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Survey based fire load assessment and impact analysis of fire load increment on fire development in contemporary dwellings

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ABSTRACT

Changing dynamics of residential fires is a result of changes in dwelling size, geometry, spatial organization, contents and building materials over the past 50 years, as well as the added complexity to the fire behaviour. While the physics of fire development has not changed over time, the socio-political and economic tendencies have influenced contemporary dwelling. A single family home has evolved due to changes in building materials and furnishings. An overview of different national codes for defining fire load in residential buildings has shown a great discrepancy and deviation in proposed fire load density. Such uncertainties and changes in the way of living result in the need to continually update fire load data through new fire load surveys.

A study on fire load density was conducted on a sample of 120 three-room family apartments, located in residential buildings and houses in Novi Sad, Serbia. Fire load was determined by the combination method (weighing and inventory) and was compared to other research results. Based on the survey results, fire load density in residential building apartments in Serbia has doubled in the past 30 years, affecting the overall fire safety by the increase of energy being released during combustion.

The influence of fire load density on fire development was studied on a representative apartment using computer code OZone. The consequences of the increase of fire load are mostly reflected on the extension of the fully developed fire stage duration and the maximum temperatures reached, leading to higher fire risk associated to residential housing.

1. Introduction

Calculation of fire loads and densities provide an input on how severe a fire can get if it occurs and what measures should be adopted to arrest it, so as to have minimum damage (Shrivastava and Sawant, 2013). Fire load density can be determined based on prescribed values provided in various standards. However, proposed values differ depending on the standard in use, resulting in a large discrepancy and deviation for the fire load values. There has been a steady change in the residential fire environment over the past decades. The changes that are affecting the fire safety of buildings are mostly influenced by the fire compartment size, geometry, contents and construction materials used (Kerber, 2012). A typical single family home has evolved during the years. Socio-political influence in Serbia during the 20th century has had a great impact on the design of apartments, specifically through spatial organization, furnishing and equipment (Brkanić, 2018). The period until 1945 was characterized by large apartments consisting of two zones (residential and service) and transit rooms forming a circular connection. In the socialism, until 1991, a corridor apartment was introduced, forming the living space around the hall, from which the access to each room is provided. In the post-socialism era, most of the apartments were organized with a central living room, evolving in recent years into a more open space design concept. The open floor plans and, in general, construction of taller ceilings, tend to remove compartmentation and add volume, which can contribute to rapid smoke and fire spread. The use of new materials in interior design, such as plastics and textiles, which are more flammable synthetic materials, and the increased quantity of combustible materials, also contribute to an increased fire load density. Another change is the continual introduction of new construction materials. Contemporary energy efficiency measures in construction building sector and the unregulated use of combustible thermal insulation materials in building facades have imposed an increased risk in external fire spread. The use of modern building technology with low-energy windows and step-noise insulated floors, leads to more severe design fires (Hertz, 2012). Finally, relatively low standard of living and high unemployment rate, have prevented the

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early independence of younger generations, often resulting in several generations of families living in the same dwelling, which naturally increases the amount of furniture and other combustibles. As the building environment is constantly changing, the standards addressing fire load in residential buildings should also be updated.

Changes in fire load density affect the fire safety by influencing temperature development inside fire compartment, as it is used to determine the heat release rate when modelling a fire using performance based design. The influence of fire load density on the development of the design fire is determined by conducting sensitivity analysis using mathematical model based on physical fire behaviour, implemented in the software code OZone (Cadorin, 2001).

2. Fire load survey in residential family apartments

2.1. Fire load calculation methodology

According to Serbian standard (SRPS, 1976), total fire load in apartment Z [MJ] is expressed as multiplication product of fire load density Pi [MJ/m^2] and building floor area S [m^2]. In order to enable extrapolation to different sized compartments, heat content is measured per observed unit floor area, expressed as fire load density.

$$P_i = \frac{\sum_{i=1}^{N} \gamma_i \cdot V_i \cdot H_i}{S}$$

γ_i = specific density of material, kg/m^3
V_i = volume of combustible substances, m^3
H_i = net calorific value of the material, MJ/kg
S = floor area of the fire compartment, m^2.

Values of fire load for residential occupancies vary depending on the standard applied. The fire design verification method of the New Zealand Code assumes design value of 400 MJ/m^2, while Eurocode standards prescribe a much higher average of 780 MJ/m^2, for fire load in dwellings (Buchanan and Abu, 2002).

Fire load can be divided into two categories: movable (furniture, equipment, goods, etc.) and fixed fire load (walls cladding, ceilings, floors, doors, windows, shelves etc.), which are to a large extent bio-based products.

In the French survey process a further distinction is made between objects with a simple geometrical shape (e.g. desk, cupboard) and those where characteristic dimensions are hard to estimate (e.g. chair) (Thauvoye et al., 2008). Also, types of furnishings, interior finish, and occupancy trends are changing considerably over the last decades, so new fire load surveys for different type of occupancies are being conducted in various countries, using modern surveying techniques. In a study by (Gross, 1977), the magnitude of room fire loads and live loads was reported to be related to the use of the room.

According to EN methodology (Vassart, 2014), fire load can be determined based on deterministic and statistical methods. Selection of appropriate method relies on the purpose of collected data, i.e. its justification on the field and its reliability.

Based on the deterministic approach, fire load density can be estimated by summing all fire loads present in the building. The characteristic fire load density is defined by the equation:

$$q_{f,k} = \frac{1}{A_f} \sum_i (\psi_i m_i H_{ui} M_i)$$

M_i = mass of the material, kg
H_{ui} = net calorific value, MJ/kg
m_i = factor describing the combustion behaviour
ψ_i = factor assessing protected fire load
A_f = floor area of the fire compartment, m^2.

The survey techniques, used to determine fire load, include: weighing, inventory, combination on weighing and inventory, questionnaire and website review method (Kumar and Kameswara Rao, 1995). The combination of direct weighing and inventory method makes it possible to directly measure those items which are present in the fire load measuring area and at the same time could easily be weighed, while fire load of large items or items embedded in the interior, are determined with inventory method, based on their volume and density. If the weighted item is homogenous in terms of material, the measuring error originates from the scale measurement error, but if it consists of different material types, the percentage of each type would need to be determined based on the inventory method. Irregular geometrical forms require estimations and simplifications by the surveyor regarding the item volume calculation, which could result in about 10% degree of error as compared to the direct weighing method (Zalok, 2011). Hence, the combination method, where direct weighing is not applicable, would be favourable in terms of minimizing the degree of uncertainty and error. A fire load survey in residential buildings, carried out by inventory technique in India (Kumar and Kameswara Rao, 1995) reported mean fire load values from 278 MJ/m^2 to 852 MJ/m^2. Also, as the room floor area increased, it was noticeable that the mean and maximum value of fire load decreased.

The questionnaire method is based on direct measurement made by the participants. Questionnaires include questions related to basic information about the typical furniture located in the premises, type of flooring, materials of the interior elements, floor area and other data that would enable an indicative calculation of fire load based on average fire load for the specific types of interior design. The practical application of this method is in buildings where it is not possible to provide direct access to the practitioner. As the data collected in this way are usually qualitative, this information cannot be easily verified.

The fire load can also be defined as a statistical distribution. In practice, the fire load will vary with the occupancy, location in the building and with time, and can be determined as a statistical distribution with a mean value and a standard deviation. This statistical approach is only valid for building types where similar amounts of fire load can be expected. These include specific types of buildings, such as offices and schools, but are less reliable for certain types of buildings, such as residential ones. Based on a Gumbel type I distribution, the extracted mean values of fire load density for dwellings are reported as 780 MJ/m^2, (948 MJ/m^2 for 80% fractile), with a standard deviation of 234 MJ/m^2 (Vassart, 2014). The statistical investigations made on fire load density in residential homes in Sweden in the 1970s (Pettersson et al., 1976), reported that 80% of three-room apartments have a fire load less than 148 MJ/m^2 of enclosing surface, or, converted to a floor area by a factor of 3.95 (Hertz, 2007), a fire load density of 585 MJ/m^2. In a separate study on 15 apartments of an arbitrary size in Denmark (Hertz, 2007), the reported average fire load value per unit floor area was 367 MJ/m^2 with a standard deviation of 218 MJ/m^2.

In a survey conducted in Canada in 2004 (Bwalya et al., 2011), a website review method was applied. Information was obtained through a real-estate website which offered the layout, size and photographs of main rooms. Fire loads were estimated based on the calorific value of items sufficiently similar to the fuel package. The quality of information depends on the quality of photographs, taken for the purpose of the agencies, often presenting tidy and ideal settings, which do not represent real situation. The advantage of this method is that it does not require physical presence of the surveyor, but the assumptions and estimates made based on the photographs may result in some degree of error.

2.2. Case study: Survey of fire load in dwellings in Serbia

According to the Census of Population, Households and Dwellings in the Republic of Serbia (Census, 2011), the average number of occupants in dwellings in Serbia is 2.4, with the majority of dwellings (62.3%) accommodating 2–4 occupants (Housing Units, 2013). The average floor area of dwellings is 72.3 m^2, resulting in the average floor space per occupant of 30.6 m^2, with 53.4% of residents occupying in between 10 and 30 m^2 of floor space, on average. Among the total number of

occupied dwellings in Novi Sad (114.451), the most frequent are two-room apartments (37.9%), followed by three-room apartments (26.1%). In terms of the share of the total floor area, both two- and three-room apartments are equally distributed, covering around 30% of the total dwellings' floor area, each (Fig. 1).

In a survey carried out in this study, the combination method (weighing and inventory) was chosen for calculation of fire load. A sample of 120 three-room family apartments (as the most represented, in terms of the total area share), located in residential buildings and houses in Novi Sad, Serbia, was selected and surveyed, covering a total area of approximately 8700 m^2. Since such type of survey is sensitive to the privacy related issues, only apartments with a given consent from the occupants, providing direct access for the survey, were taken into consideration.

The following assumptions were made to simplify the data collection:

- all combustible material would be involved in fire
- all combustible material in the fire compartment would be completely burnt out during fire
- the fire load contributed by doors and windows between rooms was considered as fire load of belonging rooms.

The aim of the survey was to identify the fire load density in building apartments of similar type. Both fixed and movable fire loads were considered. In order to calculate the fire loads, rooms in the apartments were categorized on the basis of their usage. Living rooms, bedrooms and kitchens were considered, as premises in which fires were most likely to start (FSA, 2018; Ahrens, 2019).

The first step in the survey was to classify the combustibles into fixed and movable fire loads. The movable loads were determined based on direct weighing of each item in the compartment. For items consisting of different materials, an estimation of the percentage share of each material, e.g. wood, metal, glass and plastic parts, was made. The volume of paper and clothes stored in wardrobes and shelves was determined assuming they were 100% full. The present materials in the rooms were classified as: wood, steel, glass, plastics, cotton and paper.

Items that are classified as fixed fire load and could not be easily weighted were assessed based on the inventory method. Their dimensions were measured and the mass was calculated by multiplying the obtained volume and the specific density of material.

The total energy value of the combustibles was calculated by multiplying the mass of each material with the corresponding calorific value found in (Kadić and Sekulović, 1985; Kumar and Kameswara Rao, 1977; Buchanan, 1994; Joshi, 1970; Babrauskas, 2002; SFPE, 2008). Fire load is calculated for each room in the apartment (Fig. 2). Finally, the fire load density was derived by dividing the total fire load in the apartment by its total floor area.

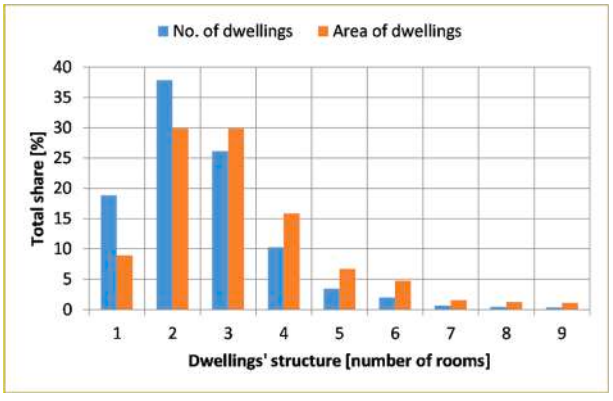


Fig. 1. Dwellings in Novi Sad according to the number of rooms (Census, 2011).

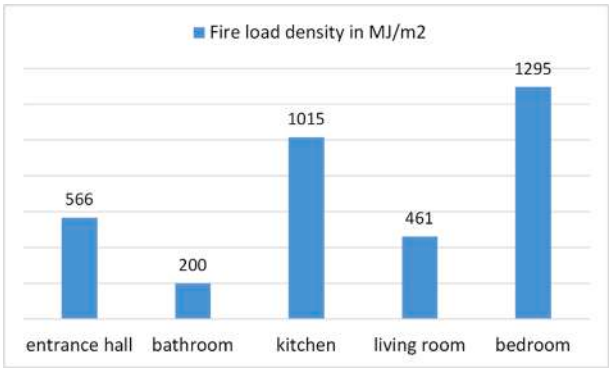


Fig. 2. Fire load density for each room in the characteristic apartment in MJ/m^2 of floor area.

2.3. Results and discussion

A mean value and standard deviation of fire load densities obtained in this study, as well as the statistical distributions presented in different studies are shown in Table 1.

The values of fire loads were found to be varying depending on the room usage, floor area and the type and quantity of material stored. The average fire load density (floor area) was 702 MJ/m^2, with a standard deviation of 59 MJ/m^2. The obtained fire load densities ranged from 617 MJ/m^2 to 768 MJ/m^2. Very high and very low fire loads were found to be less prevalent.

Kitchens with dining rooms (fire load density of 1020 MJ/m^2) had significantly higher fire load densities than other rooms due to relatively small floor areas and heavy wooden cabinets equipped with combustible materials (oil, flower, sugar, etc.). The lowest mean fire load value of 772 MJ/m^2 was calculated for living rooms, mostly due to relatively large floor areas with minimal furnished spaces. Within all apartments a major share of combustible materials were wood and bio-based materials. The most of the living rooms had laminate or hardwood flooring. Bedrooms were mostly equipped with additional carpeting, while kitchen floors were covered with vinyl flooring or ceramics.

According to this study, the fire load density in residential buildings in Serbia has increased about 110% in the last 30 years. Compared to the study performed in 1970 (Holm and Oksanen, 1970), the calculated fire load density is about 80% higher. This might be attributed to the increased quantity of combustible materials present in the buildings and the increased use of more flammable synthetic materials such as plastics and textiles. Differences might also occur due to different approaches when collecting data for the estimation of fire load. For bedrooms and kitchens, similar differences from analysed case studies are present. Obtained results are similar to values presented in Eurocode 1, part 1–2

Table 1
Mean value and standard deviation of fire load density.

[MJ/m^2]	Whole apartment	Living room	Bedroom	Kitchen
Present case study				
Mean value	**702**	**772**	**930**	**1020**
Standard deviation	**59**	**135**	**205**	**225**
Kadić and Sekulović, Serbia, 1985				
Mean value	335	–	–	–
Holm and Oksanen, Finland, 1966				
Mean value	391	–	–	–
Vassart, 1991				
Mean value	780	–	–	–
Standard deviation	234	–	–	–
Cambell, USA, 1970				
Mean value	320	350	390	290
Bwalya, Canada, 2004				
Mean value	445	412	534	801
Standard deviation	–	127	135	123

(EN, 2002), which are based on 33–46 year old fire load density studies. Fire load density values obtained in the studies performed in USA (Campbell, 1981) and Canada (Bwalya, 2004) are comparable to results from Serbia (Kadić and Sekulović, 1985) and Finland (Holm and Oksanen, 1970).

3. Numerical analysis on the influence of fire load on fire development

The computer code OZone, developed at the university of Liege, Belgium, has been validated [Borg and Njå, 2013) based on comparison of the simulations results with the results measured in various real compartment fires (Cadorin and Franssen, 2003; Cadorin et al., 2003; Remesh and Tan, 2007). The software is based on the mass and energy balance equations. It contains a model that combines two-zone and one-zone fire models, with a transition at the moment when the total energy and mass in two-zone model are equalized to the energy and mass in one-zone model. The temperature within each zone is considered to be uniform. The one-zone model is, thus, valid in case of fully developed fires (after the flashover occurs), while a two-zone model is a better representation of localized fires, taking into account a hotter layer, which is close to the ceiling and a cooler layer which is close to the floor. The transition criteria from the two-zone to the one-zone model are met if the thickness of the lower layer is small compared to the height of the compartment (less than 20% of the compartment height), or if the temperatures developed are high enough to provoke spontaneous ignition of the remaining combustibles (higher than 500 °C), as proposed in (EN, 2002). The mass balance equation considers variation of the gas mass of a zone, due to combustion and mass coming in and going out of the compartment through the vents, while the energy balance equation assumes that the energy produced in the compartment by combustion, is equal to the energy consumed by the heating of the gases in the compartment, mass loss of hot air through the openings, radiation loss through the openings and heating of the compartment enclosure surfaces (Cadorin et al. 2001).

3.1. Case study of a typical family apartment

A three-room family apartment, representing a typical sample unit from the conducted survey, is analysed to determine the temperature

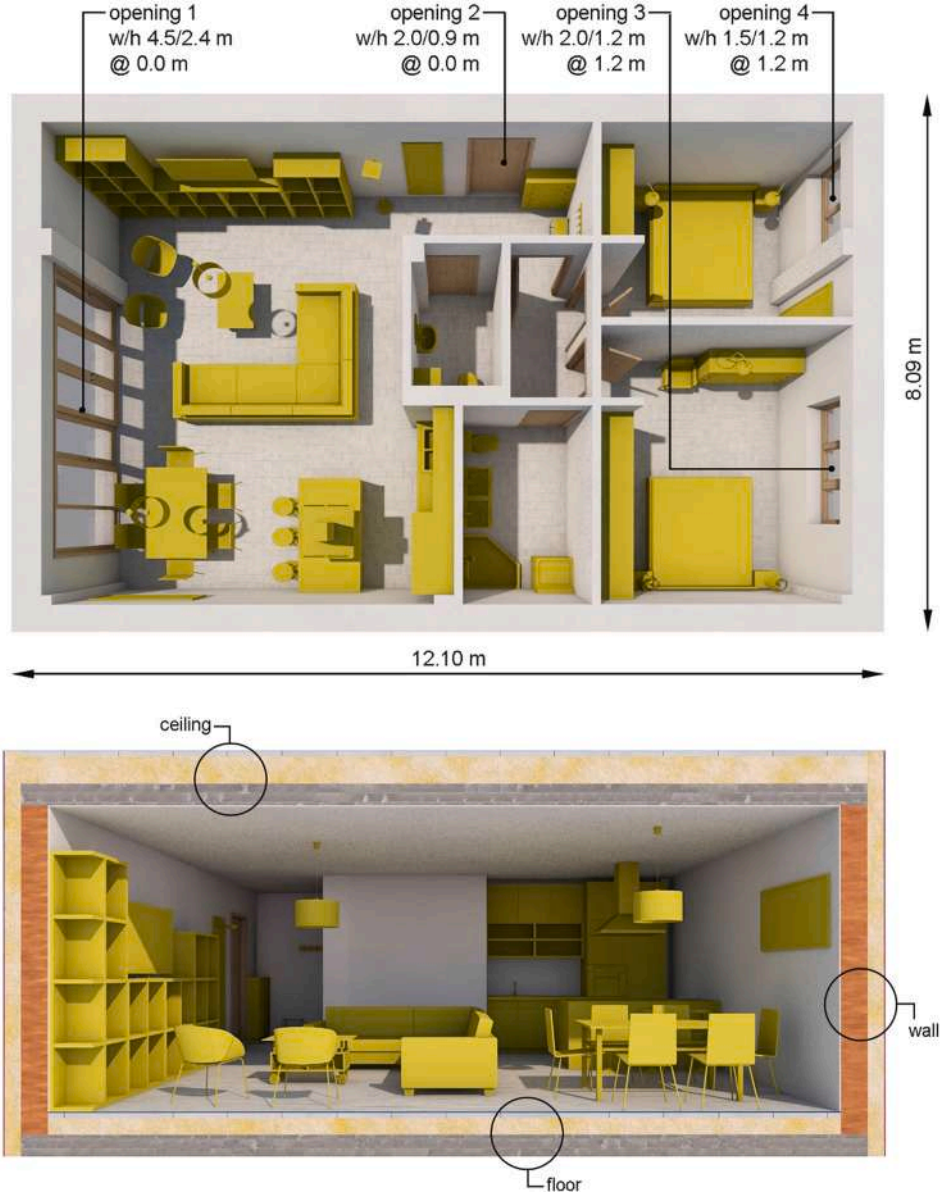


Fig. 3. Geometry, openings definition and boundary layers of analysed three-room apartment.

development of the gases during the course of fire. The whole apartment is considered as one fire compartment. Geometry, layout, openings and the layers of enclosure are presented in Fig. 3 and Table 2.

Residential buildings in Serbia are rarely equipped with forced ventilation systems, which are, therefore, not considered in the analyses. The compartment fire is defined according to Annex E of [EN, 2002], in terms of the design fire load value:

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{q1} \cdot \delta_{q2} \cdot \delta_n$$

$q_{f,k}$ = characteristic fire load density per unit floor area, MJ/m^2

m = combustion factor, assumed as 0.8

δ_{q1} = factor depending on the fire activation risk due to the size of the compartment

δ_{q2} = factor depending on the fire activation risk due to the type of occupancy

δ_n = factor taking into account active fire-fighting measures.

Implementation of active fire-fighting measures in residential buildings in Serbia is mostly reduced to designing safe access routes for fire brigades to approach the buildings and by installing fire-fighting devices, which, in a large number of inspected buildings, were found to be out of order. The reason for malfunction could be attributed to low quality of maintenance over the years and to the absence of certain components, which are free to access, given the inherent purpose, and thus, more exposed to unauthorized persons. Nevertheless, since the design codes for residential buildings require the implementation of safe access routes and fire-fighting devices, they are considered in the analyses, as well as the presence of smoke exhaust system. Other fire-fighting measures are omitted, leading to more conservative analyses results, but on the safe side. Maximum area of the fire is considered to be the entire compartment area, assuming uniform distribution of the fire load.

The adopted combustion model includes the assumption that the release of mass may be limited by the quantity of oxygen available in the compartment. The transition from the fuel controlled to the ventilation controlled fire is predicted when the oxygen inside the compartment is fully consumed, assuming that the pyrolysis rate is proportional to the oxygen coming in the compartment. Although pyrolysis is not directly dependent on the oxygen concentration, this would avoid the uncertainties on the maximum pyrolysis rate per unit floor area, in order to be on the safe side concerning the fire duration (Cadorin et al., 2001).

The opening factor of the enclosed space, which depends on the opening area of windows and doors, the height of the openings and the total area of the surfaces of enclosure, need to be known during all phases of the process of fire development (Magnusson and Thelandersson, 1970). Unlike for parametric fire models, where the openings are considered as constant by the overall opening factor (EN, 2002), in zone models, each opening is defined by the dimensions and position. During the course of fire, ventilation properties could vary significantly, as a result of glazing breakage, automatic opening or firemen arrival, affecting the air flow coming in and out of the compartment. To account for various scenarios, different criteria are adopted, modifying the opening size, and thus, influencing the development of fire. The opened vent size can be defined as a function of the temperature of the zone in contact with the glass, or as a function of time, resulting in five different cases analysed, describing the openings modification as presented in Fig. 4. The influence of the compartment height on fire development is determined by varying the height of the compartment, as 2.6, 2.8 and 3.0 m.

Sensitivity analysis of the fire load increase on fire development is performed by varying the characteristic fire load density within the limits reported in studies presented in Table 1.

Table 2
Layers and openings of the compartment enclosure.

	Material	Thickness	Unit mass	Conductivity	Specific heat
		[cm]	[kg/m^3]	[W/mK]	[J/kgK]
Floor	Ceramic tiles	1	2300	1.28	920
	Concrete screed	5	2200	1.40	1050
	Rock wool	15	60	0.037	1030
	Normal weight concrete	20	2300	1.60	1000
Ceiling	Mortar	1	1700	0.85	1050
	Normal weight concrete	20	2300	1.60	1000
	Rock wool	25	60	0.037	1030
	Concrete screed	5	2200	1.40	1050
Wall	Mortar	1	1700	0.85	1050
	Thermo-block	25	1400	0.61	920
	Rock wool	15	60	0.037	1030
	Mortar	1	1700	0.85	1050

3.2. Results and discussion

The opening factor, corresponding to the constant type of openings, i.e. to the maximum opening size for the analysed compartment, is equal to 0.09 m$^{0.5}$ (EN, 2002). Depending on the criteria of the opening size modification, the temperature development inside the compartment is presented in Fig. 5. In case of temperature dependent opening modification, assuming fully closed compartment until a temperature of 400 °C is reached, the fire has self-extinguished due to the entire oxygen consumption after 11 min (Fig. 6), reaching a maximum temperature of 335 °C, which is below the threshold. In all other cases, flashover has occurred, leading to a fully developed fire. The time at which the fire has become fully engulfed is dependent on the amount of air being able to enter the compartment through the openings, but is not less than 17 min from the beginning of fire. In case of stepwise modification, assuming relatively small opening size of 10% until the temperature of 400 °C is reached, the temperature rise is controlled by the amount of oxygen available in the compartment and is slowly increasing, postponing the time of flashover to 1 h from the beginning of fire. Since a certain amount of fire load has been consumed before flashover occurs, fully developed fire stage in case of stepwise modification lasts shorter, compared to other criteria types, for the same fire load density and compartment height. Nevertheless, maximum temperatures reached are practically independent on the opening size modification, providing that the flashover has occurred, and reach around 830 °C for assumed compartment height of 2.6 m and fire load density of 500 MJ/m^2.

Assuming constant opening factor, the influence of fire load density on temperature development is presented in Fig. 7. Since the decreasing fire stage begins when 70% of the total fire load is consumed (EN, 2002; Cadorin et al., 2001), the duration of a fully developed fire stage increases with the increase of total fire load, linearly, resulting in the extension of 6 min for an additional 100 MJ/m^2 of fire load (Fig. 8), regardless of the compartment height. Comparing fire load density values obtained by surveys in Serbia, duration of the fully developed fire stage corresponding to the present study is 38 min, almost 2.5 times longer compared to the results of the survey conducted by (Kadić and Sekulović, 1985), resulting in 16 min, for a given compartment.

Maximum temperatures developed in the compartment are also influenced by the fire load values, as presented in Fig. 9. Although the relation is not linear, maximum temperature rise is approximately 25 °C for an additional 100 MJ/m^2, ranging from 781 °C to 867 °C, corresponding to fire load density obtained by (Kadić and Sekulović, 1985) and in current study, respectively. Assuming that the openings position is not affected by the height of the compartment, the duration of the fire is not affected, while slightly higher temperatures are computed in case of lower compartment heights, resulting in just 2% increase in temperatures for compartments with a height of 2.6 m, compared to 3.0 m.

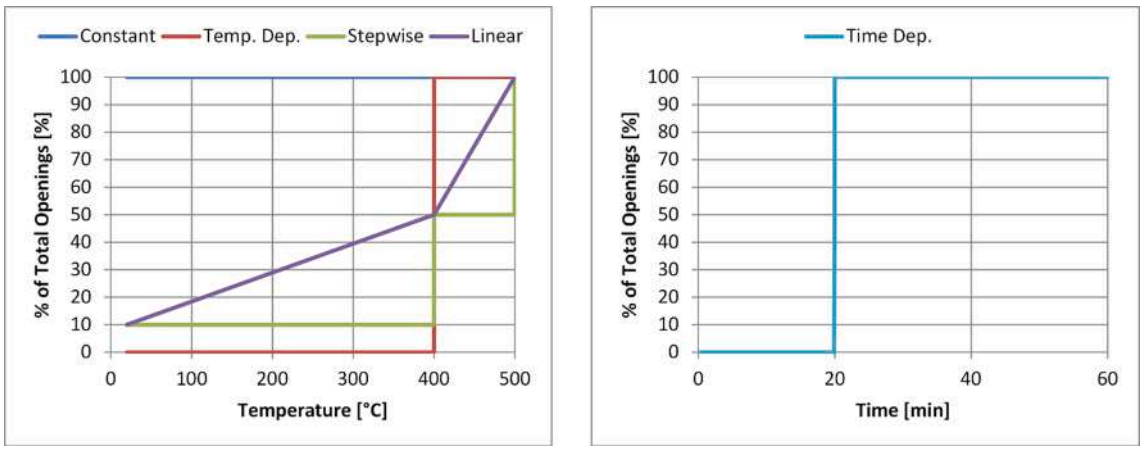


Fig. 4. Opening size modification, as a function of temperature in contact with glass (left) and as a function of time (right).

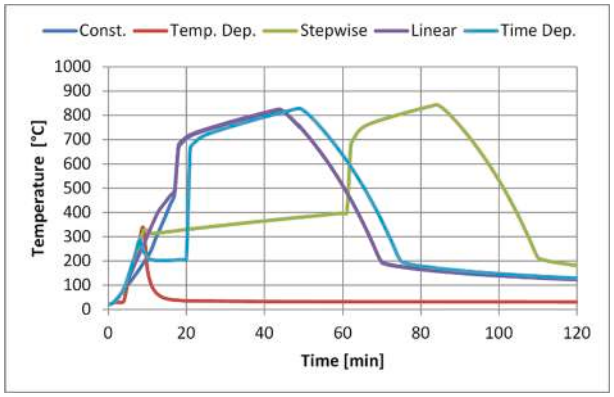


Fig. 5. Temperature development for different opening size modifications, for compartment height of 2.6 m and fire load density of 500 MJ/m$^{2.}$

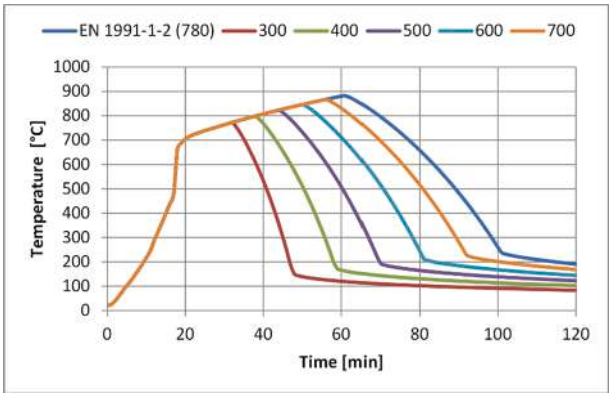


Fig. 7. Temperature-time development for different fire load density values.

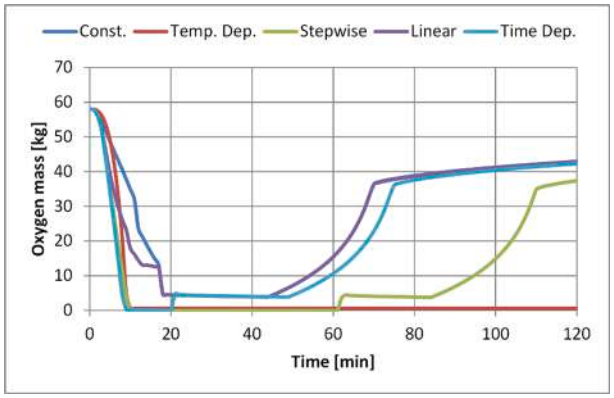


Fig. 6. Oxygen mass inside the compartment for different opening size modifications, for compartment height of 2.6 m and fire load density of 500 MJ/m$^{2.}$

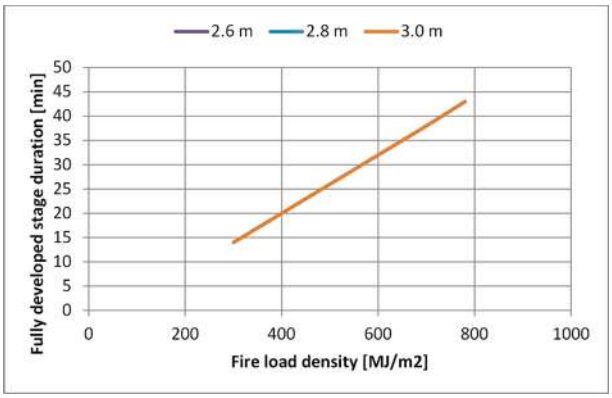


Fig. 8. Duration of the fully developed fire stage for different fire load density values.

4. Conclusion

The evolution of a typical family dwelling, in terms of size, geometry, contents and construction materials used, has influenced the available quantity of fire load, and indirectly, the dynamics of residential fires. Also, the use of materials with unknown composition and uncertain flammability behaviour, has contributed to the rapid onset of untenable conditions and shortening of escape time. These changes impose the need to continually update fire load data through new fire load surveys.

Differences in proposed fire load values, noticeable in various standards and textbooks, could lead to the uncertainty when calculating fire performance, imposing a need for more comprehensive direct approach in determining fire load values in order to predict the fire behaviour more accurately. Recognizing disadvantages of individual methods for determining the fire load, combination of direct weighing and inventory method was applied, as this approach mostly reduced measurement errors that appear when applying individual methods.

From the survey on 120 three-room family apartments in Novi Sad, Serbia, it can be concluded that the fire load density has increased by a factor of 2, compared to the period 30 years ago, resulting in an average value of 702 MJ/m^2 of compartment floor area. Results of the presented

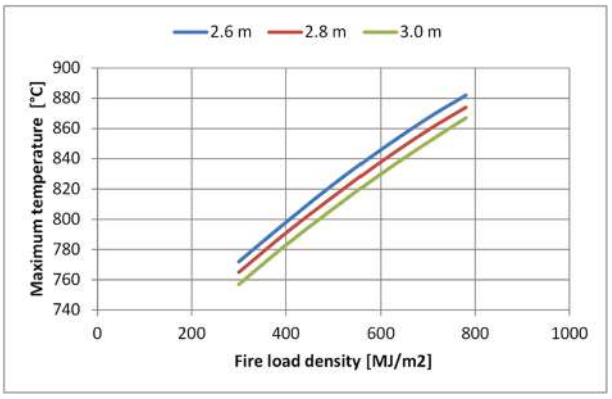


Fig. 9. Maximum temperatures obtained for different fire load values.

study are in support of the Eurocode standard regarding the fire load density values to be adopted in the calculation of the design fire in residential dwellings. Application of methodology, presented in the study, on a larger sample of family apartments of various sizes, would lead to more distinct results that could be adopted as an average and updated values of fire load that occurs in residential buildings. The research should be done by scientific and experienced professionals' cooperation, with the aim to inform policy makers and fire safety designers about ongoing trends in residential fire load.

The influence of fire load density increase in residential apartments on the fire development was analysed on a representative three-room family apartment, using numerical procedures. Different criteria regarding the opening size modifications were adopted, in order to include various scenarios that could affect the ventilation properties of the compartment during fire development. For a constant opening size, as proposed by the Eurocode standard, leading to most conservative results in terms of fire duration prior to flashover, the increment in fire load resulted in the extension of the duration of fully developed fire stage of 6 min/100 MJ/m^2 of fire load increase, providing almost 2.5 times longer duration of fully developed fire stage and approximately 10% increase of maximum temperatures reached in the compartment, compared to the period 30 years ago. In situations where flashover occurs, this would affect the ability of firefighters to extinguish the fire, given that more heat would be released, prolonging the time of suppression. Depending on the type of structure and structural materials, longer fire duration could affect the load bearing capacity and stability of the structure, leading to a higher risk associated to structural fire performance, as well as to the safety of rescue teams, which need to be taken into consideration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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