FIRE RISK ASSESSMENT AND EVACUATION TIME OF SCHOOL BUILDING

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Abstract: The subject of the research presented in this paper is the assessment of the fire risk of a secondary school in Kumanovo, North Macedonia. The research was carried out in four steps. The first step was collecting data for the school building by "in situ" inspection. The second step was defining the fire risk by implementation of the semi-qualitative Matrix method. The third step was definition of all parameters that influence the fire risk according to the Euro-alarm Method which is quantitative method and is based on the fire risk of the building and the fire risk of the contents in the building. Based on the analysis results, the need for the installation of a fixed automatic fire suppression system and additional measures for protection against fire have been defined. As last step, the evacuation time was defined by using the program „Pathfinder".

Key words: Matrix Method, Euroalarm Method, evacuation, fire, risk assessment, risk management

1. INTRODUCTION

Fire, as a term, is defined as uncontrolled combustion, either of a part of a structure or of a flammable material in its vicinity, which can cause injury to people and material damage. In order to prevent the occurrence of fire and if it happens to guarantee the safety of tenants, employees, customers, as well as the building itself and the material goods in it, appropriate measures should be taken. The measures depend on the level of risk of fire. For reliable fire risk assessment, it is necessary to conduct an appropriate analysis. The defined risk level directly influences the risk management measures that should be taken to prevent fire or reduce consequences.

According the definition given in the ISO 31000:2009 standard, risk management includes risk assessment and management. Fire risk management is a process of developing risk control measures, improving possible existing measures and proper implementation of the envisaged measures, all in order to reduce or eliminate the risk itself. Therefore, fire risk analysis is only one part of the fire risk management process and serves as a basis for deciding whether to take risk mitigation measures or to select appropriate measures to deal with it.

To be able to ascertain the level of risk and either quantify/qualify its impact, a number of methods and approaches can be undertaken. This can be defined as a 'fire risk analysis or assessment' which utilises the principles and methodologies of risk that are currently available and apply them in the context of the built environment [1, 2].

There are five main steps in the Fire Risk Assessment process.

- Step 1 – Fire Hazards Identification: potential sources of ignition, fuel and oxygen.
- Step 2 – Identification of People at Risk.
- Step 3 – Evaluate, Remove, Reduce and Protect from Risk Occurrence.
- Step 4 – Record, Plan, Inform, Instruct and Train.
- Step 5 – Review.

The assessment methods that are currently available can be devided into three categories. These are noted to be Qualitative, Semi-Quantitative and Quantitative methods [1, 2].

Quantitative Risk Analysis uses available relevant and verifiable data to produce a numerical value which is then used to predict the probability (and hence, acceptability) of a risk event outcome. Qualitative and Semi-quantitative Risk Analysis, on the other hand, applies a subjective

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assessment of risk occurrence likelihood (probability) against the potential severity of the risk outcomes (impact) to determine the overall severity of a risk.

Within this research, a fire risk assessment was conducted for elementary school in city Kumanovo, North Macedonia. As first step „in situ“ survey was conducted and based on the data collected by observation, the Semi-Quantitative 5x5 Matrix Method was used for defining the fire risk. As second step, the Euroalarm, as Quantitative method for fire risk assessment, was applied. The fire protection measures are considered from the aspect of whether they exist and, if they exist, whether they are adequate and sufficient for the fire hazard management or whether they should be improved. Based on the results obtained from the both analysis, additional fire protection measures are recommended. As last step, the evacuation time was calculated by using the program “Pathfinder”.

2. FIRE RISK ASSESMENT OF SCHOOL BUILDING

2.1. Basic data on the school building

Based on the „in situ“ survey, it was found out that the analysed building of the Secondary school is a reinforced concrete structure. The building consists of four parts. Three parts have only ground floor and only one part has two floors (Figure 1). The main part of the building is used for students from secondary school „Naim Frašeri“ and the other part for students from primary school „Vuk Karadžic“. Over the years, various changes have been made, such as: designing a new floor for additional classrooms, demolition of the stairs with the aim of creating one classroom, renovation of the toilets and few toilets were transfered into classrooms. The rooms are separated from each other by brick walls (d=20cm), the floor structure is made of reinforced concrete and the roof is wooden structure. In the interior of the building, there are various materials, such as: wooden materials, textiles, paper, plastic, etc., which influence the spread of the fire and/or cause the fire to occur. They also contribute to the appearance of smoke and/or the release of toxic products, which would be harmful to the health of those present in the building, as a result of inadequate ventilation. The number of occupants is 440 on the ground floor and 200 on the first floor.

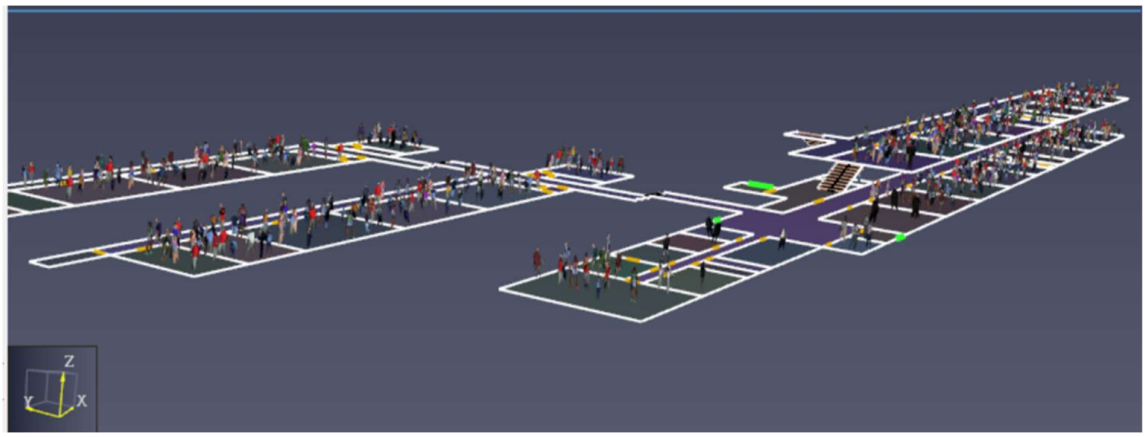


Figure 1- Floor plan of the school building

The fire risk analysis was conducted by using both, Semi-quantitative „5x5 Matrix method“ and Quantitative „Euro-alarm“ method.

2.2. Semi-quantitative Matrix method for fire risk assessment

The matrix method for fire risk assessment is carried out in such a way that the fire hazard is defined as probability that a fire will occur, while the damage that would occur from that hazard is defined as fire risk (impact) [1,2,4]. According to this method the risk value is obtained as product between the probability and the impact.

Value of the fire risk = **fire hazard** (probability**)** x **fire risk** (impact**)**

The numerical value of the fire risk is defind according to Table 1, while the Matrix method is presented in Figure 2. According to the „in situ“ observation and the questionnaires filled by the occupants it was found out that fire is **Possible (3)** event. The poor condition of the building ensures rapid spread of the fire, due to the presence of flammable materials inside the building, lack of devices for protection against fire, lack of an alarm system for detection of fire and lack of trained personnel. This means that the fire will be folowed by enormous consequences, especially from the aspect of losing human's lives. The fire risk (impact) is **Medium (3)** and finally the **valye of the fire risk is 9**. According to Figure 2 the **fire risk belongs to category Medium**.

Table 1- Relationship between fire hazard (probability) and fire risk (impact)

Fire risk (impact)	Value	Fire hazard (probability)
Very Low	1	Rare
Low	2	Unlikely
Medium	3	Possible
High	4	Probable
Very High	5	Highly probable

	Fire risk (Impact)						Category of fire risk
Fire hazard (Probability)		5	4	3	2	1	Low
	5	25	20	**15**	10	5	**Medium**
	4	20	16	12	8	4	High
	3	15	12	9	6	3	Very High
	2	10	8	6	4	2	
	1	5	4	3	2	1	

Figure 2 - 5x5 Matrix method for defining the numerical value of the fire risk

2.3. Fire risk assessment by quantitative “Euro-alarm” method

The „Euro-alarm“ method is based on the fire risk of the building (Eq 1) and the fire risk of the building content (people, furniture, etc.) (Eq 2), as two highly related components [4].

$$Ro = \frac{((Po * C) + Pk) * B * L * S}{W * Ri} \quad (1)$$

where:

Ro – fire risk of the building;

Po – coefficient of fire load of the building content;

C – coefficient of combustibility of the contents in the building;

Pk – coefficient of fire load of materials installed in the construction of the building;

B – coefficient of size and position of the fire sector;

L – coefficient of delay in the start of extinguishing;

S – coefficient of a width of the fire sector;

W – coefficient of fire resistance of the load-bearing structure of the building;

Ri – fire risk reduction coefficient.

The fire load has been adopted in accordance with the standard MKS. U.J.1.030 [3] and for classrooms it's value is q=251 (MJ/m^2). The coefficient of fire load of the building content (Po) is determined according to Table 2.

The coefficient of combustion of the contents in the building (C) depends on the class of fire danger and is given in Table 3. The coefficient of fire load of materials built in the structure of the building (Pk) is obtained based on the calorific value of all combustible materials in the building (Table 4). For RC structure has no caloric value, and P_k**=0**. The coefficient of size and position of the fire compartment (B) depends on the size of the fire compartment's floor area, the height of the premises and the number of floors. For fire compartment of up to 1500 m^2, height of premises of up to 10 m and three storeys at the most, this coefficient is ***B*=1.**

The coefficient of delay in the start of the intervention (L) depends on the type and equipment of the fire brigade, its distance from the building and the condition of the roads (Table 5). The fire compartment width coefficient (S) is determined based on the fire compartment width (Table 6). The coefficient of fire resistance of the load-bearing structure of the building (W) is determined depending on the elements from which the building is constructed. In this case the RC structure has fire resistance that is usually higher than 90 minutes (Table 7).

Fire risk can be reduced by using the fire risk reduction coefficient (Ri), in regard to the type of combustible materials, combustion rate, storage method and other factors [5]. In this case the flammability is not particularly high, normal speed of fire spreading is expected and in the process of functioning, there are normal sources of ignition. The value is ***Ri*=1.3**.

Table 2 – Coefficient of fire load of the building content (Po)

Fire load *q (MJ/m^2)*	0-251	252-502	503-1004	1005-2009	2010-4019
Po	1	2	3	4	5

Table 3 - Coefficient of combustibility of the content in the building (C)

Category of fire resistance	VI	V	IV	III	II	I
Combustibility coefficient C	1	1	1	1.2	1.4	1.6

Table 4 - Coefficient of fire load due to materials built-in the structure of the building (Pk)

MJ/m^2	0-419	435-837	845-1675	1691-4187	4203-8373
P_k	0	0.2	0.4	0.6	0.8

Table 5 - Coefficient of delay in the start of the intervention (L)

Time until beginning of extinguishing (min)		up to 10	10 to 20	20 to 30	over 30
Distance (km)		1	1 to 6	6 to 11	over 11
Type of firefighting unit	Professional industrial firefighting unit	1	1.1	1.3	1.5
	Voluntary industrial firefighting unit	1.1	1.2	1.4	1.6
	Territorial Fire Fighting Unit	1	1.1	1.2	1.4
	Territorial voluntary firefighting unit that is permanently on duty	1.1	1.2	1.3	1.5
	Territorial voluntary firefighting unit that is not permanently on duty	1.3	1.4	1.6	1.8

Table 6 – Coefficient of the width of the fire compartment (S)

The least width of the fire compartment (m)	up to 20	20-40	40-60	Over 60
S	1	1.1	1.2	1.3

Table 7 - Coefficient of fire resistance of bearing structure (W)

Fire resistance in (min)	up to 30	30	60	90	120	180	240
W	1	1.3	1.5	1.6	1.8	1.9	2

By incorporating the defined parameters into Eq. 1, the value of fire risk besomes: R_o**=0.53.** In case $R_o < 1$, the structure should be protected by manual extinguishers as are portable and vehicle mounted extinguishers. **This criterion is satisfied.**

The fire risk of the building content is defined by Eq.2.

$$R_s = H \cdot D \cdot F, \tag{2}$$

where: H is coefficient of danger to humans; D is asset risk ratio; F is coefficient of smoke action.

The risk factor for people (H) depends on the possibility of timely evacuation of people from the facility. In case when there is danger for the people in the structure, but they can save themselves, the value is ***H*=2.** The asset risk ratio (D) depends on whether the destroyed property can be recovered and the extent of material losses. In case when the contents of the structure are not of high value and have a low tendency to destruction the value is ***D*=1.** The appearance of a larger amount of smoke increases the threat to people and property, which is taken into account through the coefficient of action of smoke (F). In case when more than 20% of the total weight of all flammable materials cause smokiness, or release poisonous products from combustion the value is ***F*=1.5** [4]. For the analysed building, the final value of Rs is: R_s**=3.**

The obtained values for these two components are plotted on the ordinate and abscissa of the Fire risk decision diagram (Figure 3). Each combination of building fire risk and fire risk of the contents of the building corresponds to a particular point on the diagram. The position of the point can be used to decide whether it is justified to take additional fire protection measures. In this case zone 3 means that the installation of a **fire alarm will be required, the automatic fire extinguishing installation does not respond to the risk - it is not necessary.**

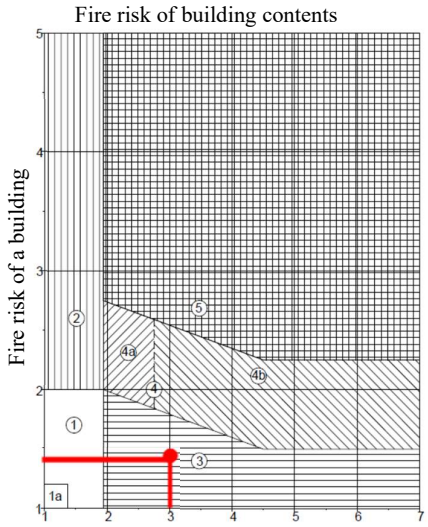


Figure 3 - Fire risk decision diagram

2.4. Time of evacuation of school building

Time of evacuation of school building was calculated by using the program „Pathfinder“ [5]. The building floor plan is presented in Figure 1. The maximum number of employees and students that can be present in the building is N = 615. The farthest room from the evacuation exit from the building is L = 90 m. The width of the exit door which leads directly to a safe place is 1.0 m and is located in the main hall. The total time of evacuation is sum of times for leaving the rooms, mooving through the halls and stairs and arriving at the safe place. For example, Figure 4 presents the time of evacuation when ocupants are using the stairs.

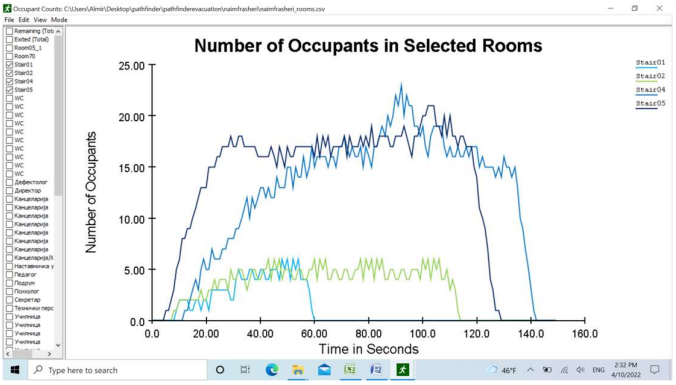


Figure 4 – Stairs walking time

According to the calculations, the total time of evacuation is **t=8.8 min. This time is enough for the fire brigade to arrive and start extinguishing the fire.**

3. CONCLUSIONS

In accordance with the conducted research, it can be concluded that the Secondary school is in bad condition and does not fulfill all the neccesary measures for protection against fire. This is due to a number of factors: lack of fire protection system, lack of adequate signalisation, lack of evacuation plan, lack of proper exit routes and lack of trained staff.

The analysis has shown that, for fast and initial, but still sufficiently accurate assessment of the risk of fire outbreak, the qualitative methods, as Elementary Five-Step Method, and Semi-quantitative methods, as the Matrix Method, may be used.

Compared to these methods, in accordance with the conducted research, it can be concluded that the application of quantitative methods, as the Euroalarm Method, is more effective and these methods are used for more detailed analyses in assessing the risk related to fire outbreak in a specific structure.

4. REFERENCES

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