Admissible Evacuation Time

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Abstract. **Fire always is unexpected. Therefore, to decrease count of victims during the panic, it is essential to timely leave a dangerous place. Unfortunately, quick and smooth evacuation is not possible in many buildings where fire safety should be at the highest level. One of the greatest civil threat risks is obstacles that impede escape from fire or other incident that can happen in the building.**

Therefore, more precise research and methododoly are needed for determination of admissible evacuation time.

Key words: **evacuation time, fire, fire hazard factors.**

I. Introduction

It is important not only to understand a hazardous nature of fire but also dangers caused by panicked people during evacuation.

Global tragedies during people evacuation are associated with massive people crushing. See Table 1. [5]

TABLE 1

GLOBAL TRAGEDIES OF PEOPLE MASS CRUSHING

No.	Year	Place, Event	Number of people killed / injured
1	1953, 9 March	Russia, Moscow, Red Square, Stalin's funeral	about 2000/-
2	1968, 23 June	Argentina, Buenos Aires, Stadium, (football match)	74/150
3	1982, 20 October	Russia, Moscow, Stadium (football match)	340/-
4	1990, January	Mecca, Hajj	1426/-
5	1994, January	Mecca, Hajj	270/-
6	1996, 16 October	Guatemala, Stadium	83/180
7	1998, January	Mecca, Hajj	118/-
8	1999, 31 January	Belarus, Minsk, entrance to metro station	53/150
9	2000, December	Brazil, Stadium (football match)	200/-
10	2001, 9 May	Africa, Stadium (football match)	100/-
11	2004, January	Mecca, Hajj	244/-
12	2005, 25 January	India, church service	150/-
13	2006, January	Mecca, Hajj	345/-
14	2006, February	Philippines, Stadium	80/322
15	2009, November	China, Cambodia, bridge	347/329

It is important to mention a recent tragedy associated with massive people crushing in China, Cambodia, at the water festival on the bridge during panic in crowd there were killed 347 and injured 329 people. Most of them were women and children. Uncontrollable crowd is very dangerous and unpredictable. In similar situations it is necessary to remain calm and move along with crowd, because it is impossible to resist.

It is necessary to recall a tragedy related to reduced ability of evacuation during a fire that has struck recently. Fire broke out in the night club *Khromaya Loshad* (Russian: *Хромая лошадь*, meaning *Lame Horse*), which was located in the city of Perm, in Russia, as a result, fire caused death of more than 100 people and more than 100 gained various degrees of burns. The fire was caused by ignoring fire prevention measures. The tragedy happened during celebration of the seventh anniversary of the nightclub. In the club there were mainly club employees, their relatives, friends and persons close to the club – a total of more than 200 people. Fire was caused by pyrotechnics used indoors.

Sparks from pyrotechnics set out the fire to the ceiling that was made of wicker; fire immediately transferred further and within minutes took over the club, which ignited like a match box. Most people were killed by suffocation, but many simply were crushed by crowd, in panic rushing out of the premises. Almost every day from hospital there was news about death of people with burning wounds; in all fire fatalities were close to 150 people. [16]

Most modern construction and fire safety standards rule out building design.

The origin of legislation regarding fire safety matters can be found in the 19th century.

Requirements for buildings and structures were determined based on actual fires that had taken away a number of human lives. The requirements were based on experience rather than the science of fire phenomena.

The traditional requirements for evacuation from the building are based on geometric parameters of building. Legislation sets requirements for escape routes and exits; it determines the number of exits, maximum width and length of escape routes, maximum evacuation time, availability and security of escape routes.

Regulatory requirements set out for escape routes are based on the provision of facilities with accessible and safe escape routes and exits for people.

Escape route width, length and number of exits depend on the building utilization type and number of people who will use a building. Generally, these parameters are sufficient for safe people evacuation. Proven that during fire, by-products are formed and conditions created that can cause harm to human health and substantially increase evacuation time. Therefore, it is necessary to apply an engineering approach to evacuation of people from buildings and structures in case of fire.

II. DETERMINING ADMISSIBLE EVACUATION TIME

It is necessary to determine the actual evacuation time of people from buildings in general and the time after which fire hazards will be dangerous for human health. If an actual evacuation time exceeds the required time, then people evacuating from the building will be threatened. [4, 5, 6, 9, 10, 11, 12]

Main condition for timely evacuation of people:

$$T_{evac} < T_{inadm} \quad (1)$$

where:

T_{evac} – actual evacuation time, min.;

T_{inadm} – time of inception of dangerous fire factors or admissible evacuation time, min..

$$T_{\text{evac}} = T_{\text{inf}} + T_{\text{start}} + T_{\text{t}} \quad (2)$$

where:

T_{inf} – fire detection system activation speed, min.;

T_{start} – time from receiving an alarm signal till evacuation start, min.;

T_{t} – time from people evacuation start till complete evacuation of building, min.

Evacuation process consists of several stages, from fire start till complete people evacuation from a building. See. Figure 1.

Fire detection system activation time depends on characteristics of applied fire protection systems and specifics of fire expansion.

Nowadays in Latvia an important issue has come up, regarding admissible evacuation time in case of fire, because of regulatory documents governing fire safety – the Regulation No. 567 of the Cabinet of Ministers regarding Latvian Construction Standard LBN LBN 208-08 "Public Buildings and Structures" adopted on 21 July 2008 [3] and the Regulation No. 498 of the Cabinet of Ministers regarding Latvian Construction Standard LBN 201-10 "Fire Safety of Structures" adopted on 28 June 2011 [1], which do not prescribe the requirements for permitted evacuation time.

RTU specialists offer a methodology [4], which may be used to estimate admissible evacuation time.

Admissible evacuation time is directly subjected to accession moment of the dangerous fire factors. The most important fire factors are: human heating of the air-gas convection, heating due to the heat radiation, toxic combustion products, lack of oxygen, the deterioration of vision due to smoke. Special studies led to the critical values of these factors:

- average air temperature in the room – ^{o}C – 70 (158 F);
- thermal radiation – 500kJ;
- carbon monoxide (CO) – 1,7 g/m^3;
- carbon dioxide (CO_2) – 144 g/m^3;
- oxygen content – 17%;
- deterioration of vision due to smoke – 2.4 times.

Statistical data and experimental analysis show that the dominant factors are the high-temperature and toxicity of combustion products. These factors are especially characteristic of fires at public and residential buildings. Admissible evacuation time is determined before accession moment of the dangerous fire factors, because in general it cannot be determined which of critical factors will appear first. For mathematical modelling of these dangerous factors, different mathematical formulas can be used.

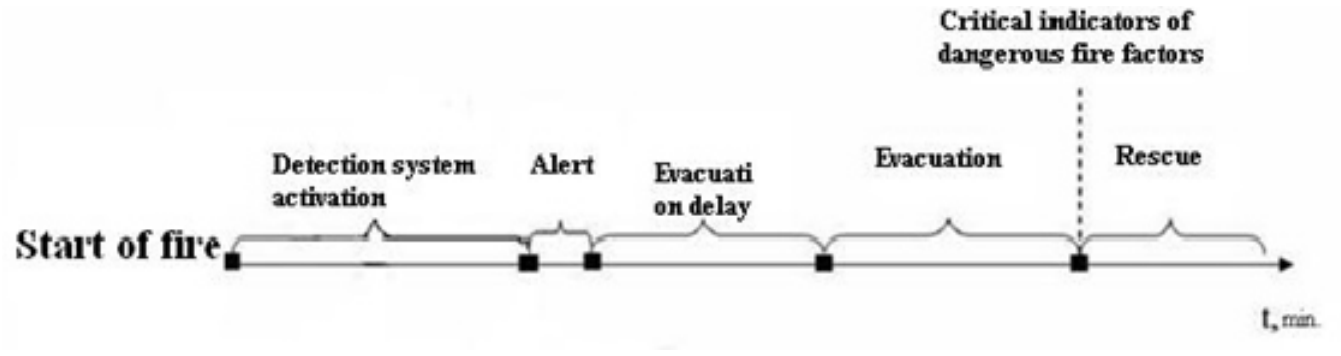

Fig. 1. Stages of evacuation

The assessment of an escape route safety is offered in an analytical manner, based on the following relationship verification:

$$\tau_{\text{adm}} > \tau_{\text{nec}} \quad (3)$$

where:

τ_{adm} – admissible evacuation time (time of inception of dangerous fire factors), min.;

τ_{nec} – necessary time for evacuation, min..

τ_{adm} is determined by the formula:

$$\tau_{\text{adm}} = k_0 \cdot \min(t_t, t_{co}, t_{co2}, ..., t_{o2}) \quad (4)$$

where: t_t – critical temperature occurrence time, min.;

t_{co}, t_{co2} – critical CO and CO^2 concentration occurrence time, min.;

t_{o2} – time of reaching minimum concentration of oxygen, min. ;

k_0 – safety coefficient which is set as 0.8.

In case of fire, heated gases through doorway reach nearby hallway, lobby or an adjacent room. Using gas condition equation and capacity of room in which gases spread, it is possible to determine time in which a critical air-gas temperature will arise. If combustible materials are solid and there is insignificant air exchange with other rooms and windows t_t can be determined using the formula:

$$\tau_t = \sqrt[3]{\frac{W \cdot c \cdot (t_{crit} - t_{start})}{(1-\varphi) \cdot \pi \cdot Q \cdot n \cdot v^2}} \quad (5)$$

where:

W – capacity of air in rooms, m^3;

C – air heat capacity, which can be taken equal to 0.285 kcal / (m^3 * degree);

τ_t – critical and room temperature before fire;

φ – coefficient characterizing heat losses during heating of surrounding objects and constructions, which can be taken equal to 0.5;

Q – heat of substance combustion, kcal / kg.;

n – combustion loud rate, kg / (m^2 * min);

v – fire (flame) linear distribution velocity, m / min (at the early stage of fire – 0.05 m / min.)

Critical fire duration, after which dangerous concentrations of toxic substances arise, can be estimated by the following formula:

$$\tau_{CO,CO_2} = \sqrt[3]{\frac{W \cdot \rho}{g \cdot n \cdot \pi \cdot v^2}} \quad (6)$$

where:

ρ – the maximum permissible concentration under fire conditions, kg/m^3,

g – discharge quantity of toxic substances, depending on the quantity of flammable substance, g / g.

After reduction of oxygen in air, critical time can be determined using the formula:

$$\tau_{O_2} = \sqrt[3]{\frac{0{,}07 \cdot W}{\pi \cdot n \cdot W_{O_2} \cdot v^2}} \quad (7)$$

where:

W_{O_2} – oxygen consumption during burning of 1 kg of substance, m^3/kg.

During combustion of solid substances in a room, vision impairment usually occurs later than critical temperature is reached.

Values used in the formulas – Q, n, g, W_{O_2} ,v – can be estimated from manual data. [4]

III. CONCLUSION

Regulatory documents governing fire safety – the Regulation No. 567 of the Cabinet of Ministers regarding Latvian Construction Standard LBN LBN 208-08 “Public Buildings and Structures” adopted on 21 July 2008 [3] and the Regulation No. 498 of the Cabinet of Ministers regarding Latvian Construction Standard LBN 201-10 “Fire Safety of Structures” adopted on 28 June 2011 [1], must be improved, imposing additional requirements on admissible evacuation time. Further research in the field of admissible evacuation time is necessary.

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Vladimirs Jemeļjanovs, Jeļena Sulojeva, Māris Ziemelis, Jānis Bartušauskis, Oļegs Sņegovs. Pieļaujamais evakuācijas laiks
Šis raksts aplūko jautājumus, kas saistīti ar cilvēku drošību ēkās, ārkārtas evakuācijas laikā, ugunsgrēka gadījumā.
Pastāvošā normatīvo aktu sistēma, kas reglamentē ugunsdrošības prasības civilo ēku projektēšanas posmā, nosaka prasības tikai ugunsgrēku ārkārtas evakuācijas ceļu ģeometriskajiem parametriem, kopumā nesniedzot pienācīgu kopainas atspoguļojumu ugunsgrēka gadījumā.
Ugunsgrēka gadījumā uz cilvēka organismu iedarbojas kaitīgie riska faktori, kuri saistīti ar bīstamo toksisko vielu izdalīšanos degšanas procesa laikā, kā arī skābekļa daudzuma samazināšanās, redzamības pasliktināšanās kura saistīta ar piedūmojumu, un temperatūras paaugstināšanās virs pieļaujamās normas telpas iekšienē. Šos bīstamos faktorus var raksturot kā kritiskus un to realizācijas laiku iekštelpās – pieļaujamais laiks piespiedu evakuācijas gadījumā. Par pamatu pieļaujamā laika aprēķināšanai autori piedāvā pieņemt visīsāko laiku, kurā realizēsies kāda no četriem bīstamajiem ugunsgrēka riska faktiem vai tā sauktajiem kritiskajiem faktoriem.
Galvenais - pēc autoru domām – vai reālais cilvēku evakuācijas laiks no ēkas sakrīt ar pieļaujamo evakuācijas laiku, kurš ir dominējošais cilvēku evakuācijai no ēkām. Savukārt, jāatzīmē ka Latvijas būvnormatīvos vispār nav izvirzītas prasības pieļaujamajam cilvēku evakuācijas laikam ugunsgrēka gadījumā.
Galvenā problēma ir tāda, ka nav izstrādāta efektīva metodika pieļaujamā cilvēku evakuācijas laika noteikšanai ugunsgrēka izcelšanās gadījumā.
Autori pirmo reizi Latvijā piedāvā šādu metodiku, kuras integrēšana likumdošanā palīdzētu risināt iepriekš minēto problēmu – kas attiecīgi paaugstinātu cilvēku drošību ārkārtas evakuācijas laikā, ja iekštelpās noticis ugunsgrēks.

Владимир Емельянов, Елена Сулоева, Марис Зиемелис, Янис Бартушаускис, Олег Снегов. Допустимое время эвакуации
В данной статье рассмотрены вопросы, связанные с безопасностью людей при вынужденной эвакуации в случае возникновения пожара внутри здания.
Существующая система нормирования противопожарных требований при проектировании зданий , в которых находятся люди, выдвигает требования только к геометрическим параметрам путей эвакуации при вынужденной эвакуации в случае возникновения пожара, что искажает реальную картину, которая возникает при пожаре. В случае реального пожара на человеческий организм воздействуют опасные факторы связанные с выделением опасных токсичных продуктов сгорания, понижение концентрации кислорода,потери видимости,повышение среднеобьёмной температуры внутри помещения выше допустимой. Эти опасные факторы можно назвать критическими и время наступление которых внутри помещения- допустимым временем при вынужденой эвакуации. За основу определения допустимого времени при вынужденой эвакуации авторы предлагают принимать наименьшее время достижения одного из четырех опасных факторов пожара или критических факторов при пожаре.
Главное, по мнению авторов, – совпадает ли фактическое время эвакуации людей из зданий с допустимым, которое является доминантой при эвакуации людей из зданий. В свою очередь в Латвийских строительных нормативах вообще не выдвигаются требования к допустимому времени эвакуации. Основная проблема состоит в том , что отсутствует методика определения допустимого времени эвакуации людей в случае возникновения пожара внутри здания. Авторы впервые в Латвии предлагают такую методику, принятие которой на законодательном уровне позволило решить данную проблему, что обеспечивало бы повышение безопасности людей при вынужденной эвакуации в случае возникновения пожара внутри здания.