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INFLUENCE OF THE TRAINING IN RELATION TO THE FIRE-FIGHTING EFFECTIVENESSUNDER THE CONDITION OF THE INDOOR FIRE SIMULATION

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Research article

Abstract: Fire Dynamics in a confined space is considerably difficult. Flashover container enables experimental examining of many of its aspects in controllable conditions. For this reason there is an extensive research in form of large scale tests goes in Zbiroh where large container complex for liquefied gas fuel was built. In this time a human factor and its effect on the environment is in the research. Among others the tests were aimed to examining the influence of the training on the efficiency of the intervention under indoor fire conditions, namely the ability of a fire-fighter affect the thermal field and the thermal radiation in the right direction. The article describes the experiments that were carried out.

Keywords: Fire in Confined Space, Heat Transfer, Fire Dynamics, Water Fog, Fire fighting.

Introduction

Fighting an indoor fire is one of the most difficult situations fire-fighters may encounter. The presence of firefighters under indoor fire conditions significantly increases the risk rate for the intervening persons. It is considerably problematic to predict generally the fire behaviour during firefighting process, its going out progress and changes of the thermal balance because fire and water as an extinguish agent generate a highly complicated dynamic system.

The so-called flashover containers (FOK) are facilities that simulate real fire conditions and are used for training to this type of operations. In these facilities, it is possible to simulate conditions that are close to conditions during fire just before total flashover. Therefore, fire-fighter participating the training gains not only the needed knowledge and skills based on a practical experience with the response of the environment when indoor fire occurs. In this sense, the fundamental questions are, first "what is the relationship between subjective experience in the given stress and objective conditions in the wider surroundings of the fire-fighter during training" and second "to which extent does subjective experience affect the range of the undertaken training".

The FOK facility in Zbiroh is the only one of its kind in the CzechRepublic, where it has been possible to implement large-scale experiments designed to investigate various aspects of the dynamics of the fire in the confined space. In this regard the amount of space, facility performance and the degree of similarity of the conditions prevailing in FOK when burning the liquid propane to the conditions of a real fire in the confined space is decisive. The series of measurements under the conditions of the FOK took place between 2011 and 2015. The experiments involved the following entities: Faculty of Safety Engineering at VŠB – Technical University of Ostrava, CTU Prague, Plzeň Fire and Rescue Service, the Fire and Rescue Service of Central Bohemia region and the Fire and Rescue Service of the Capital City of Prague, Fire, the Headquarters of the Fire and Rescue Service of the Czech Republic and National Institute for Nuclear, Chemical and Biological Protection (Balner at al., 2014).

To date, most scientific theses have been concerned with the indoor fire dynamics or/and the effect of extinguishing agents under indoor fire conditions. Data from indoor experiments for effect of human factor is either not available or completely absent. Therefore one of the many milestones of above mentioned research was to obtain values of selected physical quantities that characterise the conditions of individual training spaces within the FOK, specifically in chambers no. 1, and to try and find the relation between extend of absolved indoor firefighting training and values obtained through measurement. The obtained findings will mainly

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serve as the basis for optimising training methods and are of great significance when examining the relation between a learning process and effectiveness of firefighting.The article describes the tests executed; it especially focuses on the measurement methods used, the FOK and its construction, basic features of the water stream in connection of the nozzle handling, including a comparison of changes of the water supply parameters. In the conclusion, attention is paid to the successful carrying out a long pulse as basic extinguishing techniques of an intervention against the indoor fire. There were among others these objectives in this context:

- to record, qualify and quantify some of the aspects of a long pulse under conditions similar to the real indoor fire,
- compare the electivity of a pulse depending on the amount and quality of absolved training.

Materials and methods

Description of the training simulator in Zbiroh

Description of the multipurpose training facility in Zbiroh, specifically the training facility of flashover containers has been thoroughly addressed in the literature and is subject to contents of selected papers published in this collection (Žižka, 2012) (Bernatíková at al., 2012) (Balner at al., 2014). The FOK is located within the training area in Zbiroh of the Third Rescue Company of the Fire Rescue Service of the Czech Republic. The facility has a form of several types of training workplaces for units of the Fire and Rescue Service where it is possible to simulate conditions when an indoor fire occurs. The model of FOK for training of fire fighting in a constrained space with highlighted monitored areas is shown on Fig. 1 is presented.

Fig. 1 Model of the FOK training simulator in Zbiroh

The training simulator is built of modified ISO containers of class 1AA class (twenty and forty feet versions) commonly used in transportation, supplemented by a covered steel staircase and a walkway entrance. The container modifications consisted of their separation, fitting with windows, doors, ventilation chimneys and vents and of removing some walls. Construction of each of the containers is self-supporting. In each container there is a 300 mm x 300 mm x 33 mm concrete floor fitted into sand bed with thickness of 20 mm. There are holes in the container walls for window and door frames and ventilation chimneys. Door and window sashes are made of welded steel profiles; the filling is made of steel sheet of thickness of 1.8 mm (Tomášek, 2010). They are fitted with lever closing mechanisms. Air vents are equipped with adjustable sheets to regulate the air supply to the burners.

To produce flames for training purposes and to simulate fire in a contained space, there are three main propane burners with a maximum power of 6 MW, 3 MW and 1.5 MW installed for chambers no. 1, 3, and 2 and for the staircase area. The regulation of the burner's power is done through controlling the propane supply using a ball valve with a servo. The servo is controlled via buttons placed on the cabinet. Propane is the fuel for the training simulator. Technical parameters are taken from (Tomášek, 2010).

Description of the test areas

Individual experimental measurements within FOK Zbiroh took place in chamber no. 1. Chamber no. 1 consists of a space formed up by two ISO transport containers of class 1AA, which's selected technical parameters are shown on Fig. 2. Chamber no. 1 is represented by a large volume space designed for training efficient supply of extinguishing agent in the form of the so-called 3D water fog where the energy source is placed directly in front of the fire-fighters. The geometry and dimensions the chamber no. 1 resembles halls, lobbies or large room. Selected technical parameters of individual spaces are shown on schemes on Fig. 2.

Description of the measuring device and the method

Based on previous experience obtained both during large-scale fire experiments and during training, distribution of individual sensors of temperature and heat flux was designed. Height positions of the thermocouples on individual columns for chambers no. 1 are listed in Tab. 1. Sensor positions for chamber no. 1 are shown on

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Fig. 2. To scan temperatures in chamber no. 1, a total of 12 NiCr/Ni (type K) thermocouples and 40 thermocouples made of type K thermocouple wire (HH-K-24) of a diameter of 0.5 mm were used. For chamber no. 3, a total of 44 NiCr/Ni (type K) thermocouples and 12 thermocouples made of K type thermocouple wire (HH-K-24-500) of a diameter of 0.5 mm were used. A total of 40 NiCr/Ni (type K) thermocouples and 90 thermocouples made of K type thermocouple wire (HH-K-24) of diameters of 0.5 mm; 1.0 mm and 1.5 mm were used to monitor the staircase area.The thermocouples were placed on positions listed in table 1 and marked with the symbol Sx. They were market with the symbol SH when laced on fire-fighting position. Height positioning of the couples on individual positions was addressed in consideration to obtain values to determine the most accurate temperature field distribution. The installation was carried out on steel stands and on chains fitted to the ceiling of chamber no. 1; the chains were loaded with steel weight.

Before the test started, the correct positioning and functionality of each thermocouple was checked. Measuring centres were placed outside the container so it was easy and safe to operate and protect them from weather.SCHMIDT-BOELTER SBG01 radiometers were used to measure the density of the heat flux and were placed in chamber no. 1, close to the fire-fighters and the lecturer. The location is marked with an **R**. As shown in Tab. 2, density value of heat flux from different directions was scanned. The radiometers were fitted to a stand.

The cooling of radiometers was carried out through gravity water from a tank placed on the roof of the container on 2nd floor of the training facility. Output signal wiring, input and output of cooling water and the radiometers with the exception of their front surfaces, were protected by thermal insulation and shielding reflective aluminium foil.

Tab. 1 Height positions of thermocouples placed on individual columns of chambers no. 1

Height from the floor [mm]	Thermocouple column	
	Sx	SH
18		
280		YES
480		YES
680		YES
780		YES
880	YES	YES
1 080	YES	YES
1 280	YES	YES
1 480	YES	YES
1 680	YES	YES
1 880	YES	YES
2 080	YES	YES
2 230	YES	YES

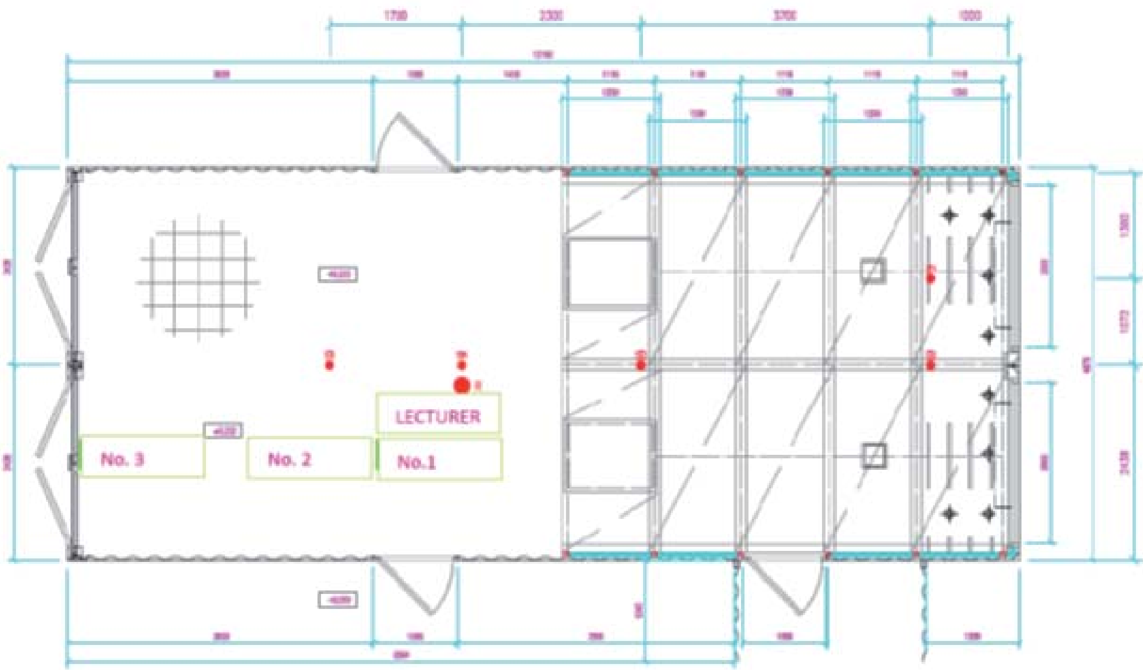

Fig. 2 Ground plan of chamber no. 1 with sensor positions

The experimental measurements were carried out under constant set operation burner output. That corresponds 90 % of the maximum flow rate of the liquid phase of the propane. The selected operating output values match those used in the standard training of fire-fighters in FOK. Each test included 2 x four cycles with 5 activations of the main burner (pulses). In the test for chamber no. 1, the time of activation of the main burner was always 4 s, the time between activations then corresponded to the time interval in which the firefighting operation was carried out. The time between the cycles then corresponded to time needed to move the probands on individual positions. Before start of the measurement, one test cycle at 90 % of maximum set limit was carried out. Positions of vents during measurement in chambers no. 1 are listed in Tab. 3. Every part of the experiment for the designated monitored space was divided into five tests depending on the set the parameters of water stream. When tested in FOK Zbiroh the Quadrafog 500 the streamline was tested at various defined water flaw rate of 250 litres per minute and 100 litres per minute and pressures of 8.0 bars, 7.0 bars, 6.0 bars, 5.0 bars and 4.0 bars. This article focuses only on the parameters of water flow 250 l/min under 7.0 bars.

In total, each measurement was always attended by eight fire-fighters who were divided into groups "A" and "B" - each consisting of four men. Each team was made up of a lecturer and fire-fighters no. 1, no. 2 and no. 3. Probands of team A were selected from the members of the Fire and Rescue Service of the Czech Republic who have undertook at least 75 hours of training within the Zbiroh training facility. Team B was composed of fire-fighters who undertook 8 hours of regular training in the FRS Fire Protection and Training centre in Brno. Group formations for tests in chambers no. 1 is in Fig. 9. After each cycle the positions of training fire-fighters changed (shift), thus each fire-fighter changed during the test every position twice. The shift always occurred after the completion of the intervention operation of a fire-fighter at the position no. 1 (five times burner activation = five time extinguishing). Conditions inside chamber 1 during measurement with water supply show Fig. 3–8. The shift was always performed by one position counter clockwise, as seen in the Fig. 9.

Tab. 2 Positions of radiometers during the measurement in chamber no. 1

Position	**Serial number**	**Maximum measuring range (heat flux density [kw/m^2])**	**Radiometer orientation^x**	**Height [mm]**
R1	1071–100	100	horizontal 0°	1,200
R2	1053–200	200	inclination 45°	1,200
R3	1072–100	100	vertical 90°	1,200
R4	1062–50	50	rear 180°	1,200
R-left	1061–50	50	left 0°	1,200
^{X}Relative to the longitudinal axis of the container				

Tab. 3 Vent configuration in chamber no. 1

Vent	**Configuration**
Entrance gate of container 1	Open
Entrance gate of container 2	Open
Side door of container 1	Closed
Side door of container 2	Open
Side door of container 2 - passage to container 3a	Closed
Flap of ventilation chimneys of containers 1 and 2	Closed
Opening for air intake under the burner	Open (opening size 270 mm)

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Fig. 3 to 8 Conditions inside chamber 1 during measurement with water supply

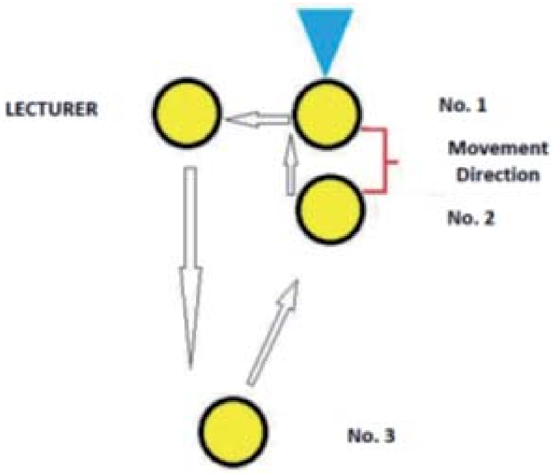
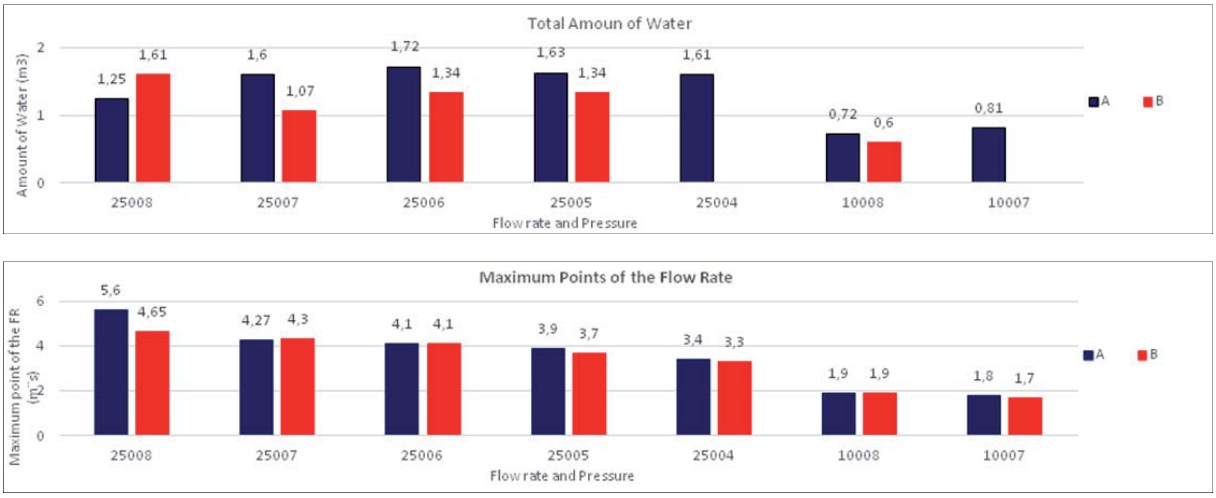


Fig. 9 Fire-fighters shift at individual positions during the test in the space of the chamber No. 1

Results

Water supply

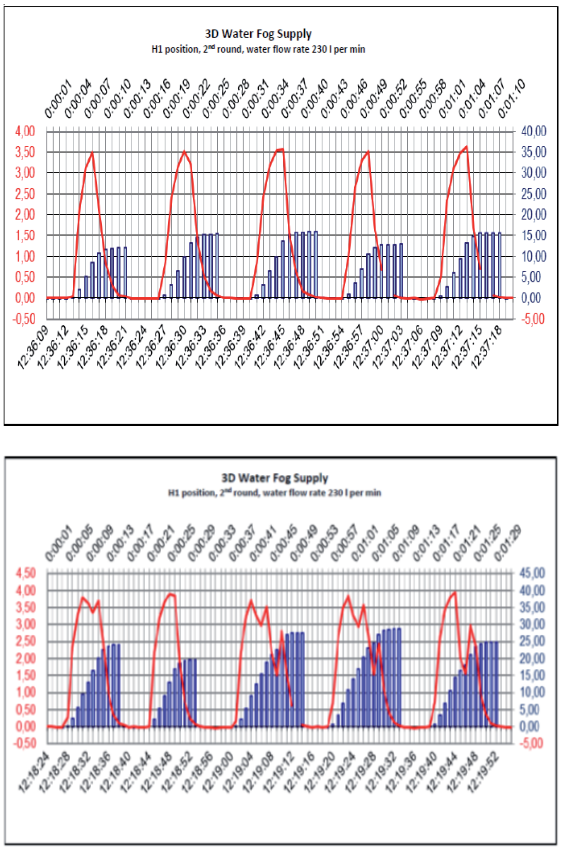
Apparently the intensity of water flow in the space depends among other factors on the pump pressure and water flow (Särdquist, 2002). However, as appeared during the tests, other important factors were optimal timing and technical performance of the pulse (Grimwood, 2002), see Graphs 1 and 2. We suppose that the ability to operate the nozzle correctly depends on the amount and the form of the training. The samples of work with the nozzle depending on the amount of training can be seen on the Graphs 3 and 4. Moreover, the extinguishing effect of water in confined space is determined by the size of the droplet, droplet kinetics and even distribution of water (Layaman, 1940), (Noskievič; Šťáva, 1986), (Särdquist, 2002).



Graphs 1 and 2 Comparison of the total amount of water and global maximum points of the flow rate, depending on the group of probands, the water flow and the pump pressure

The comparison between the series of attempts indicates that the water supply is inversely proportional to the pressure and directly dependent on the flow rate. When the water flow rate is reduced from 250 l.min^{-1} to 100 l min^{-1}, the water supply has to fall by 40 %. But the fall of the water supply was 50 % - from 1.55 cubic meters to 0.81 cubic meters - in case of the group A. The measured values were in accordance with the prognosis when group B was operating. Upon closer examination a proportional prolongation of the pulse is apparent in case of the team A. When the team B was operating the length of the pulse varied randomly. In comparison, the total maximum flow volume depending on the group of probandes, we find that the flaw rate is slightly higher in case of the team A under the same conditions.

The ability to effectively perform the required extinguishing is determined by the level of experience gained both during the actual intervention, but in particular during the direct and organized training. Various works with the pulse during the experiments has been evident from the graphical evaluation of measured values in Graphs 3 and 4. Therethe red curve shows the flow rate values here. Its course indicates the work with the streamline. The local maximums represent the operating lever of the fully open control lever of the nozzle, i.e. individual pulses. Blue colour then indicates the amount of water supplied into the space in a particular time.



Graphs 3 and 4 Sample of graphic evaluation of work with the streamline of the B3 fire-fighter and sample of the graphic evaluation of the work with the streamline of the A3 fire-fighter.Blue colour then indicates the amount of water supplied into the space in a particular time, see auxiliary axis y. The red curve shows the flow rate values, see main axis y. The local maximums represent the operating lever of the fully open control lever of the nozzle - power 90 %; flow rate 250 l.min^{-1}; pump pressure 0.7 MPa

Heat flow density

The heat flux density changing was measured on radiometers which were oriented differently (Drysdale, 1998), (Quantiere, 2002), (Bendgtsson, 2001). The obtained data show that the intensity depended on the orientation radiometer and, when fire-fighters were operating, on the water flow rate and the pump pressure – some examples show Graph 5 and Graph 6. The highest values of heat flow density were obtained during the first test cycle when the water supply was not carried out, as mentioned below, see Graphs 7 and 8. There were obtained these global maximum and minimum points here:

R1 45°:	86 kW.m^{-2}	–	2.02 kW.m^{-2}
R2 0°:	90 kW.m^{-2}	–	1.55 kW.m^{-2}
R3 90°:	17 kW.m^{-2}	–	1.82 kW.m^{-2}
R4 180°:	26 kW.m^{-2}	–	0.41 kW.m^{-2}
R5 left:	34 kW.m^{-2}	–	1.04 kW.m^{-2}

When the water was supplied, as seen on Graphs 9 and 10, the obtained global maximum points were falling but the global minimum points were rising or stayed the same:

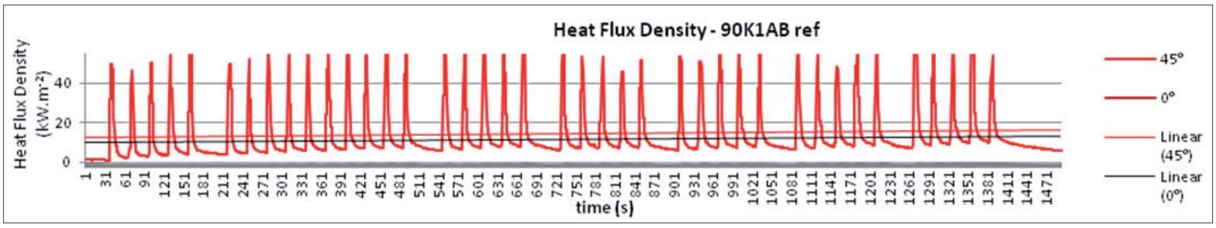
R1A 45°:	59 kW.m^{-2}	–	2.84 kW.m^{-2}
R1B 45°:	53 kW.m^{-2}	–	3.12 kW.m^{-2}
R2A 0°:	32 kW.m^{-2}	–	2.89 kW.m^{-2}
R2B 0°:	9 kW.m^{-2}	–	2.63 kW.m^{-2}
R3A 90°:	22 kW.m^{-2}	–	1.22 kW.m^{-2}
R3B 90°:	32 kW.m^{-2}	–	1.25 kW.m^{-2}
R4A 180°:	22 kW.m^{-2}	–	0.33 kW.m^{-2}
R4A 180°:	32 kW.m^{-2}	–	0.47 kW.m^{-2}
R5B left:	32 kW.m^{-2}	–	1.27 kW.m^{-2}
R5B left:	40 kW.m^{-2}	–	1.92 kW.m^{-2}

The local maximum points had a tendency to increase and oscillated in intervals, which are mentioned below:

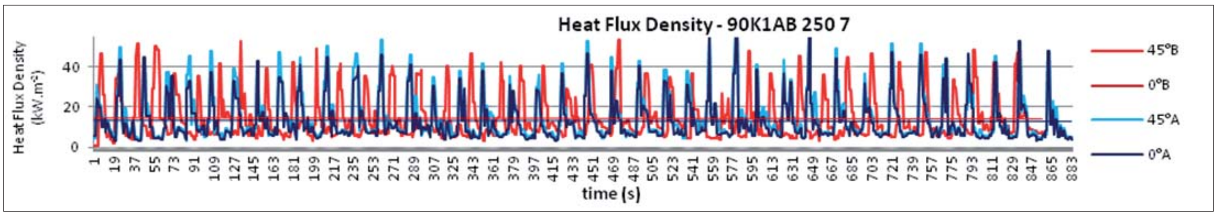
R1A 45°:	59 kW.m^{-2}	–	24 kW.m^{-2}
R1B 45°:	53 kW.m^{-2}	–	27 kW.m^{-2}
R2A 0°:	32 kW.m^{-2}	–	31 kW.m^{-2}
R2B 0°:	9 kW.m^{-2}	–	26 kW.m^{-2}
R3A 90°:	22 kW.m^{-2}	–	5.5 kW.m^{-2}
R3B 90°:	32 kW.m^{-2}	–	5 kW.m^{-2}
R4A 180°:	22 kW.m^{-2}	–	10 kW.m^{-2}
R4B 180°:	32 kW.m^{-2}	–	8 kW.m^{-2}
R5A left:	32 kW.m^{-2}	–	17 kW.m^{-2}
R5B left:	40 kW.m^{-2}	–	13 kW.m^{-2}

The local minimum points stayed almost constant except the measurement without the water supply. After the water was at presence in the space the values of heat flux density measured on the radiometers R1 and R2 were falling down by about 35 % while the others – R3, R4, Rleft – were increasing, see graph 8 and 10. The local minimum points were increasing when the water was supplied in. In general the values of heat flux density had a tendency to increase when the water had not been supplied while they were constant after the extinguishing had been carried out.

Upon closer examination of the arithmetical average, median and mode we can solve the effectiveness of firefighting from the point of view of the heat flux density reduction, see Graphs 11–14. It allows making a conclusion that the team A is more effective then team B.



Graph 5 Comparison of heat flux density, radiometers inclination 45° and 0°, without presence of probands – power 90 %



Graph 6 Comparison of heat flux density, radiometers inclination 45° and 0°, depending on the group of probands - power 90 %; flow rate 250 l.min^{-1}; pump pressure 0.7 MPa

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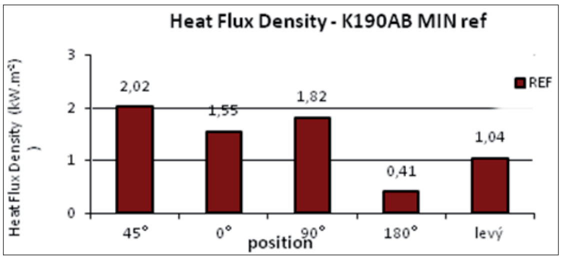
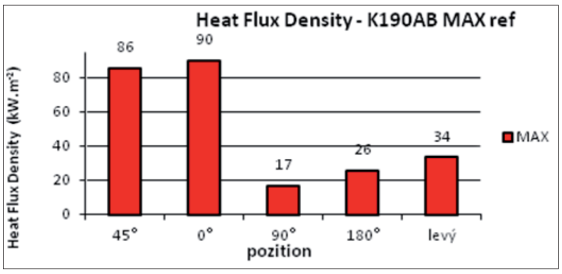
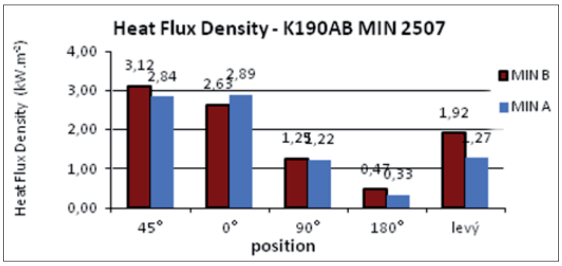
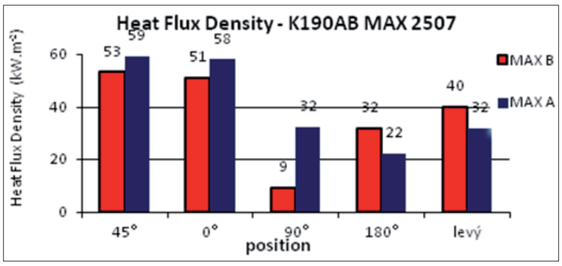


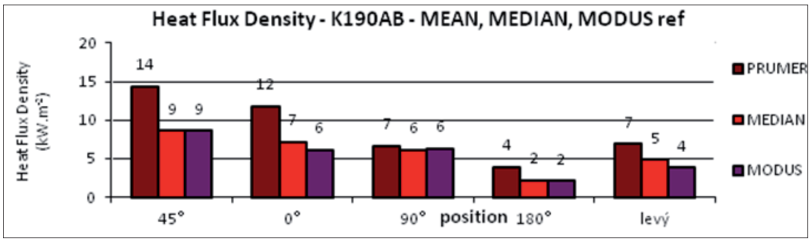


Graph 7 and 8 Minimum and maximum points of heat flux density, radiometers inclination 0°, without presence of probands – power 90 %

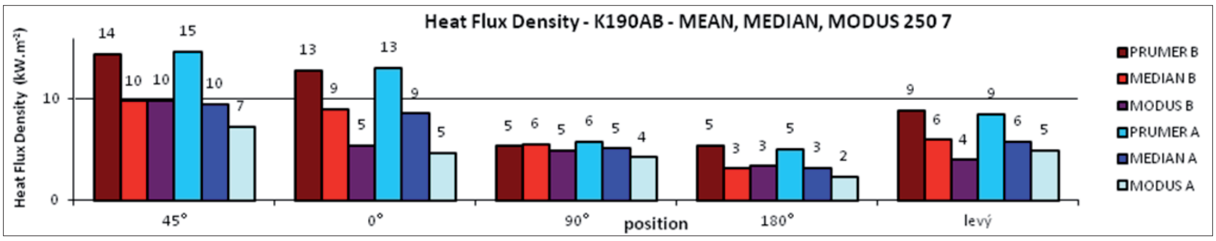




Graph 9 and 10 Comparison of minimum and maximum points of heat flux density, radiometers inclination 0°, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa



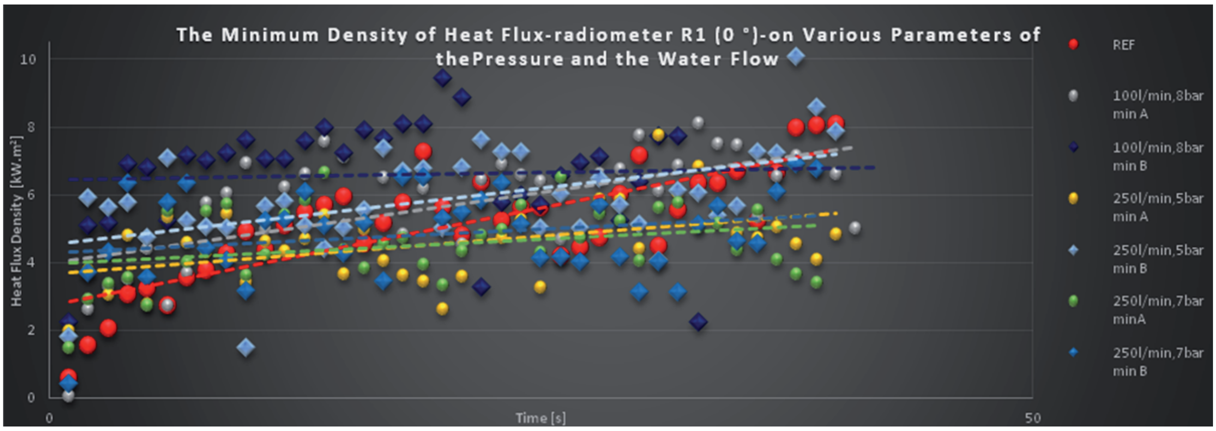
Graph 11 Values of arithmetic mean, median and modus of heat flux density values, radiometers inclination 0°, without presence of probands – power 90 %



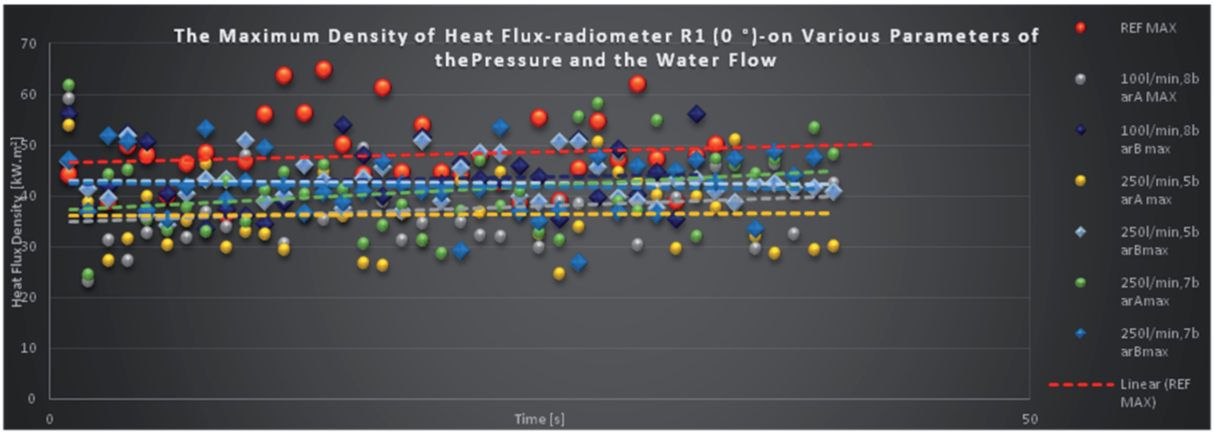
Graph 12 Comparison of arithmetic mean, median and mode of heat flux density values, radiometers inclination 0°, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa

Temperature

When we examine the dependence of temperature conditions in FOK on the personal training status, the comparison of the performance between different teams of fire-fighters is necessary. Therefore there was looking for a relation between efficiency of the water distribution and changes in the thermal field aimed to the quantitative determination of the nozzle operating here (Smutník, 2014). Thus it was possible to measure the extinguishing efficiency in various parts of the space, see Graphs 15–17. Subsequently the arithmetic average, the median and the mode were determined. It makes it possible to make a correction of possible failure of the measurement and finally to formulate general conclusions.



Graph 13 Comparison of the local maximum points of heat flux density and linear trends it, radiometers inclination 0°, depending on the group of probands, water flow and pump pressure



Graph 14 Comparison of the local minimum points of heat flux density and linear trends of it, radiometers inclination 0°, depending on the group of probands, water flow and pump pressure

Based on the local maximum and minimum points and on mean, median and mode, the vertical distribution of the temperature values depending on the measuring level is obvious – see graphs 18–23. After that, when the water was at presence in the space, the values of the temperature were falling, see graphs 22–23. However, measurement showed that the local maximum and minimum points obtained from the thermocouples situated in the lower and the middle part of the column were increasing. Apparently it is caused by the turbulence in the hot gases provoked due the penetration of the hot layer by the water stream (Schopper at al., 1997), (Drysdale at al., 2000), (Hartin, 2014). Upon closer examination of the arithmetical average, median and mode we can solve the effectiveness of firefighting from the point of view of the temperature reduction. It allows making a conclusion that the team A is more effective than team B because it achieved the higher reduction of the temperature in the fire-fighter vicinity.

In the further environment, the higher temperature is apparent when team A is operating. Like that this phenomenon is noticeable when an increase of the flow rate or/and reducing the pump pressure occurs. For various reasons there enormous droplets are created. These droplets are too large to evaporate completely in hot gas layer when going through it. They penetrate it instead, hit the overheated structure and there finally evaporate. This process is connected with cooling of the structures and its vicinity (Drysdale at al., 2000), (Särdquist, 2002), (Strakošová, 2014).

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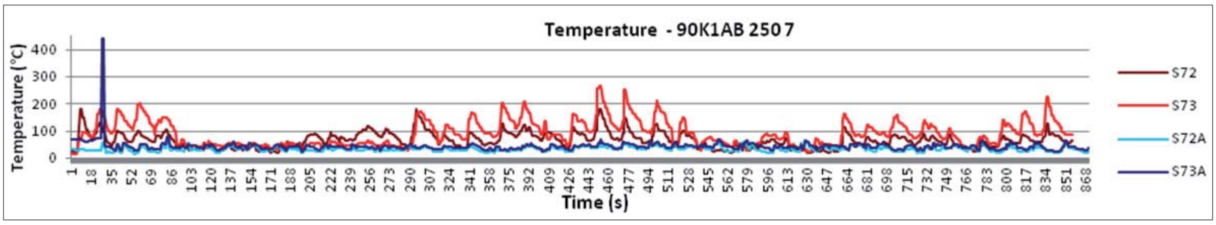
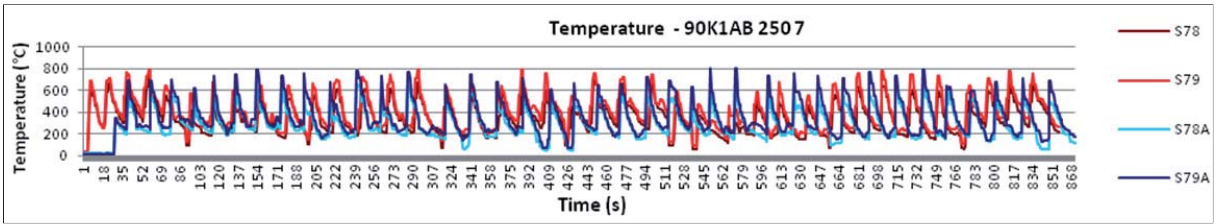
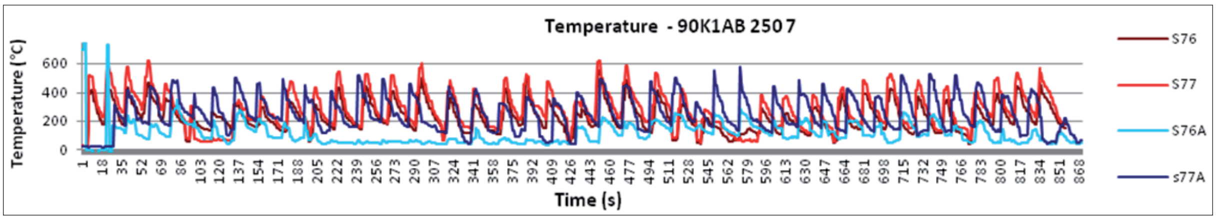


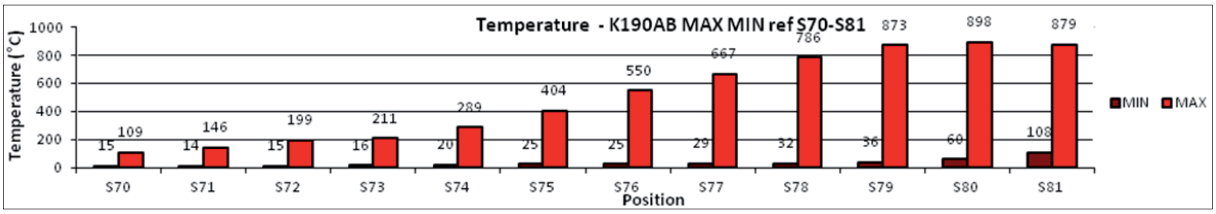
Graph 15 Comparison of temperatures on position ST4 S72 and S73 – 7.000 mm from the burner and 480 mm and 1.080 mm from the floor in dependence on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa



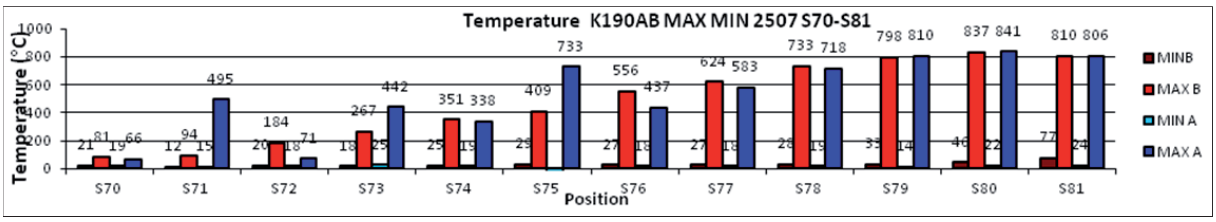
Graph 16 Comparison of temperatures on position ST4 S76 and S77 – 7.000 mm from the burner and 1.080 mm and 1.280 mm from the floor in dependence on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa



Graph 17 Comparison of temperatures on position ST4 S78 and S79 – 7.000 mm from the burner and 1.680 mm and 1.880 mm from the floor in dependence on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa



Graph 18 Global minimum and maximum points of temperature on position ST4 S70-S81 – 7.000 mm from the burner - power 90 %; without presence of probands



Graph 19 Comparison of minimum and maximum points of temperature on position ST4 S70-S81 – 7.000 mm from the burner, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7 MPa

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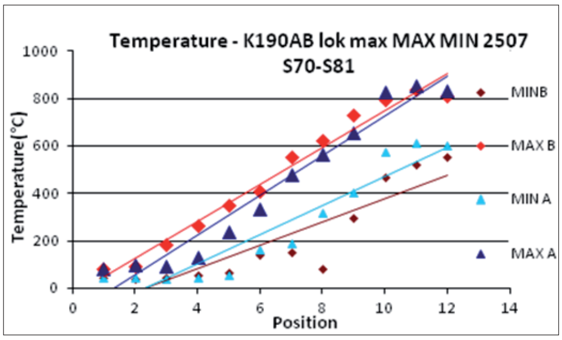
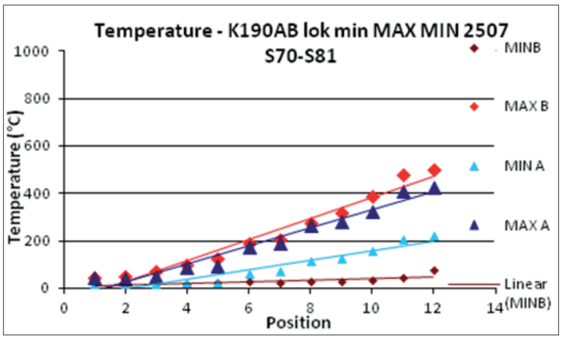
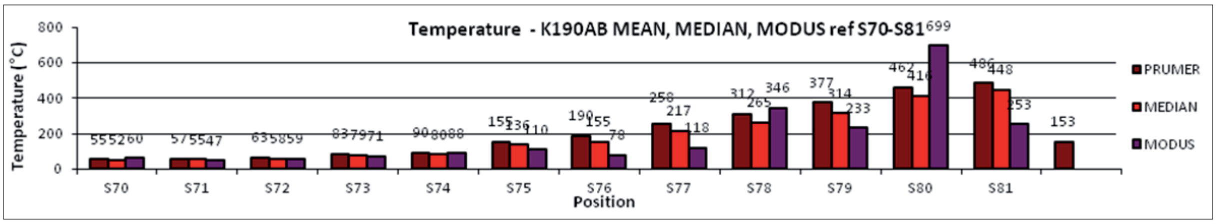
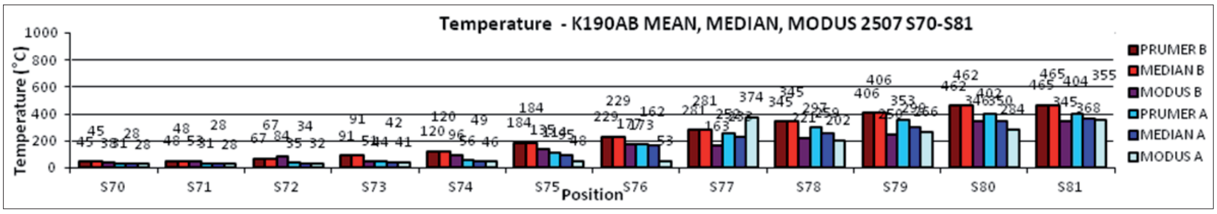




Graph 20 and 21 Comparison of the global maximum points of temperature and its linear trends, on position ST4 S70-S81 – 7.000 mm from the burner, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$ and pump pressure 0.7MPa. Comparison of the global minimum points of temperature and linear trends of it, on position ST4 S70-S81 – 7.000 mm from the burner, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$ and pump pressure 0.7MPa



Graph 22 Values of arithmetic mean, median and modus of temeparture values, on position ST4 S70-S81 – 7.000 mm from the burner – probandes' absence, power 90 %



Graph 23 Comparison of arithmetic mean, median and mode of temperature values, on position ST4 S70-S81 – 7.000 mm from the burner, depending on the group of probands - power 90 %; flow rate 250 $l.min^{-1}$; pump pressure 0.7MPa

Discussion

Based on the collected data and their analysis, there is evident correlation between the ability of efficient water supply and conditions in the near and wider environment of fire-fighters. It is obvious that standardized level training plays a great role, which is decisive for being able to effectively and safely operate under a high heat stress. This results in changing of indoor fire condition in the right way and ultimately minimizing the physical stress and reduction of heat exposure.

Taking a closer look at the thermal field in the device it comes out that the curves describing this physical quantity have a similar wave form regardless if water is at presence or not. But the sufficient intervention against an enclosure fire is determined among other things by the interval between the local extremes and the ability to affect positively their trend.

Upon closer examination the heat flux density, mainly when the higher values are measured in case of the water supply, contrast with the test where no water occurs. It can be assumed that there a radiation source appeared even after the flames had gone out. This further identification is possible through selective measurements (Bitala, 2012).

Conclusion

We use a real training process for achievement all the goals of the experiment Based on the collected data, it can be state that conditions close to conditions of a real indoor fire with similar geometry and disposition prevail within the facility. For a safe movement through such environment it is necessary to control not only a nozzle operating technique and others routines but also a short-term prediction of the current situation's development based on subjective and intersubjective principle is crucial. It is important to meet all these requirements to reduce a high risk of injury and death(Königová, 2001), (Šikulová, 2011), (Prokeš, 2012). (Hon at al., 2013). On the basis of conducted tests the question, whether the current form of firefighting training for indoor operations is sufficient to carry out an effective and safe operation, becomes justifiable. In a broader context it is possible to ask a similar question on the form of firefighting training in general.

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