

Computer Simulation of Parameterized Module for Testing of Thermal Stability in the Room

Hana Charvátová, Martin Zálešák, Stanislav Sehnálek, Dagmar Janáčková, Vladimír Vašek and Rudolf Drga

Abstract—The paper deals with the development of multi-functional software application for testing the thermal stability of modern intelligent buildings using commercial software tools for simulation of physical processes. It describes method designed to parameterize the simulation module for the temperature distribution in a room heated by two heat sources by using COMSOL Multiphysics software. A parameterized model allows you to change the requirements of the geometric dimensions of all elements of the module and Their spatial distribution, as well as a choice of physical properties and pasting real measured data needed to assess the distribution of temperature in the room depending on the ambient temperature and the heat input of the considered sources. Parameterization enables to insert all necessary data into COMSOL Multiphysics by using external txt files, which can be up to this end through a sub-application. Connecting COMSOL Multiphysics to a sub-application allows comfortable loading parameters to external users via a web interface without knowledge of the work environment in COMSOL Multiphysics.

Keywords—COMSOL Multiphysics, parameterization of the room module, simulation of temperature distribution, thermal stabilization of building.

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Hana Charvátová, Tomas Bata University in Zlín, Faculty of Applied Informatics, Regional Research Centre CEBIA-Tech, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: Charvátová@fai.utb.cz).

Martin Zálešák, Tomas Bata University in Zlín, Faculty of Applied Informatics, Department of Automation and Control Engineering, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: Zálešák@fai.utb.cz).

Stanislav Sehnálek, Tomas Bata University in Zlín, Faculty of Applied Informatics, Department of Automation and Control Engineering, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: Sehnálek@fai.utb.cz).

Dagmar Janáčková, Tomas Bata University in Zlín, Faculty of Applied Informatics, Department of Automation and Control Engineering, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: Janáčková@fai.utb.cz).

Vladimír Vašek, Tomas Bata University in Zlín, Faculty of Applied Informatics, Department of Automation and Control Engineering, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: vasek@fai.utb.cz).

Rudolf Drga, Tomas Bata University in Zlín, Faculty of Applied Informatics, Department of Security Engineering, Nad Stráněmi 4511, 760 05 Zlín , Czech Republic (e-mail: rdraga@fai.utb.cz).

I. INTRODUCTION

At present, the design of the intelligent building is in terms of optimization emphasis on minimizing energy consumption while minimizing investment and operating costs. In the design optimization is needed based on stationary parameters buildings, and also include non-stationary boundary and user conditions. In order to make a comprehensive assessment of all major factors, it is necessary to use a combination of experimental testing with modern computer technology that are continuously being developed for engineering and scientific calculations of stationary and non-stationary processes. In order to use the available software tools for the simulation of the thermal behavior of systems with accumulation, we performed testing program COMSOL Multiphysics using the comparative tests described in the work [1], published within the IEA BESTEST methodology. The results confirmed the suitability of the program COMSOL Multiphysics [2], [3].

Now we want to use the program COMSOL Multiphysics to create a complex software tool for the assessment of energy performance of selected models of building parts. Simultaneously, we would like to ensure the possibility of universal use of this tool not only for specialists w

For this purpose we are preparing a set of room modules in which users can specify both geometric and physical properties. In the subsequent sections we describe the chosen procedure of parameterization using the example of one of the modules, and also mentioned the possibilities of external loading of parameters required by the program Microsoft Excel.

II. DESCRIPTION OF HEAT TRANSFER IN THE STUDIED MODULE

As a module we used the room heated by two heat sources, as you can see in Fig. 1. The external temperature, temperatures of the heat source surfaces and power of the heating sources were measured in dependence on time.

Under the conditions of the temperature gradient existence, heat transfer takes place in the direction of decreasing temperature. The transfer of thermal energy in our tested module can occur by combination of the three possible mechanisms - conduction, convection and radiation [4].

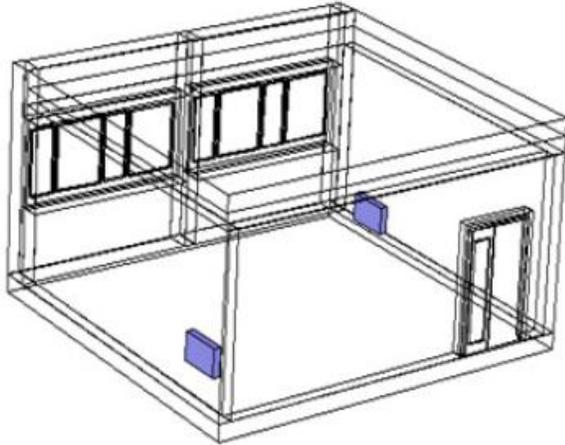


Fig. 1 Geometry sketch of the tested room module

A. Heat transfer by conduction

This process occurs in solid bodies of the room. Thermal energy is transferred from more energetic particles to less energetic particles due to their direct contact [5]. If the temperature of each point of body is a function of time τ , we are talking about non-stationary temperature field, which is described by function (1):

$$t = f(x, y, z, \tau). \quad (1)$$

If the temperature of each point in time does not change, then it is a stationary temperature field (2):

$$t = f\left(x, y, z, \frac{\partial t}{\partial \tau}\right) = 0. \quad (2)$$

The basic relationship describing conduction of heat is Fourier's law (3):

$$\vec{q} = -\lambda \nabla t, \quad (3)$$

where

$$\vec{q} = \vec{i}q_x + \vec{j}q_y + \vec{k}q_z = -\lambda \left(\frac{\partial t}{\partial x} \vec{i} + \frac{\partial t}{\partial y} \vec{j} + \frac{\partial t}{\partial z} \vec{k} \right). \quad (4)$$

Symbol q is the density of heat flow, ∇t is the temperature gradient, λ is the thermal conductivity. The symbols \vec{i} , \vec{j} , \vec{k} are unit vectors oriented in the direction of the coordinate axes x , y , z .

The temperature field in the body without heat sources balanced differential equation of heat conduction:

$$\frac{\partial t}{\partial \tau} = a \nabla^2 t, \quad (5)$$

where ∇^2 denotes the Laplace differential operator:

$$\nabla^2 = \frac{\partial}{\partial x^2} + \frac{\partial}{\partial y^2} + \frac{\partial}{\partial z^2}. \quad (6)$$

Symbol a represents thermal conductivity considered environment:

$$a = \frac{\lambda}{\rho \cdot c_p}, \quad (7)$$

where λ is thermal conductivity, ρ is density and c_p is specific thermal capacity of the body.

B. Heat transfer by convection

In general, the convection occurs in fluids, which are held macroscopic movement flows. In general, the convection occurs in fluids, which are held macroscopic movement flows. In his motion adopted by heat sources heat and bear it with you as a form of thermal energy. In the tested module, heat transfer by convection occurs between every surfaces and surrounding air. This process can be described by Newton's law of cooling (8):

$$\frac{dQ}{d\tau} = \alpha A \Delta t, \quad (8)$$

where Δt is the time-dependent thermal gradient between average temperature of environment and surface of the solid body ($t_w - t_o$). The symbol A denotes the heat transfer surface. α denotes the heat transfer coefficient.

The heat transfer coefficient depends upon physical properties of the fluid and the physical situation in which convection occurs. Therefore, a single usable heat transfer coefficient must be derived or found experimentally for every analyzed system.

C. Heat transfer by radiation

In our case, this mechanism of heat transfer applies mainly due the radiation of heat from the surface of radiators in the room. Generally, each body whose temperature is higher than the absolute 0 (i.e. $T = 0$ K) emits radiation whose composition depends on the temperature of the body.

Thermal radiation is energy transfer by the emission of electromagnetic waves which carry energy away from the emitting object. For ordinary temperatures, the radiation is in the infrared region of the electromagnetic spectrum.

The calculation of radiative heat exchange between two real surfaces can be computed according to Stefan-Boltzmann law (9):

$$\Phi = \varphi_{1-2} A \varepsilon_{1-2} 10^8 \sigma \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]. \quad (9)$$

Symbol φ_{1-2} is a angular coefficient whose value depends on the spatial angle between the surfaces, which can transmit heat by radiation.

T_1, T_2 are absolute temperatures of surfaces, A is heat receiving surface, σ is Boltzmann constant. Symbol ε_{1-2} represents a total emissivity, which depends on the emissivity of both surfaces $\varepsilon_1, \varepsilon_2$ according to equation (10):

$$\varepsilon_{1-2} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}. \quad (10)$$

D. Heat passage

If we suppose, the all of bodies in the tested module are in form of plate, then one-dimensional heat passage through multi-layer wall from surrounding liquid at a temperature t_A into surroundings liquid at a temperature t_B (where $t_A \neq t_B$)

can be computed according to equation (11):

$$\Phi = k \cdot A \cdot \Delta t. \quad (11)$$

Symbol A is heat receiving surface. Δt is difference of temperatures t_A and t_B . Symbol k denotes a heat passage coefficient which is computed by relation (12):

$$\frac{1}{k} = \frac{1}{\alpha_A} + \sum_{j=1}^{\infty} \frac{\delta_j}{\lambda_j} + \frac{1}{\alpha_B}, \quad (12)$$

where α_A, α_B are heat transfer coefficients between surfaces of the wall and surrounding liquid at average temperatures t_A, t_B . δ is thickness of the layer, λ is thermal conductivity of the layer.

III. COMPUTER SIMULATION OF HEAT TRANSFER IN THE TESTED MODULE

For the simulation of non-stationary heat transfer, the COMSOL Multiphysics uses the finite element method [6]. The thermal analysis is based on solving partial differential equation under the defined initial and boundary conditions [7], [8]. Heat transfer in the room module is computed according equations described in previous section.

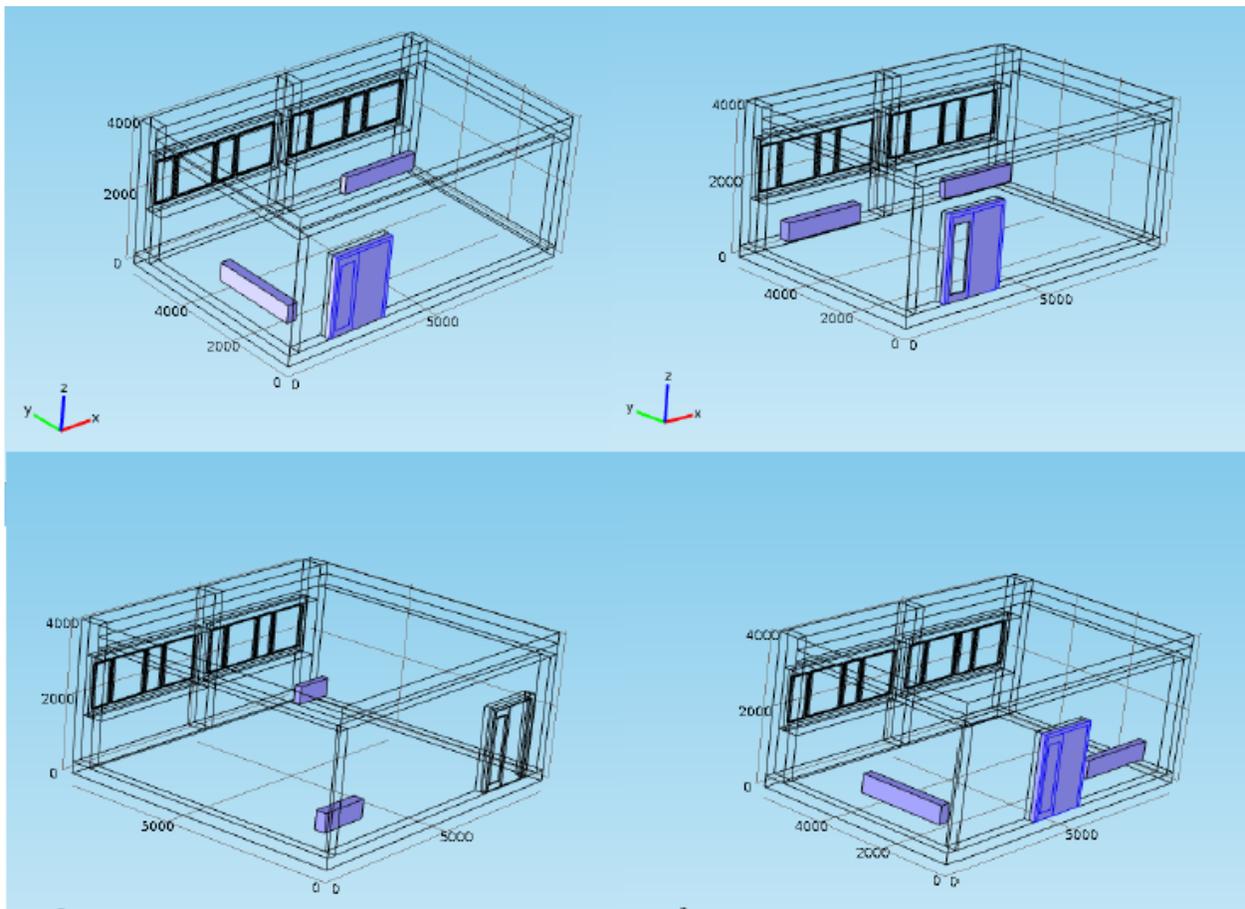


Fig. 2 Change of the geometrical dimensions, location and size of the heat sources and door in the parameterized module

A. Parameterization of the tested module

In order to be provided to potential users of the module, with the option to change the geometrical dimensions of all elements of the module and also modify the physical parameters without interfering with the source file in COMSOL Multiphysics, we proposed the possibility of external loading all the required parameters and their subsequent loading into the application itself in the form automatically generated txt files.

In Fig.2 is shown how it is possible to vary due to the geometric parameters of the room dimensions, location and

size of the heat sources and the other required parameters. The Fig. 6 shows a change in the geometrical dimensions of the room, location and size of the heat source and doors in the parameterized module.

For comfortable inserting of the input parameters can be used the form that we have created in Microsoft Excel (see Fig. 3). This form is for clarity when entering geometric dimensions accompanied by drawings, in which the required dimensions are marked in color.

The inner dimensions of the room:		
length:	3.2	m
width:	7.32	m
height:	3.2	m

The thickness of the walls of the room:		
bottom:	0.3	m
ceiling - the bottom layer:	0.3	m
ceiling - the top layer:	0.3	m
front wall:	0.3	m
back wall:	0.6	m
the left side wall:	0.3	m
the right side wall:	0.3	m

Fig. 3 User form for insertion of module parameters

File with embedded data can be exported to txt file (Fig.4). Created txt file is then imported into the table designed for definitions of parameters in COMSOL Multiphysics user interface (Fig. 5, Fig. 6). Also the measured dependences of

temperature and power of the heating sources can be imported from txt files into the table for insertion of parameters in the COMSOL Multiphysics user interface.

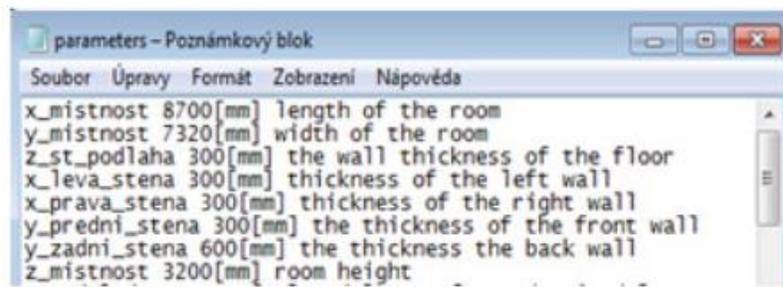


Fig. 4 The txt file with data exported from Microsoft Excel

P_i Parameters

Parameters

Name	Expression	Value	Description
x_mistnost	8700[mm]	8.7 m	length of the room
y_mistnost	7320[mm]	7.32 m	width of the room
z_st_podlaha	300[mm]	0.3 m	the wall thickness of the floor
x_leva_stena	300[mm]	0.3 m	thickness of the left wall
x_prava_stena	300[mm]	0.3 m	thickness of the right wall
y_predni_stena	300[mm]	0.3 m	the thickness of the front wall
y_zadni_stena	600[mm]	0.6 m	the thickness the back wall
z_mistnost	3200[mm]	3.2 m	room height

Fig. 5 Table with data imported from txt file into the COMSOL Multiphysics user interface

Model Builder: modul 1 geom varianta 2 V8 jen heat trar

Global Definitions

- P_i Parameters
- a= Variables 1
- T_NiCr_nad_oknem_D307 (T_NiCr)
- P_primotop_2kW (P_primotop_2kW)
- T_NiCr_D306 (T_NiCr_D306)
- T_kulovy_teplomer_D307 (T_kulov)
- T_NiCr_stativ_D307 (T_NiCr_stativ)
- T_NiCr_zadni_cast_D307 (T_NiCr_z)
- T_corridor (T_coridor)
- I_pyrometr_dvere (I_pyrometr_av)
- T_pyrometr_ram_okna (T_pyrometr_ram_okna)
- T_pyrometr_sklo_okna_D307 (T_pyrometr_sklo_okna_D307)
- T_pyrometr_stena_chodba (T_pyrometr_stena_chodba)
- T_pyrometr_stena_D306 (T_pyrometr_stena_D306)
- T_pyrometr_stena_D308 (T_pyrometr_stena_D308)
- T_D207 (T_D207)
- T_D306 (T_D306)
- T_D308 (T_D308)
- T_outside (T_outside)
- P_primotop_2kW (P_primotop_2kW)

Settings: Parameters

Data source: Table

Function name: T_pyrometr_ram_okna

t	f(t)
0.0	17.3
15.0	14.6
25.0	15.2
39.0	12.2
49.0	13.1
63.0	11
73.0	11.9
87.0	10.8
97.0	11.2
111.0	11.5
121.0	11.9
125.0	22
145.0	23.9
159.0	25.3

Fig. 6 Table with measured data imported from txt file into the COMSOL Multiphysics user interface

B. Display results of the simulation

The distribution of temperature in the room simulated by Comsol Multiphysics under the required input parameters can be displayed as 3D plot and as 2D plot. The 3D temperature distribution and the heat flow in the module are shown in Fig. 7. The 2D graph that represents temperature distribution

in a required line through the room for a selected time. All computed plots can be exported as a graphic files (bmp, jpeg, png) or a txt files. The 3D plot can be also animated and exported to avi or gif files.

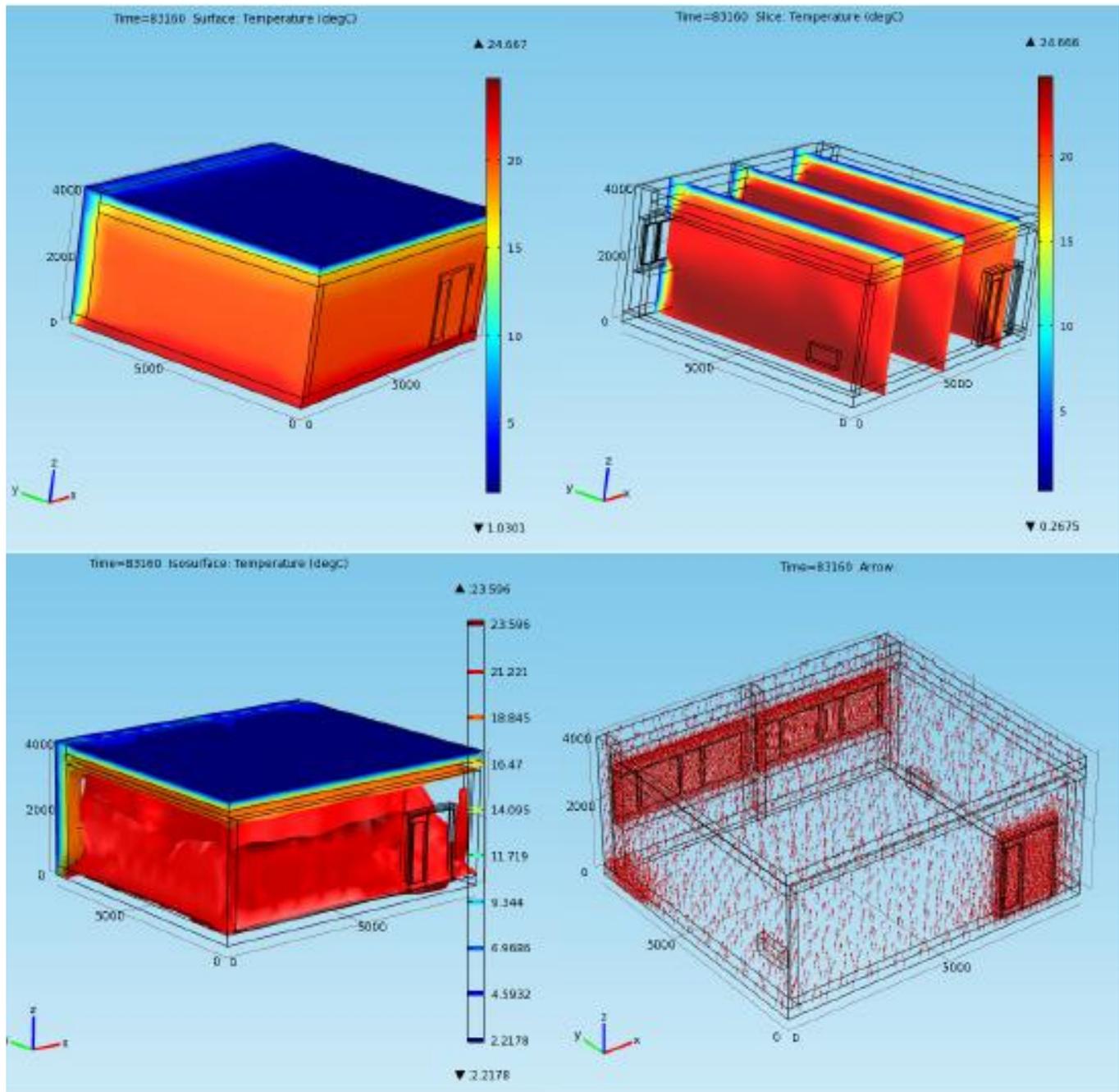


Fig. 7 3D temperature distribution and the heat flow in the module

IV. CONCLUSION

In the paper described parameterized module allows you to change the geometric dimensions of all elements of the module and their spatial distribution, as well as a choice of physical properties and pasting real measured data needed to assess the distribution of temperature in the room depending on the ambient temperature and the heat input of the considered sources. Parameterization also enables to insert all necessary data into COMSOL Multiphysics by using external txt files, which can be up to this end through a helper application in Microsoft Excel. Linking program COMSOL Multiphysics with applications created in Microsoft Excel allows comfortable loading parameters to external users via a web interface without knowledge of the work environment in COMSOL Multiphysics.

V. LIST OF SYMBOLS

a - thermal diffusivity, [$\text{m}^2 \cdot \text{s}^{-1}$];
 A - heat transfer surface, [m^2];
 c_p - specific thermal capacity, [$\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$];
 \vec{i} - unit vector, [-];
 \vec{j} - unit vector, [-];
 \vec{k} - unit vector, [-];
 k - heat passage coefficient, [$\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$];
 t - temperature, [$^{\circ}\text{C}$];
 q - heat flow density, [$\text{W} \cdot \text{m}^{-2}$];
 Q - thermal energy, [J];
 T - absolute temperature, [K];
 x - space coordinate, [m];
 y - space coordinate, [m];
 z - space coordinate, [m];
 α - heat transfer coefficient, [$\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$];
 δ - thickness, [m];
 ε - relative emissivity, [1];
 $\varepsilon_{1,2}$ - total emissivity, [1];
 Φ - heat flow, [W];
 $\varphi_{1,2}$ - angular coefficient, [1];
 λ - thermal conductivity, [$\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$];
 ρ - density, [$\text{kg} \cdot \text{m}^{-3}$];
 σ - Stefan-Boltzmann constant ($\sigma = 5.67 \cdot 10^{-8} \text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$);
 τ - time, [s].

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Hana Charvátová is a research worker in the Regional Research Centre CEBIA-Tech, Faculty of Applied Informatics, Tomas Bata University in Zlín. Her research activities include recycling technology, transport processes and mathematical modeling of natural and synthetic polymers treatment.

Martin Zálešák is an Associate Professor in the Department of Automation and Control Engineering, Faculty of Applied Informatics, of Tomas Bata University in Zlín. His research activities include energy audits, technology of energy systems, ventilation, heating and cooling systems, energy management, Building Energetics, energy conception.

Stanislav Sehnálek is a doctoral student in the Department of Automation and Control Engineering, Faculty of Applied Informatics, of Tomas Bata University in Zlín. His research activities include energy systems, computer analysis and network communication protocol for intelligent buildings.

Dagmar Janáčová is a Professor in the Department of Automation and Control Engineering, Faculty of Applied Informatics, Tomas Bata University in Zlín. Her research activities include: modeling of treatment processes of natural polymers, transport processes, recycling of tannery waste, optimization and ecological approach of tannery processes.

Vladimír Vašek is a Professor in the Department of Automation and Control Engineering, Faculty of Applied Informatics, Tomas Bata University in Zlín. His research activities include: microcomputer applications in technology processes, computer monitoring and control systems, discrete deterministic controllers approach of tannery processes.

Rudolf Drga is an Associate Professor in the Department of Security engineering, Faculty of Applied Informatics of Tomas Bata University in Zlín. His research activities include electronic security systems.