ASSESSMENT OF THE SUMMER THERMAL STABILITY OF THE ATTIC ROOM USING TWO DIFFERENT SOFTWARE

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Abstract

This paper presents the calculations of the summer thermal stability of a critical room of the given building. In this case, the critical room of the building is an attic room. Using two different software (SIMULACE and DesignBuilder), the summer thermal stability of the attic room was evaluated according to the Czech standard ČSN 73 0540-2 [1]. This standard compares the calculated and required value of the maximum internal temperature in the summer period. The results from both software were compared with the Czech standard and also with each other. The resulting temperature courses in the interior differ by a few Celsius degrees. In conclusion, the causes of different results are discussed as well as the advantages and disadvantages of both software.

Keywords:

SIMULACE;
 DesignBuilder;
 Thermal stability;
 Overheating;
 Attic room.

1 Introduction

In warm-summer humid continental climate, which is typical for the Czech Republic, buildings are designed in terms of heat loss in winter to ensure a reduction in heating costs. This leads to improved thermal insulation properties of the building envelope and its tightness. However, due to climate change in recent years, we can assume that there will be more tropical days in the summer months in the world and our climate zone. For this reason, more attention should be paid to the topic of room overheating in the summer months and we should focus on finding long-term efficient solutions to protect these rooms.

Of all parts of the building, this topic is most relevant to the attic space. Living under a sloping roof has an inimitable atmosphere, but on hot days, there may be unbearable heat. It is because of the solar radiation incident on a building envelope, which is partly reflected and partly absorbed by surfaces of the opaque elements of the envelope. The share of solar radiation absorbed depends on the solar absorptivity of the wall surface. The heat from solar energy is nowadays, thanks to good thermal insulation and the high thermal capacity of buildings, trapped within it and cannot “get out” naturally [2]. The effect of solar radiation on the structure is influenced by climatic conditions [3] and by the location of the building. It is different if the building is completely shaded or fully exposed to incident solar radiation. It also depends if the building is located in the city, in the suburbs or the countryside.

Proper design of the building is necessary to prevent overheating of the interior during the summer months and to ensure thermal comfort of people in the rooms. One solution is the use of air conditioning in the building. The disadvantage is the associated energy consumption for air conditioning operation, which of course harms the environment. Chwieduk [2] used numerical simulations of the dynamics of a building and its surroundings to create several patterns of the heating/cooling demand. The results show that attic apartments facing the four principal directions can need nearly two times more cooling energy than heating energy in a high latitude country.

Besides, the increase in glazed areas in buildings hurts the thermal stability in the rooms during the summer. These areas lead to significant heat gains. The intensity of the insolation of these areas depends on the orientation towards the cardinal points. The fact is that a skylight will have higher heat

gains than a vertical window with the same parameters. One of the possible protections for vertical windows is the application of external fixed shading devices. Aldawoud [4] explained how to reduce heat gains through windows thanks to these external fixed shading devices. It is also possible to use the electrochromic glass, known as smart glass, which can regulate the solar gains entering a space, usually by tinting. This glazing technology can change the physical characteristics of glazing in response to external conditions [4]. Long et al. [5] compared the properties of three types of glazing and their impact on the thermal properties of the room. In this study, they combined the VO₂ film and double-glazed window to form a VO₂ double window. Olivieri et al. [6] were focused on the integration of STPV (semi-transparent photovoltaic) elements. The results show that for intermediate and large facade opening, the energy-saving potential provided by the STPV solutions is between 18 % and 59 % compared to the reference glass.

The application of innovative storage materials - Phase Change Materials (PCMs) integrated into building envelope structure or different internal elements can also be a suitable measure against overheating in the summer. By integrating these materials into lightweight structures, their heat storage capacity increases due to the use of latent heat as their phase changes. The effect of PCMs on the thermal stability of a room can be positive throughout the year. From the experimental measurements in [7], we can see the effect of PCMs integration on the interior temperature of the attic room. As shown by Sajjadian et al. [8], an appropriate level of PCM with a suitable incorporation mechanism in the building structure has significant advantages for residential buildings in terms of reducing the total discomfort hours and cooling energy loads. Bečkovský et al. [9] investigated the impact of using PCMs in lightweight building structures. They describe how these materials react throughout the year and how they affect the summer thermal stability of a room.

The correct design of the roof structure is also important. The roof surrounding the attic room has a large area directly exposed to incident solar radiation. Therefore, the properties of the roof (color, reflection) are very important for how much heat from the solar radiation enters the attic. Al-Obaidi et al. [10] stated that the temperature of normal dark roofs reaches 66 °C or more during hot days. In contrast, a reflective roof in similar environmental conditions remains approximately 28 °C cooler. Their Innovative Roofing System (IRS) is designed by using glazing technology (polycarbonate), pigment technique (reflective and radiative) as well as the ventilation process (hybrid turbine ventilator) applied in the attic zone to represent a new model for sustainable roofing design. The IRS was able to reduce the indoor air temperature compared with a conventional roofing system by approximately 2.1 °C under daylight conditions. Pisello et al. [11] explored the same issue on a building in Italy. They compared a roof covered with traditional "hot" brown-colored brick tiles and a roof covered with innovative "cool" light-colored clay tiles. Amornleetrakul et al. [12] investigated the thermal properties and heat gain reduction of a new roof tile design called Ventilated Roof Tile (VRT) compared with an ordinary corrugated concrete roof tile (CCR). The VRT tile was composed of upper cement plate and lower cement plate, with an air gap of 3 cm between the plates. Experimental results showed that the room temperature with VRT was about 1.41 °C lower than with CCR for average temperature. Ferreira et al. [13] applied a reflective barrier with low emissivity (radiant barrier) under a metal roof. Their simulations indicate that the use of radiant barriers in the roof contributes to the regulation of the attic temperature and prevents it from overheating. These solutions to reduce heat gains through the building envelope and thus reduce energy costs associated with air conditioning operation can be called passive cooling strategies. Lapisa et al. [14] focused on the effectiveness of three passive cooling techniques on roof level (cool roof coating, thermal insulation on the ceiling and natural air ventilation in the attic zone) and their results showed that the simultaneous implementation of these passive cooling techniques can significantly reduce overheating and thermal discomfort by 37.3 % in Indonesia, a tropical region.

This paper shows the comparison of the results of the summer thermal stability calculation of the attic room. The room was assessed by two software, SIMULACE software using an analytical calculation method and DesignBuilder software, which uses a dynamic simulation method to determine summer thermal stability. Němeček et al. [15] also present simulation results of summer overheating using the software SIMULACE and the dynamic method in the software BSim. Morávková [16] evaluated the results of the summer thermal stability in KOMFORT - DEKSOFT and DesignBuilder software. However, an older computation method in SIMULACE and KOMFORT was used in these two researches. The software DesignBuilder is widely used in the world. Chowdhury et al. [17] used DesignBuilder to evaluate the thermal comfort of a building in Australia. Zhang et al. [18] present the thermal comfort of the school building in northern China. They used DesignBuilder to calculate the building cooling demand while taking into account the local outdoor thermal conditions.

Strachan et al. [19] published model empirical validation of several software tools using dynamic simulations, including EnergyPlus in DesignBuilder. Svoboda [20] presents the validation of SIMULACE software according to ASHRAE 140.

To assess this issue, the requirements for summer thermal stability in the Czech Republic are given by the mandatory standard ČSN 73 0540-2 [1]. The standard compares the calculated and required values of the maximum internal temperature in the summer period. According to the Czech standard ČSN 73 0540-2 [1], for nonproductive buildings, the maximum internal temperature in the summer period must not exceed the required value $\theta_{ai,max,N} = 27\text{ }^{\circ}\text{C}$.

This research aimed to assess the summer thermal stability in the chosen attic room, which is located in the Institute of Building Structures at the Brno University of Technology in Brno in the Czech Republic. Subsequently, the results obtained by different calculation methods in two different software were compared to see how much they would differ and how it can affect the design of the building. We also evaluated the complexity and accuracy of entering the individual parameters of the room and the whole building. Finally, the advantages and disadvantages of both software are summarized.

2 Standard requirements

The requirements for the assessment of summer thermal stability in the Czech Republic are given by the standard ČSN 73 0540-2 [1]. The assessment is based on the comparison of the maximum internal temperature in the critical room in the summer period $\theta_{ai,max}$ with the required value according to the standard $\theta_{ai,max,N}$ [1].

$$\theta_{ai,max} \leq \theta_{ai,max,N} \quad (1)$$

The critical room in the building is the one with the largest area of openings directly exposed to the sun oriented to the W, SW, S, SE, E in relation to the floor area. The evaluation is carried out without internal gains in the room [1].

The required value of the maximum internal temperature in the summer period $\theta_{ai,max,N}$ is $27\text{ }^{\circ}\text{C}$ for non-productive buildings. For residential buildings, the standard permits exceeding the required value by $2\text{ }^{\circ}\text{C}$ for a continuous period of no more than 2 hours during the standard day, if the investor agrees [1].

The standard also includes requirements for buildings with air conditioning, in which the maximum internal temperature in the summer period $\theta_{ai,max}$ must not exceed $32\text{ }^{\circ}\text{C}$. In this case, the calculation does not include the cooling output of the air conditioner nor the heat gains from the technological equipment [1].

In both software, the summer thermal stability was evaluated according to Czech standards. This means that the calculation was made for the standard day of August 21 and without heat gains. Fig. 1 shows the course of temperature in the exterior for the standard day, and also the daily air exchange was set in a naturally ventilated room according to Fig. 1. This course corresponds to one window 50 % open at night and 10 % during the day according to the Czech standard ČSN 73 0540-3 [21].

Fig. 1: Air temperature in exterior and air exchange rate according to ČSN 73 0540-3 [21].

The Czech standard ČSN 73 0540-4 [22] specifies the calculation method for the summer thermal stability of a room and allows the use of simplified or more accurate procedures in compliance with defined standards. The calculation procedures also include software algorithms for evaluating the complex dynamic thermal behavior of buildings.

3 Building description

The Institute of Building Structures at the Brno University of Technology in Brno in the Czech Republic was chosen for this research. The building has a basement, four floors, and a hip roof. Two rooms were built in the unheated attic space. The critical room in this building is one of these attic rooms, which is adjacent to the exterior in the southwest, to the other attic room in the southeast, and to the unheated attic in the northwest and northeast. The load-bearing structure is made of steel profiles jacketed with gypsum plasterboards. The thermal insulation of each wall and ceiling are made of fibrous thermal insulation with a thickness of 200 mm. There is one skylight facing southwest without shading devices [23]. The roof structure of the unheated attic consists only of clay tiles. Fig. 2 shows the floor plan and section of the room with its dimensions.

Fig. 2: Floor plan and section of the room.

4 Methods

Two software were selected to assess summer thermal stability. The first software is SIMULACE [24], which uses an analytical approach to calculate the maximum internal temperature in the summer period. The second software is DesignBuilder [25], which uses dynamic simulations. In this case, the given building is modeled in 3D, allowing a more detailed calculation.

4.1 SIMULACE

SIMULACE software is most often used in the Czech Republic to evaluate summer thermal stability. This software uses the general hourly calculation method according to clause 6.5.6 of EN ISO 52016-1 [26] to calculate the room's response to the thermal load in the summer. The basis of this method is a repeated compilation and solution of the system of balance equations in individual hours of the day. This system arises gradually from energy balances (balance between heat gains and losses) at the level of [20]:

- the zone according to (38) in EN ISO 52016-1 [26];
- the internal surfaces of all building envelope structures according to (39) in EN ISO 52016-1 [26];
- the external surfaces of all building envelope structures according to (41) in EN ISO 52016-1 [26];
- and the internal nodal points in opaque structures according to (40) in EN ISO 52016-1 [26].

SIMULACE software uses only a simplified calculation method. It is not possible to include the whole building in one calculation, but only one room. If we are not sure which room is critical, it is necessary to perform the calculation for more rooms.

The values of the global horizontal solar radiation were set in SIMULACE software by Table H.8 of the ČSN 73 0540-3 [21]. Entering the environment parameters of an unheated attic as an adjacent room is problematic in this software. It was necessary to enter it as an external environment with a known temperature course. Therefore, the simulation of environmental parameters in the unheated attic was first calculated, and the results were then used as a boundary condition for the investigated zone. The temperature in the unheated attic ranges from 11 to 58 °C, which corresponds to the normal temperature course in the similar attic spaces. When modeling a shading building, it is only possible to enter the distance and superelevation of the shading building and the azimuths of the center of the vertical window from the left and right boundaries of the shading building [20]. It is not possible to define more complex shapes of shading buildings, and it is also problematic to take skylights into account.

4.2 DesignBuilder

The second software is DesignBuilder, which is not so widespread in the Czech Republic. In this software, not only the individual parameters of the structures are entered, but also the entire building, including the surrounding shading buildings, is modeled in detail. In the model, we then run the dynamic simulations in the EnergyPlus interface. EnergyPlus is an energy analysis and thermal load simulation program. Based on a user's description of a building, EnergyPlus will calculate the heating and cooling loads necessary to maintain thermal control set points, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would [27].

DesignBuilder is British software, but its settings can be modified to calculate according to Czech standards. The applications of this software are wide, but in this research, we were only interested in temperatures in the critical attic room during the standard day.

The entire building, including the surrounding buildings that shade the attic room, was modeled in DesignBuilder software. The building model is shown in gray in Fig. 3. The shading building is purple. Fig. 4 shows the floor plan of the modeled attic.

Fig. 3: 3D model of the given building.

Fig. 4: Floor plan of the attic.

First, the correctness of the 3D building model was assessed. The measured and calculated indoor air temperature values were compared. Between June 8 and June 15, 2019, measurements of indoor air temperature in the attic room were performed using the globe thermometer Ahlborn. The exterior temperature was recorded using the shielded digital thermometer of the TUBO weather station [28] also located at the Brno University of Technology. Measured values of the outdoor environment in the given period were set in the DesignBuilder software and simulation was started. Fig. 5 shows the values measured in the attic room and the values calculated in the DesignBuilder software. The model was created correctly.

Fig. 5: Correctness of the model.

For the simulation, two time steps per hour were set in the DesignBuilder software. For the sky simulation in Summer Design Weather Data, the solar model ASHRAE Clear Sky with sky clearness 1.000 was used. The values of the global solar radiation of this solar model most correspond with the values in Table H.8 of the ČSN 73 0540-3 [21].

5 Results and discussion

5.1 SIMULACE

The parameters of the attic room, the parameters of the rooms adjacent to this room were entered in the SIMULACE software and the maximum internal temperature in the summer period was calculated. The results are shown in Fig. 6.

Fig. 6: Air temperature in interior calculated in SIMULACE.

The maximum internal temperature in the summer period in the given room calculated in SIMULACE is 38.94 °C. The required value according to ČSN 73 0540-2 [1] is 27 °C. The room does not meet the requirement of the standard; it will be necessary to design suitable shading devices and possibly air conditioning.

5.2 DesignBuilder

After assessing the correctness of the model, the standard day conditions were set in the software according to the Czech standard ČSN 73 0540-3 [21]. Then, a simulation for August 21 was started. The simulation results are shown in Fig. 7.

Fig. 7: Air temperature in interior calculated in DesignBuilder.

The maximum internal temperature in the summer period in the given room calculated in DesignBuilder is 35.31 °C. The required value according to ČSN 73 0540-2 [1] is 27 °C. The room also does not meet the requirement of the standard; it will be necessary to design suitable shading devices.

It was found that the attic room without shading devices did not meet the standard requirement in either case. However, by calculating with dynamic simulation in DesignBuilder, we obtained more favorable results. The difference in the calculated values is 3.63 °C. Table 1 shows the maximum internal temperature in the summer period in the given room.

Table 1: The maximum internal temperature in the summer period $\theta_{ai,max}$.

	Maximum internal temperature in the summer period $\theta_{ai,max}$	Required value of maximum internal temperature in the summer period $\theta_{ai,max,N}$
SIMULACE	38.94 °C	27 °C
DesignBuilder	35.31 °C	

The results obtained from both software indicate the difference in temperature course during the standard day. Fig. 8 shows the curves obtained from both software and it is obvious that the curve obtained from the SIMULACE software reaches higher values.

Fig. 8: Comparison of results from both software.

Fig. 8 shows that the indoor air temperature in the morning is very similar according to both calculations. In the afternoon, the curves start to differ by several °C and during the night, they approach each other again. A small difference can be caused by a simplified way of entering shading buildings in the SIMULACE software. Due to the orientation of the attic room to the southwest and the

small superelevation of the shading building, this difference will not become evident until the evening. The difference in air temperatures in the interior during the day can be caused by the parameters of the adjacent unheated attic that surrounds the attic room from several sides. In the SIMULACE software, only approximate values of temperatures in the unheated attic were entered, determined thanks to the simulation of the unheated attic space. Since in the SIMULACE software, we calculate several spaces with unknown temperature courses, it is difficult to determine how they will influence each other. Therefore, when modeling the entire building in DesignBuilder software, the course of air temperatures in the unheated attic is more realistic. The difference in the results will also be caused by a simplified calculation method and simplified parameter entry in the SIMULACE software. Therefore, the results of the SIMULACE software can be expected to be safer.

Fig. 8 also shows a comparison of solar gain radiation. The SIMULACE software uses the values of the global horizontal solar radiation by Table H.8 of the ČSN 73 0540-3 [21]. The DesignBuilder software uses the ASHRAE Clear Sky solar model. It can be seen that both courses are very similar. The entire curve from DesignBuilder software is shifted slightly to the left. Only if the critical room is oriented directly to the north side, the results from DesignBuilder software can be more favorable than from SIMULACE software. In our case, however, the room is oriented to the southwest. The graph shows that despite the higher global solar radiation during the morning in DesignBuilder software, the air temperatures in the interior do not reach higher values compared to SIMULACE software. Therefore, the difference in global solar radiation input is not the cause of the difference in air temperatures in the interior obtained from both software.

The SIMULACE software, which is commonly used in the Czech Republic, allows quick calculation for one critical room, and entering parameters is very simple. In our case, however, the results do not correspond to reality so much, and the calculation methodology considerably increases the cost of shading devices. Partly because of the higher values of the maximum internal temperature in the summer period and also because, in practice, only one critical room is selected for which the shading devices are calculated and designed, and these shading devices are then used in all rooms in the building. It is possible to calculate each room in a building separately, but this, in turn, will increase the cost of assessing the summer thermal stability [16]. A further disadvantage is that it is not possible to realistically define an adjacent space corresponding to the unheated attic. Also, it is not possible to realistically model the surrounding shading buildings with intricate shapes affecting the air temperature in the interior through the skylight.

DesignBuilder software is not very widespread in the Czech Republic and is not commonly used in practice. Results from this software are more complex and realistic thanks to dynamic simulations. The advantage of the DesignBuilder software is that we do not have to perform individual calculation/simulation for each room. After modeling the whole building and running the simulation, we immediately get the maximum internal temperature in the summer period in each room in the building, so it is possible to quickly design individual shading devices for each room in the building. Also, the results are more favorable, which leads to cost savings on shading devices. Since the entire building, including the surrounding buildings, is modeled in detail, there is no problem with entering adjacent spaces, as realistic conditions are simulated in each space of the building. This software is, of course, more complicated, and it takes more time to model the entire building. However, if we wanted comparable results from the SIMULACE software, we would have to calculate each room separately, which significantly extends the time spent entering each room's parameters.

6 Conclusion

This research aimed to assess the summer thermal stability of the attic room according to the Czech standard ČSN 73 0540-2 [1]. Software SIMULACE and DesignBuilder were used for evaluation. The aim was also to compare the results obtained from both software.

The results of the values of the maximum internal temperature in the summer period in the given room obtained from both software are different and therefore the design of the shading will be different. It was found that the different inputs of global solar radiation and the simplified method of entering shading buildings in SIMULACE software do not have a large effect on the different courses of air temperatures in the interior. The reason for the difference will be the approximate determination of the temperature course in the unheated attic in the SIMULACE software and the simplified method of calculation and entering the room parameters in this software. Calculation using the software DesignBuilder is more complex, but the results are more realistic. However, SIMULACE software is more commonly used in the Czech Republic. The assessment of summer thermal stability using

DesignBuilder software takes more time, but with realistic results reduces the cost of shading devices for the investor.

In further research, we will focus on the solution to the overheating of attic rooms. In the first phase, we will design suitable shading devices for our assessed attic room so that the requirement for summer thermal stability according to the Czech standard ČSN 73 0540-2 [1] is met. We will design shading devices according to the results from both software and we will compare the costs of their installation. In the next phase, we will investigate the effect of phase change materials PCMs on the internal temperature. These materials cannot be defined in the SIMULACE software; therefore, only the DesignBuilder software will be used for further evaluation.

Acknowledgements

The paper was supported by the Student Grant Competition VSB-TUO. The project registration number is SP2020/118. This paper has been elaborated in the framework of the grant programme „Support for Science and Research in the Moravia-Silesia Region 2018" (RRC/10/2018), financed from the budget of the Moravian-Silesian Region.

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