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COMPUTER SIMULATION STUDY REGARDING THE INFLUENCE OF VENTILATION OPENINGS ON THE FIRE DYNAMICS IN A CLOSED AREA

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Abstract: *The authors use computer simulations (B-RISK software platform) to assess the evolution of a fire in an enclosed space, for different scenarios, using the. The scenarios differ to one another due to modification of some factors with influence on fire development: the surface of the ventilation openings and the wall finishing materials. The simulations will lead to different values for temperature value and smoke level in the considered enclosure. The values of those two (temperature and smoke level) influences the chances of survival for both civilians and firefighters involved in a fire emergency. With the help of the data and conclusions obtained with this study, a test space will be arranged on the premises of the Fire Officers Faculty in Bucharest.*

Key words: *closed area, B-RISK software, ventilation holes, compartment, smoke layer, fire spread, fire safety engineering.*

1. INTRODUCTION

In order to assess the different effects given by a number of factors to the dynamics of fires in enclosed areas, a relatively new software platform was used for research related to this paper, namely B-RISK from BRANZ. B-RISK is based on an accurate combination of both deterministic and probabilistic calculations [1].

B-RISK is a fire simulation program comprising a fire risk simulator in which one can analyze the influence of a number of variables that on the fire spread. Those set variables can be: fire load density, compartment geometry, fuel and ignition source characteristics [2, 3]. Values for each of these variables can be set between boundary and statistical distribution. A number of iterations are simulated, each iteration randomly varying one of the parameters throughout the predetermined boundaries. After the analysis, results and probabilities of fire spread are presented for the specified configurations [4, 5].

Compared to the traditional deterministic manner, B-RISK supports the designer in the process of decision-making. This is possible based on risk information, by using a physics-based model, together with the probabilistic functionality of Monte-Carlo sampling techniques [6].

The main goal of fire engineers is to reduce or prevent the fire occurrence by determining whether such a potential exists. This can be achieved by undertaking a fire risk assessment of an enclosed area [7].

B-RISK is used to model phenomena that take place inside a fire compartment before performing actual experiments, thus using the concept of "*blind modeling exercise*" [8].

B-RISK, a two-layer zone model, was used to model the smoke movement inside a fire compartment, analyzing the chances of survival of building occupants based on the time in which the CO_2 concentration reaches a certain value [9].

In some studies, the program was used to estimate the fire spread rates in informal settlements, finding an overestimation of them, one of the reasons being that the human factor was neglected [10].

B-RISK was also used in the past to predict the ignition time of combustible objects inside a fire compartment, depending on the distance between the radiative source and the object [11].

Based on the validations obtained in the studies conducted so far, in this present article and study, the B-RISK program is used by the authors to identify both the highest values of temperature and the height of the smoke layer, aquired by burning of five different materials (wood chipboard, gypsum board, concrete, polyvinyl chloride and polystiren), while changing the configuration of the ventilation openings. The results obtained after performing the simulations will contribute to the validation of the dimensions and the position of the ventilation openings, necessary for the arrangement of the real test space (to be located on the premises of the *the Fire Officers Faculty* in Bucharest.

The present study refers to a numerical and graphical analysis of a fire developed in a fire compartment which was built using a light structure. The research had as a starting point the influence of ventilation openings and the influence of the combustible materials inside the studied fire compartment.

2. CASE MODEL DESCRIPTION

The studied compartment is equipped with an office table and an armchair. It has a door opening and a window, both located on different walls. The model to be used in the study will be finished-off – both on walls and on ceiling – with a different construction material (wood chipboard, polystirene, plasterboard, foam polyvinyl chloride (PVC) and concrete) for each simulation.

In order to analyze the influence of ventilation openings on the dynamics of a fire in an enclosed space, the following four situations were considered: * both the window and the door are closed; * both the window and the door are opened; * the window is open and the door is closed; * the window is closed and the door is open.

In these four situations, the influences of the building materials that will be part of the studied compartment will be analyzed. The walls are considered to be made of brick, the floor of concrete and the surface of the walls and the ceiling are considered to be of different types of construction materials. These materials will be studied within each ventilation type mentioned above.

2.1. Description of the compartment where the fire simulation will be carried out

In order to implement a fire compartment in B-RISK software, the actual dimensions of the concrete container situated in the Fire Officers Faculty premises were used.

To be noted that this container has a *two ridged* roof, built of concrete, and when entering the compartment data on B-RISK software, it was established that the roof of the compartment will be a terrace type, with linear ceiling. After measuring the container, the following interior measures were established: length = 5.4 m; width = 3.1 m; height = 2.1 m.

As mentioned above, in the present study, the used construction materials are wood chipboard, gypsum board, concrete, PVC and polystiren.

2.2. Ventilations elements (openings) description

In this study, the ventilation elements are initially considered to be open, but they will be closed or opened according to the scenarios under study.

The geometry of the compartment is presented in figure 1 (Smokeview snapshot).

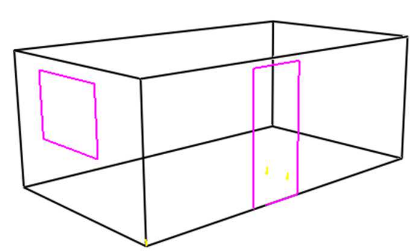

Fig. 1. The geometry of the considered compartment

2.3. Description of flammable items and their location inside the compartment

Two combustible items were considered inside the compartment, an office table (desk) and a chair, as shown in Figure 2. The office desk was placed on the front of the compartment, on the door side, and the office chair was placed under the desk.

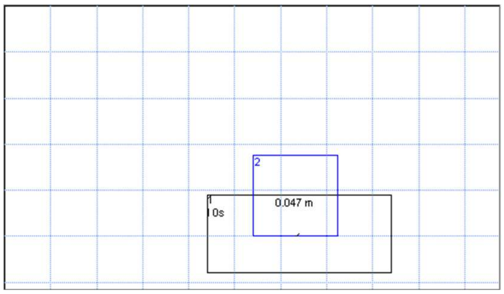

Fig. 2. Items positioning inside the compartment

After inserting an object, setting the dimensions and positioning, it is necessary to set the heat release rate (HRR). In figure 3 the HRR for the chair [12] is presented.

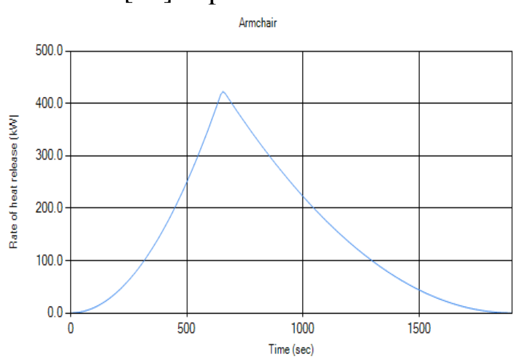

Fig. 3. Heat Release Rate (HRR) of an office chair [3]

Similarly for the desk, after setting the dimensions and positioning it, the heat release rate (HRR), was introduced. The HRR for the office desk is presented in Figure 4. The desk has been selected from the same database and has the following characteristics: * length = 2 m; * width = 0.85 m; * height = 0.75 m.

The combustion heat was established for both items, at a value of 80 kJ/g for the office table and 25 kJ/g for the armchair. By entering this numeric data, the software automatically calculated the fuel mass for both items, thus being 22.93 kg for the office table, respectively 10.821 kg for the armchair.

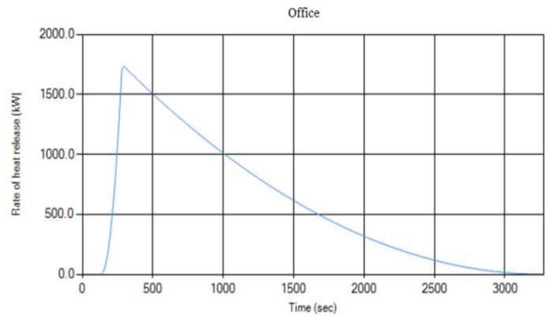

Fig. 4. HRR values for the office desk[3]

2.4. Defining the parameters subject to analysis

The parameters to be detailed and which will best describe the differences between how the position of a ventilation opening influences the dynamics of the fire development within the studied compartment are: * temperature of the upper layer; * temperature of the lower layer; * height of smoke layer.

3. RESULTS AND DISCUSSION

3.1. Analysis of the influence of ventilation holes on the dynamics of fire inside the studied compartment

As mentioned above, four scenarios were considered: **Scenario 1** - the window and door are opened; **Scenario 2** - the window is open and the door is closed; **Scenario 3** - the window is closed and the door is open; **Scenario 4** - the window and door are closed.

In each scenario, the interior walls (constructed of 100 mm brick) and the ceiling are considered to be finished with different materials, and discussions are given to each case. Those materials are:* Nida Standard gypsum board with a thickness of 12 mm; * Particle board made of wood chips P2 (PAL) with a thickness of 12 mm; * Decorative polystyrene panel injected with resin, embossed brick texture, unpainted, 20 mm thick; * Classic Venetian IV (Polyvinyl Chloride) wallpaper with a thickness of 3 mm; * Concrete with a thickness of 100 mm. Concrete is being considered a particular case, and it is used as a reference system for the other types of materials. For the concrete case, we consider the walls as being built only of concrete, without brick substrate.

Within each scenario of the four presented above, the influence of the ventilation openings on the enclosed space was analyzed.

3.1.1. Scenario 1 – the window is opened (Ow) and door is opened (Od)

This situation is the most favorable in terms of fire safety because it creates natural ventilation, thus leading to the evacuation of smoke and hot gases resulting from the combustion. After running simulations for each material separately, all results were exported in an Excel file, and the parameters presented in the previous subchapter were extracted.

For the upper layer temperature parameter, according to figure 5, one can observe that the highest temperature values, of approximately 672 °C, are reached when PVC was used as a building material in the compartment; one has to mention that the simulation in this case was finalized after 290 seconds due to the combustible materials that have been consumed. According to the graph presented in figure 5, one can see that in the case of polystyrene, likewise, all the materials burn in the first 270 seconds, thus consuming all the fuel, and the simulation is completed before the preset time, namely 1800 seconds.

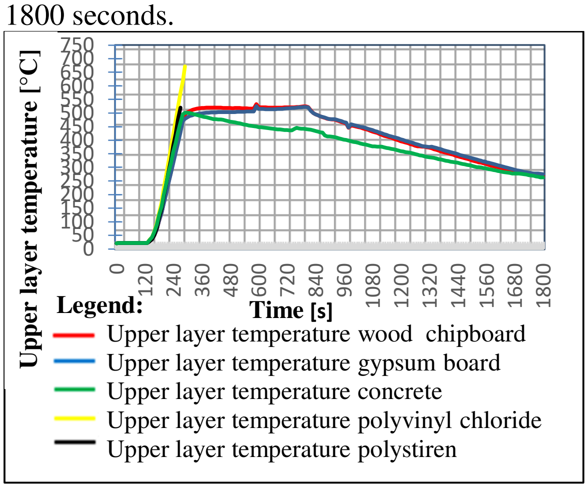

Fig. 5. Evolution of the temperature of the upper layer diagram [Ow-Od]

When the simulation involves walls built entirely of concrete with a thickness of 100 mm, the maximum temperature value reached in the upper layer is about 500 °C, lower than in the other situations. During the regression phase, the temperature value drops *significantly* when the walls are made of concrete. In the case of gypsum-board and wood chipboard, the same temperature values are reached in the regression phase; also, the curves for wood chipboard and gypsum-board have about the same aspect.

According to figure 6, the maximum value of the lower layer temperature reached in the case of Scenario 1 was about 304 °C and it was achieved even if the compartment had wood chipboard finishing on the surface of the interior walls. The temperature values for all the building materials have the same evolution, with the indication that the temperature values are much lower, thus being called "comfort temperatures" for the intervention teams. In the case of polystyrene and PVC, the experiment ends at 270 seconds, respectively 290 seconds, due to the fact that the fuel material was consumed. In the case of walls made entirely out of concrete, the temperature value in the lower layer is much lower, almost half the value compared to the one obtained in the case of brick walls with wood chipboard or plasterboard finishing.

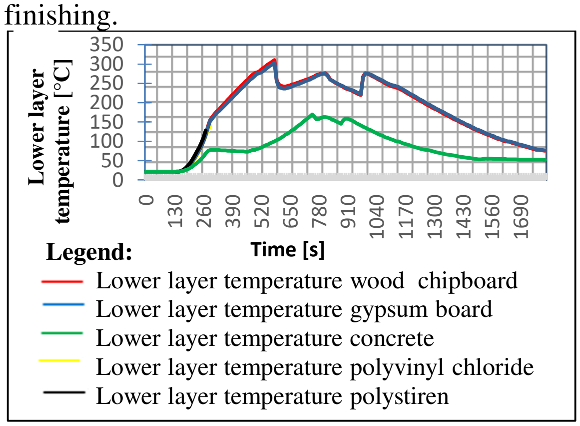

Fig. 6. Evolution of the temperature of the lower layer diagram [Ow-Od]

In the diagram in figure 7 one can see the height of the smoke layer developing in time along with the evolution of the fire. In the case of Scenario 1, the height of the smoke layer descends to approximately the same height of 0.78 meters for each material, except for PVC and polystyrene, where the smoke descends to the height of 1.4 meters, respectively 1.15 meters. In the case of walls made of concrete, a building material considered as reference element, the height of the smoke layer descends only up to a height of 1.1 meters.

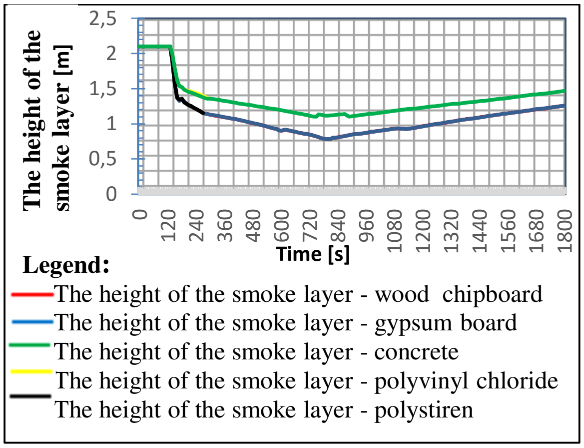

Fig. 7. Evolution grapf of the smoke layer diagram [Ow-Od]

3.1.2. Scenario 2 – the window is open (Ow) and the door closed (Cd)

In this scenario, the door was closed and the window remained in the same position; also, the rest of the parameters remained unchanged.

According to the temperature evolution curves in the upper layer, as shown in figure 8, the highest temperature value is reached if the interior walls have wood chipboard finishing. This maximum temperature value is 753 °C, followed by the temperature value in the case of plasterboard, namely 750 °C. According to the graph, in the regression phase, the temperature value of the gypsum board will exceed the temperature value of the wood chipboard. In the case of PVC and polystyrene whose simulations were completed faster than the present time for simulation due to the consumable fuel material, their maximum temperature values in the upper layer area reached a maximum of 642 °C, respectively 565 °C.

According to Scenario 2, the evolution curves of the temperatures in the lower layer area, as shown in figure 9, reached temperature values twice lower than in the case of Scenario 1, where both ventilation openings were set to zero (open). For the walls made entirely of concrete, the maximum temperature value reached in the lower layer is about 455 °C, after 820 seconds of testing. In this case, when the door is closed, the oxygen supply to the fire is much higher, and the maximum temperature values reached 627 °C in the case of PAL and 618 °C in the case of gypsum board. For PVC and polystyrene, the maximum temperature values reached 460 °C and respectively 451 °C.

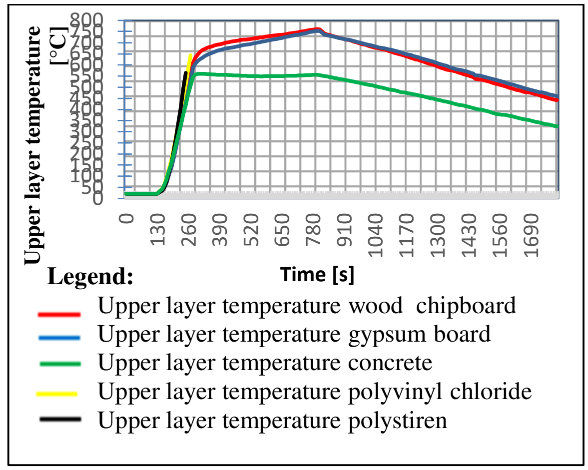

Fig. 8. Temperature of the upper layer evolution diagram [Ow-Cd]

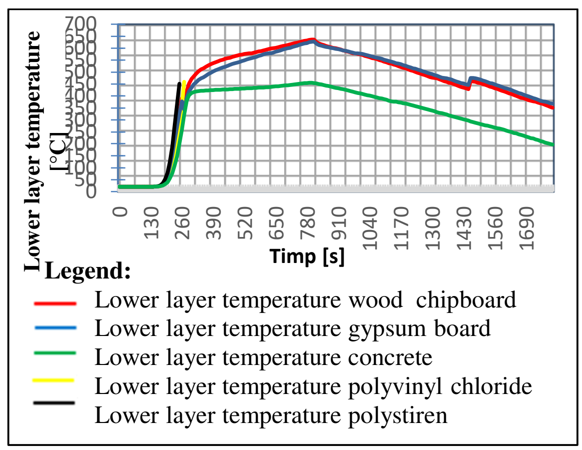

Fig. 9. Temperature of the lower layer evolution diagram [Ow-Cd]

As it can be seen, again in the regression phase, the temperature values in the case of plasterboard will be higher in comparison with the situation when the coating material of the walls was considered wood chipboard.

The smoke layer height, according to the evolution graphs shown in figure 10, goes down almost to the level of the floor when the walls were plated with gypsum board and wood/PAL. In this case, it drops to a height of 0.32 meters after the first 810 seconds. For PVC, the smoke layer height reaches a height of 1.1 meters until the end of the test, and for Polystyrene the smoke layer height descends to a height of 0.9 meters after the first 270 seconds of the test. In the case of the test on the walls made of concrete, the height of the smoke layer does not descend as low as in the case of the other materials, it reaches a maximum height of 0.7 meters after 830 seconds of testing.

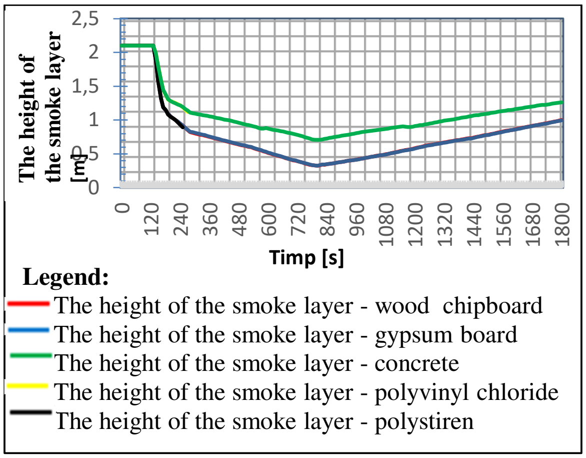

Fig. 10. Evolution graph of the smoke layer diagram [Ow-Cd]

In case of the wood chipboard used as a coating material for the walls, the height of the smoke layer is observed to descend near the floor – when the simulation is over – as seen using the Smokeview function.

3.1.3. Scenario 3 – the window is closed (Cw) and the door open (Od)

In the case of Scenario 3 (prerequisite: the window is closed, the door is open and the position of the two ventilation holes was reversed) the influence of ventilation on the dynamics of the fire in the closed space is analyzed. Under this scenario, analysis is done to observe whether the size and the walls on which the ventilation openings are found, will have an influence on the fire developed inside the compartment.

As shown in figure 11, there are two simulations (in the case of materials used for coating the walls) that ended faster and in which the temperature values of the upper layer reached values of: 1. 643 °C after 260 seconds of simulation in the case of polystyrene and 2. 629 °C after 270 seconds of simulation in the case of PVC. For the other materials, the maximum temperature values in the upper layer are lower in Scenario 3 than in Scenario 2. In the case of walls built of concrete, a material considered as a reference element for all simulations, the maximum temperature value in the upper layer is 533 °C after 320 seconds, after which the regression phase appears and the temperature values begin to drop gradually. For PAL and gypsum board the maximum temperature values in the upper layer reach a maximum value of about 646 °C after 820 seconds.

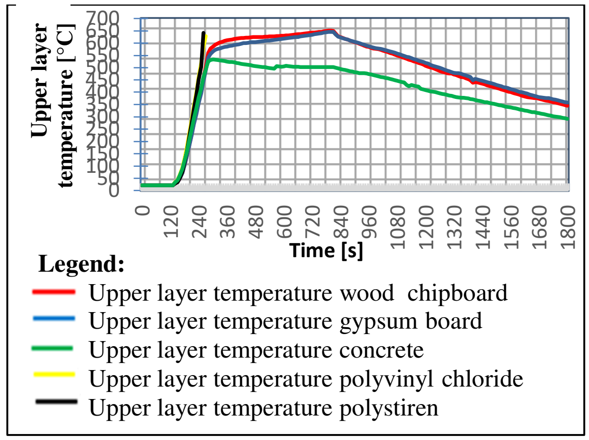

Fig. 11. Temperature of the upper layer evolution diagram [Cw-Od]

For the lower layer temperature values, according to the evolution curves shown in figure 12, one can see that they are much smaller than those in Scenario 2. This situation is due to two factors: 1. the door that have larger dimensions than the window and 2. the location of the door, from the floor level, allowing fresh air to enter through the lower part in larger quantities, thus cooling the area. The temperature value in the case of the simulation performed on the concrete walls, is a very low one, of maximum 277 °C after only 840 seconds.

For the height of smoke layer parameter, a very important one when talking about fires in confined spaces, one observed that the smoke layer height in the case of the studies based on the PAL and gypsum board, had the most negative evolution, values being about the same for both materials.

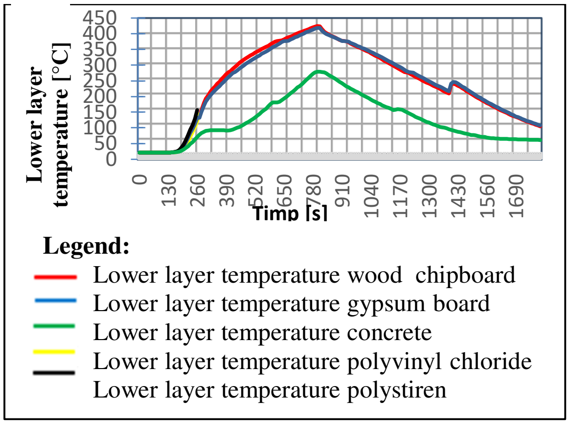

Fig. 12. Lower layer temperature evolution diagram [Cw-Od]

The height of the smoke layer in this situation reaches the height of 0,4 meters (compared to the floor level) after only 810 seconds. In the case of concrete, the reference element, height of smoke drops to a maximum value of 0.8 meters from the floor. For PVC and polystyrene, even if the combustion and finally the simulation finishes very quickly, the smoke layer position reaches a height of 1.1 meters from the floor, respectively 0.8 meters.

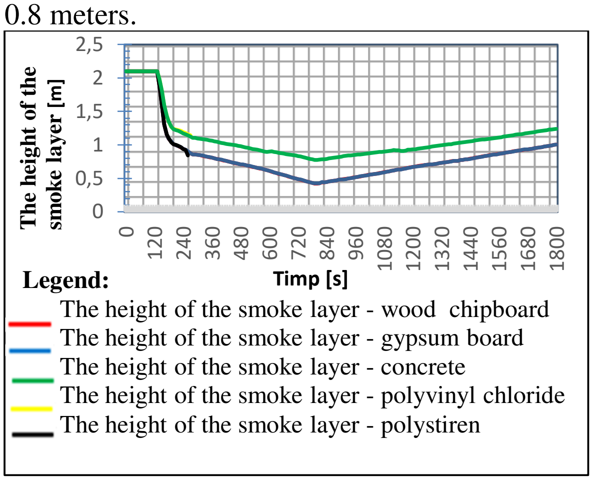

Fig. 13. Evolution grapf of the smoke layer diagram [Cw-Od]

3.1.4. Scenario 4 – the window and the door are closed (Cw and Cd)

Scenario 4 consisted of executing simulations on the different types of construction materials, used for coating the walls, with both ventilations closed. This situation is the most dangerous in terms of thermal phenomena that can occur due to the fact that the ventilation holes are closed, backdraft being the most dangerous phenomenon that can occur in such scenario.

A Backdraft phenomenon is generally caused by human external action, but it is also caused by natural causes Backdraft can occur under certain conditions such as: closed volume under pressure, incomplete combustion, considerable heat, cracking of compartmentalizing elements.

According to the evolution graphs shown in figure 14, in the case of a closed space in which the ventilation holes are closed, the temperature values in the upper layer differ from one simulation to another, depending on the construction material used to finish the walls. Compared to the upper layer temperature values obtained in the case of the previous scenarios, in the case of Scenario 4, the values of these temperatures do not exceed the value of 402 °C, except for the simulation in which the polystyrene-plated compartment was analyzed. In this simulation, in which polystyrene was used as a material for coating the walls, it was completed after 730 seconds, due to the fact that the combustible materials were consumed, and the temperature value in the upper layer reached values up to 528 °C. When the walls were constructed entirely of concrete, a building material considered to be a reference element, the temperature values in the upper layer area did not exceed 231 °C. For the rest of the tests performed (with wood chipboard, gypsum board and PVC) the temperature evolution is approximately similar. Unlike the rest of the scenarios, when using PVC wallpaper for coating the walls, the simulation was not completed faster than the present time.

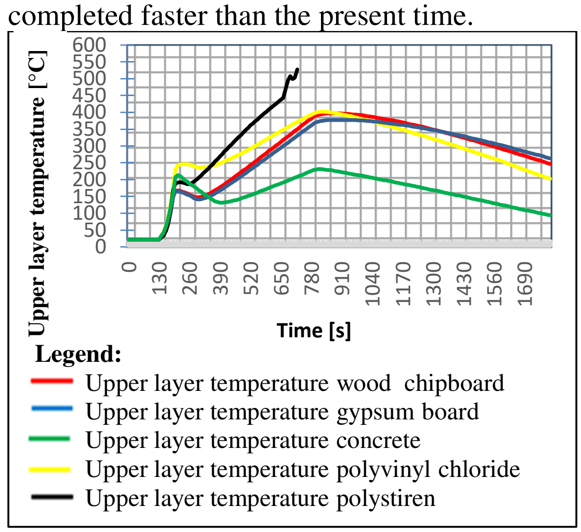

Fig. 14. Upper layer temperature evolution diagram [Cw-Cd]

Lower layer temperature values in case both ventilation holes are closed has very low values compared to the rest of the scenarios. These low temperature values are caused by the position where the ventilation holes are located, more precisely by the limited supply of oxygen from the outside environment.

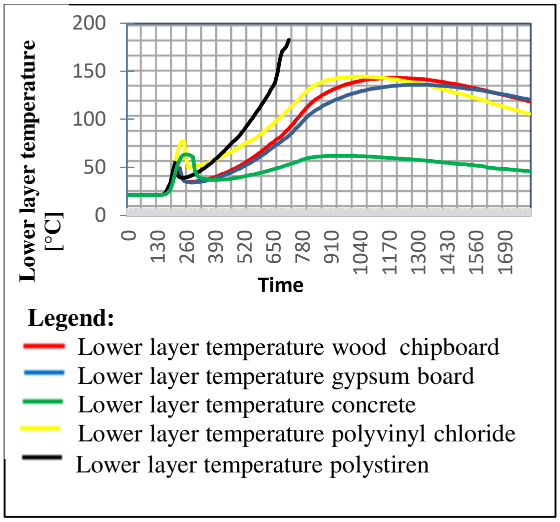

Fig. 15. Lower layer temperature evolution diagram [Cw-Cd]

According to figure 15, the maximum temperature value reached in the lower layer area is 183 °C and this value sets in when the simulation was performed on the compartment whose walls were coated with polystyrene, even if the simulation is completed after 730 seconds. And the opposite of the temperature value of the lower layer, is found in the simulation performed on the container built entirely of concrete.

The height of the smoke layer with closed ventilations, according to the conditions of Scenario 4, occupies the entire volume of the room, after the first 300 seconds. The smoke layer reaches the floor level for each test performed using each material separately.

Although the production of smoke does not substantially influence the increase of the fire, it affects the safety of the occupants because it reduces the visibility, causing disorientation. The production of smoke depends a lot on the nature of the material, so it is important that, in the volume of the escape routes, the location and use of materials that produce a lot of smoke are limited.

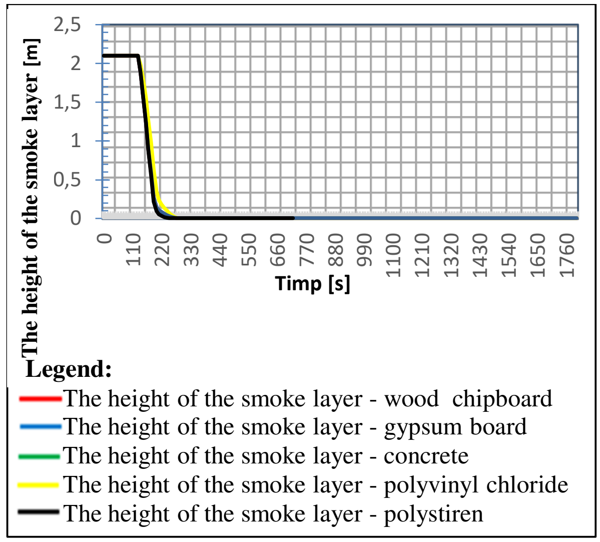

Fig. 16. Smoke layer evolution graph diagram [Cw-Cd]

3.2. Analysis of construction materials under the influence of ventilation in a fire developed in an enclosed space

Table no. 1 includes a centralization of the building materials that were used for coating the walls and the evolution of each parameter, under the influence of ventilation.

Table 1

Summary table

The studied parameter (maximum value: time to reach it)	Scenario	Gypsum board: Nida Standard cardboard [12 mm]	Particle board made of wood chips P2 (PAL) [12 mm]	Decorative polystyrene panel injected with resin [20 mm]	Clasic wallpaper la Veneziana IV (PVC) [3mm]	Concrete [100 mm]
Upper layer temperature [°C]	S 1: Od-Ow	514: 620 s	515: 610 s	520: 270 s	672: 290 s	500: 320 s
	S 2: Cd - Ow	743: 810 s	573: 810 s	565: 250 s	643: 270 s	560: 320 s
	S 3: Od-Cw	645: 800 s	648: 800 s	642: 260 s	628: 270 s	532: 320 s
	S 4: Cd - Cw	377: 880 s	397: 850 s	527: 720 s	402: 820 s	231: 840 s

Lower layer temperature [°C]	S 1: Od-Ow	300: 580 s	303: 590 s	128: 280 s	136: 290 s	165: 750 s
	S 2: Cd - Ow	618: 830 s	627: 820 s	452: 250 s	460: 270 s	455: 790 s
	S 3: Od-Cw	410: 830 s	824: 810 s	157: 260 s	144: 270 s	278: 810 s
	S 4: Cd - Cw	136: 1310 s	143: 1160 s	183: 720 s	145: 1050 s	62: 890 s
Height of smoke layer [m]	S 1: Od-Ow	0,79: 820 s	0,78: 820 s	1,2: 270 s	1,4: 290 s	1,1: 740 s
	S 2: Cd - Ow	0,3: 790 s	0,4 : 790 s	0,9: 250 s	1,2: 270 s	0,7: 790 s
	S 3: Od-Cw	0,4: 800 s	0,4: 800 s	0,8: 260 s	1,2: 270 s	0,8: 820 s
	S 4: Cd - Cw	0,01: 250 s	0,01: 250 s	0,01: 240 s	0,01: 270 s	0,01: 350 s

Note: Od – open door, Cd – close door, Ow – open window, Cw – closed window, s – seconds

4. CONCLUSIONS

In this paper the authors have presented results from a fire simulation performed in an enclosed space, emphasizing the influence of both the ventilation openings surface and the characteristics of the thermal properties of the construction materials used for the finishing materials used on walls. In the case of **Scenario 1**, characterized by the maximum surface of the ventilation openings, the maximum temperature value of the upper layer of smoke and hot gases is obtained in the case of polyvinyl chloride (PVC), and that of the lower layer is obtained in the case of wood chipboard, gypsum board, PVC. The maximum height of the smoke layer measured from the ceiling is obtained in the case of wood chipboard and gypsum board. In the case of **Scenarios 2** and **3**, both the maximum temperature of the lower and upper layers of smoke and hot gases and the maximum height of the smoke layer measured at the ceiling is obtained in the case of wood chipboard and gypsum board. In the case of **Scenario 4**, characterized by the lack of ventilation openings, the maximum temperature value of the upper and lower layers of smoke and hot gases is obtained in the case of polystyrene. The maximum height of the smoke layer measured from the ceiling is obtained for all tested materials.

One main conclusion is that high values of the ventilation opening surfaces will lead to high peaks of temperature of the upper layer of smoke and hot gases, of about 672 ° C, in a given time of 290 s after ignition (PVC as burning material).

Thus, in order to create the worst case scenario conditions, the large ventilation openings will be considered for the testing facility that will be arranged on the premises of the Fire Officers Faculty in Bucharest.

Acknowledgement

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Studiul simulării computerizate privind influența deschiderilor de ventilație asupra dinamicii incendiului într-un spațiu închis

Autorii folosesc simularea computerizată (platforma Software B-RISK) pentru a analiza evoluția unui incendiu într-un spațiu închis, pentru diferite scenarii. Scenariile diferă între ele în urma modificării unor factori care influențează arderea: suprafata deschiderilor de ventilație, materialele folosite pentru acoperirea pereților interiori. Simulările au ca rezultat diverse valori pentru temperatura și pentru nivelul stratului de fum în spațiul închis. Valorile acestora influențează în mod direct șansele de supraviețuire ale persoanelor implicate în incendiu, atât civili cât și pompieri. Cu ajutorul datelor și concluziilor obținute în prezentul studiu, se va amenaja un spațiu de testare în curtea interioară a Facultății de Pompieri din București.

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