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Original Research Article

Summer overheating of a passive sports hall building

T. Kisilewicz*, A. Dudzińska

Department of Building and Building Physics, Faculty of Civil Engineering, Cracow University of Technology, ul. Warszawska 24, 31-155 Kraków, Poland

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ABSTRACT

Reported measurements were intended as a preliminary check of a free run of a sports hall passive building in summer conditions. Indoor microclimate measurements lasted for three hot summer days and were carried out at the time when there was no building occupancy. In adverse conditions of high ambient air temperature and switched off ventilation acute overheating was observed. Night cooling, easily available measure of overheating protection was not applied, so there was no chance for discharge of high internal capacity of this building. A specific mode of building management had a critical impact on its internal microclimate and would raise user dissatisfaction. In close perspective of widespread implementation of near zero energy building standard, often reported overheating problem becomes an important issue. It was also shown that thermal comfort measurements may be unexpectedly and substantially affected by window location and solar radiation geometry.

1. Introduction

Common process of low energy building design is usually oriented on minimization of heating demand and enough attention is still not paid to protection against overheating. A lack of precise knowledge and also deficiency of designing tools, that would make it possible to predict dynamic course of indoor temperature in relationship to expected heat gains, thermal storage and possible heat sinks often result in low consumption of heating energy in winter but big cooling load, thermal discomfort or even unbearable thermal conditions in summer and in transition periods [1–4]. Traditional buildings with poorly insulated massive walls, intensive ventilation, leaky outer shell and moderate window area, were very forgiving to extra energy gains or design modifications. On the other hand, low energy buildings with robust thermal insulation, airtight building shell and often oversized window area are extremely vulnerable to overheating [1,5–7]. It is quite obvious by now that within the sustainable building development process the only reasonable approach is to minimize simultaneously heating and cooling loads and to avoid – if possible – extra investment, operation and maintenance costs of mechanical cooling system [8,9]. To achieve this goal, the designer has to assess, as accurately as possible, heat gains and their reduction measures, building

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* *Corresponding author*. Tel.: +48 12 6282397.
E-mail address: tkisilew@pk.edu.pl (T. Kisilewicz).

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thermal capacity and heat rejection capabilities [1,6,10]. Contemporary designing practice is based on routine procedure that starts with architectural concept and is followed by the subsequent engineering stages. The first crucial decisions regarding building orientation and window sizing are usually made only based on esthetic or fashion reasons. Further engineering steps are aimed at meeting heating and cooling demand of designed object by means of available technical systems. In this procedure no optimization or rational modifications are possible or even expected. On the contrary, it was proved that optimum south window area is in the given climate conditions a complex function of building heat transfer index and internal gains, its thermal capacity and glazing characteristic [11]. Further control of solar gains may be achieved by the standard shading measures and building operation mode [6,7]. Unfortunately, technical requirements do not usually stipulate any form of optimized design and are restricted to control measures only [8]. In [12] an approach based on the wide concept of the ideal indoor environment was presented to determine the suitability of dwelling-houses for living. Unfortunately, constant air temperature value was selected as a single thermal comfort criterion.

Optimization of south window area is also a good example of the necessity of an integrated approach to building design process. Not only total energy demand but also internal thermal comfort is, to a significant degree, a direct consequence of the design decisions made at the initial stage of the whole process [4]. Author of [13] stated that in some places people feel uncomfortable, realizing that they are not suitable for the activities they attempt to do in them. On the other hand, in existing building the actual monitoring and control solutions usually are not able to meet all the requirements and prevent overheating [2]. Jenkins [4] proposed a probabilistic tool, based on dynamic simulation results, that allows to assess overheating in a designed standard dwelling building. Unfortunately, there are no tools and reports available for sports buildings.

Below reported measurements of internal microclimate in a passive sports hall building prove that design oriented on low heating demand only may be not successful in hot summer conditions. The direct aim of the presented study was to examine and analyze thermal conditions in summer and explain why the passive protective measures against overheating were not sufficiently effective in this case.

2. Sports hall of Cracow University of Agriculture

Sports hall of Cracow University of Agriculture has been designed according to the German passive building standard. This standard, devised by Passive House Institute, requires yearly demand on final energy for heating no higher than 15 kWh/m^2. Sports hall envelope is efficiently insulated and airtight. Thermal transmittance U-value of the external walls is 0.1 W/(m^2 K) (40 cm of EPS Neopor). Flat green roof is insulated with 12 cm of polyisocyanurate foam and 40 cm EPS, floor on the ground with 40 cm of high density EPS. U-value of the triple glazed windows is 0.8 W/(m^2 K). The main load bearing structure is made of reinforced concrete and filled with silica brick, 25 cm thick, thus assuring high thermal capacity and low built in energy.

Total area of the three story building is equal to 18,000 m^2. The main part of the building is playing field with the stands for 150 spectators and furthermore cloakrooms, fitness, technical rooms and storage. The main entrance is located in south part of the building, Fig. 1. East and west elongated facades are substantially glazed, Figs. 2 and 4. Unfavorable building orientation (large east and west windows) was due to the specific shape of building site and its limited area and it was a conscious decision of architects and investor. Building height is 10.35 m to the top of attic wall. Roof inclination angle is equal to 2°. Vegetation was designed on the whole roof area and partially on the building facades to increase biologically active area of the building site. Mechanical exhaust–supply ventilation system combined with air heater and recuperator was designed (heat recovery efficiency 75%). Additionally, building may be heated by the radiant water floor system. Sports hall building is located in Polish III climatic zone with outdoor design temperature equal to −20 °C. Indoor air setpoint temperature was designed as [14]:

24 °C – cloakrooms and bathrooms
20 °C – playing field
16 °C – vestibules.

Measured air-tightness of the building envelope meets with an excess the requirements of the Passive House Institute with ($n_{50} = 0.2$ l/h). Electric external blinds provide protective shading of east and south oriented windows against excessive solar gains. Total solar transmittance coefficient g of window glazing is 60%.

3. Monitoring conditions and basic assumptions of evaluation

Reported measurements were intended as a preliminary short test of a passive building without mechanical cooling in summer conditions. The authors did not influence in anyway building operation and use during the testing period. Sports hall internal microclimate measurements lasted for two summer days with high outdoor temperatures, maximum ambient air temperature in this period raised to the level of 39 °C. Integrated microclimate data logger BABUC A was used for data collection. Single measuring device was placed on the playing field floor, next to the east emergency exit, Fig. 2.

Device location was a compromise between equipment safety and expected quality of measurement. All the data were recorded in 5 min intervals, at mean height of 1.35 m above the floor level. Measurements were carried out at the time when there was no occupancy of the sports hall, so there were no extra heat gains from people and lighting. It is very important to emphasize that only thanks to the fact that the building was not used it was possible to carry out continuous testing and leave measuring equipment unattended and unprotected for

Fig. 1 – South facade of sports hall building.

such a long time. Mechanical ventilation system was within the whole period switched off, all the windows were closed. Undisturbed free thermal run of the considered building was observed within the testing period.

During the first day of data logging external electric blinds were not in use and solar radiation fully penetrated tested space. On the second day, since 9 o'clock, east and west windows were covered by the blinds, Fig. 2.

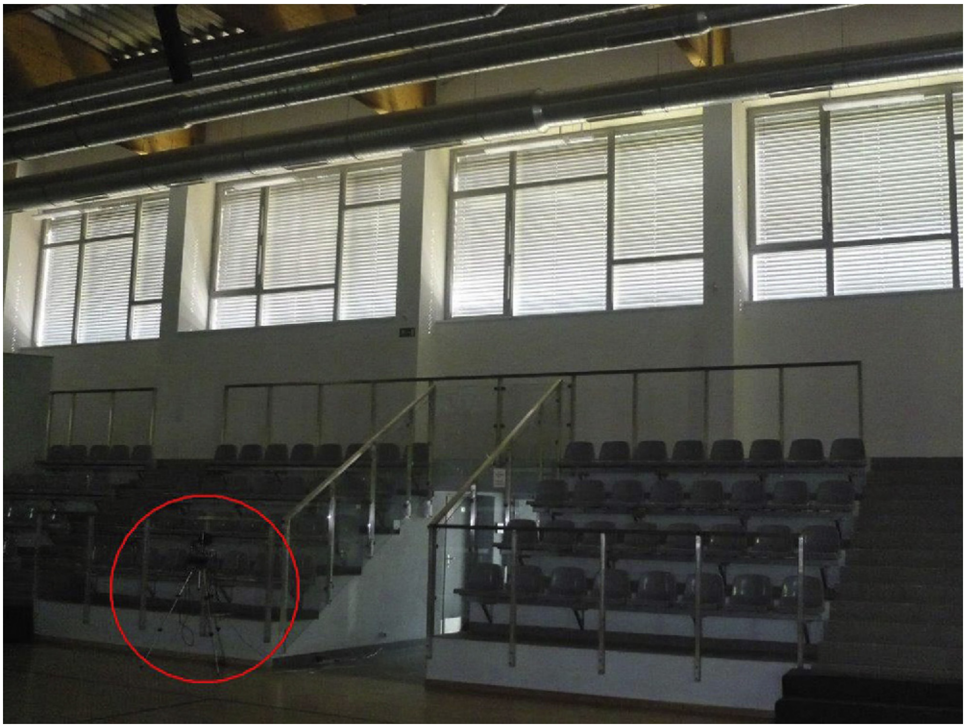

Fig. 2 – Internal view of the east wall on the second day of testing, at the bottom of the wall emergency exit may be seen. Red circle indicates location of measuring device.

Table 1 – Recommended values of thermal comfort indexes for respective comfort categories [16].

Category	Thermal sensation	
	PMV	PPD (%)
A – high requirements	$-0.2 < \text{PMV} < +0.2$	<6
B – medium requirements	$-0.5 < \text{PMV} < +0.5$	<10
C – moderate requirements	$-0.7 < \text{PMV} < +0.7$	<15

In order to calculate the values of thermal comfort indexes PMV and PPD for people who would have practiced sports in those conditions the following assumptions were made:

- clothing thermal resistance – 0.3 clo (0.046 m^2 K/W)
- activity level – 1.60 met (92.80 W/m^2)

According to EN ISO 7730:2006 [16] three categories of thermal comfort are available. University sports hall, as a newly erected building should be qualified as an object with the expected medium thermal requirements, i.e. category B (Table 1).

4. Testing results

4.1. Data collection

The following thermal microclimate parameters have been measured:

- indoor air temperature t_a (°C), accuracy ±0.5 °C,
- indoor air relative humidity RH (%), accuracy ±3%,
- radiant temperature of the surrounding components t_r (°C), accuracy ±0.5 °C,
- air velocity v_a (m/s), accuracy ±0.20 m/s, and calculated:
- operative temperature t_{op} (°C)
- Predictive mean vote: PMV
- Predicted percentage of dissatisfied: PPD (%)

Table 2 – Internal microclimate parameters.

	t_a (°C)	RH (%)	t_r (°C)	v_a (m/s)	t_{op} (°C)	PMV	PPD (%)
Mean value	27.9	58	28.8	0.0	28.3	1.1	33
Minimum	26.9	54	27.2	0.0	27.1	0.8	17
Maximum	29.0	62	39.1	0.2	32.4	2.4	91
Standard deviation	0.6	1	1.8	0.0	1.0	0.3	13
Median	28.0	58	28.3	0.0	28.2	1.1	31

All the symbols used in Table 2 have been explained in the text.

Radiant temperature was recorded by the globe thermometer (150 mm diameter matt black copper sphere), according to the standard EN ISO 7726:2002 Ergonomics of the thermal environment – instruments for measuring physical quantities.

The following formula was used to count operative temperature

$$t_{op} = a \times t_a + (1 - a) \times t_r$$

where $a = 0.5$ for air velocity v_a lower than 0.2 m/s; $a = 0.6$ for v_a from 0.2 to 0.6 m/s; $a = 0.7$ for v_a from 0.6 to 1.0 m/s.

During the whole measurement period 663 sets of data have been collected. Because of the big number of data the basic statistical measures were calculated, Table 2.

4.2. Indoor air and operative temperature

Indoor air temperature t_a during the analyzed period was within the range of 26.9–29.0 °C, Table 2 and Fig. 3.

On the third day, at noon internal air temperature was 29.0 °C. It was the highest internal air temperature during the whole testing period. The diagram displayed in Fig. 3 shows the growth of mean indoor air temperature as a result of day-by-day accumulated energy and no heat discharge.

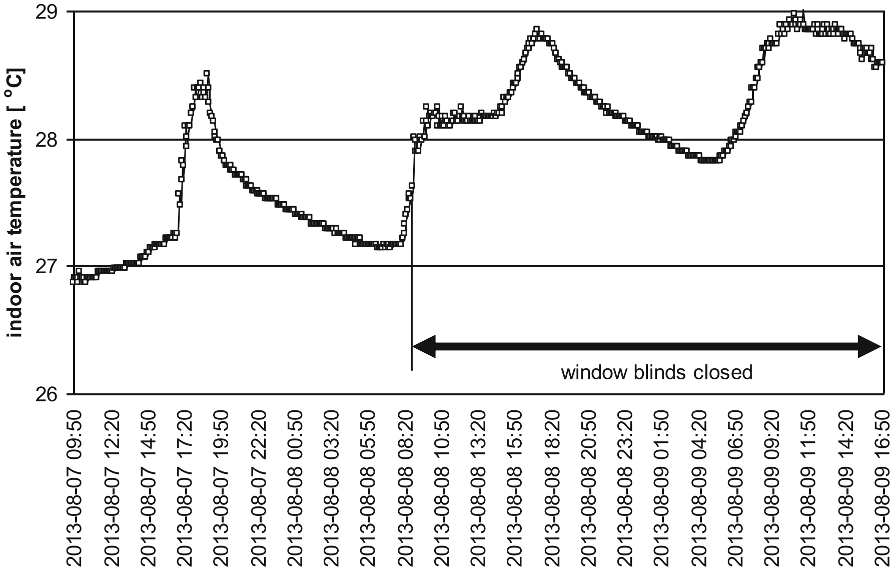

Fig. 3 – Indoor air temperature during the whole monitoring period.

A closer look at the diagram of indoor air temperature with magnified temperature scale, Fig. 3, allows, however, to detect some unexpected, irregular aspects of temperature course. In the first day afternoon, slowly increasing air temperature, at 16:35 started to rise rapidly

This kind of dynamic leap cannot be explained merely by outdoor temperature growth, but rather by a sudden change of thermal conditions around the testing device. Subsequent analysis of solar geometry and glazing distribution revealed that most probably low angle evening solar radiation entered this building through unprotected glazing in west wall, red oval in Fig. 4. Only the regular horizontal strip of windows was protected by the roller blinds hidden in window lintel box.

Radiant temperature of the surrounding component surfaces oscillated within the range of 27.2–39.1 °C. The most frequent value of radiant temperature was 27.42 °C and mean value was equal to 28.8 °C. In case of PMV evaluation in moderate climate conditions maximum allowable radiant temperature is 40 °C [15,17]. According to Jenkins et al. [4,8], overheating time in a non-domestic building is specified in UK as percentage of hours with whole house average temperature above 28 °C.

Mean operative temperature t_{op}, i.e. weighted average of indoor air and surrounding surfaces temperatures, was equal to 28.3 °C.

Mean relative humidity of indoor air was 58% and mean air velocity v_a was 0 m/s. Air was practically still, momentary higher value of air velocity, shown as a maximum in Table 2, was caused by the operator movement around the data logger.

4.3. *Predictive mean vote measurement*

Mean value of the PMV (predictive mean vote) index, Table 2 and Fig. 5, was equal to 1.1, but even the minimum value (0.7) was out of the thermal comfort range. Maximum value was 2.4. According to the Fanger's seven-point comfort scale [16,18] such conditions may be defined as hot environment. Generally low values of the standard deviation coefficient prove that all the calculated results are pretty close to the mean values.

During the hottest part of this period predicted mean vote index PMV was significantly higher than the uppermost thermal comfort limit value equal to 2.0 [15,19]. During the whole monitoring period internal thermal conditions were in discomfort range. Mean value of predicted percentage of the dissatisfied index (PPD) was higher than 30%, while maximum value exceeded even 90%.

According to the standard PN-EN-27243:2005 [15], the above conditions should be treated as a hot environment that ‘‘exerts heat stress on a man’’. On the other hand Kwong et al. [3] proved that in Singapore classroom acceptable temperatures ranged from 27.1 even to 29.3 °C, implying that the prescriptions of the standard were not applicable in free-running buildings in warm climates.

However, routine statistical analysis of the collected data is also in this case not sufficient to evaluate thermal conditions in tested space. PMV value variability should be carefully checked and explained. A relatively small PMV rise during the first and the second afternoon (1 and 3) was caused by air temperature increase due to unprotected part of west glazing, that was mentioned earlier. Abrupt leap in the morning (2) could be seemingly easy explained by direct east solar radiation reaching the sensors. But in spite of the closed blinds in the morning of the last day similar abrupt leap of PMV value occurred again (4). The real reason of the observed PMV value increase was direct solar radiation through the emergency exit glazing, Fig. 2. PMV change due to local direct and diffuse radiation, suggested by Hwang and Shu [7] as the next

Fig. 4 – Internal view of the west wall with horizontal and vertical strips of glazing.

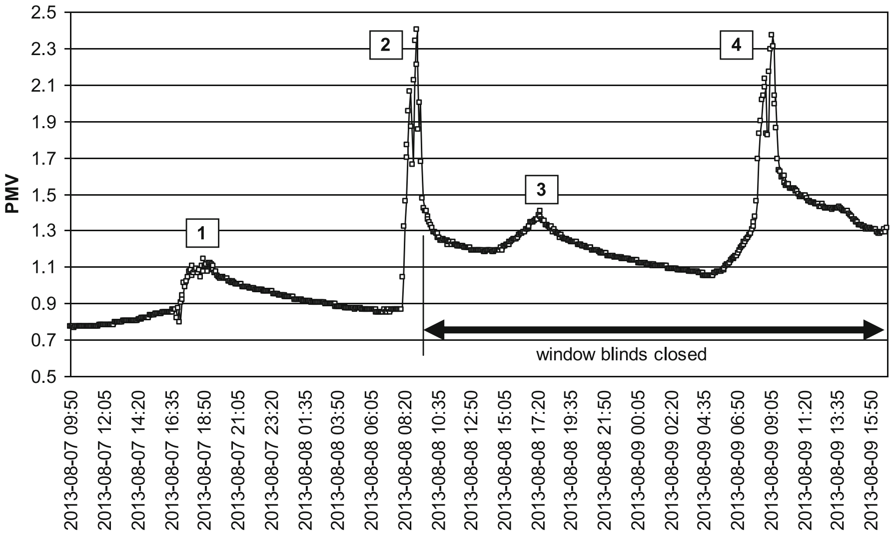

Fig. 5 – PMV-index values during the whole monitoring period, clothing thermal resistance – 0.3 clo, activity level – 1.59 met.

comfort parameter, was not further considered here because of its short very duration and small impact area.

In fact observed variability of PMV value is due to the radiant temperature values fluctuations, Fig. 6. PMV index is a function of the multiple local climate parameters. Because of the negligible changes of air speed, relative humidity and small changes of air temperature, PMV is practically identical with the radiant temperature course, Figs. 5 and 6.

5. Discussion

Data collected during the hot summer monitoring period of sports hall building enable authors to specify a few preliminary observations and remarks regarding internal microclimate and protection against overheating of the low energy sports building.

Over 33% of building users would be dissatisfied with average thermal conditions in discussed building and in extreme momentary conditions over 90%.

According to European standard [15] maximum allowable indoor air temperature, specified for the moderate climate conditions and constant use, is 30 °C. Due to the closed blinds maximum measured air temperature in sports hall building (29 °C) was slightly lower than the limit value. Sports hall was not occupied during monitored period, so internal gains connected with human activity did not increase any further indoor air temperature. In case of building regular use, because of the closed blinds artificial intensive lighting would be necessary to illuminate playing fields and significant extra energy gains would occur. Unfortunately, this kind of discrepancy (blocked solar radiation and switched on artificial lighting) is quite a common practice nowadays.

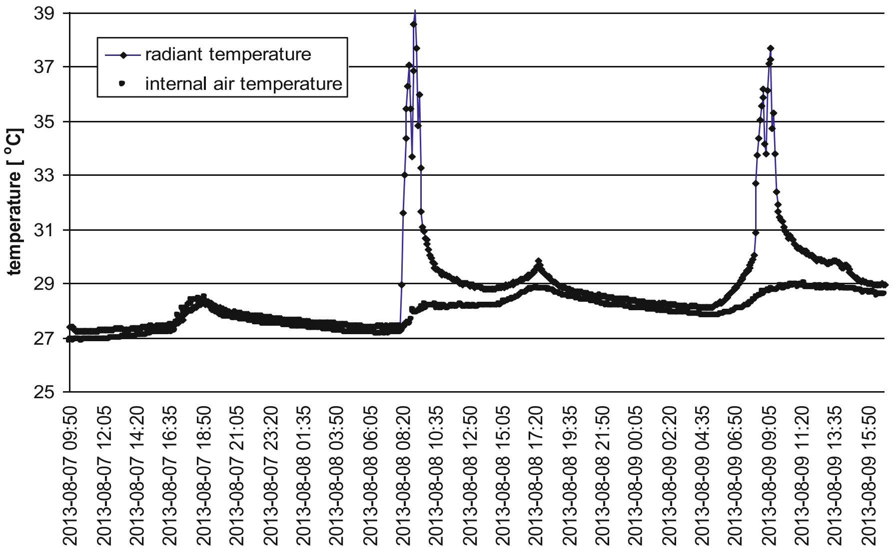

Fig. 6 – Radiant temperature and indoor air temperature vs. time.

In accordance to EN ISO 7730:2006 [16] all the specified criteria of thermal comfort should be satisfied simultaneously for each A, B or C category. In case of the assessed sports hall building tested during the short summer period, it is not possible to classify it in any of the three existing categories on the base of the conducted measurements.

Following classification given in EN 15251:2005 [19] with the four comfort categories based also on PMV index, tested building could be theoretically classified in open category IV. Theoretically only, because the standard categories have been developed for office buildings with relatively low users' activity and mechanical cooling. In fact, in case of increased and variable activity a model which calculates the transient thermal sensation for transient conditions should be used, where only static response comes from Fanger's PMV model [20,21].

In case of natural or forced ventilation but without mechanical cooling, adaptive comfort categories shall be used [17,22]. Unfortunately, this approach is also connected with the numerous restrictions. Adaptive comfort conditions widely tested in habitable or public use buildings was not intended to be transferred directly to sports building [23]. But in general, adaptive PMV index is more flexible to the indoor conditions than Fanger's method [17]. It was mentioned that the regular PMV index often overestimated the thermal sensation of occupants [3].

Another problem is connected with the specific way of building use. There is no chance for physiological or psychological adaptation to the internal conditions [25,26], when users only occasionally visit this building and train sport for a few hours per week. Clothing adjustment is not possible any further and building operation mode (window opening, ventilation intensity, etc.) [22,24] is difficult or even out of reach of the users. Those restrictions practically preclude this approach from use in tested building.

Described above short time testing is of course not a sufficient measure to categorize building microclimate and to evaluate its design. According to the international standards and common practice, temporarily (10 or even 20% of total time) exceeded limit values are usually accepted under the condition that internal microclimate would not endanger user's health. In the discussed case the conditions were close to dangerous for people at high physical activity [15,19].

Important benefit of such an approach, where temporary malfunction of the building is accepted, is that mechanical cooling i.e. increased investment and operating costs may be easily avoided. In the monitored building a simple and cost effective measure against overheating in form of window blinds has been completed, some others may be easily used when needed, e.g. efficient ventilation or night cooling. A course of outdoor air temperature oscillations during the monitoring period was shown in Fig. 7. Relatively low temperature in night, much lower than indoor air or operative temperature, could be used to discharge internal thermal capacity of this building by intensive night cooling. In report Kwong et al. [3] identified that Malaysian can be acclimatized to higher environmental temperatures when the natural ventilation with enhanced air circulation significantly improved the thermal comfort of occupants.

Heavy walls made of silica brick, designed to provide high thermal capacity and cooled down during the nighttime, would create an efficient heat sink for heat gains during day hours [1,5]. Unfortunately, this simple and usually efficient procedure was not used during the monitoring period. It is not clear whether building user was not aware and well informed about building dynamic operation or deliberately decided not to use this opportunity. Automatic control system was designed to close the windows in strong winds or rain and night cooling in such conditions would not work either. Apart from designed procedure, the real, used in this building oversensitive system responds rapidly even at small amount of condensed water vapor – what is practically a daily effect in night – and the windows are closed again. Once closed by the controlling system windows will not be open later.

Another difficulty is connected with unprotected glazed area. Due to the presence of the windows, that were not shaded by the blinds, direct solar radiation reached the sensors of monitoring device and increased final value of PMV index. Momentary and local increase of operative temperature is not reflecting well the average conditions in

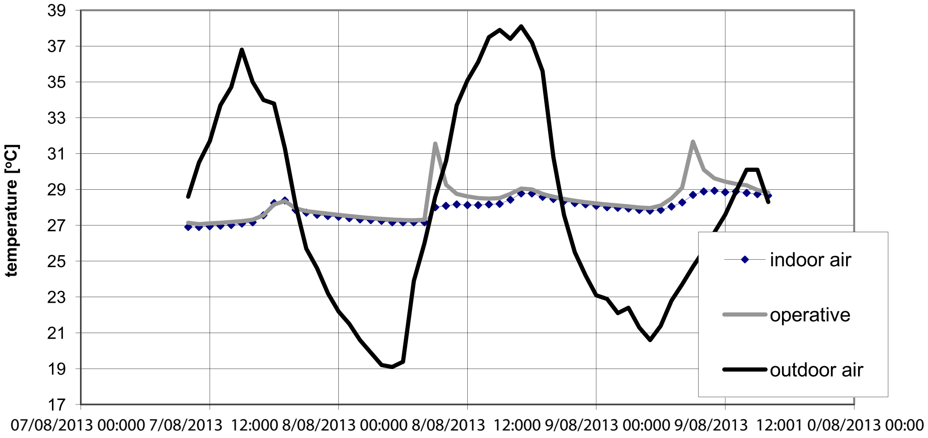

Fig. 7 – Temperature vs. time, t_a – indoor air, t_{op} – operative temperature, t_{out} – outdoor air temperature.

the whole space. On the other hand, it is very difficult or even impossible to eliminate completely such effects. Researcher responsible for measurements should be able to predict and asses all the consequences of equipment location.

6. Conclusions

Conducted measurements and research work revealed that thermal microclimate issue is not enough recognized in design process of low energy buildings and completely new in case of low energy sports buildings. In the same time well-being of a building user is a crucial element of sustainable development strategy and passive building idea. Passive measures of thermal comfort control are known as the general rules, but quantitative approach is rather complicated. No design tools, beyond advanced simulation software, are available to practitioners, who would like to adopt these solutions in their design. Presented research was intended as a new step toward better understanding of a summer free-run of low-energy building and a chance for improvement of design strategy.

A reasonable aim to minimize overall energy consumption and to maintain simultaneously thermal comfort conditions without mechanical cooling is very difficult to achieve. The designers and users of the tested sports hall building did not succeed in this field due to the numerous reasons.

1. Unfavorable orientation of analyzed building and poor operation mode resulted in summer overheating. Even in case of a massive structure its thermal capacity was not enough to protect building against overheating for such a long time. Window blinds were closed too late and night cooling was not used to avoid overheating.
2. It is not known what heat discharging scenarios have been considered at the design stage and to what extent building users have been trained. Without close cooperation of the designers and users, advanced passive buildings would be poorly managed and would raise dissatisfaction of users.
3. According to the Fanger's comfort scale, conditions observed in sports hall building should be defined as hot environment, out of the thermal comfort range. When using adaptive comfort approach, short time of monitoring and high physical activity of building users also stir up doubt regarding the validity of this evaluation. Thermal adaptation in sports building and intermittent use conditions is not yet recognized in available bibliography. So finally it must be stated, that there is no specified objective method for thermal comfort evaluation in sports buildings.
4. Described above short term preliminary testing will be followed by further experimental measurements in order to check building thermal efficiency in the moderate and cold climate conditions. It is also expected that the advanced dynamic simulations, fine tuned by means of conducted monitoring and collected data, will allow to investigate building operation in extreme conditions and also the whole year period in order to optimize its management mode and elaborate minimum total energy demand scenario.

Acknowledgements

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