COMPUTER APPLICATION FOR SIMULATION OF COOLING THE ROOM

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Abstract

The paper deals with testing of thermal storage parameters and insulation properties in the building constructions by computer simulation with COMSOL Multiphysics software. The computer application programmed for this purpose in the Application Builder user interface can simulate cooling of 2D room model under the required winter conditions. The output data from simulations can be used for subsequent assessment of the thermal stability of the room, depending on the thickness of the outer wall thermal insulation under the simplified assumptions. The tested model of the room proved the dependence of the time constant τ_c of cooling the room and the coefficient α on the thermal insulation thickness.

1 Introduction

The specialization of the field of Integrated Systems in Buildings solved at the Faculty of Applied Informatics of Tomas Bata University in Zlín is focused on the selected aspects of system optimization made up of the building and its systems of environmental engineering including energy (heating, ventilation and lighting) and the management of these systems. From this perspective, the field of our research includes systems of environmental techniques in relation to the thermal storage parameters and insulation properties of the building. The goal is to minimize total energy consumption while maintaining the required indoor environment parameters.

In terms of the heat accumulation parameters assessment, consideration should be given to the time delay of the response of the indoor environment to changing outdoor conditions. These problems are solved in the technical standard CSN EN 13790 [1] and related CSN EN 13792 [2], CSN EN 13786 [3], CSN EN 15251 [4] and CSN 06 0220 [5], CSN 73 0540 [6]. However, to find a complex solution to this problem according to the Czech and European technical standards is difficult and the most accurate methods are sought using modern computer tools with simulation methods based on numerical solution of non-stationary multiphysical processes on models describing studied objects under simplified conditions.

In this paper we present the use of the COMSOL Multiphysics software in testing of the thermal stability of buildings. For this purpose, we proposed a computer application in the Application Builder which can simulate cooling of the room as a 2D model under the selected winter conditions. The first part of the paper includes theoretical background of the studied problem. The second part describes model of the tested room. The following parts demonstrate using of the proposed computer application by testing of thermal stability of the room in case of its cooling with respect to the thickness of the outer wall thermal insulation under the simplified assumptions.

2 Method Used for Thermal Stability Testing

For computer simulation of cooling the room by COMSOL Multiphysics we use Laminar Flow Interface of the Conjugate Heat Transfer Module, which is used primarily to model slow-moving flow in environments where temperature and energy transport are also an important part of the system and application, and must coupled or connected to the fluid-flow in some way. The interface solves the Navier-Stokes equations together with an energy balance assuming heat flow through convection and conduction. The density term is assumed to be affected by temperature and flow is always assumed to be compressible [8].

The used method consisted in a computer simulation of non-stationary heat transfer in the assembled simplified model of the tested room under the required initial and boundary conditions, which corresponds to the conditions of the real experiment. Based on the results of the measurements, theoretical calculation of heat flow through outside wall of the room was performed in accordance with the Czech Technical Standards CSN EN 15251 [4] and CSN 06220 [5].

COMSOL Multiphysics uses the balance equation (Eq. (1)) [8] for numerical calculation of the non-stationary heat transfer :

$$\rho \cdot c_p \frac{\partial T}{\partial t} + \rho \cdot c_p \cdot u \cdot \nabla T = (\lambda \nabla T) + \Phi_S, \tag{1}$$

ρ - density, [kg.m^{-3}];
c_p - heat capacity at constant pressure, [J.kg^{-1}.K^{-1}];
λ - thermal conductivity, [W.m^{-1}.K^{-1}];
u - fluid velocity, [m.s^{-1}];
Φ_S - heat capacity at constant pressure, [W];
T - temperature, [K];
t - time, [s].

The theoretical calculation of the heat flow through the wall of room according the CSN 06 0220 [8] is described by Eq. (2):

$$\Phi = AU\left(\theta_i\left(t\right) - \theta_e\left(t\right)\right), \tag{2}$$

A - heat transfer surface, [m^2];
U - overall heat transfer coefficient, [W.m^{-2}.K^{-1}];
θ_i - temperature of air inside the room, [°C];
θ_e - temperature of external air, [°C];
t - time, [s].

The overall heat transfer coefficient (U) through the multilayer wall of the room can be calculated according to Eq. (3) [8]:

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_e} + \sum_{j=1}^{n} \frac{\delta_j}{\lambda_j}}, \tag{3}$$

h_i - heat transfer coefficient of the inner wall surface, [W.m^{-2}.K^{-1}];
h_e - heat transfer coefficient of the outside wall surface, [W.m^{-2}.K^{-1}];
δ_j - thickness of the layer, [m];
λ_j - thermal conductivity of the layer, [W.m^{-1}.K^{-1}];
n - number of the layers, [$-$];
j - layer number, [$-$].

For a theoretical calculation we determined the outside air temperature as a daily mean air temperature calculated from measured values of the outside air temperature in a given timeframe. An assessment of the energy performance of buildings is recommended according to Czech Technical Standard CSN EN 15251 [4]to determine the temperature of the outside air as a running mean external temperature (Eq. (4)):

$$\theta_{rm} = (1 - \alpha)\left\{\theta_{ed-1} + \alpha\theta_{ed-2} + \alpha^2\theta_{ed-3}\ldots\right\}. \tag{4}$$

The Eq. (4) can be simplified as follows:

$$\theta_{rm} = (1-\alpha)\,\theta_{ed-1} + \alpha\theta_{rm-1}, \tag{5}$$

θ_{rm} - running mean external temperature for the evaluated day, [°C];
θ_{rm-1} - running mean external temperature for the previous day, [°C];
θ_{ed-1} - daily mean external temperature for the previous day, [°C];
θ_{ed-2} - daily mean external temperature two days before the evaluated day, [°C];
θ_{ed-3} - daily mean external temperature three days before the evaluated day, [°C];
α - coefficient from 0 to 1. Its recommended value is 0.8, [−].

The degree of utilization of heat gains or thermal heat losses are directly related to the thermal inertia of the building. Based on the inner heat capacity of the building, a time response to changing environmental conditions can be determined as the time constant, which generally indicates the time at which the transient process of a monitored variable decreases from maximum to zero value, if the process proceeds at constant velocity or linearly.

According to the Czech technical standard CSN EN ISO 13790 [1], the constant velocity is given by the equation (6) for cooling moode:

$$\tau_c = \frac{C_m/3600}{H_{tr,adj} + H_{ve,adj}}, \tag{6}$$

τ_c - time constant of the building or building zone in the cooling moode, [h];
C_m - inner heat capacity of the building, [kJ.K^{-1}];
$H_{tr,adj}$ - representative value of the total specific heat flow by heat transfer converted for a thermal difference between the interior and the external environment, [W.K^{-1}].
$H_{ve,adj}$ - representative value of the total specific heat flow by ventilation converted for a temperature difference between the interior and the external environment, [W.K^{-1}].

For determination of the time constant by COMSOL Multiphysics, simulations of the tested room cooling under the required initial and boundary conditions was performed. The time constant was determined from the time course of the air temperature inside the room (see Figure 1). The aim of our research is to find a relationship between the time constant τ_c and the constant α.

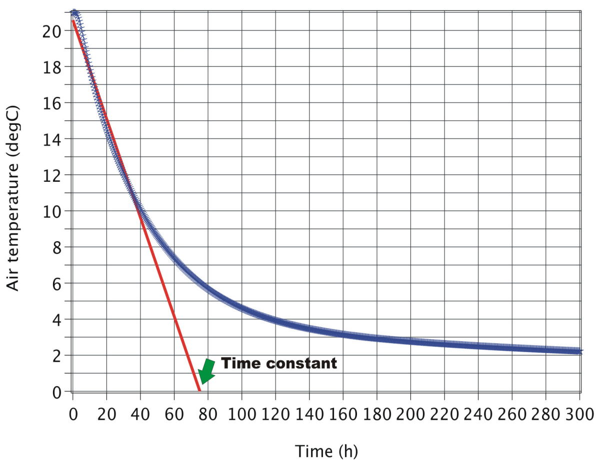

Figure 1: Determination of the time constant from the air temperature course in the room.

3 Description of Model of the Tested Room

A geometry sketch of the tested model is shown in Figure 2. It is evident that the used geometry is simplification of reality. Therefore it contains only elements that significantly influence heat flow between the room and its surroundings. One of the walls and ceiling of the room are surrounded by the outside environment. Other walls and floor are surrounded by rooms and corridor inside the building. All elements of the room are defined by their geometric dimensions and material properties (thermal conductivity, density and specific heat capacity). The initial conditions of the model are given by initial temperature of all elements of the room and external and internal air temperatures. The boundary conditions are given by heat transfer through all walls which is defined by supposed heat transfer coefficients and temperatures of air inside and outside the room.

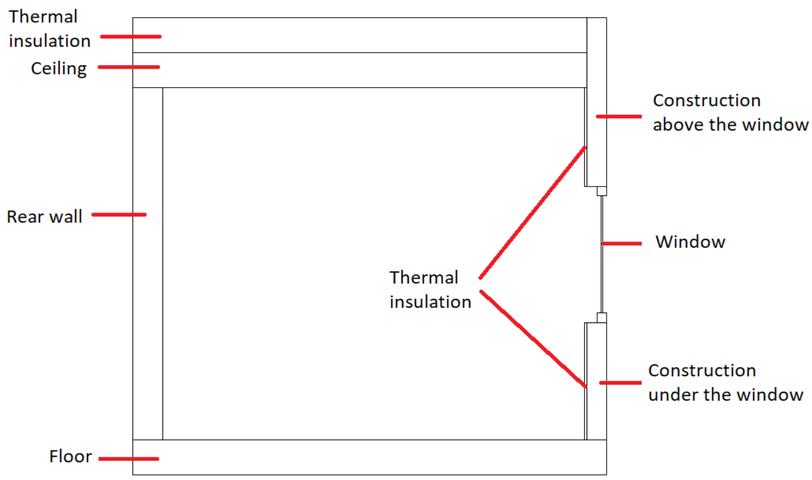

Figure 2: Geometry sketch of the studied model of the room.

4 User Interface of the Application for Simulation of Cooling the Room

The model described in the previous section was used as the basis of an computer application for cooling the room simulation. The output data can then be further processed to determine the time constant and the parameter α that were described in Section 2. The model was formed in Model Builder interface of COMSOL Multiphysics. After then it was converted into the Application Builder environment and user interface the required inputs and outputs for the application were defined.

The user interface of the final application is shown in Figure 3. The application allows the user enter dimensions of all model elements, material properties of all solids (thermal conductivity, density and specific heat capacity). Properties of air are automatically specified from Material Library of COMSOL Multiphysics. The user can also enter initial temperatures of all elements and heat transfer coefficients inside and outside the building. The temperature of air outside the building obtained from real data is inserted into the model in Model Builder interface and it can be changed as needed.

The application can compute and display the time course of air temperature for selected place (point) inside the room, temperature distribution in the room and heat flow through the external wall in selected time of cooling. The output data can then be exported to TXT file and further processed and evaluated by MATLAB or other computer algebraic software.

Figure 3: User interface of the application for simulation of cooling the room.

5 Example of the Application Using

We demonstrate the use of the programmed application by testing of the influence of the thickness of the thermal insulation of the outside wall on the thermal stability of the room in the winter.

The conditions used for computer simulation and theoretical calculations:

- initial air temperature inside the room 21 $^{\circ}\mathtt{C}$,
- air temperature of all neighboring rooms 0 $^{\circ}\mathtt{C}$,
- heat transfer coefficient between the walls of the room and the air inside the building 8 $\mathtt{W.m}^{-2}.\mathtt{K}^{-1}$,
- heat transfer coefficient between the walls of the room and outside air 23 $\mathtt{W.m}^{-2}.\mathtt{K}^{-1}$,
- thickness of the inner walls, ceiling and floor was 30 cm,
- physical properties of all elements of the models shows Table 1,
- course of outside air temperature is shown in Figure 4.

Table 1: Physical properties of the main geometrical elements of the tested room.

Geometrical element	**Thermal conductivity** $[\mathrm{W.m^{-1}.K^{-1}}]$	**Density** $[\mathrm{kg.m^{-3}}]$	**Specific heat capacity** $[\mathrm{J.kg^{-1}.K^{-1}}]$
Inner and external walls	0.1765	817	953
Floor	1.43	2300	1020
Ceiling	0.8185	1251	1021
Window frame	0.20	420	2510
Ceiling insulation	0.039	30	1270
Thermal insulation of external wall	0.18	400	5000

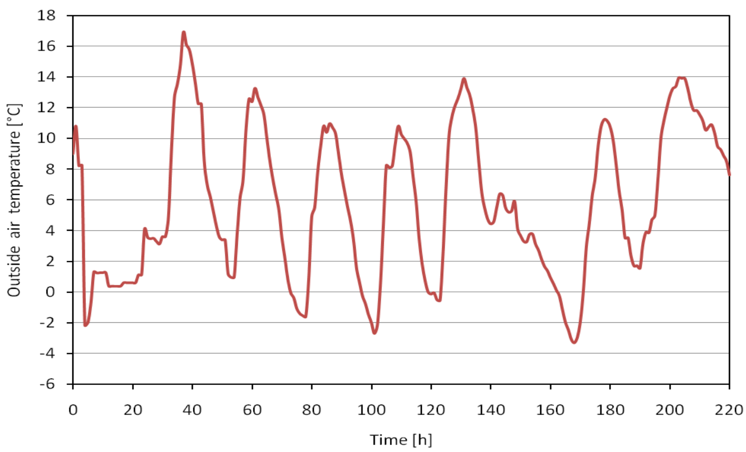

Figure 4: Course of outside air temperature used for computer simulation - measured data.

Results of our experiment are presented in Figures 5 and 6. Figure 5 shows a decrease of the air temperature inside the room during its cooling down in dependence on the thermal insulation thickness. Simulations were compared for wall of 200 mm thickness. It is evident, that maximum temperature decrease occurred for the wall without thermal insulation and that the temperature drop has decreased with the increasing thickness of the thermal insulation.

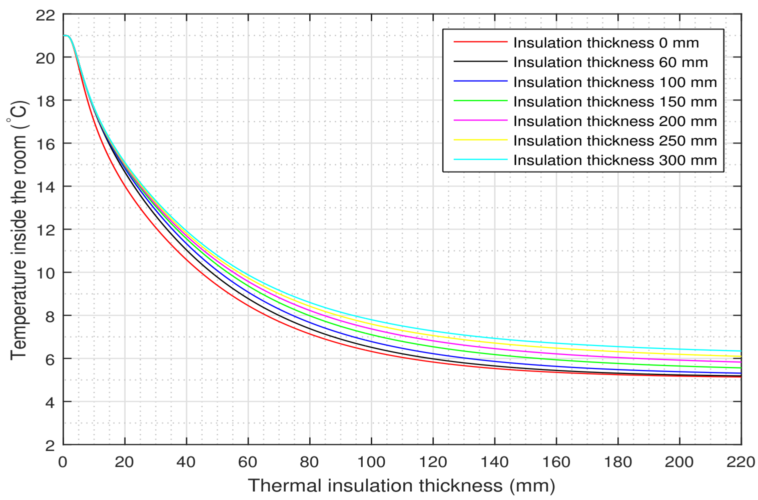

Figure 5: Dependence of the air temperature decrease on thickness of the external wall thermal insulation.

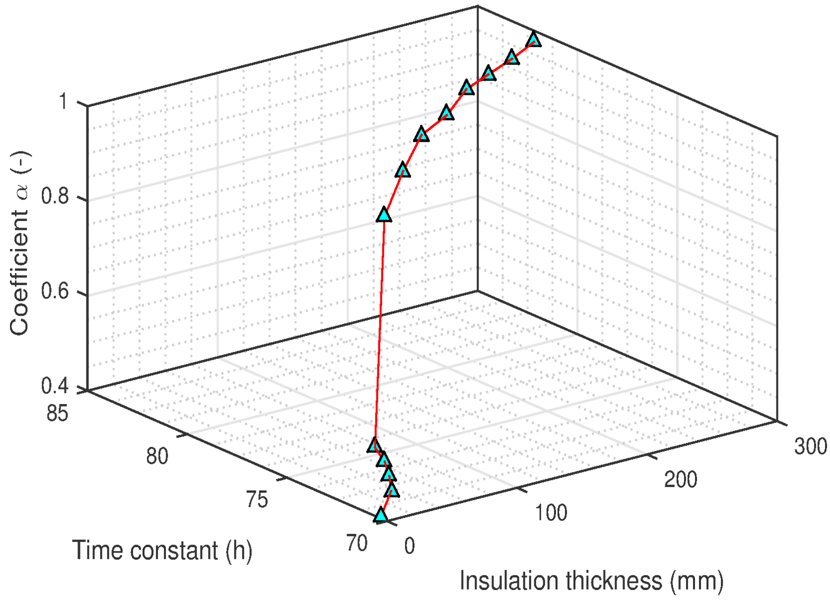

Figure 6: Dependence of the coefficient α on the thermal insulation thickness and the time constant.

Figure 6 summarizes the relationship between the calculated values of the coefficient α and the time constant for the tested thermal insulation thickness. It is evident that for increasing thermal insulation thickness the thermal stability of the room increases due to better thermal accumulation properties of the wall. Under the studied conditions the thermal accumulation has a steep increase of the time constant and the coefficient α values at the insulation thickness of about 70 mm.

6 Conclusion

In the paper described computer application which was formed in the COMSOL Multiphysics user environment, was used to test the cooling the room in the winter. In this example, we demonstrate the use of output data from simulations for post-processing and the assessment of the thermal stability of the room to be tested, depending on the thickness of the outer wall insulation under the simplified assumptions for the 2D model of the room with respect to the Czech and European technical standards used in construction and architecture. The tested model of the room show dependence of the time constant τ_c by cooling the room and the coefficient α on the thermal insulation thickness.

Further work will be focused on verifying the validity of our procedure for other boundary conditions as well as for other types of construction structures. The application for more difficult 3D model of the room will also be programmed.

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