MATHEMATIC MODELING OF FIRE EXPERIMENT IN A DETACHED HOUSE IN BOHUMIN WITH SOFTWARE FLUENT

Milada KOZUBKOVA, Marian BOJKO, Otto DVORAK, Jaroslav KRUTIL
milada.kozubkova@vsb.cz, marian.bojko@vsb.cz, odvorak@mvcr.cz,
jaroslav.krutil@vsb.cz

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Abstract

The issue of CFD simulation of burning and spread of the fire in enclosed buildings is a very complex process which requires both basic knowledge of the physical flow of burning and detailed information about the object, its marginal conditions and thermo-physical properties of the materials. Thermo-physical properties of some materials have a signifacant impact on the actual fire spread and heat transfer through combustion. Proper determinations of these properties have a large influence on the results of numerical simulation. These characteristics were obtained either from tables or from the results of the experiment. The calculated results were compared to those obtained through the experiment.

The aim is therefore the assessment of a mathematic model using computer software FLUENT for fire technical expertise and thereby to contribute to better understanding of fire behavior in the living room, to prevent its possible spread to other areas of the house and thus avoid unnecessary losses of tangible property and especially of human lives.

Keywords
CFD, combustion, fire, burning, numerical simulation, FLUENT, heat transfer.

INTRODUCTION

The article deals with fire spreading in a detached house through a mathematic model and consequent numeric simulation in program FLUENT. This mathematic model is to represent as best as possible a large-scale fire experiment which was carried out on November 19, 2009 in a selected detached house in Bohumin. (6) The scenario of the experiment was as follows. Intentionally set fire in a dining room of a three-floor house consequently spread into a large part of the first floor. After considerable spreading, the fire was put out. The objective of this involvement is the development and validation of fire mathematic models for determination of the emergence/spread of the heat and smoke, toxic gases, pressure

waves for simulation/interpretation of fire scenarios and their destructive effects with SW FLUENT.

Mathematic modeling itself involves burning, heat transfer through walls of a model and air flow in a respective area.

EXPERIMENTAL PART WITH MARGINAL CONDITIONS

The objective of the fire experiment was to imitate as most authentically as possible real spreading of fire with the fire loading as far as kinds of flammable materials and their location in the area and total amount is concerned. Location of fire loading in a dining room is obvious from Fig. 1. [6]

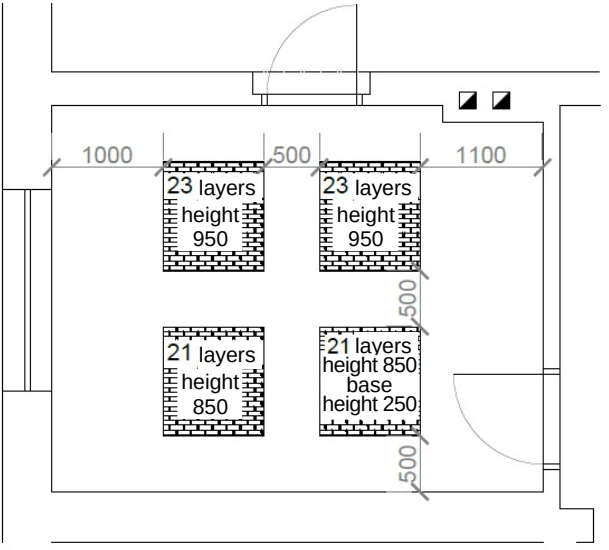

Fig. 1
The scheme of the location of the small heap on wood in a dining room

This loading is during the fire experiment ensured with small heaps on wood consisting of squared logs of 4 x 4 x 100 cm.Total weight of wood is 730.2 kg and heating power is 16,75 $MJ.kg^{-1}$ .Further, it is necessary to include into the fire loading also the ignition accelerators. These accelerators are toluene of the amount of 2 *l* and heating power 41 $MJ.kg^{-1}$ in two glass flasks volume 1 *l* and heptane of heating power 45 $MJ.kg^{-1}$ on a plate under one heap on wood volume 14.5 *l*.

After the experiment we found out that from the fire loading on wood squared logs about 374 pieces weighing approx. 305 *kg* left. Other important physical information on materials used for fire loading is given in Table 1.

Table 1
Physical parameters of materials used for fire loading

Parameter	**Wood**	**Heptane**	**Toluene**
ρ [kg.m^{-3}]	515,5	680	867
Q_{heat} [MJ.kg^{-1}]	16,75	45	41

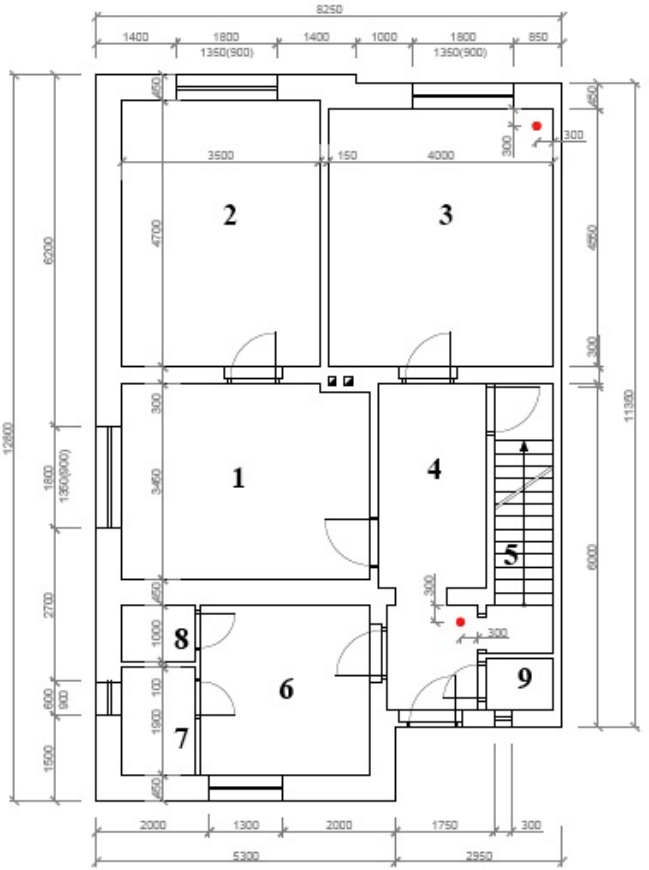

Fig. 2
1st floor ground plan

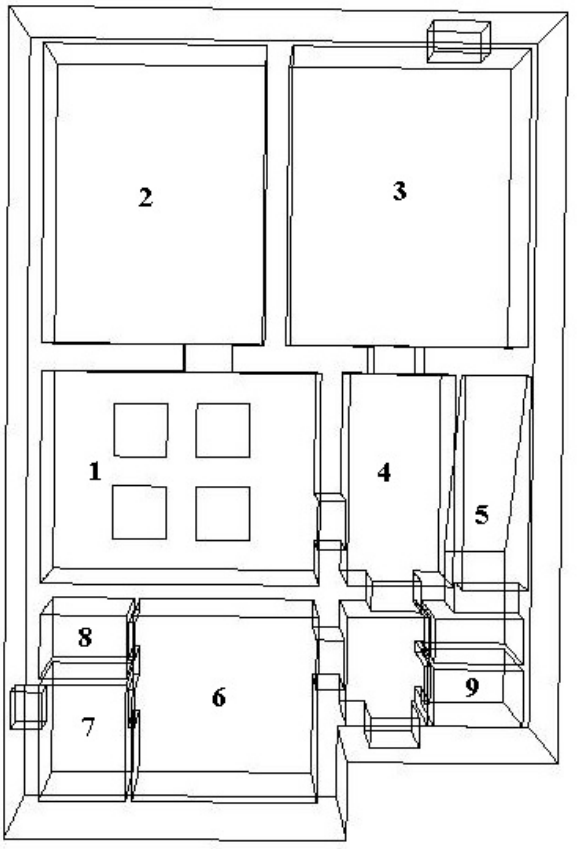

Fig. 3
Model of the house 1st floor

Explanatory notes: 1 – dining room, 2 – bedroom, 3 – living room, 4 – lounge, 5 – staircase to 2nd floor, 6 – kitchen, 7 – bath, 8 – pantry, 9 - WC

Other necessary information for successful mathematic simulation is drawing documentation of a given object. As the fire attacked the second floor only, mathematic model was focused just on this area. 2 [6] you can see a detailed drawing documentation of this floor.For better demonstration, in Fig. 3 a special model of the area is visualized.

The description of the state of windows and doors during the experiment is another very important aspect for the consequent successful solution. The state of these marginal conditions is described in details in Table 2 [6].

Table 2
The description of the state of windows and doors in the building on the first floor during the experiment

	Opening	Room	Size (w x h) /mm/	State	Note
1st floor	Window	1	2x (500 x 1280)	Glass	Double window two-wing
	Door	1/2	800 x 1970	Open	No door wing
	Door	1/4	800 x 1970	Open	No door wing
	Window	2	2x (500 x 1250)	Glass	Double window two-wing
	Door	3/4	800 x 1970	Open	No door wing
	Window	3	2x (400 x 1080)	1/2 Glass	One wing without glass
	Door	4/6	800 x 1970	Shut	Wood door
	Door	4/ext.	800 x 1970	Shut	Iron
	Door	4/5	800 x 1970	Open	Without door wing
	Door	6/7	600 x 1970	Open	Without door wing
	Door	6/8	600 x 1970	Open	Without door wing
	Window	7	800 x 900	Shut	Shut with wood sheet
	Window	6	1200 x 1200	Shut	Bricked
	Door	4/9	600 x 1970	Open	Without door wing
	Door	4/1PP	800 x 1970	Shut	Wood door

NUMERIC MODELING

1 Mathematic model:

1.1 Mathematic model of the fire with the source of heat input

This task is solved, with regard to the flow with burning in a given object, as turbulent. Mathematic model consists of the formulas of continuity, Navier-Stokes formula, formula of energy and formula for the spread of ingredients. In a range of practical calculations of turbulent circulation we use time centered magnitudes which are in consequent paragraphs and formulas marked with a stripe

above a given physical magnitude. It is due to the fact that at high values of Reynold number it is not possible with regard to needful number of net cells and possibility of IT to use a direct method (DNS). Also the method of large eddies (LES) is at such complex geometry time-consuming.

1.1.1 The formula of continuity for circulation of pressed liquid

The formula expressing the mass conservation law is called "continuity formula". For unstable, therefore time-dependent, circulation of pressed liquids we can express in a differential form as follows [3]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \left(\rho \overline{u}_j\right)}{\partial x_j} = S_m \quad , \tag{1}$$

where $\overline{u}_i$ is „time-centered part of velocity" of circulation $(m \cdot s^{-1})$, x_j is the coordinate (m), p is the density $(kg \cdot m^{-3})$ and S_m is the volume source $(kg \cdot m^{-3} \cdot s^{-1})$.

1.1.2 The formula of continuity for circulation of pressed liquid

The formulas expressing mass conservation law are called "Navier-Stokes formulas". After installing time-centered magnitudes into Navier-Stokes formulas, these formulas become so called "Reynolds formulas". Formulas for transfer of dynamics with compressible liquids are therefore as follows [3]:

$$\frac{\partial \left(\rho \overline{u}_i\right)}{\partial t} + \frac{\partial \left(\rho \overline{u}_i \overline{u}_j\right)}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu_t \frac{\partial \overline{u}_i}{\partial x_j}\right) + \rho \delta_{i3} g \, , \tag{2}$$

which responds to a differential form of the "formula for transfer of dynamics", where $\overline{p}$ is pressure (Pa), μ_t is turbulent viscosity $(m^2 \cdot s^{-1})$, δ_{i3} is Kronecker delta $(-)$, $g = -9{,}81\ (m.s^{-2})$ is „gravitation acceleration" in case of uplift pressure.

1.1.3 Formula for turbulent magnitudes

By the formulas for expressing turbulent magnitudes we mean formulas for "turbulent kinetic energy" k and "velocity of dissipation" ε. The exact formula for k we can deduce from Navier-Stokes formulas and this is [3]:

$$\frac{\partial k}{\partial t} + \frac{\partial \overline{u_j} k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{v_t}{\sigma_k} \cdot \frac{\partial k}{\partial x_j}\right) + v_t \left(\frac{\partial \overline{u_j}}{\partial x_l} + \frac{\partial \overline{u_l}}{\partial x_j}\right)\frac{\partial \overline{u_i}}{\partial x_j} - C_D \frac{k^{3/2}}{l} \quad , \tag{3}$$

where v_t is turbulent viscosity $(m^2 \cdot s^{-1})$, σ_k is the empiric constant $(-)$, C_D is constant $(-)$.

"Turbulent kinetic energy" k $(m^2 \cdot s^{-2})$ is given in a formula (3) where it is defined as [3]:

$$k = \frac{1}{2}\left(\overline{u_1'^2} + \overline{u_2'^2} + \overline{u_3'^2}\right) = \frac{1}{2}\overline{u_j'^2} \tag{4}$$

The exact formula for ε $(m^2 \cdot s^{-3})$ we can again deduce from Navier-Stokes formulas and this is [3]:

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial \overline{u}_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\nu_t}{\sigma_\varepsilon} \cdot \frac{\partial \varepsilon}{\partial x_j}\right) + C_{1\varepsilon}\nu_t\left(\frac{\partial \overline{u}_j}{\partial x_l} + \frac{\partial \overline{u}_l}{\partial x_j}\right)\frac{\partial \overline{u}_l}{\partial x_j} - C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{5}$$

The relation for "turbulent viscosity" ν_t is then defined as follows [3]:

$$\nu_t = C_\nu \frac{k^2}{\varepsilon}$$

1.1.4 The energy formula

The energy formula expresses "energy conservation law" according which "the total change of energy" of $\overline{E}$ liquid in a specific „volume *V* is determined by the change of „internal energy" and „kinetic energy" and circulation of both energies by „surface" *S* constraint volume *V*. The final formula is as follows [3]:

$$\frac{\partial}{\partial t}\left[\rho \overline{E}\right] + \frac{\partial}{\partial x_j}\left[\rho \overline{u}_j \overline{E}\right] = -\frac{\partial\left(p\overline{u}_j\right)}{\partial x_j} - \frac{\partial \overline{q}_j}{\partial x_j} + S_h \ , \tag{7}$$

where S_h is a source term $(\mathrm{J.s^{-1}.m^{-3}} = \mathrm{W.m^{-3}})$.

1.1.5 Transport formula for transfer of ingredients

Model FLUENT counts with "time-centered values of local mass fractions of ingredients" $\overline{Y}_{i'}$, where i' is the index expressing the number of ingredients which are described through a similar balance formula as it is with the energy formula encompassing the solution of convective and diffusion sections of the transfer. The index expresses the number of ingredients. We use the relation which is in a conservative form as follows [3]:

$$\frac{\partial}{\partial t}\left(\rho \overline{Y}_{i'}\right) + \frac{\partial}{\partial x_j} \cdot \left(\rho \overline{u}_j \overline{Y}_{i'}\right) = -\frac{\partial}{\partial x_i} J_{j,i'} + R_{i'} + S_{i'} \quad , \tag{8}$$

where $\overline{u}_i$ is „time-centered section of velocity" of circulation $(m \cdot s^{-1})$ and on the right side there is $R_{i'}$ "the velocity of ingredients production i'" influenced by chemical reaction and $S_{i'}$ „the velocity of the production of augmentation from distributed ingredient". The distribution of ingredients can be done under various

conditions. During turbulent circulation FLUENT for expressing diffusion circulation of i' section we apply the relation [3]:

$$J_{i'} = -\left(\frac{\mu_t}{Sc_t}\right)\frac{\partial \overline{Y}_{i'}}{\partial x_j} \quad , \tag{9}$$

where Sc_t is „Schmidt turbulent number“ $(-)$ (pre-set for the value 0,7).

1.2 Mathematic model of the source of energy and combustion products

The solution of the fire lies in the solution of stoichiometric formulas combustion of exactly defined source of fire (coal, wood, oil, plastics etc.). When modeling the fire it is often difficult to specify exactly the composition of flammable substances. Therefore the approach for modeling is simplified in the way that the source of the fire is defined by the volume in which it is defined:

- the source of energy (better heat input) in the formula of energy and the formula of continuity,
- the source of mass fraction in the formula for mass fraction of CO, CO_2, vapor, H_2O and the decrease of O_2.

As the source terms are defined for the volume unit, it is necessary to determine first the size of the volume of the source using the integration (Report-Volume Integral).

The volume source of weight (for one or more ingredients) in the formula of continuity is defined by the relation:

$$S_m = \frac{Q_m}{V} \qquad [\mathrm{kg.m^{-3}s^{-1}}] \tag{10}$$

By analogy it is possible to define the source term in the energy formula S_h, therefore the source of heat energy per second (heat input) related to unitary volume is defined in the energy formula by the relation:

$$S_h = \frac{E}{t \cdot V} \qquad [\mathrm{J.s^{-1}.m^{-3}=W.\ m^{-3}}] \tag{11}$$

The size of the source is determined from the fuel heating power, burnt amount in *kg*, density and finally volume. The power determined this way is converted for $1\,m^3$.

Turbulent kinetic energy S_k and the velocity of dissipation S_ε was not defined, therefore was not considered.

In case of the extension of a model with the transport of combustion products, the source term (mass flow of combustion products) is moreover laid the same way into the formulas for mass fraction CO_2, CO, O_2 into the energy formula. This adjustment moreover will precise the emergence of heat.

$$
\begin{aligned}
CO_2\ mass\ fraction\ source &= \frac{Q_{mCO2}}{V} \qquad [\mathrm{kg.s^{-1}m^{-3}}] \\
CO\ mass\ fraction\ source &= \frac{Q_{mCO}}{V} \\
O_2\ mass\ fraction\ source &= \frac{Q_{mO2}}{V} \\
H_2O\ mass\ fraction\ source &= \frac{Q_{mH2O}}{V}
\end{aligned}
\qquad (12)
$$

where CO_2, CO, O_2, H_2O, *mass fraction source* is the concentration expressed by mass fraction.

In case of sources whose parameters change in dependence on time (which is typical for burn-up of fuels), we can describe the dependencies of sources on time with user´s functions UDF.

Basic construction elements of fuel (wood) is carbon, oxygen and hydrogen which amount approximately to 95 – 98 % of dry material and which bind into polymer substances. This fact led to the introduction of a general chemical formula of wood in the form of $C_{100}H_{144}O_{66}$ [10]. Chemical composition of wood is set as follows: lignin (20 – 30 % of mat.), hemicellulose (20 - 30 % of mat.), organic substances (1 - 3 % of mat.), and inorganic substances (0,1 - 0,5 % of mat.). The formula during thorough combustion is as follows:

$$C_{100}H_{144}O_{66} + 103\,O_2 = 100\,CO_2 + 72\,H_2O \qquad (13)$$

In case of incomplete combustion the coefficients are dependent on the level of oxidation and generation of CO_2 and CO. Therefore:

$$a\,C_{100}H_{144}O_{66} + b\,O_2 = c\,CO_2 + d\,CO + e\,H_2O \qquad (14)$$

Hereat the coefficients must be chosen so as the stoichiometric formula could be applied, therefore:

$$
\begin{aligned}
a*100 &= c + d \\
a*144 &= e*2 \\
a*66 + b*2 &= c*2 + d + e
\end{aligned}
\qquad (15)
$$

2 Physical properties

In the entire area of mathematic model we consider two basic materials. It is flowing medium (liquid) and walls (solid material). We consider the air a flowing medium. The air is a mixture of oxygen and nitrogen defined by parameters which are given in Table 3. [5]

As far as the mixture density is concerned, the parameter of ideal gas was

set. It means that the density of a gas mixture is counted according to a condition formula of gases.

$$\rho = \frac{p \cdot M}{R \cdot T} \quad ,$$

where ρ is the mixture density $(kg \cdot m^{-3})$, T is temperature (K). p is pressure (Pa), R is gas constant $(J \cdot mol^{-1} \cdot K^{-1})$ and M is molar weight $(g \cdot mol^{-1})$.

Setting of mixing-law with relevant parameters suggests that these parameters are calculated on mixing-laws.

FLUENT enables to use a range of models for radiation solution. In our case a model DO (Discrete ordinate model) was applied. It represents the most complex model of all radiation models which basically is not limited in usability as long as the synergism with other setting of a mathematic model is concerned.

The solution for which we use a radiation model DO, FLUENT enables to set the absorption coefficient for gas mixture applying so called weighted-sum-of-gray-gases (WSGGM) - cell-based model which uses optical length for absorption coefficient calculation which is dependent on characteristic size of a cell net [3]. This means that it is considerably influenced by the quality of a mathematic model net. The advantage of this model is the fact that it is not necessary to define other inputs and parameters.

Table 3

Setting of physical parameters into the program FLUENT for floating mixture

Composition of mixture (air) on entry	**Units**	**Volume fraction**	
nitrogen	-	0,79	
oxygen	-	**0,21**	
Sum		1	
Mixture density (ρ)	$kg.m^{-3}$	Ideal-gas	Ideal-gas
Specific heat capacity (Cp)	$J.kg^{-1}.K^{-}$	Mixing-law	Mixing law
Coefficient of heat conductance (λ)	$W.m^{-1}.K^{-}$	Ideal-gas-mixing-law	Ideal-gas-mixing-law
Dynamic viscosity (η)	$kg.m^{-1}.s^{-1}$	Ideal-gas-mixing-law	Ideal-gas-mixing-law
Diffusion coefficient (D)	$m^2.s^{-1}$	$2,88e^{-5}$	
Absorption coefficient (σ_A)	m^{-1}	Wsggm-cell-based	
Scattering coefficient (σ_S)	m^{-1}	0	
Phase function variance	-	Isotropic	Isotropic
Refractive index (I)	-	1	

Fire brick is another material used in a model. This material is set for all solid and immobile parts in a house (ceiling, floor and walls inside the house). Physical parameters are described in details in Table 4. [9]

Table 4
Physical parameters of a fire brick

Density (ρ)	$kg.m^{-3}_{N}$	750	
Specific heat capacity (Cp)	$J.kg^{-1}.K^{-}$	1040	
Coefficient of heat conductance (λ)	$W.m^{-1}.K^{-}$	Piecewise-linear	Piecewise-linear
Absorption coefficient (σ_A)	m^{-1}	50000	
Scattering coefficient (σ_S)	m^{-1}	0	
Phase function variance	-	Isotropic	Isotropic
Refractive index (I)	-	1	
Emissivity (ε_T)	-	0,8	

From Table 4 is obvious that all walls, ceiling and floor are defined through Piecewise-linear function which enables to define heat conductivity versus changing heat in the form of a table describing heat conductivity using four points which is sufficient. Numeric values at certain degrees of temperature are given in Table 5. [9]

Table 5
Functions describing dependence of heat conductivity on temperature

Parameter	**1**	**2**	**3**	**4**
Temperature [°C]	0	200	300	600
Coefficient of heat conductance (λ)	0,36	0,36	0,38	0,455

3 Computing net

Geometry and computing net is completely presented in enclosed drawing documentation. Computing net of a house was made in program GAMBIT 2.4.6 with a total number of cells 309977. It is a non-structured net developed using elements of a many-sided form of variable shapes. The area with supposed source of heat is networked in details and slightly. It is done this way because of a significant influence of flowing and with it coherent distribution of temperatures in

a monitored field. Geometry of a mathematic model of a house and its detail in the spot of the net concentration is displayed in Fig 4 and Fig 5.

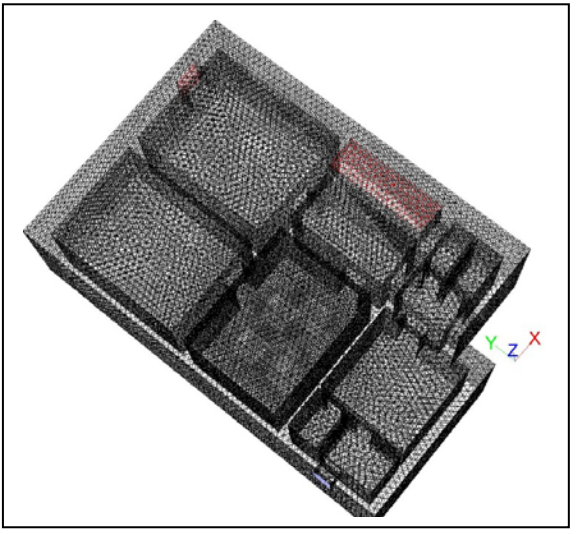

Fig. 4
Computing net of a house

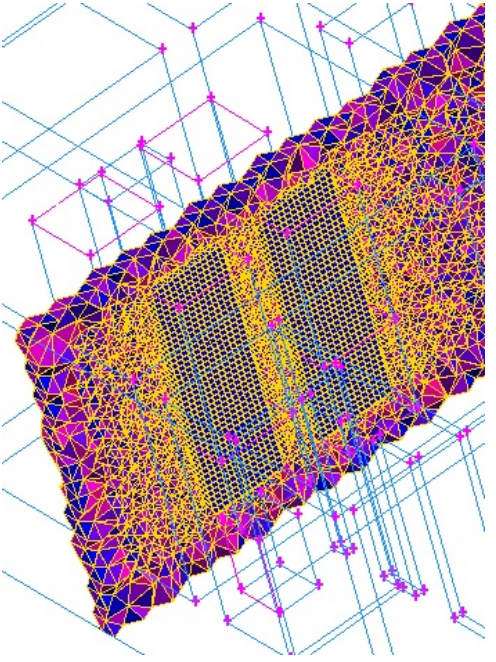

Fig. 5
Detailed concentrated net

4 Marginal conditions

All marginal conditions were mostly taken from available documents about the experiment. Both main marginal conditions both pressure-like and thermal which were defined in our tasks were obtained from available information on weather conditions during the course of measurement. Marginal condition on the input was defined as pressure-inlet. Marginal conditions for both outputs were both defined as pressure-outlet. Heat condition on the input and outputs reached the value $T = 10\ °C$. Flowing medium of the whole area - air is defined as composition of $N_2 = 79\ \%\ vol.$ and $O_2 = 21\ \%\ vol.$

Another important marginal condition which significantly influences the results of mathematic simulation is the definition of properties of interior walls, ceiling and floor of the house. These areas were defined as coupled, e.g. they allow to model the heat transfer.

Regarding more detailed and complex results, radiation was included into mathematic modeling. Radiation represents the transfer of electromagnetic energy in the form of waves with cross oscillation with regard to the direction of their space spreading. For radiation solution we applied so called DO radiation model (Discrete ordinate model [3]. After the selection of a radiation model DO in the panel of material properties, we set the following magnitudes with these parameters:

- Absorption coefficient $\sigma_A = 50000\ m^{-1}$
- Scattering coefficient $\sigma_S = 0\ m^{-1}$
- Refractive index $I = 1$

However, in these conditions the wall behaves only as a solid which accepts the radiation from the outside source (along with this it warms up proportionately), but it does not generate the radiation itself (the wall does not emit the heat in the form of radiation).

For proper function of a radiation model it is indispensable to define at marginal conditions of the inside wall its emissivity and it is 0,8. [6]

The last marginal condition defined for this mathematic model belongs to the outside walls of a house. For these walls we set a constant temperature of the surroundings obtained from the measurements of weather conditions. This temperature equals the value $T = 10\ °C$. The emissivity of the outside wall equals again 0,8. [6]

5 Source Definition

From the detail of a geometry net Fig. 3 is obvious that the location of fire loading in the form of heap of logs in the dining room is the as at the experiment. These heaps will be in a mathematic model defined as a volume source of heat input. The initiation of the fire was ensured by the flammables toluene and heptane which were also included into the total input of a heating source. The calculation of a total input of a heat source which is in the calculation defined by the volume of all four heaps is given in Table 6.

Table 6
Calculation of total input of heat source

Parameter	Wood	Heptane	Toluene
Weight [kg]	425	10,54	1,734
Heating power [MJ.kg^{-1}]	16,75	45	41
Density [kg.m^{-3}]	515,5	680	876
Total input of heat source connected to volume of 1 m^3 [W.m^{-3}]			167851,11

When calculating the total input, we had the volume of the heap consisting of wood, accelerators and air in a modeled area. Since the heat input of the air is zero and the input of wood and accelerators equals the value $P_c = 1632358{,}9\ W\ .\ m^3$, then this input must be re-counted to the volume of the heap.

To achieve a required curve of the temperature at a measured interval according to the experiment we used for simulation a user´s function UDF in language C++. The interval equaled the value $t = 3600\ s$.

The curve of the course in measured interval was estimated from the results of temperatures obtained from the experiment. When setting time dependent input, this function will copy the course of the temperature change at time in the vicinity of the source obtained from the fire experiment describing this course as follows: ignition, burning, intense fall of temperature due to the decrease of burning material and consequent afterburning, hereat the medium value of the input equals the constant input value. For this functional dependence we set six elementary points whose distribution is more obvious from Fig. 6 which is displayed below.

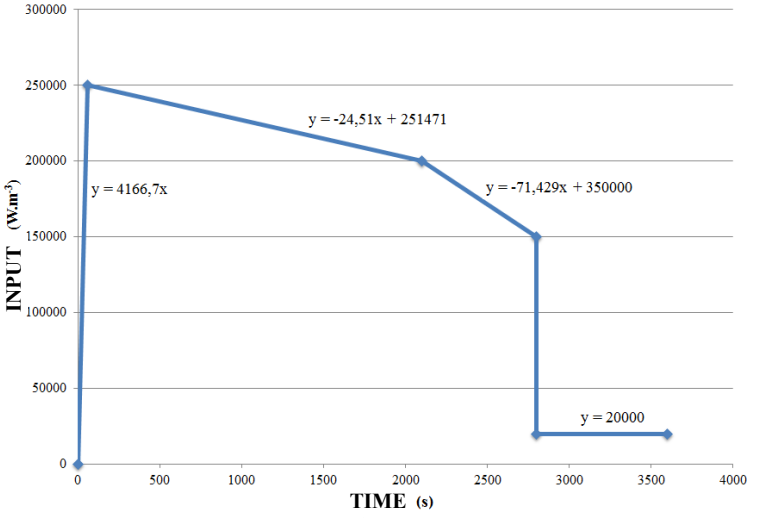

Fig. 6
The definition of the total input set versus time

The description of these points is analyzed in details in Table 7. Here you will find also numeric values pertaining to a given time.

Table 7
Numeric values for set points

Time [s]	0	60	2100	2800	2800	3600
Input [W.m^{-3}]	0	250000	200000	150000	20000	20000

When setting this curve (see Fig 6) into UDF function, we used parameterization of vectors. This parameterization lies in the division of a curve of total input into separate totals (vectors). For each of these vectors by means of the regression formula we gained their parametric formula. This way we obtained very precise description of the curve for the total input. The advantage of the UDF function is that it enables to set practically arbitrary shape of the energetic curve.

6 Results

The object of the interest was to observe the changes of a speed field and especially a thermal one. This was the starting point when evaluating the results of the solution. The following pictures (see Fig. 7 and 8) illustrate in the form of completed contours the results of the calculation of a thermal field. The demonstration of this field is for better visibility performed by means of suitably placed sections across modeled area. In order to compare and illustrate in a better way, all graphic pictures are completed with a colored scale.

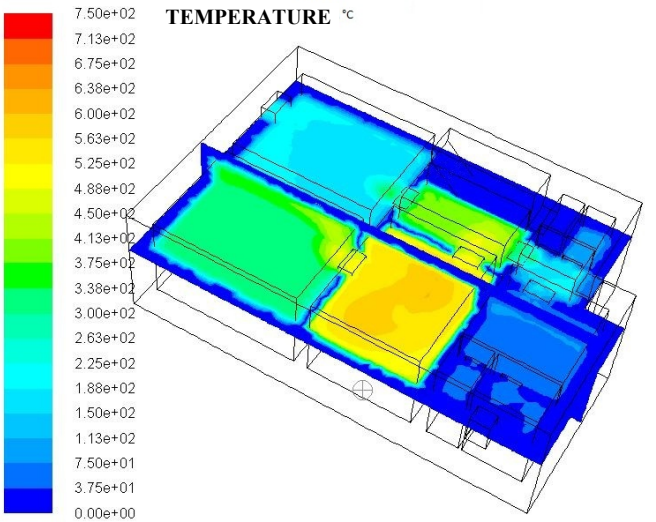

Fig. 7
Contours of thermal field in time t=200s

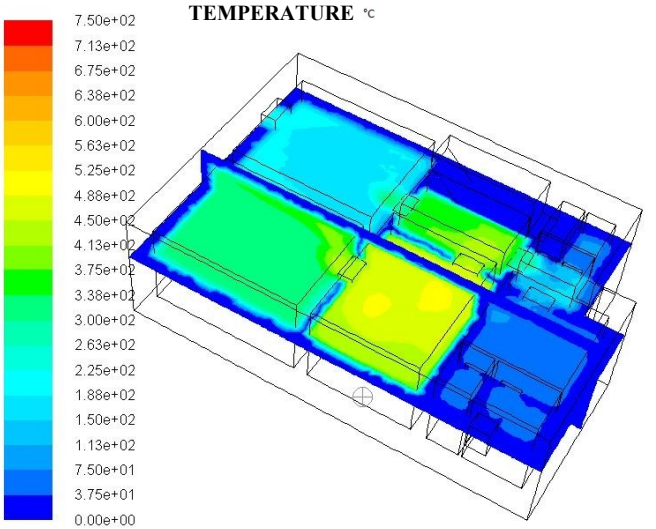

Fig. 8
Contours of thermal field in time t=2400s

In the final part the evaluation of results, the temperatures of the experiment were compared to a model in places where thermocouples were located. The location of thermocouples in the experiment is consistent with the location in a numeric model. For better understanding of results, the notation of thermocouples in a mathematic model is the same as in the experiment. Due to the calculation which is time consuming and requires high IT.

Since the calculation is disproportionately difficult as far as the calculation extent and time, only some thermocouples in a dining room and bedroom were chosen. Other reason for the choice of only some thermocouples is the fact that the consequent evaluation of all thermocouples results does not provide an easy survey.

The following three thermocouples were chosen for the comparison:

- T4Bl, T12B (dining room),
- T12 (bedroom).

At selected points of the area responding to the location of thermocouples we wrote down the temperatures and drew graphically the dependence on time. For the comparison we used the graphs from measuring.

In Fig. 9 [6] you can see the record of thermocouples temperatures during the experiment at all measured points in the dining room and in Fig. 10 you can see time dependence of the temperature responding to thermocouples T12B and T4B.

In Fig. 11 [6] you can see again the record of temperatures measured by all thermocouples located in the bedroom and the comparison with a numeric experiment is in Fig. 12 where the record of temperatures dependent on time was performed in the location responding to the thermocouple T12.

As it is obvious at the first glance, resulting temperatures at all compared thermocouples in mathematic simulation and fire experiment differ from each other

insignificantly. Maximal temperatures which are reached by observed thermocouples labeled T4B and T12B during the experiment, equal approximately values $T_{4B} = 500\,°C$ a $T_{12B} = 615\,°C$. In a mathematic model the temperatures in the same thermocouples reach values $T_{4B} = 520\,°C$ and $T_{12B} = 585\,°C$. The temperature at an observed thermocouple located in the bedroom (thermocouple T12) reaches during the fire experiment maximal values of $T_{12} = 325\,°C$. In performed simulation the temperature of this thermocouple goes to the value of $T_{12} = 380\,°C$.

Both comparisons show that the numeric calculation of this task while using time dependent source of energy slightly overvalues the temperature in a searched area in comparison with the experiment.

We also reached a very good compliance of the temperature change during the time course, where the numeric simulation describes very precisely the fire behavior during the experiment. And its course is almost perfectly copied. Therefore: ignition, burning, rapid cooling due to the reduction of burned material and consequent afterburning.

For the calculation of temperatures we used the model of complete combustion. Generation of combustion gases is defined upon the experiment i.e. in dependence of mass fractions on heat input.

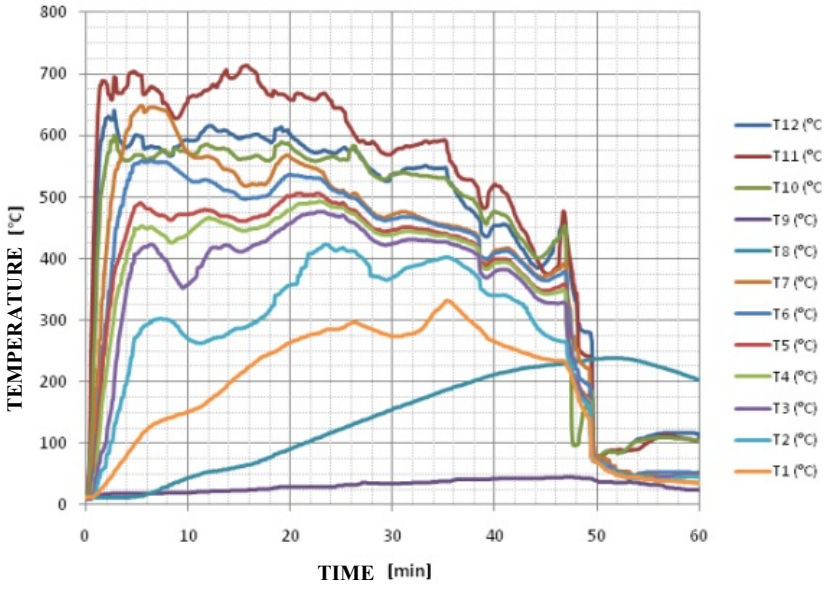

Fig. 9
The record of the course of temperatures in the dining hall obtained from the experiment

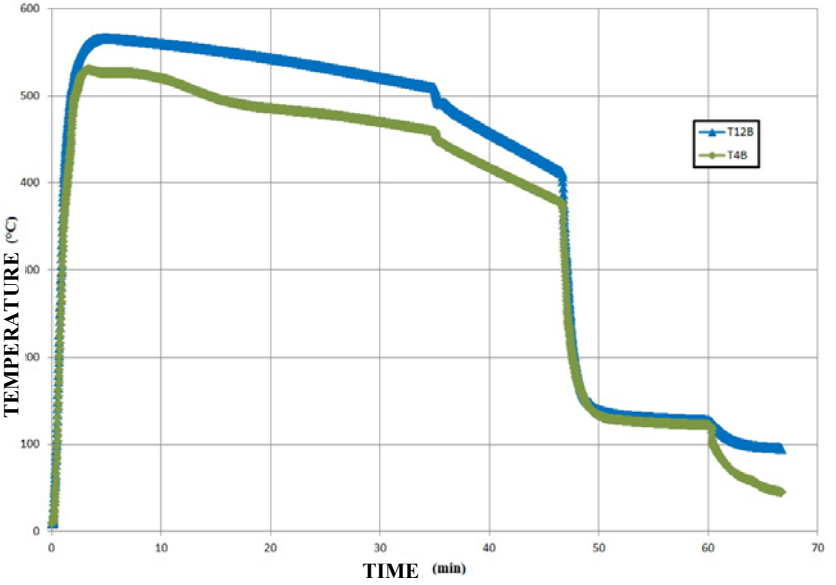

Fig. 10
The record of the courses of temperatures of selected thermocouples in the dining room obtained from numeric simulation

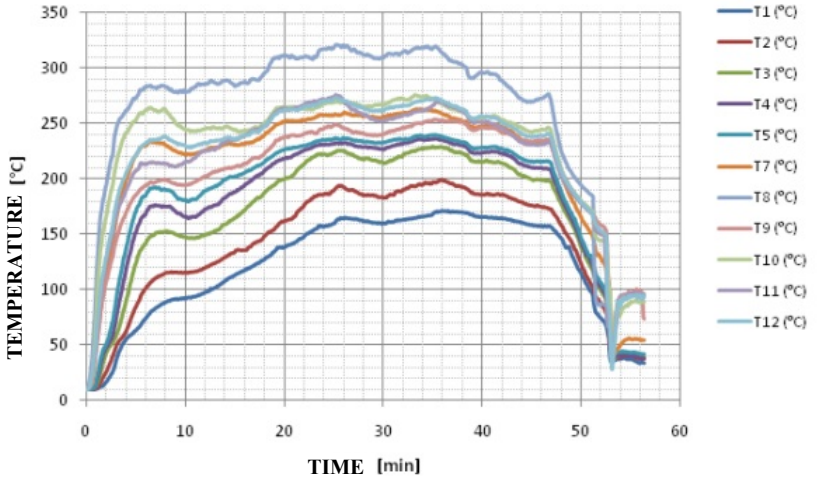

Fig. 11
The record of the course of temperatures in the bedroom obtained from the experiment

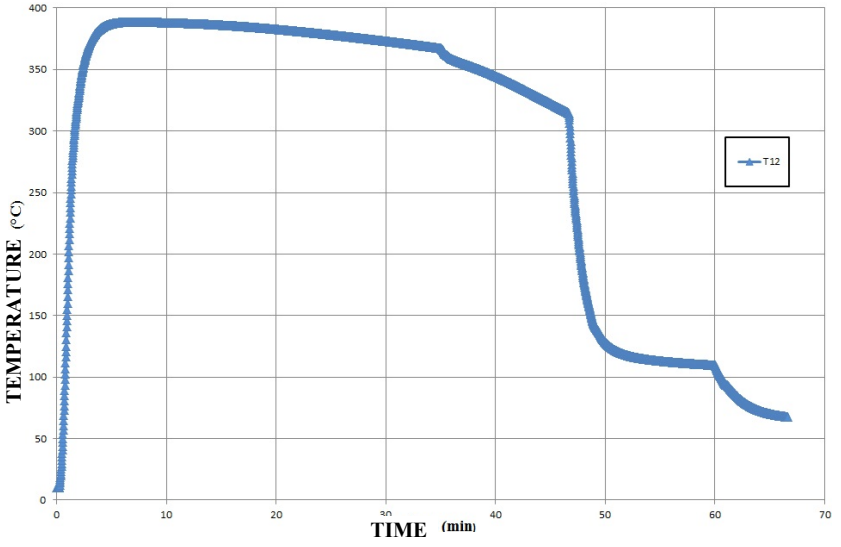

Fig. 12
The record of the course of temperature at a selected thermocouple in the bedroom obtained from numeric simulation

CONCLUSION

The paper describes the simulation of fire spreading on the first floor in a detached house. Mathematic model of a house is a true copy of a real house. The model has the same marginal conditions as the experiment including meteorological data. The first part of the article describes the large-scale fire experiment, elementary issues and all information needed for the understanding of the core of the task. Further you can see the numeric solution of the task. This part includes a mathematic model of the fire using the source of the heat input. Basic formulas used for the solution of a subject issue are described here. Subsequently the article contains the description of physical parameters, net geometry, marginal conditions and definitions of the source of heat input which were defined into the computing program FLUENT.

At the beginning of the solution of this task, a constant power curve was tested. The results of this solution were dissatisfactory because the observed temperatures during rapid cooling due to the reduction of burned material and consequent afterburning to surrounding temperatures did not drop. It was necessary to leave this variant. Therefore the calculation was specified with a power curve dependent on time. Its shape was estimated from fire experiment. Power curve could have been estimated also by another technique e.g. from the theory of burning of materials.

Due to achieved results we can say that mathematic simulation using program FLUENT reaches high compliance with fire experiment. Thermal field which was obtained from measurements with the help of thermocouples is almost identical to numeric simulation and differs very little. The recording of the course of temperatures in time with these thermocouples is well done because it is almost identical to reality.

Minor deviations of results between numeric and experimental data which were found out can be explained as follows:

- during fire experiment there was significant lack of oxygen (about 1%), which causes considerable problems in mathematic simulation,
- the spread of fire was influenced by decreased volume of oxygen during the experiment and by marginal conditions defining the flow in a mathematic model,
- the exact course of burning in dependence on time was not available and was roughly estimated from the course of temperatures,
- the changes of marginal conditions were not taken into account in the calculation because of the door opening etc.,
- generation of combustion gases should have been more specified pursuant to the experiment for given materials, therefore also the estimate application from stoichiometric formulas for complete and incomplete combustion was less precise.

The main benefit of the experiment is obtaining detailed information and data about the spread and behavior of fire in residential buildings. This information can be generalized in case of a real fire for the needs of fire technical expertizes, by virtue of the comparison of calculated and measured values of observed magnitudes in defined positions and time, for the rescue of human lives and prevention of damage on property both due to technical failures on electrical installation or electrical appliances and due to carelessness during manipulation with an open fire.

Résumé

The paper describes the simulation of the fire spread on the first floor of a detached house. Mathematic model of the house is a true copy of a real house. The model also has the same marginal conditions as the experiment, including meteorological data. The first part of this paper describes a large-scale fire test, basic problems and all the necessary information for understanding the characteristics of the experiment. This is followed by numerical solution of the task. Here the section covers mathematic model of fire with a thermal power source. It also describes basic comparisons used for problem solving. The next part of the paper contains the description of physical parameters, geometry net, marginal conditions and a heat source definition defined by computer program FLUENT.

At the beginning of modeling, the source with constant power value was tested. The results of this solution were dissatisfactory because the observed temperatures during rapid cooling due to the reduction of burned material and consequent afterburning to surrounding temperatures did not drop. Therefore it was necessary to leave this variant. The calculation was refined by using performance curves depending on time, whose shape was estimated from the fire test. The power curve can also be estimated by other means such as the theory of burning materials.

Based on the obtained results we can say that mathematic simulation using FLUENT achieves high compliance with the fire experiment. The temperature field, which was obtained from the measurement using thermocouples is nearly identical to the numerical simulation and differs very slightly. Capturing of the time dependent temperature of these thermocouples can also be described as very successful, since it again almost exactly coincides with reality.

Slight deviations between numerical results and experimental data, which were found out could be attributed to the following:

- *The fire test was marked by lack of oxygen (around 1%), which causes considerable problems with mathematical simulation.*
- *The fire spread was influenced due to reduced oxygen in the experiment and the marginal conditions defining the flow in a mathematical model.*
- *The exact course of burning in dependence on time was not available and was roughly estimated from the course of temperatures.*
- *In numerical calculation the changes of marginal conditions were not taken into account due to the openings, doors, etc.*
- *Generation of combustion gases should have been more specified pursuant to the experiment for given materials. Therefore also the estimate application from stoichiometric formulas for complete and incomplete combustion was less accurate.*

The main contribution of this paper is to obtain detailed information and data about the distribution and behavior of fires in residential buildings. This information can be generalized in case of a real fire for the needs of fire technical expertizes by virtue of the comparison of calculated and measured values of observed magnitudes in defined positions and time in order to safe human lives and prevent the damage on property both due to technical failures on electrical installations or electrical appliances and due to carelessness during manipulation with an open fire.

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Literature

[1] ANGELIS, J., DVORAK, O. *Protocol on mathematic modeling No. 05/MOD/2009*. Prague, 2010. 8 pp.

[2] ANGELIS, J., KUNDRATA, T., DVORAK, O. *Protocol on mathematic modeling No. 05/MOD/2010.* Prague, 2010. 10 pp.

[3] Ansys, Inc. *ANSYS FLUENT 12.1 – Theory Guide.* 2010.

[4] Ansys, Inc**.** *ANSYS FLUENT 12.1 – UDF Manual.* 2010

[5] Ansys, Inc. *ANSYS FLUENT 12.1 – User´s Guide.* 2010.

[6] DVORAK, O., DUDACEK, A**.** *Report on results of fire experiment in a detached house in Bohumin on 2009-11-19 2009.* Prague, Ostrava: TUPO MI – GD FRS Prague and FBI TU Ostrava, 2010. 51 pp.

[7] DVORAK, O. et al. *The development and evaluation of fire models for the determination of the emergence/spread of the heat and smoke, toxic gases, pressure waves for simulation/interpretation of fire/explosions scenarios and their destructive effects.* [Final research report on results of the solution of partial research task DVU No. 2 of a research project VD20062010A07]. Prague: MI – GD FRS CR, TUPO, 2011. 141 pp.

[8] KOZUBKOVA, M., BOJKO, M., ZAVILA, O. *Report on solution of fire modeling given by thermal power and chemical reaction.* Ostrava, 2009. 45 pp.

[9] MERKA, J. *The proposal of a sandwich layer with optimal thermal resistance for interior applications.* [Graduation thesis.] Zlin: Institute of physics and material engineering, Faculty of technology, Tomas Bata University Zlin, 2010. 68 pp.

[10] STIOVOVA, K. *Research of wood burning in open fires of small inputs.* [Dissertation thesis.] Ostrava: Research energy center, Faculty of engineering, Technical University Ostrava, 2008. 218 pp.

[11] ZAVILA, O. *Mathematic modeling of turbulent flow, spread of heat and pollutants in marginal layer of atmosphere focused on tunnel constructions.* [Dissertation thesis.] Ostrava: Department of fire protection and protection of population, Faculty of safety engineering, Technical University Ostrava, 2007, 114 pp.