Arkadiusz AMBROZIAK[1], Magdalena STASIAK-BIENIECKA[1], Piotr BORKOWSKI[1]

Lodz University of Technology (1)

doi: 10.15199/48.2018.04.10

Thermal analysis of smart building

Abstract. *In the paper the simulation and measurements of temperature distribution and humidity in a room of smart building are discussed. Initially, mathematical model has been created. For this purpose ANSYS Fluent has been used. The simulation has concerned changes in solar radiation, temperature, humidity, air velocity and the real structure of walls, ceiling and the floor of the room. Then, the measurement results and simulation results have been compared.*

Streszczenie. *W artykule zaprezentowano model matematyczny pomieszczenia w inteligentnym budynku oraz dokonano analizy termicznej na podstawie symulacji wykonanych przy użyciu pakietu Ansys Fluent. W symulacji uwzględniono zmiany nasłonecznienia i związanej z nim temperatury oraz prędkosci powietrza, a także rzeczywistą strukturę ścian, sufitu i podłogi pomieszczenia. Wykonano również analizę rzeczywistych pomiarów temperatury i wilgotnosci.* ***(Analiza termiczna inteligentnego budynku)***

Keywords: smart building, thermal analysis, relative humidity, CFD **Słowa kluczowe:** analiza termiczna, inteligentny budynek, symulacja CFD

Introduction

According to the direction set by the European Union there are actions leading to improve energy efficiency in all domains. Buildings in the EU countries use about 30–40% of primary energy [1]. It is clear that there is a huge potential to minimize electricity consumption in building objects. This is achieved by implementing building management systems. The major part of the energy is used for maintaining the thermal comfort of the occupants. In order to analyse sources of heat and their impact on temperature and humidity distribution in a room, usually Computational Fluid Dynamics modelling software is applied.

Simulated room

The considered room is located on the third floor of a three-storey building at the Lodz University of Technology. The dimensions of the room, positions and sizes of windows and doors are shown in figure 1. The roof, south and west walls are external walls of the building.

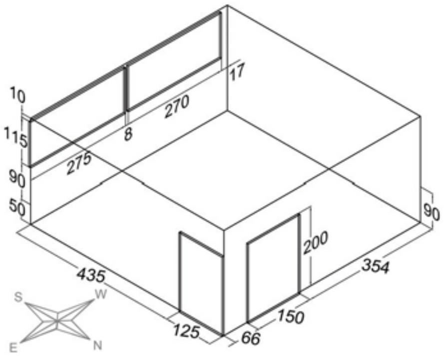

Fig. 1. Dimensions of the room (in centimeters)

The room is equipped with building management system produced by LCN company. Therefore all sensors used in measurements are compatible with this system. For measuring the temperature LCN-GRT sensors have been used. The resolution of these sensors is 0.1°C and the accuracy is 0.3°C (for temperatures between 15°C -30°C). For measuring the relative humidity LCN-EFS sensors have been used. Their resolution is 1% and the accuracy is $\pm$4% in the range 20%-80%. Based on the guidelines contained in Norm [2] and own experiments the positions of the temperature and humidity sensors have been set in the centre of the western wall at 0.1, 0.8 and 1.1 m.

LCN is a distributed building management system. It does not keep any archival data from devices and sensors. In order to control and visualize all LCN system data an additional module made by DOMIQ company has been installed. It collects all current data from every module in LCN network. Data acquisition is done via LAN. A Raspberry Pi microcomputer with its own program connects to the DOMIQ module at regular intervals. All data are collected and stored in the PostgreSQL database.

The weather data needed to complete the boundary and initial conditions for the simulations have been collected from the weather station located at Lodz Reymont Airport. The sunlight data comes from the weather station inside the considered room. The sun sensor is connected to the intelligent building system and it is located at the southern wall of the room. The sensor provides the sunlight data in luxes and the values must be converted into W/m^2 [3], which is used in Fluent. This relation has been determined experimentally [5].

Mathematical model

The energy balance of air in the room is described by the partial differential equations (1).

(1)
$$C_p \frac{\partial T_r}{\partial t} = \dot{Q}_d - \dot{Q}_o$$
$$C_p = m_p c_p = \rho_p V_r c_p$$

where: $\dot{Q}_d$ – heat flux supplied to the system (e.g. solar radiation), $\dot{Q}_o$ – heat flux emitted by the system, C_p – heat capacity of the air, T_r – air temperature, m_p – air mass, c_p – specific heat at constant pressure of air, V_r – volume of the room and ρ_p – air density.

Walls are defined by 2R1C model (figure 2). It's mathematical description is given by equation (2).

(2)
$$\rho_w V_w c_w \frac{\partial T_w}{} \quad \overline{\qquad\qquad} - \frac{T_w - T_r}{R_2} + \dot{Q}_{rad}$$

where: T_r – air temperature in room, c_w – specific heat of wall material, V_w – volume of the wall, ρ_w – density of wall material, T_w – temperature of the wall, T_{ext} – external air temperature, R_1 – thermal resistance from the outside to the wall, R_2 – thermal resistance from the wall to the room, $\dot{Q}_{rad}$ – heat flux related to solar radiation.

In this research, Ansys Fluent has been used to the solve the partial differential equations (1). Boundary conditions for external walls are mixed (convection and radiation), but for internal walls the equations consider only convection. In Ansys Fluent [4] the convection boundary condition is described by equation (3).

(3)
$$q = \alpha(T_w - T_p)$$

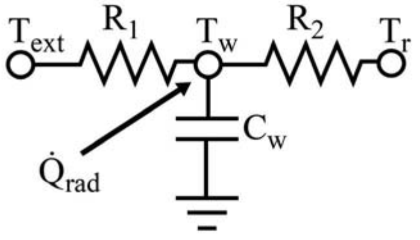

Fig. 2. 2R1C model of wall

where: q – heat flux, α – convective heat transfer coefficient, T_w – wall surface temperature, T_p – air temperature.

In the external radiation boundary condition the heat flux to the wall is computed by equation (4) [4].

$$q = \epsilon_{ext}\sigma(T_\infty^4 - T_w^4) \tag{4}$$

where: q – heat flux to the wall, ϵ_{ext} – emissivity of the external wall surface, σ – Stefan-Boltzmann constant, T_∞ – temperature of the radiation source on the exterior of the domain, T_w – temperature of the wall surface.

Our simulation involves calculating the temperature and relative humidity distribution in the considered room. The calculations have been conducted for 10 days (from 30 May to 8 June) in two versions: taking into account weather data (statistic weather data from 30 years) released by Ministry of Infrastructure and Construction and the second version with real weather data from the following period.

Initial conditions of air in simulation have been set at 25.3°C and 45% of relative humidity. At the beginning of simulation those values have been constant in every point of domain in the room. Initial values of temperature and humidity have been adopted according to their values at the start of measurements. After the initialization of solution in the next steps always current data (e.g fluid properties) has been used as the starting point.

In order to improve the accuracy of the simulation, the procedure in C (script User Defined Function [6]) has been developed and the mesh density for the window model has been optimized. The input data for this script are as follows: month, day, and start time of the simulation, the time zone, the duration of the simulation, and the path to the weather data file. On this basis, the data required to calculate the boundary conditions are determined by: heat transfer coefficient for external walls, direct and diffuse radiation, outdoor temperature, increase in the temperature on the surface of the walls related to the solar radiation. ASHRAE papers and models have been used to calculate the heat transfer coefficient [7] and the natural convection heat transfer coefficient for inner walls [8]. Stefan-Boltzmann's law has been used to calculate the increase of the temperature on the wall caused by the solar radiation.

The walls of the building have layered construction. For the purpose of the simulation the parameters of the materials for each layer have been used (figure 3). Their parameters have been determined according to the bill of materials and information released by producers. Due to the complex structure of the walls, floor and ceiling in the considered room, it has been necessary to determine the average thermal conductivity, density and specific heat for each wall. Parameters of equivalent materials have been calculated with use of weighted average. Each parameter has its own weight which is a physical quantity. The weight for density is volume, for specific heat – mass of the specific layer and for thermal conductivity it is the thickness of an element.

Table 1 and figure 3 present the complex structure of the selected wall.

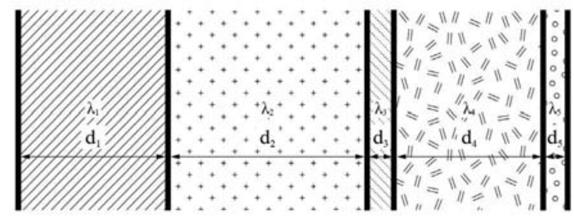

Fig. 3. Visualization of western wall (d – material thickness, λ – thermal conductivity of material)

Table 1. Real materials and equivalent material of western wall

	Thickenss [m]	Density [kg/m3]	Specific heat [J/kg*K]	Thermal conductivity [W/m*K]
Styrofoam EPS 70-040	0.12	20	1460	0.04
Prefabricated concrete element	0.16	2300	1000	2.3
Styrofoam	0.02	20	1460	0.045
Aerated concrete	0.12	500	840	0.17
Plaster	0.01	1700	840	0.8
Equivalent material	0.43	1041.4	975.364	0.102

Results and conclusions

Simulations and measurements have been conducted for city of Lodz – longitude 19°23'53"E, latitude 51°43'19"N. Sunrise at this time is around 4:30, and sunset is around 20:50. Figures 4 – 7 and 8 – 10 show the results of simulation for one typical day respectively: temperature and relative humidity for two cases of weather data and values measured for the same time.

Temperature in the room rises along with height of measurements. Differences between results are related to statistical and real data used in simulations. In statistical data solar energy is higher than values measured by sunlight sensor in those days. According to this fact, temperature in the room grows faster and it's maximal value is also higher. Maximum value in both cases is achieved in the same time.

Maximal temperature values obtained from simulations and measurements are similar. Differences could come from simulation model assumptions – properties of walls, floor and ceiling, scripts calculating approximate values etc. Relative humidity in the room in case of simulation and measurements are significantly different. This is due to the fact, that Fluent program ignores water vapour exchange through walls and natural convection of air. Because of that the quantity of water molecules stay constant but distribution of particles in area is changing. Relative humidity depends on temperature so it's value decreases until the noon (when temperature rises) and rise through the afternoon. This correlation is shown in Figures 6 and 9.

Summary

The performed simulation has allowed for analysing of heat and relative humidity distribution inside the room. With an additional data from building management system, it is possible to reproduce dynamic conditions in that space. The differences in temperature values (in summer season) are mostly the result of solar radiation. For the simulated period a significant difference has been observed between statistical and real data.

After conducting the simulations, archiving measurement data, analysis and verification of the simulations results it appears, that additional simulation with revised thermal properties of walls, floor and ceiling has to be performed.

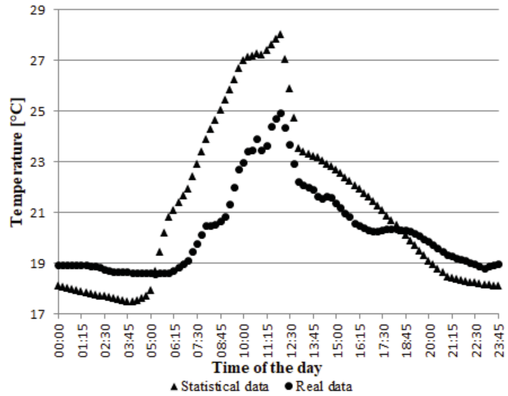

Fig. 4. Temperature values at height 0.1 m for statistical and real weather data

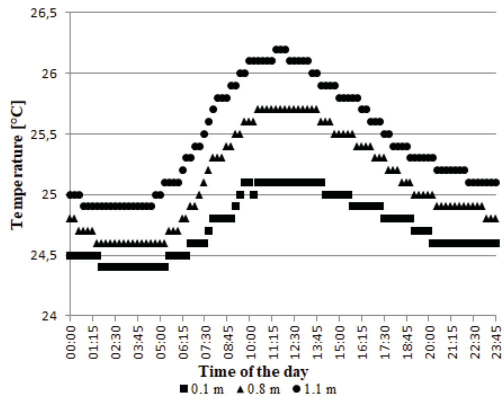

Fig. 7. Temperature values measured with sensors

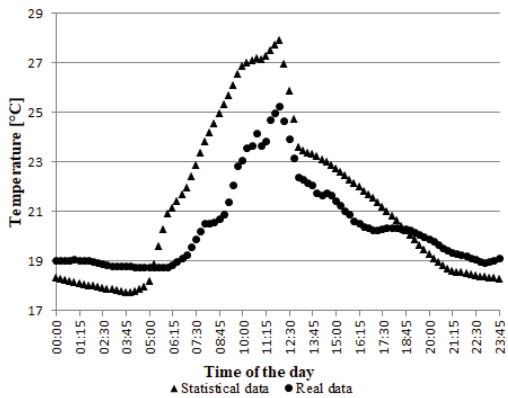

Fig. 5. Temperature values at height 0.8 m for statistical and real weather data

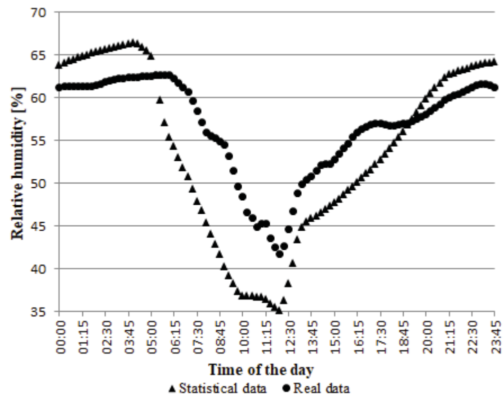

Fig. 8. Relative humidity values at height 0.1 m for statistical and real weather data

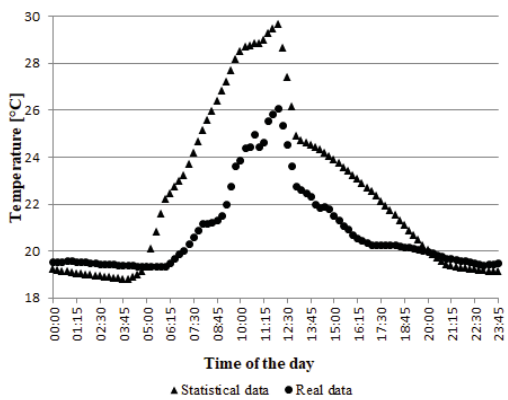

Fig. 6. Temperature values at height 1.1 m for statistical and real weather data

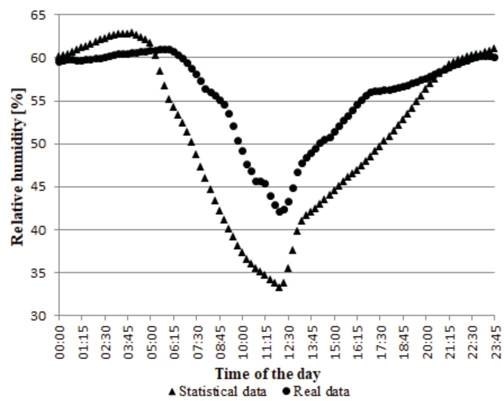

Fig. 9. Relative humidity values at height 1.1 m for statistical and real weather data

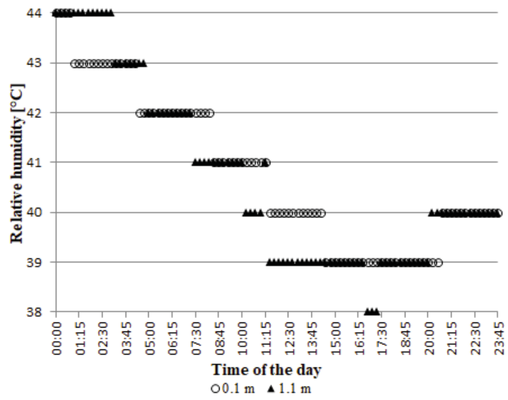

Fig. 10. Measured relative humidity values at height 0.1 m and 1.1 m

In the future we plan to introduce other elements of the simulation which are occupants, computers and heaters.Their presence is an additional source of heat.

Authors: *A. Ambroziak, M.Sc., M. Stasiak-Bieniecka Ph.D., prof. P. Borkowski, Department of Electrical Apparatus, Faculty of Electrical, Electronic, Computer and Control Engineering, Lodz University of Technology, B.Stefanowskiego 18/22 90-924 Łódź, Poland, email: arkadiusz.ambroziak@p.lodz.pl, magdalena.stasiak@p.lodz.pl, piotr.borkowski@p.lodz.pl*

REFERENCES

[1] Perez-Lombard L., Ortiz J., Pout C.: A review on buildings energy consumption information. Energy and Buildings, Vol. 40, pp. 394-398, 2008.
[2] PN-EN ISO 7730:2006 – Ergonomia środowiska termicznego – Analityczne wyznaczanie i interpretacja komfortu ter-micznego z zastosowaniem oblicczania wskazników PMV i PPD oraz kryteriów miejscowego komfortu termicznego.
[3] [web page] http://bccp.berkeley.edu/o/Academy/workshop08/08%20PDFs/Inv_Square_Law.pdf [Accessed on 06 Oct. 2017.].
[4] Ansys Inc.: Ansys Fluent User's Guide, 2011.
[5] [web page] http://mib.gov.pl/2-Wskazniki_emisji_wartosci_opalowe_paliwa.htm [Accessed on 06 Oct. 2017.].
[6] Ansys Inc.: Ansys Fluent UDF Manual, 2011.
[7] ASHRAE Task Group: Procedure for determining heating and cooling loads for computerized energy calculations: Algorithms for building heat transfer subroutines, New York, 1975.
[8] ASHRAE Task Group: 2001 ASHRAE Handbook: Fundamen-