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Dynamic Heat Transfer through the External Wall of a Timber Structure

SKOTNICOVÁ Iveta[1,a] , LAUSOVÁ Lenka[2,b*] and BROŽOVSKÝ Jiří[3,c]

[1, 2, 3] Faculty of Civil Engineering, VŠB-Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava-Poruba, Czech Republic

[a]iveta.skotnicova@vsb.cz, [b]lenka.lausova@vsb.cz, [c]jiri.brozovsky@vsb.cz

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Abstract. The article compares results of temperature and heat flux measurements in the external wall of the real timber structure with the results obtained by numerical modeling using the finite element method in the ANSYS software. The measured temperature values are compared with the results obtained from numerical simulation of the dynamic heat transport using non-stationary boundary conditions. In the article there is evaluated a suitability of theoretical numerical calculations for a thermal field and heat flux prediction in a building structure.

Introduction

The main aim of this paper is a comparison of experimental measurement results and numerical analysis of a temperature development and a heat flux value in the external structure [1, 2] of the real timber structure in winter period. Experimental measurements of the temperature response were made in the real timber building of the passive standard placed at the site of the Faculty of Civil Engineering at the Technical University of Ostrava. Material based on a timber has got the main influence on the thermal comfort of the inside setting [3]. Comparison of temperature and heat flux distribution in the structure was processed for the selected two days in winter. The target of this analysis is a verification of a suitability of numerical simulation methods application for a thermal field and thermal flux prediction in the light timber building structure.

For a theoretical analysis of thermal behavior there was chosen a numerical implicit method – the finite element method in the ANSYS software. This method is suitable for a solution of non-stationary multidimensional thermal tasks and enables to get solution of thermal problem in the finite number of discrete places (nodes) of the generated mesh in the whole area or just in the part of it.

Comparison of the experiment results and thermal behavior numerical simulation of the external wall of the timber structure was assessed for the chosen detail (see Fig. 1). Theoretical analysis of detail was carried out for the real boundary conditions for a winter period obtained by experimental measurements.

Experimental Measurements

External structures of the assessed timber passive house are solved as diffusion open structures with wood fibre thermal insulation. Table 1 shows the composition of the assessed detail of the external wall and basic thermal technical properties of used building materials.

There are placed sensors (1-5 – see Fig. 1) in the external walls for a long-term temperature monitoring (and also humidity) in the cross structure profile. There was also the ambient temperature measured by shielded temperature sensor as well as the interior air temperature.

The local heat flux by the peripheral wall was measured in two places simultaneously with the temperature measurement in the structure by heat flux sensors (see Fig. 1).

Fig. 2 and Fig. 3 demonstrate time dependent temperature of the external wall in winter time for two chosen days in January (26.1. - 27.1. 2013), when the external air temperature reached low values close to standard values [4, 5]. Measured temperatures show how the structure due to its thermal insulated properties deals with the winter low temperature on the external surface. Whereas external surface of the structure was loaded by the difference of surface temperatures during the day which fluctuated between -13.9 °C and -3.1 °C, inside of the structure including internal surface show very little differences in temperatures (between 17.8 °C and 18.8 °C – see Table 2 - time dependent temperature of the inside surface was influenced with the internal temperature and operation mode of heating).

The average value of heat flux in the measuring point was derived from the measured values of heat flux which was q = 1.8 W/m^2.

Table 1 Composition of the external wall of the timber passive house in solved detail

External wall	Layer thickness	Density	Thermal conductivity coefficient	Specific heat capacity	Thermal diffusivity
	d [m]	ρ [kg/m^3]	λ [W/(m.K)]	c [J/(kg.K]	a [m^2/s]
Fermacell board	0.015	1250	0.320	1000	2.56×10^{-7}
Wood fibre thermal insulation	0.060	50	0.039	2100	3.7×10^{-7}
Fermacel Vapor board	0.015	1250	0.320	1000	2.56×10^{-7}
Wood fibre thermal insulation/ Wall SW90 beam	0.300	50	0.039	2100	3.7×10^{-7}
Fermacell board	0.015	1250	0.320	1000	2.56×10^{-7}
Wood fibre thermal insulation	0.080	0.053	2100	1.00×10^{-7}	0.053
Wood fibre thermal insulation	0.060	0.047	2100	0.93×10^{-7}	0.047
Baumit plaster	0.007	0.800	850	5.23×10^{-7}	0.800

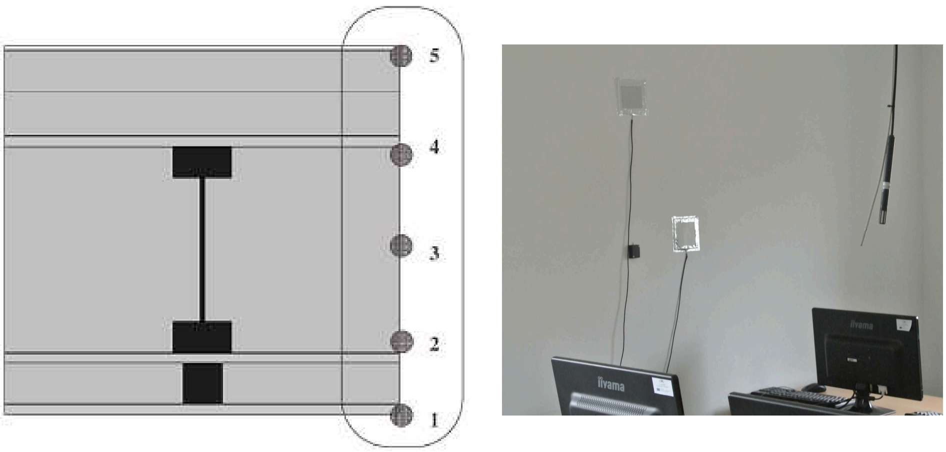

Fig. 1 Placing temperature sensors (1-5) and a heat flux sensor to the structure

Numerical Simulation Calculation

Numerical calculation by the finite element method in the ANSYS software has been used for numerical modeling of a thermal performance and a heat flux value.

The solved model of the peripheral structure has been created by applying the finite elements of PLANE55 type (Fig. 4). Width of the model corresponds to the axial distance between the timber pillars of the peripheral wall (0.6 m). Each material has been defined by thermal and technical features: density, specific heat capacity, thermal conductivity coefficient.

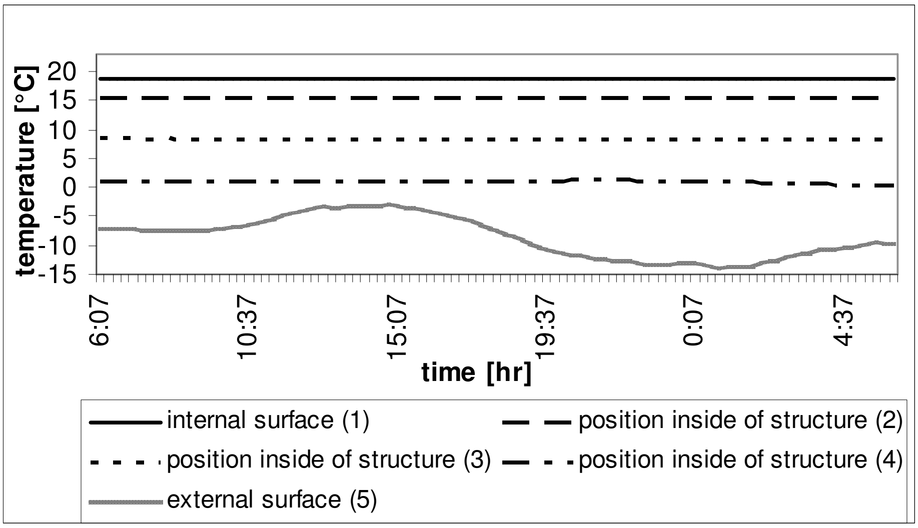

Fig. 2 Time course of temperature in sensors of the external wall

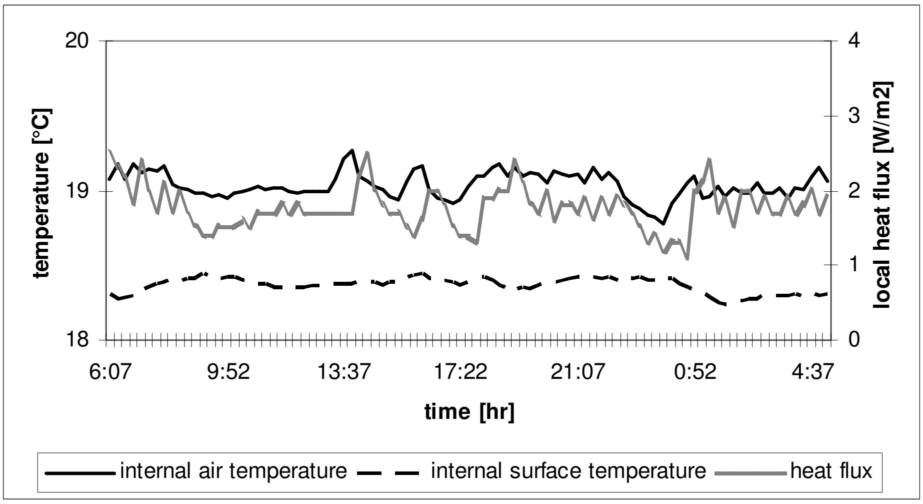

Fig. 3 Time course of heat flux in the external wall

Thermal analysis has been solved as a two-dimensional non-stationary task. The non-stationary task requests loading of time and time step. The time step equal to the time step of measurements (3600 sec.) has been applied for calculations. The total duration of the assessed time interval has been chosen as 24 hours.

The initial condition of calculation describes temperature distribution in the body at the beginning of the phenomenon in time t_0 and it has been applied by simulation calculation of a heat field for stationary conditions (θ_{se} = -6.5 °C, θ_{si} = 18.8 °C) and this state was further used as an initial condition for non-stationary calculations. The initial condition of a heat field distribution was verified by simulation calculations, so that the initial thermal state of the structure corresponded to the real measured temperatures.

All boundary conditions of calculations have been defined as the Dirichlet boundary conditions. External surface temperatures of the structure have been substituted from the real measured values. For the internal structure side the boundary conditions have been considered constant during the whole time interval 24 hours. The boundary conditions for the calculation of heat flux in the structures have been set up for stationary boundary conditions - external and internal surface temperature of the structure was achieved for the average real measured values (θ_{se} = -8.6 °C, θ_{si} = 18.8 °C) see Fig. 4.

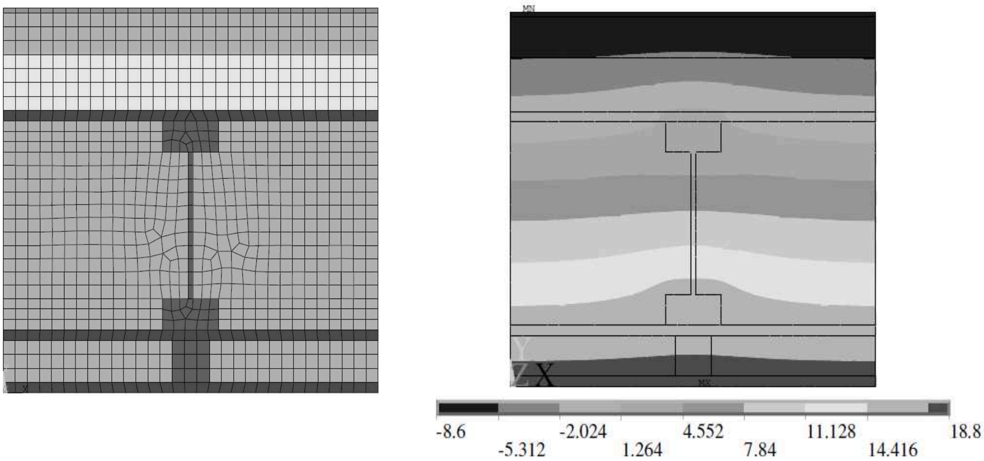

Fig. 4 Numerical model PLANE55 and thermal field for stationary boundary conditions

Table 2 shows the calculated and measured temperatures in individual positions of the temperature sensors for solved external wall detail in the selected hours from the both representative days in winter period.

Table 2 Experimental temperatures and numerical calculation during the selected day in January

temperature [°C]												
	time [hour]	sensor					time [hour]	Sensor				
		1	2	3	4	5		1	2	3	4	5
Experim.	6:00	18.7	15.6	8.4	1.2	-7.3	22:00	18.8	15.6	8.4	1.2	-12.9
Ansys		18.8	15.5	8.3	1.1	-7.3		18.8	15.5	8.3	1.1	-12.9
Experim.	10:00	18.8	15.8	8.4	1.1	-7	2:00	18.7	15.6	8.4	0.9	-13
Ansys		18.8	15.7	8.8	1.0	-7		18.8	15.5	8.3	1.0	-13
Experim.	14:00	18.8	15.6	8.4	1.0	-3.2	5:00	18.7	15.6	8.2	0.4	-10.1
Ansys		18.8	15.5	8.5	0.9	-3.2		18.8	15.7	8.5	0.2	-10.1
Experim.	18:00	18.8	15.6	8.3	1.1	-7.6						
Ansys		18.8	15.5	8.4	1.0	-7.6						

Fig. 4 shows the temperature field in the selected detail of the wall with timber column which causes thermal bridge. This temperature distribution was determined for stationary boundary conditions for which heat flux was calculated.

Fig. 5 shows a result of theoretical calculation of heat flux on that inner surface of the structure. The graph shows a significant increase of the flux at the place of a thermal bridge. The calculated value of the local heat flux q = 1.8 W/m^2 is obtained at the center between the columns. The value of heat flux determined by numerical simulation at the point between the columns is the same as the measured mean value of the local heat flux. A value of heat flux for inhomogeneous surface structures obtained by analytical calculation would be affected by the temperature field deformations due to the thermal bridge. Therefore, numerical calculation is more accurate method for determining the heat flux in the structure.

The value of heat flux is important for deriving of the heat transfer coefficient (thermal trasmittance) U-value of a structure. To determine this value, however, there is needed to evaluate the average value of heat flux across the whole characteristic detail, which will be the subject of further analysis [6].

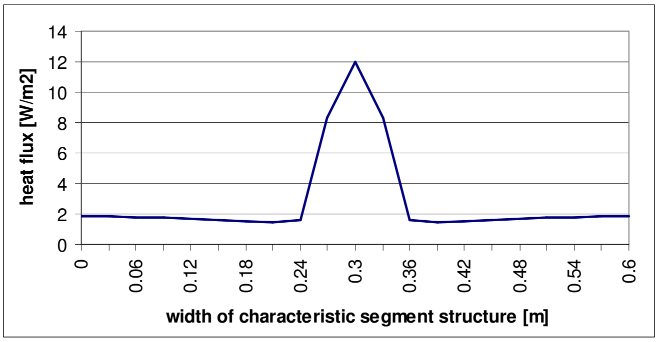

Fig. 5 Heat flux on the inner surface of the structure

Conclusion

The aim of the article is a comparison of the experimental measurement results and numerical simulation of a heat field and a heat flux in the external wall structure of the real timber building in winter and also verifying of suitability for using numerical method based on dynamic simulation of heat transfer for the prediction temperature distribution inside of the light building structure. The assessment of the obtained results can be summarized in the following points:

- Simulation calculations of heat transfer with the non-stationary boundary condition very well correspond with the measured values in each thermal sensor position. The obtained temperature distribution in dependence on time much better describes the real conditions than stationary solution.
- Calculated heat flux corresponds to the average value of measured heat flux in the assessed place, by numerical simulation there is determined the influence of the thermal bridge in the structure. All results of simulation calculations have got sufficient accuracy.

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