Zrínyi Miklós
National Defense University

PhD THESES

Dr univ. Laszlo Beda

TECHNICAL EVALUATION OF FIRE SAFETY OF BUILDINGS

2004 Budapest

Head of PhD School:	**Dr. László Halász** **Professor, DSc**
Supervisor:	**Dr. István Bukovics** **CSc, PhD**

1. Lead-up to the work, goals

1.1 Validity, actuality of the topic

When a fire occurs in a building, two systems, *the fire and the building* interact. The products of fire are *heat and toxic gases* that might damage *the living and material goods* in the building and the *structure* of the building.
The thought of objective fire safety assessment has been an issue for quite a while, but the development of reliable and useful estimation methods is still at its early stages. We are still lacking a transparent and uniform system of the different methods for their practical use.
In Hungary, just like in any other country, fire safety assessment is based on legal and other measures. It practically means, that the fire safety of a certain building is assessed, by checking if they meet the terms of the regulations in every single detail. If they comply, we take its safety for granted, even though we only know that it is built "according to fire safety regulations". This kind of approach does not allow for the objective representation of safety, as we cannot measure the extent of safety. In addition, with the change of legal and other regulations, some of out buildings may be "over- or under-engineered" at the time of their evaluation.
In order to adequately assess safety, we have to support the process of decision with the use of an evaluation model or method for that particular problem. In Hungary, the use of "engineering approach" in the assessment of fire safety has no traditions.
When someone wants to make a fire safety assessment, he immediately finds a handful of theoretical questions to start with. In my theses, I will answer these questions, with the following goals:

1.2 Goals

In this thesis, using the results and experience of ten years' theoretical and practical work, I will pursue the following goals:

1) As there is no comprehensive work concerning fire development in closed areas in Hungarian, however, using any of the available models requires a thorough knowledge about it, I will briefly discuss the underlying theories.
2) The location of the fire greatly influences the fire hazard, therefore I will evaluate the roles, different interiors – furniture, curtains, floor or wall coverings – might play in case of fire. I will show that when choosing the suitable interior, fire protection aspects also have to be taken into consideration. In my evaluation of the interior design, I will primarily concentrate on panel buildings very common in Hungary.
3) When solving fire protection problems, the usage of fire modeling is not common in Hungary. With the help of the available literature, I will examine the possibilities of using different fire models to determine the safety of a building, with particular attention to the likelihood of their use in Hungary. To make the selection easier, I will make a summary of all recently used fire models and will observe them from the point of view of physics, chemistry, mathematics and theory. For the evaluation of actual fires, I will use mathematical fire modeling.
4) I will compare the fire safety evaluation methods currently used in Hungary, with the engineering approach, highlighting their strengths and weaknesses. I will show, that these two different approaches can support each other, so their usage results in greater fire safety. I will develop a complex evaluation method for building fire safety and will present my results on a chart.
5) As a member of the European Union, Hungary will have to familiarize and use fire safety measures and evaluation methods of the Union, therefore I will pay particular

attention to study the accepted principles and technical safety evaluation methods and the possibilities to adopt them into the Hungarian system.

6) In determining the fire safety of today's buildings, one of the most important factors is evacuation calculation. The result of this calculation, however, cannot be the basis of the safety estimation alone, as it does not take the spreading of fire into account. That is why I find it important to monitor the actions of the people in danger and the spreading of fire at the same time. To present one possible solution to this, I will develop a method to graphically represent the "spread of danger." I will illustrate the usage of this method to evaluate an actual fire.

2. Method of approach

For my thesis, I primarily rely on the analysis of the available literature. The desk study included all the results of the more important researches in the last quarter of a century. The thesis contains 137 different reference sources. I paid particular attention to represent the different practices that are used or accepted in the European Union. I have made a *comparative analysis* of the different methods used internationally. As there is virtually no literature available in Hungarian, I had to define some of the terminology used. I have collected data, utilized a *mathematical fire model*, made *calculations* and *analyzed the results* about actual fires. From the results, I *drew general conclusions*. I have made generalizations and have *developed a complex model* for the evaluation of the fire safety of buildings. For my work I have used my twenty years of experience in training fire protection engineers and also my work as an expert on the area of fire protection.

3. Bibliographical overview

3.1 Fire characteristics in closed spaces

I would like to make it clear that, resulting from the topic, all considerations in this thesis can only be applied to fires in closed spaces, I do not deal with open air fires (ex. bushfires). A fire is in a closed space if the so called "closed-space effects" (limited amount of combustibles, limited amount of oxygen, heat radiation from surfaces) apply during the fire.
In the fire protection profession, we often say that "no two fires are the same". However, in fires occurring in closed spaces (ex. rooms) we can discover similarities, different sections can be distinguished in the "life span" of the fire. In this chapter I show and characterize the different stages in the development of fires in enclosures.

3.2 The role of the location of fire in determining fire hazard

Japanese scientists compared the characteristics of fire spread in buildings made of bricks and wood, using a stochastic fire model. From their results, we can see, that in the case of wooden buildings, flashover occurs sooner than in the case of brick buildings.
Combustibles in the rooms, like floor and wall coverings, furniture, curtains may have a major role in the case of a fire. European studies show that most of the fatalities in fires can be directly linked to the burning of different furniture pieces.
The fire protection characteristics of interiors that are regulated in Hungary are the following:

a) ignition temperature,
b) heat of combustion,
c) horizontal and vertical flame spread,
d) ignitability.

I also mention a parameter that is not used in Hungary during the fire hazard evaluation of interiors. This is the heat *release rate*.
In the case of fire, high temperatures and toxic smoke are the hazard sources.
Critical value of the temperature is set to approx. 150 C in the literature.
A not yet fully developed method concerning toxicity is the so-called effective dose ration (EDR), which can be used together with the Cone-calorimeter measurements to evaluate toxic effect. EDR is a value without measurement, that is the relation of the actually dose to the dose required for a certain effect. The bibliography also mentions the fire toxic hazard (FTH).

3.3 Fire protection measures for the building structures

To estimate the damaging effect of fire on building structures, the use of the term *fire load* is widespread. Fire load is a basic characteristic that determines many aspects of the construction. Fire load can be calculated with a formula, set in the corresponding decree of the Ministry of Interior (BM).
The *fire-resistance limit* (FR) is an important quality of building structures. In Hungary, in the FR measurement process, a function describes the relation of the furnace temperature to time.
The *fire-resistance limit* is a parameter also used in international fire protection practice. EU building principles allow for the usage of different measurement curves, corresponding the different types of fire predicted.

3.4 Variables, determining the safety of people in the building

According to the international practice, fire risk and fire hazard are different terms and are not interchangeable. By a generally accepted definition, fire risk is a value (R) from multiplying the probability of the occurrence of a fire of certain severity (P) by the severity of the fire (S). Fire hazard is a situation that influences the extent of the possible damage at a given location. It has an effect on both elements of the fire risk: probability and severity.
In general, we can say that a building is safe if the extent of the fire hazard and fire risk are below an acceptable limit. “Acceptability” is a result of several different factors.
The fire safety of buildings can also be characterized with the evacuation time. In the Appendix of 2/2002 BM decree, evacuation of the building is mentioned on the first place among the fire protection requirements. The decree also regulates the maximum time of the evacuation. The requirements are summarized in a table. The calculations are described in my thesis.

3.5 The theory of fire modeling

3.5.1Classification of the fire models

Fire models can be divided into two major groups, with further sub-classes. *See Figure 1.*

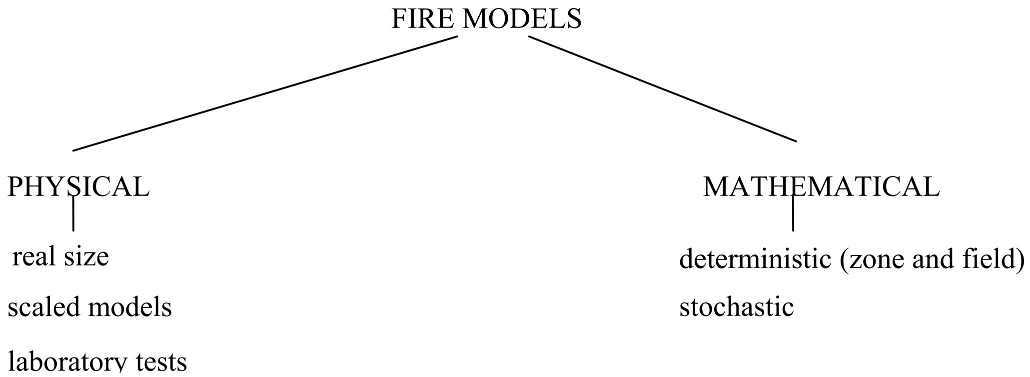

Figure 1

To save space, I will not discuss stochastic models in my work, only deterministic ones. First, I will briefly examine field models, then zone models in more detail. At zone models, as to my best knowledge it completely lacks literature in Hungarian, I will also talk about their physical and mathematical foundations.

3.6 The engineering approach in building fire safety in the European Union

Although there are harmonized fire safety regulations in the EU, most member states have kept their own rules as well. It has not yet been decided, how much longer this co-existence can be maintained. The appendix of Building Product Directive only contains general rules concerning the fire safety of buildings.
Usage of the engineering approach in determining the fire safety of buildings is not yet coherent in the EU. During the planning process of buildings they continue using methods according to legal directives and mostly use the engineering approach to support and verify the results.

4. Results

4.1 The influence of the location of fire

The location of fire consists of the building, the interior and the close environment. In the Hungarian fire protection there is no method to evaluate the influencing factor of the location itself. The fire investigation process, which could be used to collect the necessary data for the analysis, only deals with the possible cause of the fire, while ignition is only one of the initial elements of the fire. Results from the current fire investigation process do not allow for a more in depth analysis.
In my investigation of the effects building structures have on the fire, I analyzed large-panel buildings. This method of building has been fairly common in Hungary in need of the mass production of apartments. I examined fires in 6 different counties and Budapest. I had to browse through more than 5000 fire examination reports, as there was no adequate data in the database of the fire department. My results show, that in the frequency of fires, there is no considerable difference between panel and brick buildings.
Regarding the *causes of fire* there was only one distinctive element that was not present in the case of brick buildings. The rest of the fire causes are basically the same as in other types of buildings. The existence of rubbish shoots in panel buildings does not present a direct fire hazard, but enables the fire to spread vertically, between floors. From the spreading of fire, horizontally there are no differences, however, vertically fire can spread typically through rubbish akna and vents.
When examining the *interior of buildings*, we discover that their role is not purely esthetics and functionality, but, in case of fire, also determine the hazard. Therefore, when designing the interiors, fire protection considerations also have to be taken into account.

Measuring the *rate of heat release* and the *concentration of gases produced* by the combustion process makes it possible to use the engineering approach in selecting the appropriate interior for the building. That is, when furnishing a room we have the possibility during the planning process to decide which furniture setup is safer from the respect of fire protection. The method can be used when planning the interiors of hotels, offices, public buildings or hospitals. The analysis makes it easier to choose between different alternatives, for a given fire location. As in case of a fire, the main sources of danger are the heat and the toxicity of the gases, these parameters might be used to estimate the difference in the dangers they pose, when pieces of furniture made of different materials burn.

In my work, I recommend a method to estimate the relative fire hazard of furniture. I show, why the usage of the term toxic fire hazard (TFH) in itself causes uncertainness. The analysis has to be made for the given fire location. In my opinion, combining Cone-calorimetry with fire modeling might present a suitable solution.

For the calculations we need to examine the materials the furniture is made of with a Cone-calorimeter. In the appendix, I present the results I got with a Cone-calorimeter on a furniture upholstery.

4.2 Evaluation of building fire safety

4.2.1 Estimation of the safety of the building structure

It is known, that the damage in building structures is mainly determined by how much they heat up during a fire. I have shown, what problems we must face if we want to evaluate the effect of a fire on the building structure solely by the fire load, as the practice has been in Hungary.

To determine a building structure's *fire resistance limit*, we use *two different methods in Hungary*. Both methods are based on fire load, but while in the case of the first method they *use a table*, in the second they have to *make calculations*. They are free to decide which method they want to use. I showed on a newly built hall that the two methods do not always present the same result, what is more, the differences might be quite large. So large, in fact, that based on the two different results we would have had to prescribe different fire safety measures for the same building.

In the practice, even internationally fire resistance limit (TH) is a widely used parameter, but calculations based on fire load are not comparable even within the EU, as the definition of fire load is different everywhere.

To evaluate the reaction of a building structure to fire, the method has to follow the effects generated by a real fire. "Standard temperature – time curve" is a uniform model used to evaluate the performance of products exposed to a fully developed fire. The heat effect of a real fire might be smaller, or larger as the value shown on the standard temperature – time curve. EU directives allow the usage of different parameters during the examination when the expected effect is larger, or smaller. In Hungary, it is not possible.

4.2.2 Analysis of the safety of people in the building

Within fire safety, the safety of human lives has absolute priority, so evacuation plans when planning a building are of high importance. There is a race between the continuously growing fire and the escaping people. This situation is demonstrated in the hazard development diagram (figure 2.)

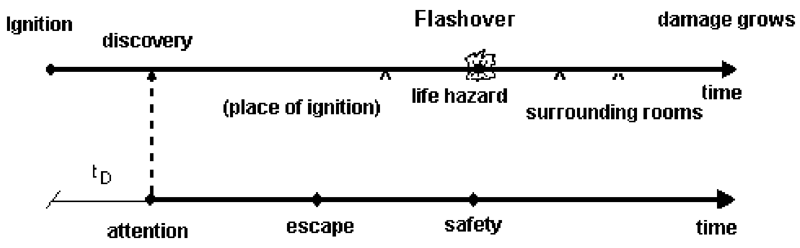

Figure 2

We can see that the race between the escaping people and the fire does not start with the ignition, but the discovery of the fire (t_D). To evaluate safety, we first have to decide whether there is a possibility to escape in a given situation. To decide this, the combination of fire modeling and Cone-calorimetry might present a solution, in my opinion. First, we have to determine the time available for the escape. I present this method in detail in my work.
We also have to estimate the needed time of evacuation. It is the time we need to fully evacuate the area in the given circumstances. I present the necessary calculations for this, in my work. The value of safety might be the time difference between the time available for the evacuation (t_R) and the time necessary for the evacuation (t_{sz}), minus the time elapsed until the discovery of the fire (t_D).

$$t_{CR} = t_R - t_{SZ} - t_D \qquad (1)$$

If t_{CR} is a negative value, the fire might be fatal. The larger positive value it is, the safer the escape can be.

4.3 Complex evaluation of building fire safety

The complex evaluation of a building's fire safety means the analysis of the safety of people in the building and the effects on the building structure in a way that combines traditional evaluation and the usage of the engineering approach. Combining the two methods has ten stages:

- I. collection of basic data
- II. definition of the worst conditions
- III. estimation of fire protection characteristics
- IV. selection of the conditions of ignition
- V. consideration of the possibilities to evacuate
- VI. fire modeling
- VII. calculation of evacuation time limit
- VIII. estimation of the stability of building structures during the fire
- IX. creation of the hazard development diagram
- X. evaluation of safety

The process of evaluation can be seen in *figure 3*.

Possible areas of usage for the complex fire safety evaluation method might be the analysis of actual fires, the usage of fire models during planning, the evaluation process of the plans or the creation of new legal regulations.

4.4 Uses of deterministic fire models

In the usage of fire models, I would like to stress two of my observations: one is, that no universal deterministic fire model exists, which could solve all fire protection problems. In general, we have to find the software for the actual task and we have to check the restrictions of its usage. The other important thing is to have a solid background knowledge, especially on the area of fire protection theory to use the software. In my work I made some additions to Friedman's 1992 collection of fire models in the international literature. In the first two parts of the table there are 31 zone and 13 field models. Then I present 16 sub-programs, which can be used to test the fire resistance of building structures, 7 sub-programs to calculate evacuation times, 6 sub-programs to test heat detectors and 3 sub-programs to analyze the interaction of sprinklers and the fire. At the end, there is a summary of the models for other purposes for special calculations like smoke ventilation, hydrocarbon fires, ventilation of mines, risk/cost estimation, fire spread in vertical walls, 10 different types in total.

4.5 Analysis of the engineering method and the regulation-based building fire safety estimation

It is difficult to decide whether the actually more modern engineering approach, or the traditional regulation based analysis is better in the fire protection of buildings. In my opinion, these two methods do not exclude the usage of the other. Both methods have their weak points. I have analyzed the methods to show the limits of their use and to make it easier to decide which one to choose. My results are summarized in a table.

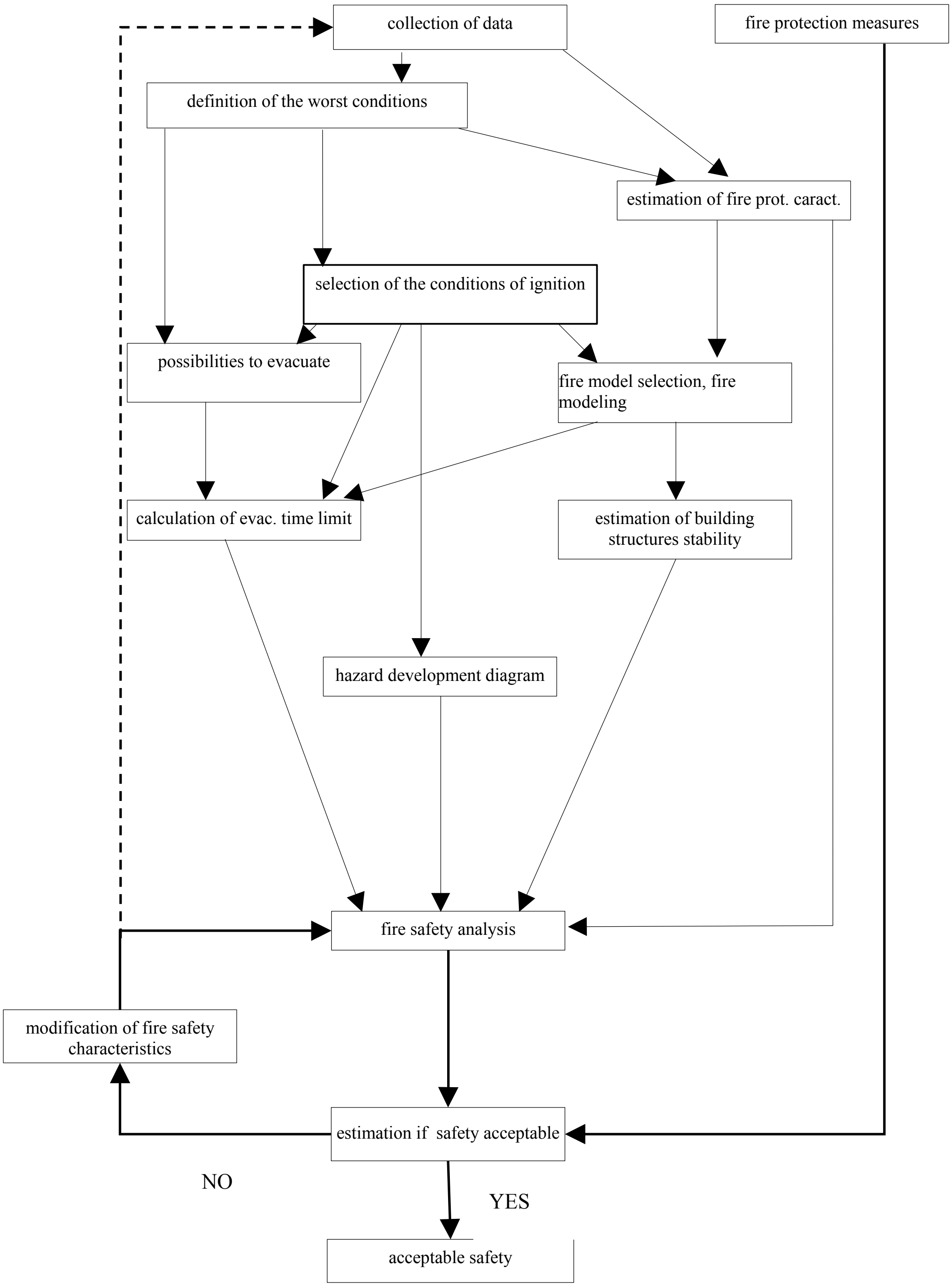

Figure 3

4.6 Case studies

I analyzed two fire cases applying engineering approach. In the first case I showed the usage of the hazard development diagram in the analysis of a fire of a roof structure. The development of the fire, was easy to follow from the time the fire detectors indicated. Indicating this on the same time

axis as the human behavior clearly shows, that delays resulted by human errors (in the security system) mean that the fire will win the race.
In my second case I chose a fire on the third floor of a multi-story brick building, which I analyzed with the HAZARD I. fire model.

5. New results

1. I regard it as a new result that my work is the first comprehensive publication in Hungarian about connections between different theories on closed space fire development, mathematical fire modeling and the theoretical background of the engineering approach in the evaluation of building fire safety. To use it directly and practically, I have built the results of my research into the curriculum of the fire protection engineer training.
2. To examine the effects building structures have on the fire, I have analyzed panel buildings. My results indicate no considerable difference between panel and traditional brick buildings in the respect of the frequency and the causes of fires. About the location of the fire, the most common place of a fire is one of the living-rooms (40%), this is followed by the kitchen (29%), the common storage places (9%), the rubbish shoots and storage room (6%), the balcony (6%), the bathroom (5%) and the other rooms (5%). We can say about the spreading of the fire that vertically, there is no difference between panel and traditionally built buildings, but vertical fire spread specifically occurs in the trash shoots and the air vents.

   While examining the fires in panel buildings, I found that the statistical fire protection system and the fire examination needs updating. We have to collect adequate data to initiate the engineering approach in safety evaluation and for fire modeling, what is more, it also enables us to process the data from various different perspectives.
3. I have analyzed the differences between the now used static and the engineering approach's dynamic attributes. I have shown that static elements (like fire load, fire safety classification and the fire resistance limit determined by them) have a major defect, namely, that we cannot observe the changes of the processes in time. Making calculations of the fire resistance limit, I have proved that the exclusive usage of static elements might cause uncertainties. (4.2.1 chapter, calculation)

   When examining the role of the fire location (4.1 chapter) I have shown that the usage of dynamic attributes (heat production speed, combustion speed, smoke production speed) enables us to estimate relative fire safety when selecting materials for the interior of the building and to use fire safety considerations in their use. I presented the examination results of dynamic parameters with the help of my own research using textiles used for building interiors in a Cone-calorimeter. (appendix 7.)
4. I have made a comparative study regarding building fire safety regulations in the EU and in Hungary. I have shown that between the evaluation curves to determine a building's fire resistance limit used in Hungary and the EU there is a 20 C difference. Based on my research it also became clear that the European Union allows the usage of a different curve in cases when the fire load differs from the usual. At present, this is not possible in Hungary, even though, it could be justified, as there is a great difference in the severity of fires. I have also shown that in the EU there is a possibility to use the engineering approach and mathematical fire models, but their use is not regulated in any way. To help introduce the mathematical fire models in Hungary, I conducted a desk research about the models at our disposal and have analyzed the possibilities of their use. The results are summed up in table 5. The table contains characteristics of a total of 86 different fire models.
5. I have shown and summed up in ten points, the disadvantages of the "regulation based" traditional fire safety evaluation method currently used in Hungary (table 6.) Similarly, I have shown the advantages and disadvantages of the engineering approach. In my opinion,

the usage of any of these approaches does not exclude the possibility to use the other one as well. From my analysis it became clear that despite its disadvantages, we cannot get around the traditional methods, however usage of the engineering approach might serve as a supportive argument both during the planning or the fire investigation stage, and occasionally might be of crucial importance. I have shown the usage of a fire model for an actual fire case. (4.5 chapter, case 2.)

6. I have worked out the process of complex fire safety evaluation, I have defined the term: "complex fire safety evaluation" and presented the method on a figure. (figure 19.) Complex evaluation of the fire safety of buildings extends to the safety of the people inside the building and the analysis of the effects on the building structure in a way that it combines the usage of traditional evaluation methods and the engineering approach, not yet used in Hungary.
7. My "hazard development diagram" enables us to follow the changes in the development of a fire and the actions of people in danger in time, when evaluating building fire safety. the diagram connects old and new methods (passive and active) and illustrates the changes in the danger situation, thus making it easier to analyze. I have shown the usage of the diagram through an example (fig. 21.)

6. Conclusions and recommendations

Based on my results in my study, I would like to sum up my recommendations as follows:

1. My work proved the fact that for the evaluation of building fire safety, the method that has been in practice for some time based on fulfilling regulations is not adequate in itself. There is no proof, that keeping the regulations can me a measure of safety.
2. It has also became clear, that together with static attributes such as fire load, we also have to use dynamic ones, like heat release rate in practice.
3. We must not be afraid to use fire spread models, primarily zone models. The models, however have to be chosen very carefully, as they are task-specific. In selecting the right model, the table I have put together can be a great help (table5.)
4. I would not recommend using the fire models on their own, as their usage requires an engineering degree and, especially in the case of input data, requires solid practical knowledge and the knowledge of connecting theories.
5. I recommend using my complex fire safety evaluation method in preparation of the new legal regulations concerning fire safety. The method's great advantage is that it fuses both the traditional and the engineering approaches, which complete each other. Fulfilling the regulations and using the engineering approach at the same time can also be justified by the fact, that with this, the results of the analysis will become clear even for the ones without a technical degree, when compared them with the relavant regulations. I would like to note, however, that the safe usage of the method requires an engineering degree.
6. The complex evaluation method can be used in creating new regulations, to analyze actual fire cases, to evaluate plans, to test existing plans, and as a supporting method to evaluate fire safety of already existing buildings.
7. I recommend the introduction of the engineering method into the school curricula as well.
8. The introduction of the engineering method into building fire safety evaluation requires a new approach in fire prevention, fire examination and the statistical data collection in fire-related damages. I would also find the extension of the fire examination process in to the examination of the fire spread attributes useful.

There are 137 bibliographical references in the thesis.

My own publications on the topic

Books

- Balogh F., *Beda L.,* Kovács I, Nagy B : Tűzvédelem, Budapesti Műszaki Egyetem, Mérnöktovábbképző Intézet (1997)
- *Beda L.* - Mórotzné Cecei K.: Laboratóriumi gyakorlatok tűzvédelmi szakos hallgatók számára - Cone kaloriméter Budapest, YMMF (1999)
- *Beda L.:* Tűzmodellezés, tűzkockázat elemzés Budapest, SZIE-YMMFK (2000)
- *Beda L.:* Mérnöki szemlélet az épületek tűzbiztonságának megítélésében, in Munkavédelem (18. aktualizálás), Budapest, Verlag Dashöfer (2003)
- *Beda L*.: Égés és oltáselmélet II., főiskolai jegyzet tűzvédelmi szakos hallgatók részére Budapest, SZIE YMMFK (2004), megjelenés alatt

Presentations

- *Beda L., Kis-Tót Sz. R: Építés- szerelési munkák során előforduló tűzkockázat hibafa analízise,* Kandó Kálmán Műszaki Főiskola Centenáriumi Tudományos Ülésszaka (1998) poszterelőadás
- *Beda L.:* Fire Risk and Fire Hazard Assessment, two-week-course organized by the Kocaeli University, Izmit, Turkey, (1998)
- *Beda L.:* Tűzkockázat elemzés, Tudományos szimpózium Siófok, Magyar Kémikusok Egyesülete, Biztonságtechnikai Szakosztály (1999)
- *Beda L.:* Épületek tűzbiztonságának mérnöki szemléletű megítélése, Országos Munkabiztonsági Tudományos Konferencia, SZIE Gyöngyösi Főiskolai Kar (2003)
- *Beda L.:* The structure of the fire investigation process in Hungary, International Conference on Fire Investigation, Fire Service College, Poznan, Poland (2003)

Other publications

- Mórotzné-*Beda*: Belső téri textíliák tűzveszélyessége Tűzvédelem 9 (1988) 14
- *Beda*-Mórotzné: Fire Spread Characteristics, in ed. Zalka : LPS Buildings in Hungary, Building Research Establishment, (1991)
- *Beda L.:* Tűzvizsgálat: új megközelítés, amely a jövő kulcsa lehet, Védelem, 4 (1994) 31
- *Beda L*.: Az épületek tűzbiztonságának megítélése, Védelem, 2 (1996)24
- *Beda L*.: A Budapest, IX. Boráros tér, Céhek Háza tetőterében 1997. augusztus 13-án keletkezett tűz szakértői vizsgálata, szakértői jelentés (1997)
- *Beda L.:* Matematikai tűzmodellek, Informatikai hírlevél, BM Tűzoltóság információs lapja (1999)
- *Beda L.:* Analytical Report on the Fire Safety of the Polishing Technological Unit at the ALCOA Wheel Product Europe Ltd. (1998) – szakértői elemzés
- *Beda L., Bukovics I.:* Új megközelítés az épületek kiürítés-számításában, Alaprajz, 8. p.50, Bertelsmann Verlag, (2004)
- *Beda L., Bukovics I.:* A tűzben képződő füst veszélyességének jellemzése, Védelem (2004) megjelenés alatt
- *Beda L., Bukovics I.:* Épületek mérnöki szemléletű tűzbiztonság-elemzése, SZIE YMMFK, Tudományos közlemények (2004) megjelenés alatt
- *Beda L., Bukovics I.:* Some Remarks on Building Fire Safety Evaluation, Annual News, (2004) megjelenés alatt