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Experimental study on examining the fire load of a small compartment

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ORIGINAL RESEARCH PAPER

ABSTRACT

In Hungary a lot of people live in condominiums or in block of flats where fire often occurs despite of precise design and effective fire protection arrangements. This means a hazard for the people living there, for the building constructions and also for the environment. A deeper knowledge of the burning process and examining the negative effects of fire load on building constructions with scientific methods are actual questions nowadays. In order to get to know the phenomena more accurately, fire spread in a bedroom was modeled and numerical simulation was carried out, which is presented in this paper in detail. These experiences may help increasing the fire safety and preventing fires in apartments. The simulations were carried out considering the characteristics of the Hungarian architecture.

KEYWORDS

apartment fire, fire load, fire modeling, numerical simulation, fire safety of building constructions

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1. INTRODUCTION

The topic of this paper is apartment fire which is widely examined by researchers from different aspects. Fire safety quality of the built-in materials, fire spread, and the consequences of the heat for the constructions is examined most frequently [1–3]. Other studies are dealing with the possibilities of reducing the heat load or with the problems of firefighting [4–8]. According to the experiences so far, heat radiation of flue-gases accumulated under the floor slabs conduces to fire spread in closed spaces like rooms beside the direct fire itself. However the high temperature caused by fire is a danger to the building constructions and to people stuck inside. Hence analyzing the damaging effects of the spreading fire, the oxygen level and the produced heat, is an important task.

As enclosure fires originated often in residential buildings, a furnished room in an average apartment is modeled in this paper, considering the characteristics of the Hungarian architecture. The fire spread in the room is analyzed. The initial model is based on preliminary calculations considering the quantity of combustible materials in the room [9]. The model used for simulation, is composed by applying the calculations in order to examine the effects more precisely.

2. ORIGIN OF RESIDENTIAL FIRES

The combustion conditions in general are right amount of fuel and oxygen and enough heat (Fig. 1). After ignition the amount of heat is increasing due to the burning of the combustibles. In addition to the amount of heat generated in the room the smoke contains many additional combustion products due to imperfect combustion. In this case, if one of the doors

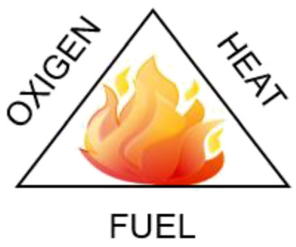

Fig. 1. Fire triangle (by authors, based on the [10])

or windows is opened and air flows into the room, the combustible materials will suddenly ignite, as the combustion conditions are met again.

Once the conditions for combustion have been met, a sudden, intense, rapid spread of fire occurs, which results in the formation of a so called backdraft, which is extremely dangerous for building structures and people in the vicinity.

In surveys it is shown that the most common sources of residential fires are cooking, incendiary, open flame, smoking, electrical distribution system or other electrical equipment or the heating system [9, 11]. Most of the statistics report cooking as the leading ignition source around the world. Kitchen fires contributed about 20–26% to the total number of fires, followed by living areas and sleeping areas with 10–15% each. However the highest numbers of injuries (about 40%) and deaths (about 60%) were reported in fires originated in living and sleeping areas [11]. These cases cannot be extinguished because of the personal element. According to the statistics of Hungarian Central Statistical Office (KSH) deaths caused by fire or its side effects (for example smoke) cannot be retained under 5% of deathly residential accidents [9]. For this reason, an average bedroom is examined as a small compartment in this paper, which properties are presented in the followings.

3. FIRE LOAD CALCULATION OF A SMALL COMPARTMENT

The examination is based on an average Hungarian apartment. This type of apartment is widely applied in condominiums in the last 50 years with its floor space and composition. Recently the two most frequent methods and applied materials for building condominiums are the followings. One is reinforced concrete skeleton combined with clay block bricks and the other is precast concrete walls and floor slabs. The test room is modeled according to the first method. Therefore the external wall, and the boundary common wall is made of 30 cm thick clay block bricks, while the partition wall is made of 10 cm thick clay block bricks. However it is not included in the present research, it is worth notifying that using drywall filled with mineral wool insulation as partition walls is becoming more and more popular. Following the constructing trends, the floor slabs of the test room are reinforced concrete. Ordinary floor layers are modeled in the test room. Above the insulation, the concrete floor is floated by edge insulation strips and finished with floor covering. The window is standard sized, tripled glazed and made of plastic. The height in the room is 2.65 m.

The interior design also follows the average scheme that is placing furniture parallel by the walls and leaving the middle area empty. The flooring is modular synthetic carpet tile. The age of the examined building is 10 years. Floor plan and 3D model of the tested room can be seen below (Fig. 2).

The furniture of the room contains a wardrobe, a drawer, an LCD TV, a desk with chair, a simple bed with mattress and two beanbags. The weight of furniture is estimated for the calculations. Materials and combustion parameters can be seen in the following Table 1. Carpet floor and clothes stored in wardrobe, are also included.

The first step was defining the temporary fire load with the following formula. The aim of calculating the temporary fire load is to get information about the harmful effects of heat. As it was mentioned, the

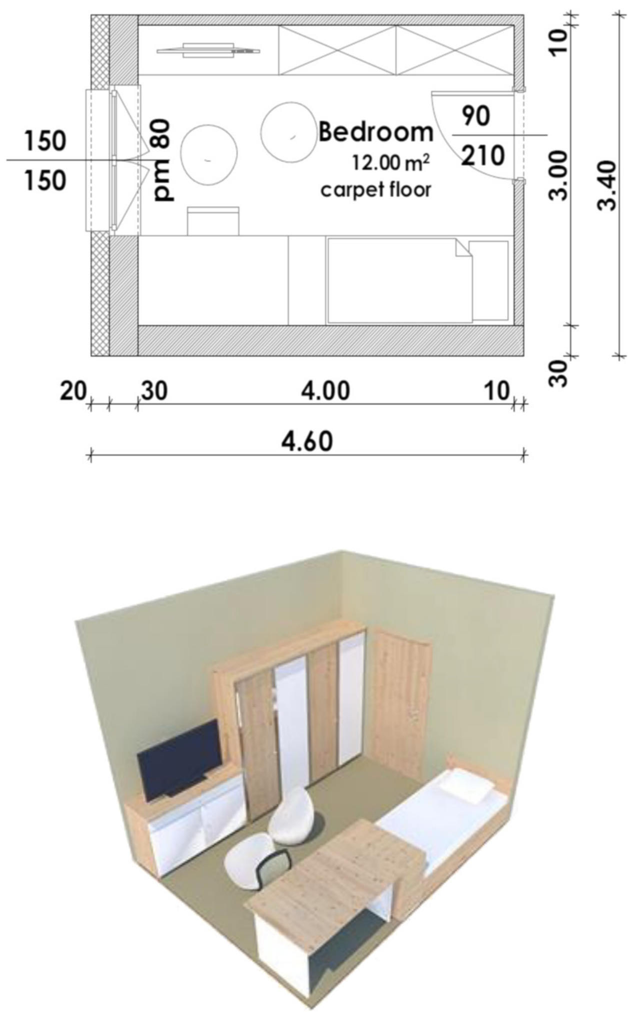

Fig. 2. Floor plan and 3D model of the tested room (edited by authors)

Table 1. Combustial parameters of fixtures and burnable built-in materials found in the tested room (edited by authors according to data in [12])

Type of material	Quantity [kg]	Ignition temperature [°C]	Combustion heat [MJ kg^{-1}]	Density [kg m^{-3}]
Wood (pine)	60	260	16.75	600–900
Fibreboard (hardboard)	100	280	18.84	800–1,500
Paper	10	230	15.9	700–1,200
Textile (synthetic carpet)	50	430	20.93	300
Textile (clothes)	20	340	23.02	60–130
Plastic (TV, fixtures)	20	460	46.47	900–920
Plastic (window)	15	460	46.47	900–920
Fibreboard (door)	40	280	18.84	800–1,500

examined room is 10 years old theoretically. Thus the calculation is based on a standard that was in force then. This standard is the Hungarian National Standard of Fire protection published by 9/2008 *Ministry of Local Government and Regional Development,* and regulation. The calculation is based on the parameters presented in the table above.

$$p_n = \frac{\sum_{j=1}^{n} M_i H_i}{S}, \quad (1)$$

where p_n is the temporary fire load; M_i is the mass of the n-th combustible material [kg]; H_i is the calorific value of the n-th combustible material [MJ kg^{-1}]; S is the floor area of building or part of building [m^2]; j is the number of materials included in temporary fire load.

Completing the calculation, the value of temporary fire load is:

$$p_n = \frac{\sum_{j=1}^{n} M_i H_i}{S} = \frac{5,484.30}{12} = 457.03\,\mathrm{MJ/m^2}.$$

According to the rules of the standard that were in force 10 years ago, the normative fire load was determined in 400 MJ m^{-2}. It is easy to admit that the fire load developed during the ignition of furniture exceeds the permitted value. The developed heat is enough to inflame the built-in combustible constructions (door, window). Therefore also the constant fire load has to be determined with the following formula.

$$p_s = \frac{\sum_{j=1}^{k} M_i H_i}{S}, \quad (2)$$

where p_s is the constant fire load.

Completing the calculation, the value of constant fire load is:

$$p_s = \frac{\sum_{j=1}^{k} M_i H_i}{S} = \frac{1,450.65}{12} = 120.89\,\mathrm{MJ/m^2}.$$

Summarizing the temporary and constant fire loads, one can get the calculated fire load:

$$p = p_n + p_s, \\ 457.03 + 120.89 = 577.92\,\mathrm{MJ/m^2}. \quad (3)$$

As the permanent fire load exceeds the value permitted by the standards, it can cause irreversible damages in the constructions if firefighting does not start in time.

4. SIMULATION MODEL

Using the calculated data above and preliminary calculations, an experimental numerical simulation using Fire Dynamic Simulator (FDS) was carried out [13]. FDS is a Computational Fluid Dynamic (CFD) [14, 15] software to simulate fire and smoke spread. In the scientific literature there are several examples of using FDS to examine fire spread in different rooms. In [16] the fire spread in a room is examined with numerical simulation and experimental study. It was assumed that a bin full of paper was ignited. It was observed that the fire growth was faster in the simulation, otherwise the simulation could capture the temperature and spread of fire and smoke well. In [17] the fire spread in different rooms and a residential building is examined with numerical simulations and full-scale tests. It was observed, that the temperature was risen to 800–1,000 °C in case of the numerical simulation, which was less than in case of full-scale tests. The peak temperature was reached faster in case of the numerical simulation. In [18] the pressure risen in different size rooms is examined. It was observed, that increasing the room size increased the pressure rise and the pressure drop. In [19] different ventilation scenarios are investigated in order to study the effect of ventilation on fire dynamics in a small room. The fire consisted of a sofa and 2 wood cribs underneath it. It was investigated how the location of openings affect the fire characteristics. Examining the available literature on the topic it can be seen that most simulations were carried out in case of larger rooms or a simplified model was used with one piece of furniture to compare the numerical results with real life tests. Most simulation used assumed fire, the reconstruction of real fire cases is rarer. Therefore our aim was to simulate a real fire case, in which the television exploded in the living room. The other purpose of the simulation was to investigate the possibility of examining the spread of fire in enclosed rooms in simulation environment. The simulation setup and the presented results will be the basis of forthcoming researches. To simplify the simulation and to reduce the calculation time, furniture was modeled as blocks (see Fig. 3).

Density of the pieces of furniture was given by the weight ratio of their materials (see Table 2). The ignition properties (reference temperature, heat of reaction, heat of combustion) were based on Table 1 and FDS reference examples.

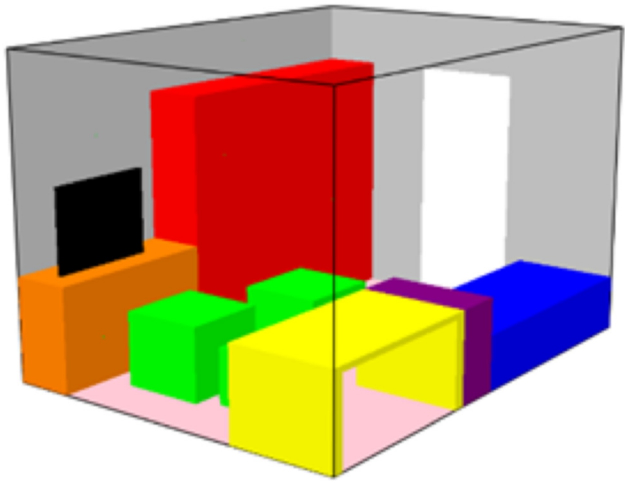

Fig. 3. Tested room in simulation environment (edited by authors)

The width of the materials was specified based on FDS simulation examples [13].

The material of the television was plastic with a thickness of 0.05 and the material of the carpet was synthetic carpet with a thickness of 0.05. The material of the wall was based on FDS simulation tutorials (conductivity = 0.6 W m^{-1} K^{-1}; specific heat = 0.84 kJ kg^{-1} K^{-1}; density = 1,440 kg m^{-3}) [13].

The size of the mesh was 5 cm. It was the smallest mesh size that could be used with using a laptop. According to [17] this mesh size is sufficient in a compartment with this size. In the future simulations a more detailed mesh sensitivity analysis will be carried out using supercomputers.

The simulation time was 15 min according to the following:

- The alarm time of a professional fire brigade is 2 min;
- The travel time to the location of the fire is 10 min;
- Preparation for firefighting is 3 min.

A 10-min time limit for the arrival of firefighting units on site is an EU recommendation [20]. In Hungary, the area of intervention of firefighting units has been defined in a way that they can keep the recommended time [21].

First, a simulation was carried out with opened door and window and then one with a totally closed room. For measurement, temperature sensors were set in simulation environment. The sensors were located as follows: 4 in the corners of the window (A1-A4), one in the center of the room (S1) and one above the wardrobe (S2) next to the wall (see Fig. 4 and Table 3).

The sensors placed in the 4 corners of the window provide important information about the heating and fire spread of the immediate surroundings. This information will be especially useful to model fire spread in façade. Additional sensors were placed at a higher point on top of the wardrobe to examine changes in the upper air layer as well as to the center of the room to examine the effects of fire spread on persons who might be in the room.

In both simulations the TV located on the drawer was the ignition source. The fire spread 5 min after the ignition is shown in Fig. 5.

Table 2. The weight ratio built in the pieces of furniture (upper row) and thickness of materials (lower row)

	Wood	Fiber	Paper	Textile
Wardrobe	0.30	0.50	–	0.20
	0.01	0.01		0.01
Bed	0.20	0.35	–	0.45
	0.01	0.01		0.01
Drawer	0.375	0.625	–	–
	0.01	0.01		
Desk	0.375	0.625	–	–
	0.01	0.01		
Folder	0.12	0.21	0.67	–
	0.01	0.01	0.001	
Chair	0.375	0.625	–	–
	0.01	0.01		

5. RESULTS

During the first simulation, the fire spread quickly to the furnishings in the room due to oxygen supply (Fig. 5). The temperature increase measured with the sensors is shown in Fig. 6.

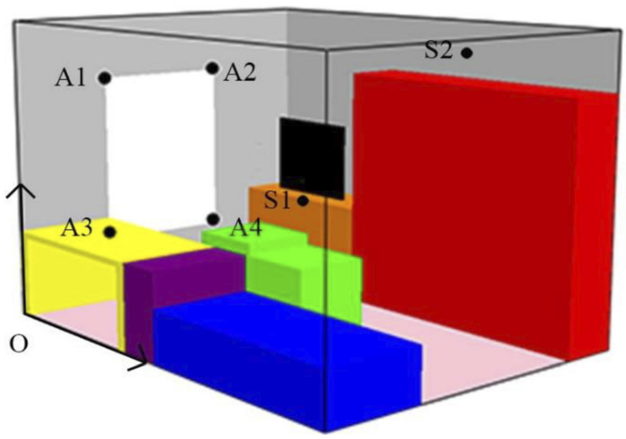

Fig. 4. Locations of sensors in the tested room in 3D (edited by authors)

Table 3. Location of sensor from the origin (O)

Pont	X	Y	Z
A1	0	0.9	2.05
A2	0	2.1	2.05
A3	0	2.1	0.55
A4	0	0.9	0.55
S1	2	1.5	0.55
S2	2.7	3	2.4

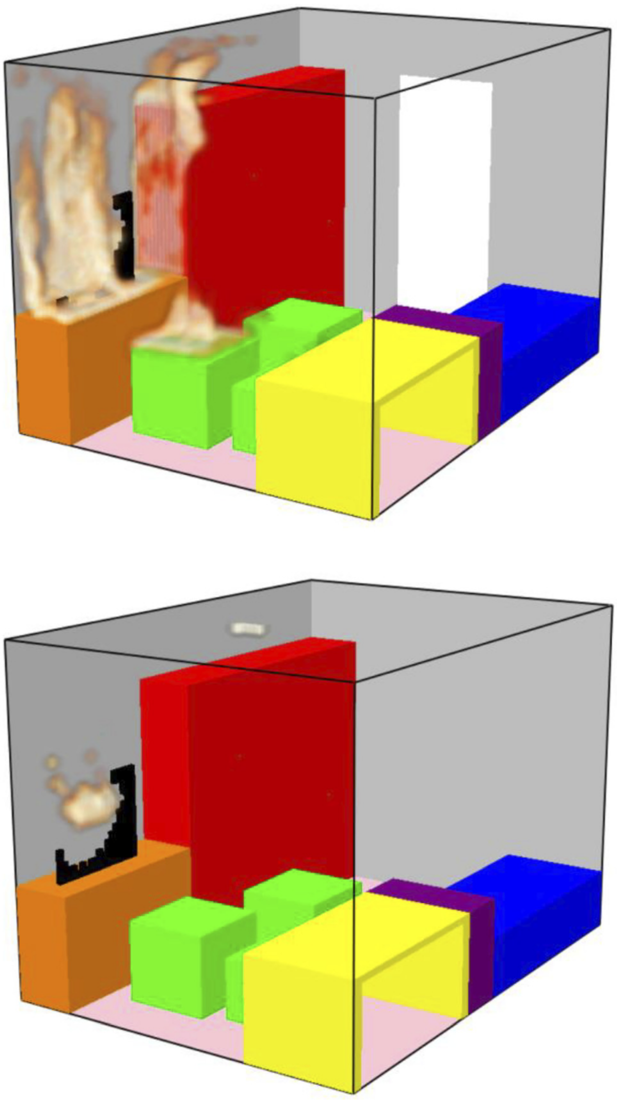

Fig. 5. Spread of fire in simulated environment, 300 s after ignition with opened and closed door and window (edited by authors)

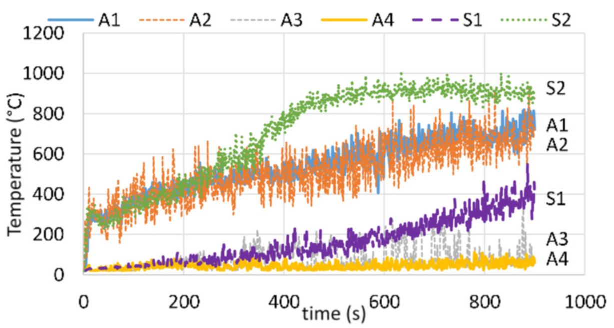

Fig. 6. Spread of fire in simulated environment, 300 and 600 s after ignition with closed door and window (edited by authors)

It can be observed that the highest temperature increase was measured with the sensor above the wardrobe (S2). The temperature is higher at the sensors, which are placed higher. This can be explained that the heat is released from the ignition and burning of the furniture and then propagated extended vertically downwards from the ceiling.

During the second simulation, the fire could not get oxygen supply due to the closed door (Fig. 5). The temperature increase measured with the sensors is shown in Fig. 7.

Examining the results, it can be seen that the highest temperature could be measured with the sensors at the top of the window (A1, A2) and above the wardrobe (S2). The cause of it is that this can be explained with the heat generated during the fire is concentrated under the ceiling. Due to decrease in the amount of oxygen (O_2) available in the room, the intensity of the combustion and then the spread of the fire were decreased. If the fire does not supply oxygen and cannot break out of the room, the oxygen concentration in the room's air starts to decrease when the rate of reduction reaches 14 vol%, the fire is extinguished.

The total Heat Release Rate (HRR) is shown in Fig. 8.

It can be seen that the heat release rate is continuously increasing till 2,500 kW in case of opened door and window. In case of closed room it increases fast after the ignition, then it drops, then increases again till 500 kW and after the fire has been extinguished it decreases till 0 kW.

From the heat release rate the fire load can be estimated with a similar formula, presented in Section 3 [22]. It is

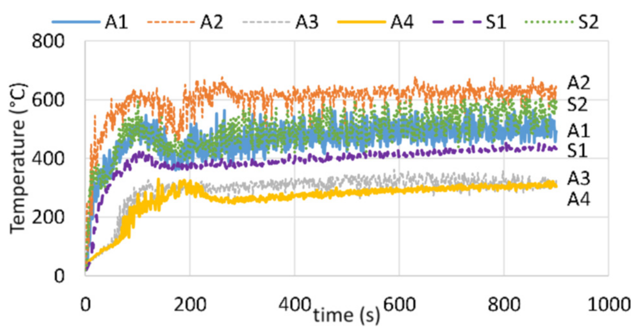

Fig. 7. Temperature versus time diagram with closed door (edited by authors)

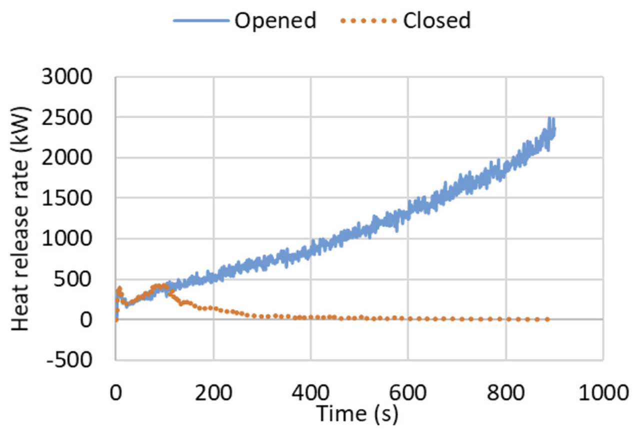

Fig. 8. Heat release rate in case of opened and closed door and window (edited by authors)

80 MJ m^{-2} in case of opened door and window and 5 MJ m^{-2} in case of closed room. It is less, than the value given in standard. This is caused by the assumption that the fire extinguish started in time (after 15 min) and that not all the furniture were burned down. Also the modeled pieces of furniture were assumed as solid blocks, which burn slowly. Further research will be necessary to investigate how detailed furniture models affect the simulation results. From Fig. 8 it can be seen that the HRR increased with time, therefore without firefighting the building would be damaged. In the future additional simulations are planned with more accurate furniture models as well to gain more accurate estimation about the fire load of buildings. New case studies are also planned, which include the braking of the window and the fire spread at facades.

6. CONCLUSION

Most fires originated in closed spaces of buildings are caused in residential buildings. Protecting the lives of people stuck in, reducing the fire loads of constructions, defending of furnishing and assisting the firefighting during fire requires continuous scientific researches. In this paper a furnished room in an average condominium is modeled and the effects and consequences of fire inflamed in the room is examined. Researches so far confirmed that computer simulations support understanding the process of ignition, the phenomenon of fire spread and how different factors affect each other. A fire originated in an average room is examined and simulated with a determined period. However it should be noted that in most of the apartments the quantity of stored combustible materials is much more, thus a fire could cause higher loads in constructions. The conditions can be modified easily in the simulation presented in this paper, in this way extreme cases could be examined also. Results can be used during designing building as well as during firefighting.

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