Fire prevention and suppression study regarding activation, evolution and functioning characteristics of fire safety systems

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The present thesis proposes all the specific tools to approach the fire safety engineering methods in order to obtain unique buildings and also to eliminate the existing barriers on the construction market when prescriptive regulations and norms are being used. Thus, both experimental methods with novelty character in Romania and analytical calculation methods in combination with computational software programs are used to assess the sprinkler activation time.

This PhD paper has a basic text of 115 pages and it is structured on 6 chapters, being based on a bibliographic list of 68 titles which contain relevant information for all the research activities presented in this paper.

Chapter 1 contains information related to fire safety engineering concept as well as minimum performance levels that should be established when this specific methods are applied.

In the past years the majority of the European Union member states were following specific design fire safety methods based on the prescriptive regulation requirements. Traditionally, these norms have resisted through time either because of their easier way of implementation or due to the lack of specialists in this field. Moreover, the prescriptive requirements can offer rapid solutions for the designers with a high level of control in the same time.

Through their nature, the prescriptive codes represent a barrier for the development of new design solutions, and also for new construction materials and building technologies. Often, these codes prove to be too rigid in the design stage as there are not endorsed on a regular base to include all the newest calculation methods or innovations in the construction realm. In the same time, the requirements for fire suppression systems that need to be installed to protect the buildings are too restrictive leading to imbalanced cost-benefit analyses.

An alternative way to solve the problems generated by the prescriptive codes is represented by the fire safety engineering approach which can aid both designers by offering them alternative calculation methods and also for architects and investors to allow them to use new construction materials and build more futuristic buildings.

Fuelled by socio-economic development in the 80's, performance-based fire safety engineering has grown in popularity and complexity in the past years, being known as an innovative and cost effective solution to the fire safety design. The limitations and lack of flexibility of the prescriptive codes along with the modern building design and new construction technologies have developed further research activities in the fire safety field. Through continuous development of fire safety engineering methods designers seek to offer new solutions for their unique projects and alternative measures that lead to a high level of safety for building occupants and the society at large. Thus, performance-based methods would lead to highly optimized fire safety design which could benefit society in terms of balancing investment costs and level of safety.

Chapter 2 presents the main types of sprinkler systems and their operating principles as well.

Sprinkler systems are known as one of the most reliable fire suppression systems. They can contribute in the same time for fire detection, alarm transmission and fire spread limitation, ensuring a smooth building evacuation, property protection and safety of the fire brigade intervention.

Sprinklers are automatic devices which have a thermal sensitive element that activates to a certain temperature and deliver a quantity of water on a conical pattern with different dimensions over the protected area. The water supply system for the sprinkler heads is made through a network of pipes mounted at the top part of the building. The sprinkler head coverage is made on a calculated distances along the network of pipes in such a way that are not any floor areas which are not protected with water.

Most of the sprinkler systems are designed to ensure that every sprinkler head will react to the temperatures generated during a fire and will spread the required quantities of water over the fire place.

Nonetheless, this chapter contains the main elements that influence the sprinkler activation time assessment, along with analytical calculation methods to determine this parameter. Parameters like response time index (RTI), time constant and conduction transfer coefficient are characteristics that should be taken into account for the sprinkler system design.

Chapter 3 offers an overview of the computational methods and programs used in the performance-based design stage. Turbulence problems encountered during fires or documentation that needs to be prepared during a simulation are covered by this chapter.

Although, an important progress in the fire safety research has been seen in the last period of time, the underlying equations for these computational programs have a wide range of limitations which users should be aware. Regardless of the difficulty level of the problem and the user friendly degree, all the fire engineers should be always familiar with fire dynamics characteristics and with possible errors that can be introduced during simulation process.

According to the simulated model complexity, the type of the underlying equations and computational program version, the computer capacity is more or less required. Starting from simulations of seconds and ending with those that last days and weeks, it is important that these computational programs are proper used and the fire engineers can truly understand the underlying models of these tools. In the same manner it is compulsory to ensure the accuracy and the validity of the computational results.

Generally, these models are used on a large scale for smoke transport problems, to evaluate the detection and sprinkler response time and for the fire investigation and reconstruction situations, as well. Advanced use implies tasks related to pyrolysis, flame spread, fire growth and fire suppression with sprinklers. Regarding to this, Emanuele Gissi emphasized in one of his papers that: “At this moment users should avoid advanced simulation use since computational programs are still on an intense research process which is not finished yet”, statement valid even today.

The most used computational programs can be divided into two groups, according to their underlying characteristics. The first category contains the so-called two zone models which has the most simplifications and assumptions included in the mathematical equations, while the second one, more complex, is the one of computational fluid dynamic (CFD) models which can solve advanced fire dynamics problems. The later requires high capacity computers and the simulation time is increasing with the complexity of the problem and the available processing features of our own computers.

Albeit two zone models are easy to use, those with fluid dynamics have known a rapid grow along with a large scale use. Given that CFD models have complex underlying equations, they can offer results close to the differential equations, being in the same time more reliable than two zone models.

Chapter 4 contains experimental data for sprinkler response time on ISO room tests.

This chapter presents the performance-based calculation methodology for sprinkler response time assessment. For this purpose, there have been used computational fluid dynamics models and mathematical calculations, while for their validation different tests were performed with fires having identical characteristics, but placed in different positions inside the standard ISO room.

Beside the available calculation methods used for the performance-based design, it was highlighted the fact that fire position inside the room has an important role in sprinkler response time assessment. Like the fire suppression systems, the fire alarm devices have the same activation characteristics, and through similitude the results obtained on the present thesis can be successfully applied for both systems aside.

When the heptanes tray was placed in the middle of the fire compartment the value of heat release rate generated was approximately 6 kW both for oxygen consumption method and mass loss rate measurement. These values show a maximum of 12 % difference comparing to analytical methods, which strengthen the idea that fires made of flammable liquids can assure a highly accuracy degree on fire research studies.

It is highlighted the fact that analytical methods available in the specific literature have some limitations on the heat release rate calculation as these where performed through several tests in open air. By placing a fire inside a compartment there are some specific aspects generated by the smoke layer on the top of the enclosure, in the same time with the construction materials from the walls that can contribute to the mass loss rate process with a direct result on the heat release rate growth.

The maximum heat release rate values are generated by the fires placed on the corner of the room as flames are limited by the room boundaries and air entrainment is decreased. This phenomenon impinges the volatiles to the upper part of the room and the burning process takes place on the top of the plume where there is enough oxygen for the combustion process.

It is obvious from the experimental results that the activation time is strongly influenced by the position of the fire inside the compartment and the rate of heat released. Although the heat release rate is the essential parameter in the fire development, for the sprinkler response time assessment it is necessary to take into account the horizontal distance from the center of the fire to the sprinkler mounting place.

The analytical calculation methods for the sprinkler response time offer valid results only when the fire is placed in the middle of the fire compartment because their mathematical equations were developed with large scale experimental tests where the dimensions of the room were big enough not to form a smoke layer on the upper part.

Although in many cases sprinkler heads are mounted well above the fire place and heat transfer process to the thermal sensitive element is made solely through convection, there are still cases on the growing stage when radiation is the main heat transportation way. Therefore, in the design stage it is recommended for the fire engineer to make a thoroughly evaluation of all the fire scenarios in order to identify all the heat transfer methods.

Even though the position of the fire in the corner of the room and near the walls, clearly influences the rate of heat released and the response time of sprinklers, it is always necessary to take into account the horizontal distance from the sprinkler head to the fire place.

Furthermore, it should be noticed that the heat release growth rate in the vicinity of the walls can be observed only when the flames are leaning on the boundary surface.

Computational programs can offer a reliable alternative for the analytical methods as they can generate valid results close to those from the experimental tests in all three cases, but their usage needs a thoroughly knowledge about their limitations and underlying errors. It is very important that simulation results are reported along with a detailed error document and their further consequences over the entire design process.

Chapter 5 of the thesis presents data regarding to the experimental sprinkler response time into the car road tunnels.

Hence, it is noted that are differences in the sprinkler activation time depending on the combustible material characteristics. To equal heat release rate values the differences are made by the net heat of combustion specific to the material, as well as by combustion efficiency. Moreover, it is observed an exponential growth of the activation time with the distance increase from the horizontal distance from the sprinklers to the fire place.

When the air velocity values of the ventilator exceeds 6 m/s, the air cools down the ceiling temperatures enough so as none of the bulbs are activated. If the air speed does not exceed 3 m/s the activation time is delayed due to the cooling effect of the smoke layer and the lagging effect of the thermal transfer from the hot gases to the sprinkler bulb. Thus, if on the design strategy it is established that the power ventilators are started after the first sprinkler activation, than the air flow speed should be calculated in such a way that the activation of the other sprinkler heads is not affected.

Oxygen enrichment caused by the air floe accelerates the combustion process through the mass loss rate. The flames are angled by the speed of the air, increasing the possibility of the fire rapidly spreading from one car to another. In such a scenario, when more than one car is engulfed by the flames, firefighting techniques are very hard to be implemented. In this case, large quantities of hot gases are generated, while temperatures can reach nearly 1000^0 C, creating conditions that could jeopardize life safety of the occupants and firefighters alike.

Thus, on the fire suppression systems design stage, engineers should carefully choose the activation temperature of the sprinkler heads according to the type of the occupancy and also the response time index RTI specific for each thermal sensitive element.

The experimental results suggest that the reduced scale tunnel model yields reliable data close to those registered during the large scale tests.

Because different and diverse combustible materials in various configurations are involved during the tunnel fires it is hard to anticipate the sprinkler activation time. However, reduced scale experiments can offer important data regarding the main parameters that influence sprinkler response time and can contribute to the design process improvement and to research activities on this field.

Chapter 6 concludes the scientific approach undertaken by the research work in the thesis, focusing on a clear manner on the conclusions and the contributions made by the researcher. Further research trends are also presented.

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