the cases performed from 4 cores to 16 cores in Block A and B

Overall, the workload distribution can be considered equilibrated (lower than 5% variation of cell number per each core). Previous analysis in fact showed high impact of uneven distribution to the calculation time.

SCALABILITY RESULTS

Results of the scalability showed that FDS 6.7.9 performances improves with an allocation of a higher number of cores. Block A had a very high efficiency in all the multi-core approaches defined, while Block B showed a lower level of scalability – due to the localization of the fire scenario which highly involved only a limited number of meshes.

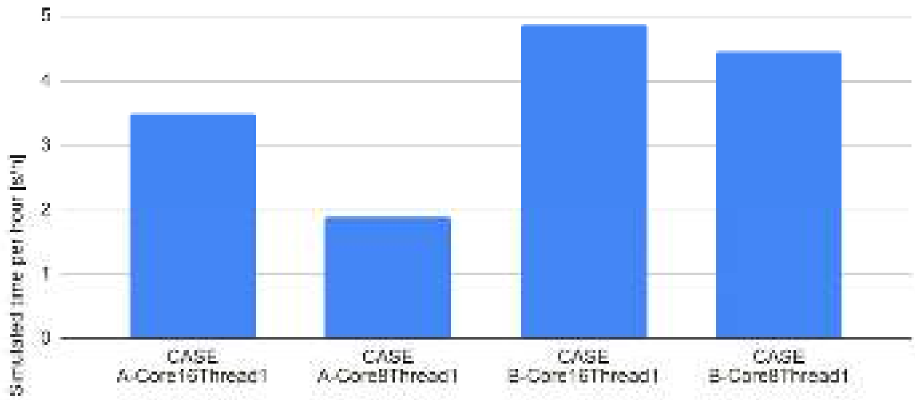

Figure 1: Comparison of the simulated time per hour in cases running on multicore approach only (Threads = 1).

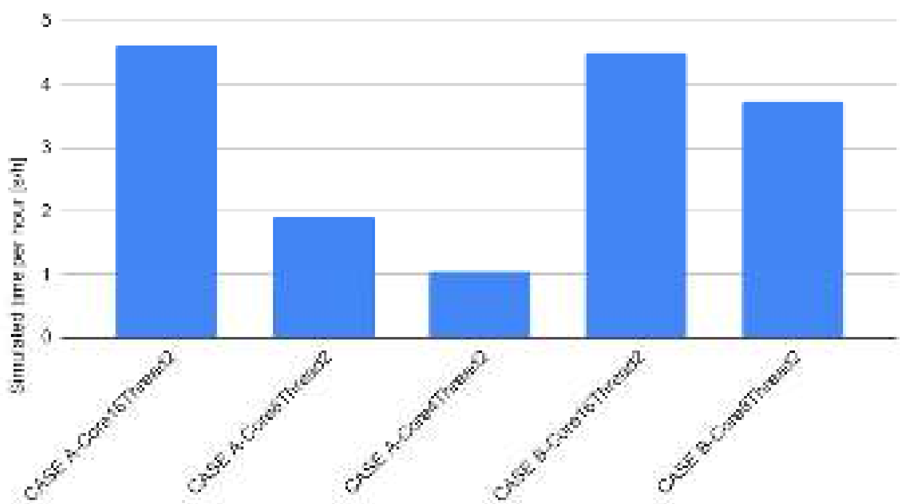

Figure 1: Comparison of the simulated time per hour in cases running on multicore with recommended multithreads (Threads = 2).

The new FDS 6.7.9 has a solver dedicated to multicore approach only and a comparison between the multicore-multithread solver and the new one has been made. The new solver seemed to be a good compromise in terms of efficiency as the multi-thread approach showed poor scalability performances compared to the new one: overall a speedup is obtained when increasing the number of threads assigned per each core but in general the speedup is poor.

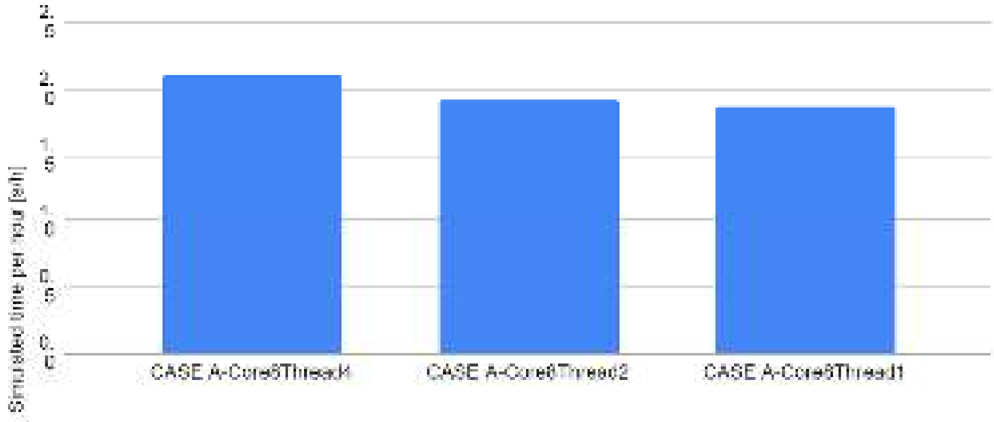

Figure 1: Comparison of the simulated time per hour in an 8 cores approach with various thread approaches from 1 to 4.

CONCLUSION

The FSE – Fire Safety Engineer allowed to verify the building structure resistance for the first 15 minutes after the fire sparks. It has also been possible to verify the implosive collapse to avoid damages to nearby activities. Compartments proved to be fairly distance to reduce radiative heat transfer. ASET/RSET analysis finally proved the occupants can leave the building safely in the events of fire.
BIM modelling has been widely used, and thanks to Pyrosim and FDS it has been possible to interact with several software and modelling in a quick and easy way – also when making engineering design iterations in the project.

In terms of scalability, the latest FDS version 6.7.9 proved to highly improve the performances when running on multi-core only approach. The scalability must be reached by evenly distributing the workload (cell number) among all the cores by splitting the MESH lines and by using the MPI_PROCESS id to assign each mesh to a specific core in the solving phase. Multithread approaches, even if available, did not showed as good scalability performances as the multicore approach when it was enabled.

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