Air temperature distribution in the glazed stair case area

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Abstract: The purpose of this paper was to investigate a temperature behaviour in glazed part of a building which is placed in Czech Republic. Measurement was done on a part of the structure, called block B and it was chosen because high air temperatures occurred in its staircase area. This air temperature was above acceptable standard limits and caused a problem with an elevator. Complete methodology is covered in the main part of the paper, followed by description of mathematical simulation. Possible solutions and further improvements are discussed at the end of the article.

Key–Words: Heat gains, simulation software, glazing space, temperature distribution, running mean temperature

1 Introduction

The share of glass used as a construction material in building's faades has increased during the last 1000 years. Particularly thanks to its specific features, such as transparency, low weight and an ability to separate different environments. As glass is so popular for use in faades, there is one important question that should be always taken into account temperature gains caused by internal and external heat sources. A special attention should be paid to habitability of these plant house buildings. A long-term research of people's comfort was executed in 26 office buildings in five European Union states. [1] Interior comfort can be achieved by ventilation systems, shading systems or by their combination. In recent years, a particular emphasis is put on sustainability of glass buildings. [2],[3],[4] Regardless of our experience and knowledge, the risk of constructing a discomfortable building is always present. Such a building is the subject of investigation in this article. The main reason for selection of this building were excessive heat gains in the glazed area, which is used for stairs and also disposes of gazed elevator shaft. The excessive heat gains were measured in immediate distance of this shaft. The structure of the paper as follows, first is mentioned process of measurement, computer simulation are described in the methods section, while gathered data are summarized in the results section. Whole paper is completed with conclusion section.

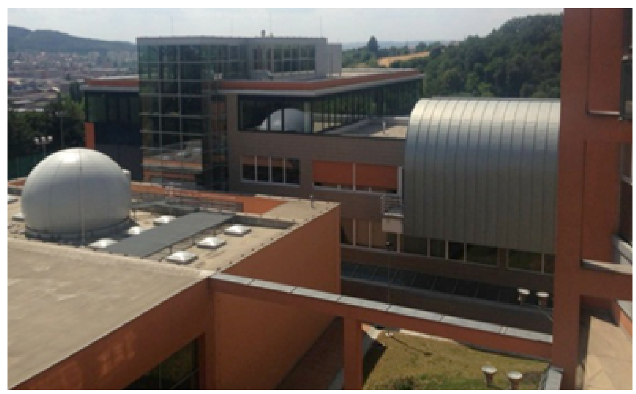

Figure 1: block B of the VTP-ICT Park

2 Methods

The measurement took place in the staircase area of VTP-ICT Parks building, displayed in Fig. 1. Exact measurement position can be seen in Fig. 2. Building is situated next to Faculty of Applied Informatics (FAI) of Thomas Bata University in Zlin. The staircase area is 17 meters tall and stands on the south hillside. The building consists of two symmetrical parts called Block A and Block B. The results of this study are restrained to Block B, even though Block A has the same staircase area. But in the morning hours Block A is shadowed by FAI building, which means that such a marginal fluctuation as in Block B is not possible. The measurement was done in the staircase area from 0^{th} to 4^{th} floor. Its construction is as follows: the east side and 2 meters of the north and the south sides are made of glass combined with supportive aluminium matrix and they are exploited to outside weather conditions; the rest of the area is surrounded by rooms and is adjacent to regulated inside conditions. The 4^{th} floor is completely embosomed by glass and supportive aluminium matrix. A weather station was used for the measurement of the outside climatic conditions, which are air temperature, humidity, climate pressure, global sunshine, wind speed, wind direction and precipitation. This weather station is placed on the roof of the FAI building. The weather station was created as a Master thesis and its detailed description can be found here [5]. For the measurement itself, 5 temperature sensors were used, each surrounded by aluminium foil, which eliminates effects of radiation heat as shows Fig. 3. Sensors were placed approximately 1.5 meters above the floor and 0.3 meters away from elevator door. A temperature sensors working radius was limited by the length of the cable. An emergency ventilation system was shut down during the measurement, in order to simulate the worst possible conditions. The measurement started at 7 a.m. on 28^{th} of July and finished at 7 p.m. This day, was the hottest day in the whole year.

The adaptive thermal comfort approach, applying the indoor operative temperature in relation to the running mean outdoor air temperature as the main performance indicator. For the mean temperature of the outside air is typical regular, periodic fluctuations in both daily and annual cycle. It is the average daily temperature and its value is given by the average values of the clock cycle. Adaptive comfort temperatures are based on outside mean air temperature during the preceding several days. Mean air temperature can be calculated as is in (1). The weighting or influence given to the outside temperature is largest for the previous day, reducing for the preceding day, reducing again for the day preceding that and so on. A weighted running mean of outdoor temperatures θ_{rm} is calculated as follows (2). The α is a constant between 0 and 1 which defines the speed at which the running mean temperature responds to the outdoor air temperature and the characteristic time period of the relationship. The larger the value of α the more important are the effects of past temperatures. [6] The calculation is described more in Czech translation of Europien standard CSN EN 15 251. [7]

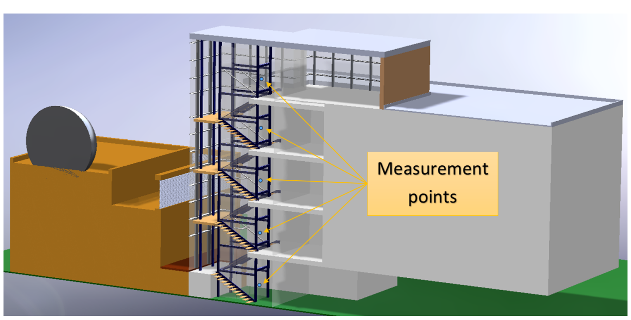

Figure 2: inside measurement position

Figure 3: shilded thermometer

$$\theta_{ed} = \frac{\theta_{7am} + \theta_{2pm} + \theta_{9pm} + \theta_{9pm}}{4} \tag{1}$$

Where	θ_{ed}	is	mean air temperature	[°C]
	θ_{7am}		air temperature at 7 am	[°C]
	θ_{2pm}		air temperature at 2 pm	[°C]
	θ_{9pm}		air temperature at 9 pm	[°C]

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

Where	θ_{rm}	is	running mean air temperature	[°C]
	θ_{ed-1}		mean air temperature from previous day	[°C]
	θ_{ed-2}		mean air temperature from previous two days	[°C]
	α		constant between 0 and 1 recomended value is 0.8	[-]

2.1 Building simulation in environmental engineering

In Environmental Engineering is now increasingly used methods of computer simulation for design, research, and evaluation of the dynamic behavior of a buildings. Many manufacturers also enables customers to freely use various design of simulation environment.

Larger environments serving designers and professionals, allow to use a much wider range and more accurate calculations. Thanks to the ever-increasing power of computers, these methods are used much more frequently. BESTEST or The Building Energy Simulation Test, is a project developed by the International Energy Agency (IEA), based on empirical validation, analytical validation and comparison analyses, which are tested on a variety of simulation software. [8] Around the world, there are developed many software tools that use different approaches to calculate the energy behavior. There are exist several ways with which to assess the accuracy of simulation programs. Empirical validation enables comparison of calculations with data from the program monitored on a real building. Analytical validation on contrary compares calculations with the already known analytical solution, or generally accepted numerical methods with limited boundary conditions. Comparative testing already presents itself comparison with other simulation programs, which can be considered accurate. As test cases used different models, such as specifically set system environment, which is subsequently applied to the adiabatic shell of the building for a longer time horizon, or even years. All parameters that comparative model poses are defined by ANSI ASHRAE Standard 140: 2011 [9], which is approved as a standard test method for assessing computer program.

Simulated model used in this study was created to by most reliable around investigated staircase area, the rest of the model was retain inaccuracy. Computation was executed only in steady-state set. Boundary conditions of the computational model was set from measured data, outside air temperature $\theta_e = 34.7°C$, temperature of the surrounded rooms with regulated conditions $\theta_i = 32.7°C$. Time of calculated model was set to 2 p.m., because at this time was most extreme conditions during the measurement.

3 Results

Fig. 5 illustrates the temperature behavior in Block B and solar radiation during the measurement period. As can be seen, the temperature progress is homogeneous at all floors of the staircase. The highest outside temperature was above $35°C$ and this value was measured at 2 p.m. This occurred two hours after the solar radiation peak, which is nothing unusual in this time of the year. The solar peak was slightly above $900\,W\,m^{-2}$, containing both global and diffusion beaming. The sky was clear during the whole day, as illustrated by the smooth curve of solar radiation. The temperature progress inside the building was completely different. As predicted, the highest temperatures were collected on the 4^{th} floor, on the contrary to the lowest temperatures, which occurred on the 0^{th} floor. This development is due to the sunshine, which was beaming whole day on the entire 4^{th} floor, in contrast to the 0^{th} floor, where the sun shined on inside walls for two hours from 8 a.m. and then one hour before sunset. The air temperature on the 0^{th} floor reached its bottom at 8 a.m. after a slight decrease, as clarified in Fig. 5. It is worth to mention, that at 8 a.m., 9 a.m. and almost at 10 a.m. the outside temperature had the same progress as the air temperature on the 1^{st} floor. The highest degrees on the 2^{nd} and the 3^{rd} floor were achieved at 12 a.m. A marginal hike on the 0^{th} and the 1^{st} floor occurred between 12 a.m. and 2 p.m. It can be assumed, that it was caused by temperature increase on the upper floors, especially on the 4^{th} floor, where temperature had reached almost $43°C$. Fig. 6 shows development of running mean air temperature and mean temperature for seven days before measurement of indoor air conditions. As can be seen running mean air temperature had periodic character. At the day of

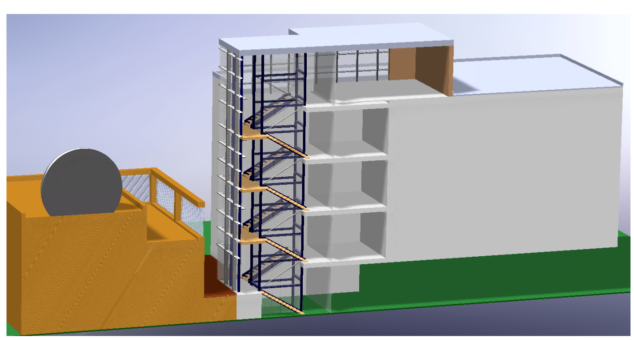

Figure 4: model of the block B in simulation software

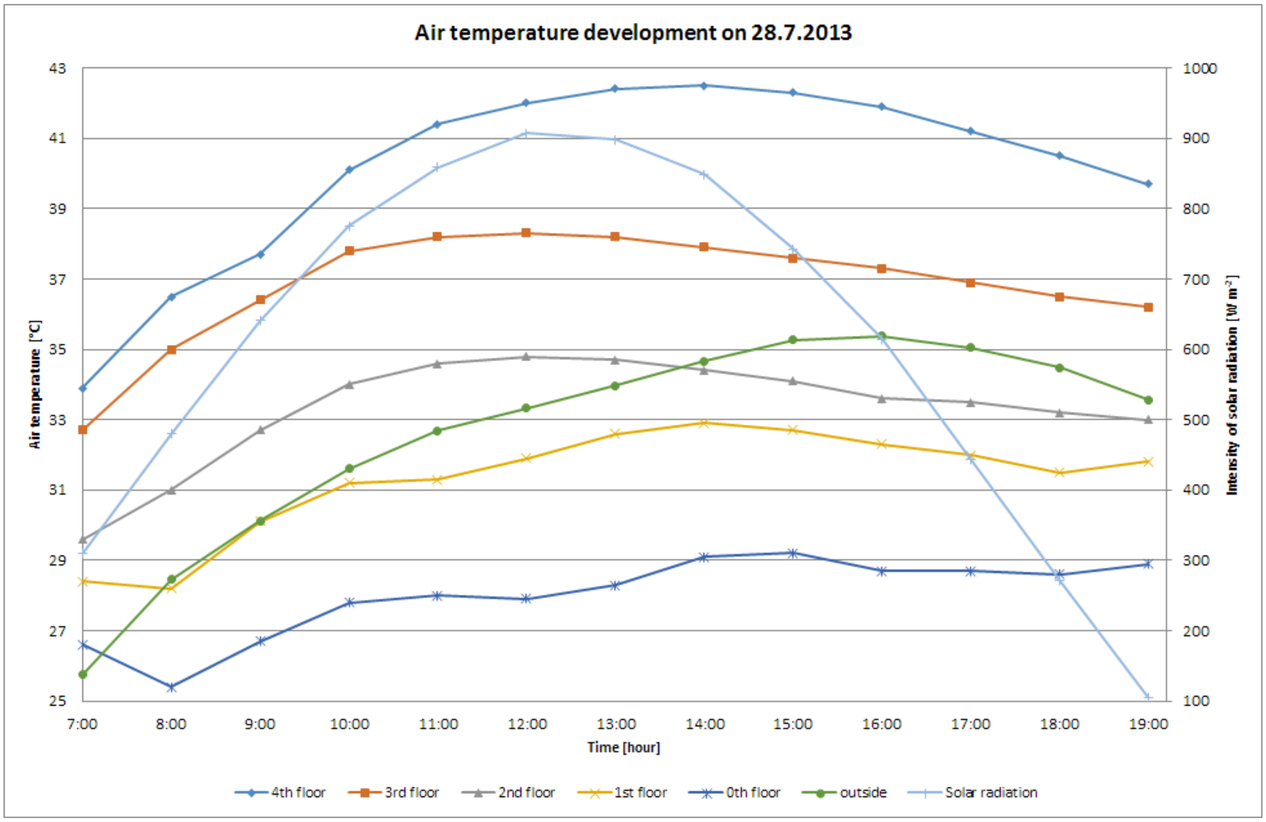

Figure 5: air temperature distribution and solar radiation distribution on the day of measurement

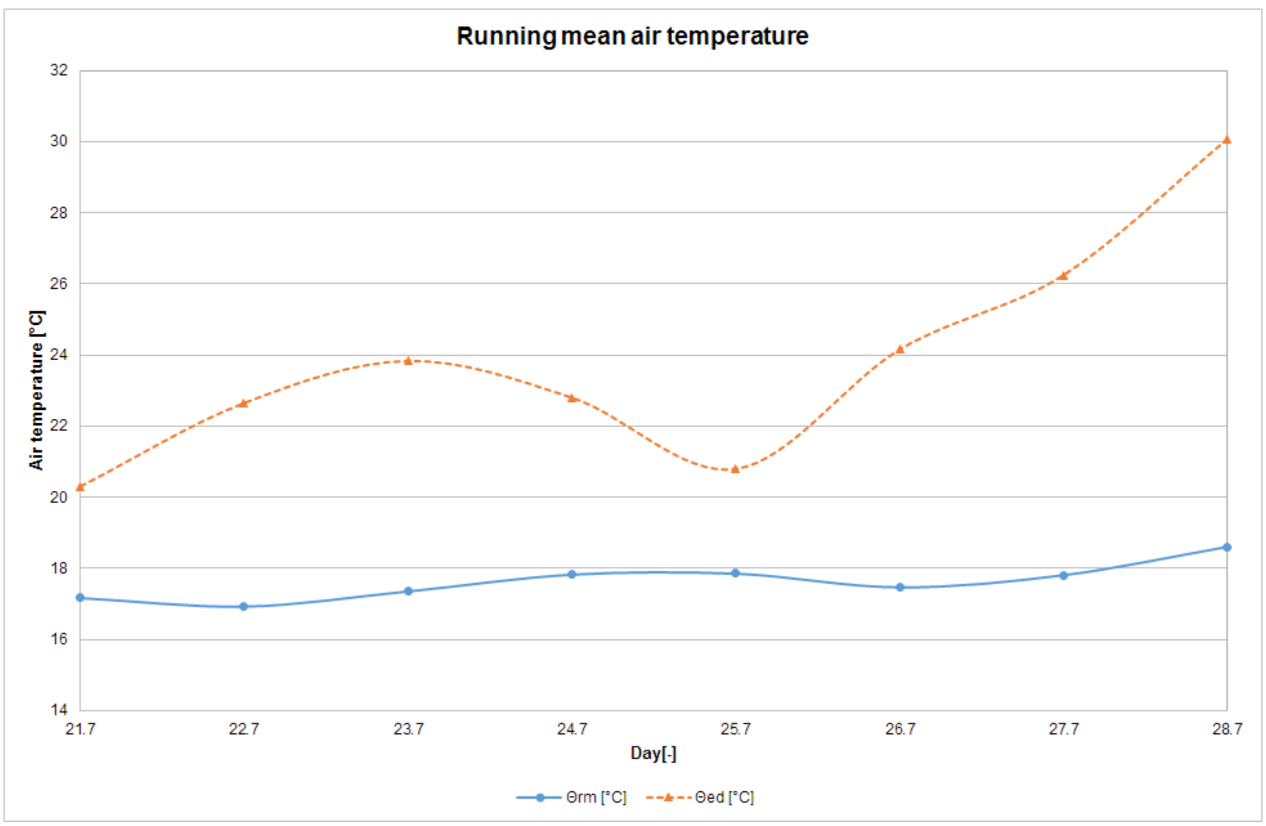

Figure 6: development of running mean temperature and mean temperature 7 day before measurement

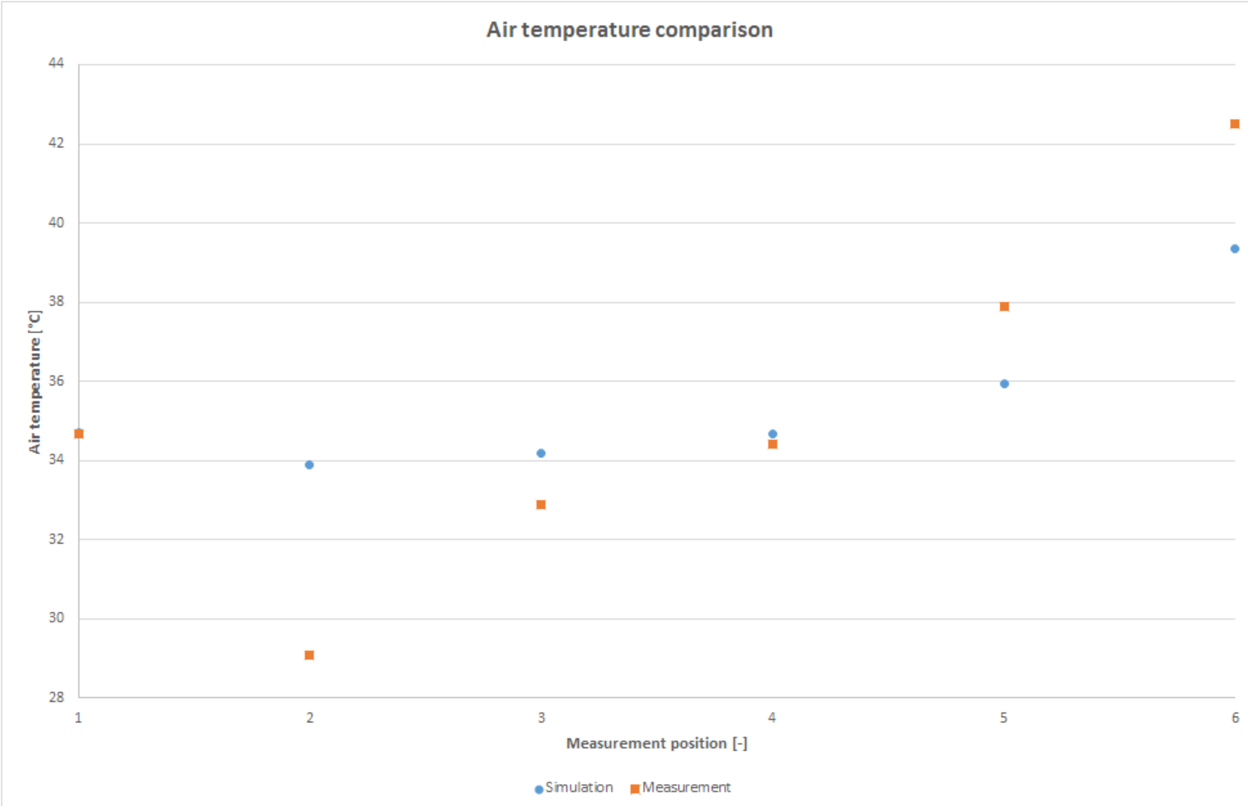

Figure 7: Measurement comparison with simulation outcome

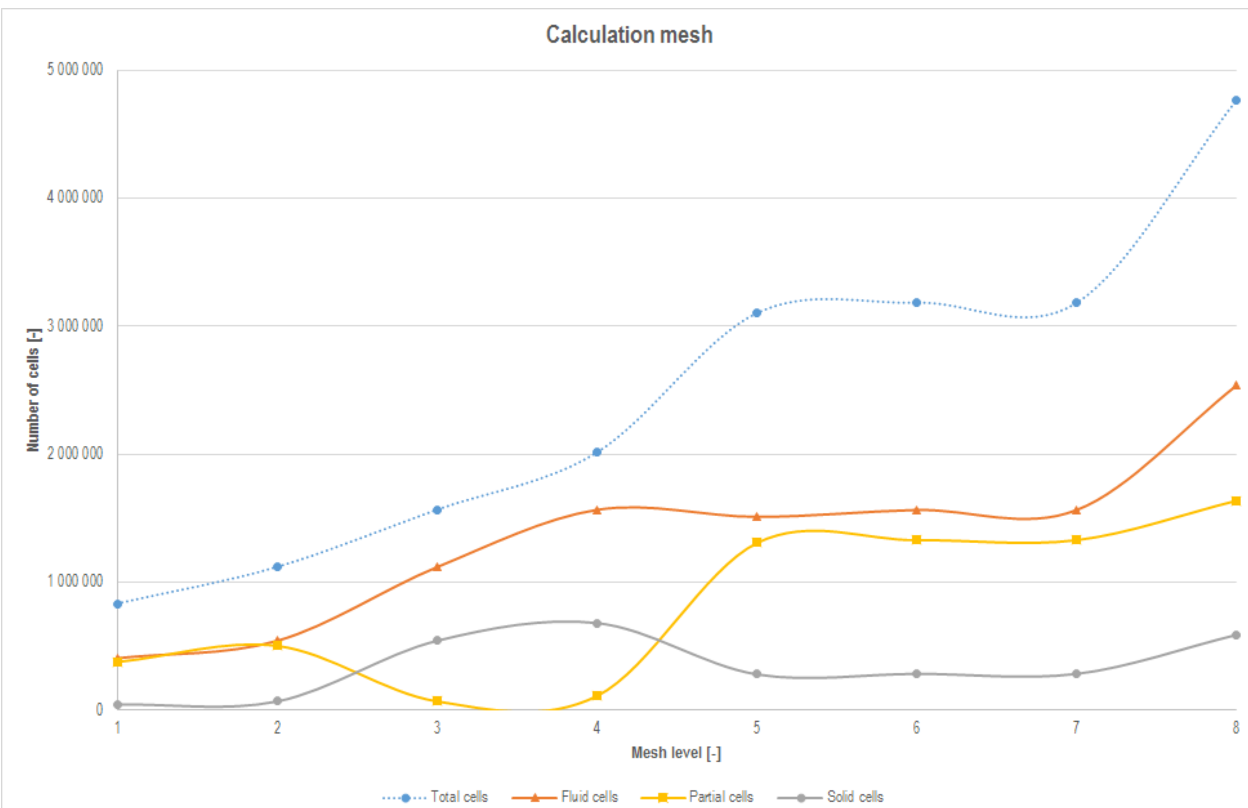

Figure 8: Calculation mesh comparison

Table 1: Air temperature comparison between measurement and computational simulation

Position [−]	Sim. [°C]	Meas. [°C]	Diff. [K]	Diff. [%]
Outside	34,72	34,67	0,05	0,14
0th floor	33,90	29,10	4,80	16,49
1st floor	34,20	32,90	1,30	3,95
2nd floor	34,69	34,40	0,29	0,84
3rd floor	35,93	37,90	1,97	5,20
4th floor	39,35	42,50	3,15	7,41

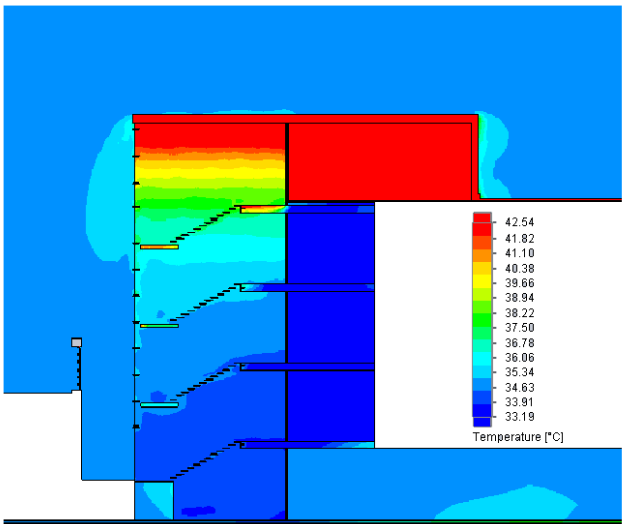

Figure 9: air temperature stratification using coarse grid

the measurement was on its rising path. Table 1 show comparison of measurement with mathematical simulation.

3.1 Calculation

Due to high computational demanding was decided to proceed only stationary simulation. Based on measurement was set 2 pm as time for solar radiation and position. Mesh level was set to 3 and with this setting was generated 1 567 366 cells. The calculation took almost 8 days to finish (653 955 s) with this set-up. It took 930 iterations before convergence criteria was acquire.

In the Fig. 8 is compared different level of meshing. As can be seen most valuable grid could be 5 because level 6 and 7 are almost same. So for the future it would be appropriate to do calculation with meshing 5. Unfortunately time needed for compute rising exponentially with each level. Due this it would be necessary to adjust model with grid issue in mind. In a table 2 is summarized meshing options with its numerical results.

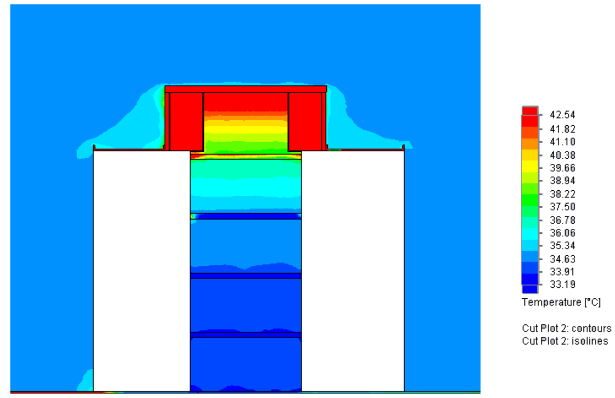

Figure 10: air temperature stratification using coarse grid (front view)

Table 2: Calculation mesh comparison

Mesh level	Fluid level	Solid level	Partial level	Total cells
1	408 563	46 356	378 766	833 685
2	544 541	71 233	504 469	1 120 243
3	1 120 243	544 541	71 233	1 567 366
4	1 567 366	682 809	113 336	2 014 082
5	1 512 238	281 909	1 308 189	3 102 336
6	1 565 774	286 403	1 330 512	3 182 689
7	1 565 774	286 403	1 330 512	3 182 689
8	2 538 381	591 321	1 638 093	4 767 795

4 Conclusion

The results indicate, overall, that the temperature gains are steep above the limit value for the daily rise in air temperature specified in Czech standard for indoor climatic conditions. [10] There is a high probability that inattention at the planning stage or under development could be the reason for such high heat gains. Disputation can be seen in a fact, that the standard was overrun because the measurement was done on the hottest day of the year. On the contrary, this is an advantage for further research, that data were collected under the worst possible conditions. Notwithstanding the limitations, this work suggests to take precautions against solar gains in Block B. A computer model of block B was created for the use of computer simulation. The simulation is performed by simulation software that has proven its credibility in the area through IEA BESTEST. [11],[12] On Fig. 9 and Fig. 10 is depicted a preliminary result of simulation using coarse resolution computational grid. Currently, the calculations with a finer resolution are computed and results will be presented. Furthermore, the simulation will be compared with the measured data, then the model will be used to simulate the modifications to the least expensive customisation of the block B. One of possible solution could be inspired from solution in Malaysia [13] or elsewhere [14]. Or other option is to use recuperation of outgoing cold air from air-conditioned spaces in rest of the building [15].

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