Thermal comfort of the sport facilities on the example of indoor tennis court

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Abstract. An opinion about the difficulties with maintaining appropriate climate conditions in the sports facilities is quite popular amongst sportsman of various disciplines. The problem can result in health and economic problems. First of all, the users of facilities are not provided with appropriate conditions for sport practicing and thus it may lead to contusions. Secondly the cost of using the object rises. Taking into account the increasing number of sports facilities, maintaining of indoor thermal comfort of them, while ensuring low maintenance costs, gains in importance. The paper presents the research conducted in a pneumatic tennis hall, a detailed analysis of maintaining thermal comfort in the hall and cognitive and utilitarian conclusions.

1. Introduction
The rules governing the construction of sports facilities do not differ from the implementation of other construction projects. However, the architecture of sport facilities is governed by its own rules. A good quality sport facility should meet the construction, functional and economical requirements. Functional features are particularly important for athletes, because apart from the right selection of materials, surface or shape of the facility, the microclimate of the interior affects the achievements of the players and safety of the sport (injuries). Regardless of the sports discipline, an important feature of any indoor sports facility is to provide athletes with comfortable conditions for practicing their disciplines. The independent factors, like: air temperature, humidity and flows play an important role here.

In the top ten most popular sports of the Biggest Global Sports ranking [1] there are four disciplines that are played in the indoor facilities or whose specificity requires training in the indoor facilities. Tennis is at the 3rd place of this ranking.

Thermal comfort of indoor sports facilities is a rarely discussed issue. World or national federations and associations of sports disciplines recommend to maintain specific thermal parameters in sports facilities. It should be noticed, that these requirements are primarily dedicated to new buildings. There are some works that discuss the fact that designers sometimes forget that the requirements appropriate for athletes do not need to be the same for the audience or service staff. This applies for example to swimming pools, which are a great challenge for designers [2, 3]. There are also works that describe difficulties with maintaining the thermal comfort of new sports facilities, especially in the aspect of overheating [4]. Overheating is one of the more frequent problems that affects sports halls. It can be a bit decreased by using efficient ventilation causing air movement and heat removal, but at the same time, the air speed cannot be high to lower the risk of draft or irritation due to air movement [5, 6].
2. A case study of thermal comfort in the indoor tennis court

2.1. Description of the facility
The pneumatic hall covering two full-size clay courts is located in the center of Olsztyn. External dimensions 36 x 36 m, height 9 m. The cover of the hall was made of multilayer PVC, supported on two columns, reinforced with cables. Entrance to the hall through revolving doors. The hall is supplied with air by the pump which maintain the overpressure inside. The same pump is also used for heating, but the heater furnace stops when the indoor air temperature exceeds 15 °C. The hall is operated in autumn and winter according to the planned training cycle, in the spring and summer season the cover is removed.

2.2. Measurements of thermal state of the facility

2.2.1. Method
The measurements were carried out in the autumn of 2015, in October from the 23rd (at 8.17 pm) to the 25th (at 1.00 pm). At that time, the hall was used on the 1st day until 8.30 pm, the 2nd between 9.00 am and 9.00 pm and the 3rd day from 9.00 am.

There was used the set of the Ahlborn thermal comfort sensors connected with a data recorder. The used sensors: Globe thermometer FPA805GTS (accuracy ±0.15°C), Thermo-hygrometer FHA646E1 (accuracy 0.1°C, ±2%RH), Thermometer FPA32L0250 (accuracy 0.1°C) Thermometer FVA605TA10U (accuracy ±1%), Pressure difference meter FDA602S1K (accuracy ±0.5%). The sensors were calibrated before use. A tripod with sensors was placed between two courts in the central part of the hall. The outdoor air temperature sensor and the pressure tube were moved through the inspection hole in the hall cover. Outdoor air relative humidity was also recorded, but the sensor moved from the original place and thus it measured the parameters of exhaust air from the hall. Data were recorded every 3 minutes.

2.2.2. Results
Figure 1a presents the registered outdoor and indoor temperature and air speed. In the analyzed period, the outdoor temperature fluctuated in the range 6.0-10.6°C. During this time, the indoor air temperature fluctuated in the range 6.77-17.44°C. The average temperature for the period of use of the hall was 14.08°C. During the night, when the heating system is switched off, the indoor temperature drops significantly and approaches the outside temperature (1-2°C difference). The maximal measured temperature difference during the day was 9.46°C. Indoor temperature fluctuations are clearly visible during the heating of the hall. It could be related to the thermostat regulation of the heating system and also the use of the hall – entering and leaving the hall. The increases of indoor temperature correspond to the decreases of the relative humidity of the air and the difference of the pressure between the hall and the surroundings.

Figure 1b presents the registered indoor relative humidity of air and the pressure difference. The relative indoor humidity was at the level 90-95% in the night and 50-83% during the day. The overpressure in the hall was maintained at the level 150-175 Pa in the night and 75-175 Pa in the period of use. Fluctuations in the pressure difference can also be related to the heating system as well as entering and leaving the hall.

The measured air speed was in the range 0.03 – 0.3 m/s. On the second day of measurements at 15.00 the sensor has turned off and since then air speed in the hall was no further registered. Revel and Arnesano conducted the sensitivity analysis of the air speed and confirmed that it is a low-sensitive parameter and it could be supposed to be constant for values <0.2 m/s [7].

The variability of the air speed could be caused by air movement caused by the air supply system and the movement of the players. Despite the revolving doors, frequent entering and leaving the hall were the reason for drafts and thus for pressure peaks. The climatic data registered in the hall were
within the limit values in ISO 7730:2006 [8], and thus enable the use of PMV and PPD indicators to determine the thermal comfort of the hall.

Figure 1. The measured values: a) air temperature indoor and outdoor and air speed, b) relative humidity indoor and pressure difference.

2.3. PMV and PPD prediction

2.3.1. Input data and assumptions.
In order to determine the thermal comfort indicators (PMV, PPD), the athlete's level of metabolism was assumed to be 4 met (232.8 W m\(^{-2}\)). The total thermal resistance of clothing was set in two variants: basic clothing (t-shirt, shorts, underwear and socks) and warm (additional sweatshirt and light trousers instead of shorts). Calculated thermal resistance of the basic variant is 0.27 clo (0.042 m\(^2\)KW\(^{-1}\)), while the warm variant 0.57 clo (0.088 m\(^2\)KW\(^{-1}\)). The PMV indicator is the most reliable for predefined conditions, but it can also be used for slow changes in the value of individual microclimate parameters of interiors in specific intervals [9].

2.3.2. Results
Figure 2a presents the PMV indicator determined on the basis of registered measurement data, metabolism and clothes of the athlete. It can be clearly seen that except the night period, PMV assumes positive values. In the later part of the paper, the PMV values will be considered only for the hall usage period. PMV values are definitely higher for the case of warm clothing where the average PMV is 1.45, while for basic clothing it is 0.84. PMV fluctuations correspond to temperature and humidity fluctuations. The maximum value of PMV for warm clothing is 1.91, minimum -0.42. The maximum value of PMV for basic clothing is 1.44, minimum -0.42. The average PPD values (Figure 2b) determined on the basis of PMV were 48.7 for warm clothing and 22.6 for basic clothing.

Comparison the PMV results with the 7-point scale of thermal sensations has been assumed that there is warm indoor environment in the tennis hall. Therefore, these are not comfortable conditions for sports. Athletes wearing warmth can feel more discomfort, what is in agreement with the users' opinions. The PMV characterizing the comfortable environment (not too warm, not too cold) should be found in the range -0.5<PMV<0.5. Such values were met in the hall only during the night, but the temperature drops below 13°C – the minimum indoor temperature for playing tennis (by International Tennis Federation).
2.4. The study on possible improvement of the thermal comfort in the examined tennis pneumatic hall

At the beginning of the analyze the linear dependence between the PMV components was checked: radiant temperature, air temperature, air relative humidity and air speed. Afterwards, the linear dependence between these components and PMV was examined. A strong linear correlation was found between radiant temperature, air temperature and relative humidity of air (0.788÷0.929). The linear correlation between these three and air speed is much smaller 2⋅E-2÷4.6⋅E-2 for correlation with temperature and 9⋅E-6 for correlation with air relative humidity.

Although, the PMV value depends on each of the measured components, a linear correlation was examined to obtain information about the proportion of individual values in PMV formation. The strongest is the correlation with air temperature 0.976÷0.977, with radiant temperature 0.947÷0.948 and air relative humidity 0.873÷0.876. The correlation between PMV and air speed 6.1⋅E-3÷8.3⋅E-3 reveals by far the lowest dependence, which may result from low air speed.

| Linear correlation       | Radiant temperature | Air temperature | Air speed | Relative humidity | PMV (0.57 clo) | PMV (0.27 clo) |
|-------------------------|---------------------|----------------|----------|------------------|----------------|----------------|
| Radiant temperature     | x                   | 0.929          | 4.6⋅E-2  | 0.788            | 0.947          | 0.948          |
| Air temperature         | 0.929               | x              | 2⋅E-2    | 0.917            | 0.976          | 0.977          |
| Air speed               | 4.6⋅E-2             | 2⋅E-2          | x        | 9⋅E-6            | 6.1⋅E-3        | 8.1⋅E-3        |
| Relative humidity       | 0.788               | 0.917          | 9⋅E-6    | x                | 0.876          | 0.873          |
| PMV (0.57 clo)          | 0.947               | 0.976          | 6.1⋅E-3  | 0.876            | x              | -              |
| PMV (0.27 clo)          | 0.948               | 0.977          | 8.1⋅E-3  | 0.909            | -              | x              |

The second step of the investigation was to simulate the PMV change due to the change of the measurable components. The reduction of radiant and air temperature, and air relative humidity as well as the increase of air velocity were analyzed. It was assumed that a satisfactory change will occur when the PMV values during the hall utility time will be in the range -0.5÷0.5.

Tables 2 and 3 present the effect of proposed changes of the PMV components on its value. Presented are the averaged values, standard deviation, maximal and minimal values of PMV. The table presents only changes that correspond to the adopted boundary conditions: maintenance of the average temperature in the hall above 13.0°C, not exceeding the air speed of 0.9 m/s, maintaining the relative humidity at the level no less than 55-60%. The temperature criterion is fundamental to protect the
health of athletes, below this temperature the risk of injury is very high. The air speed criterion is related to the risk of drafts, and interfering the ball’s flight. Lawn Tennis Association [10] recommends that in traditional constructions of tennis halls air speed should not exceed 0.5 m/s, but there is no such requirement for pneumatic halls. The air distribution in tennis hall should consider ball movement requirements as well as human thermal comfort requirements [7].

The order of presented solutions corresponds to the positions of variants selected on the basis of a multicriterial rating: from the most favourable one. The following optimization parameters were adopted: average PMV value close to 0.00 (weight 0.65) and as low as possible standard deviation (weight 0.35).

Table 2. Conception of the improvement of the thermal comfort in the case of light sportswear (0.27 clo) by changing the measurable parameters of PMV. T – indoor radiant and air temperature, RH – indoor relative humidity, v – indoor air speed.

| PMV (0.27 clo) | Base value | v+0.4 m/s; T-1°C | v+0.4 m/s; T-1°C; RH-20% | v+0.2 m/s; T-1°C | v+0.2 m/s | T-1°C |
|---------------|------------|------------------|---------------------------|------------------|----------|-------|
| Average       | 0.84       | 0.08             | -0.17                     | -0.23            | 0.28     | 0.51  | 0.63  |
| Standard deviation | 0.37       | 0.41             | 0.41                      | 0.41             | 0.37     | 0.37  | 0.37  |
| Maximum       | 1.44       | 0.76             | 0.51                      | 0.44             | 0.85     | 1.08  | 1.23  |
| Minimum       | -0.42      | -1.30            | -1.54                     | -1.58            | -0.86    | -0.65 | -0.63 |

Table 3. Conception of the improvement of the thermal comfort in the case of warm sportswear (0.57 clo) by changing the measurable parameters of PMV. T – indoor radiant and air temperature, RH – indoor relative humidity, v – indoor air speed.

| PMV (0.57 clo) | Base value | v+0.4 m/s; T-1°C; RH-20% | v+0.4 m/s; T-1°C | v+0.6 m/s | v+0.2 m/s; T-1°C | v+0.4 m/s |
|---------------|------------|---------------------------|------------------|----------|------------------|----------|
| Average       | 1.45       | 0.57                      | 0.73             | 0.79     | 0.83             | 1.04     | 0.98    |
| Standard deviation | 0.29       | 0.33                      | 0.31             | 0.31     | 0.34             | 0.28     | 0.32    |
| Maximum       | 1.91       | 1.12                      | 1.24             | 1.31     | 1.4              | 1.49     | 1.51    |
| Minimum       | 0.47       | -0.55                     | -0.31            | -0.27    | -0.31            | 0.11     | -0.08   |

The results of the analysis show that it is possible to increase the thermal comfort in the pneumatic tennis hall. In the case of a light sportswear (0.27 clo), it seems easier to achieve. For both cases of clothing it is clearly visible that reduction of temperature and relative humidity only, does not bring the desired effect. Only increasing the air speed in the hall brings the expected improvement. Among the analyzed variants of the component parameter changes for light clothing, the most favourable is the increase of the air speed by 0.4 m/s, which will give an average PMV 0.08 with a standard deviation of 0.41, and thus ideal values. The average air speed in the hall during the period of use will be increased to 0.50 m/s and the maximum values would be at the level of 0.65 m/s what is still acceptable in pneumatic halls.

In the case of warmer clothing (0.57 clo), increasing the thermal comfort is much more difficult. It was assumed no to increase the air speed by more than 0.6 m/s. Among the analyzed variants of the component parameter changes for warm clothing, the most favourable is to simultaneously: increasing the air speed by 0.6 m/s (average 0.70 m/s, maximum 0.85 m/s), reducing the air and radiant
temperature by 1°C (average air temperature 13.17°C) and reducing the air relative humidity by 20% (average RH 56%). For both clothing standards, for most favourable cases, the PPD values were determined. For light sportswear the average PPD is 8.72 with a standard deviation 7.47. For warm sportswear the average PPD is 14.63 with standard deviation 5.52.

3. Discussion and conclusions
The research revealed that sports facilities are characterized with different specification to other buildings where the state of thermal comfort was analyzed. Thermal comfort of the sports hall should be primarily provided to athletes. It is assumed that the level of metabolism of tennis players is 4 met. This means that it is over 3 times more than for someone doing sedentary activity. Thus, it means that in sports facilities it is not easy to achieve a thermal comfort conditions both for athletes and viewers or service staff. The analysis showed that the slight difference in the sportswear (long sleeve sweatshirt and light trousers instead of shorts, 0.3 clo) caused significant differences in the values of PMV and PPD.

The research carried out in the pneumatic hall revealed that the indoor thermal sensation is too warm. This is particularly interesting because the temperature in the hall was kept at the level 14±16°C with occasional peaks up to 17.44°C. The specificity of the pneumatic hall - continuous drafts caused by the air supply system do not provide indoor thermal comfort for athletes, what is in accordance with their opinion.

Although the linear correlation of PMV with air speed was small, the analysis revealed that increasing the air speed in the hall was the fastest way of improving indoor thermal comfort there. This is also the easier way of receiving heat from tennis players. On the other hand, in all of the interval exercises, like tennis playing, the high physical effort is interrupted with rest. This is why the air speed in indoor tennis courts should not be too high. It is also connected with the tennis ball movement [11].

It can be concluded that achieving a satisfactory level of thermal comfort is not always achievable. Clothing plays the major role in thermal sensitivity of someone involved in the activity with high metabolism. It was possible to achieve the almost ideal PMV level for light sportswear by increasing the air speed in the hall by 0.4 m/s. Increasing the air speed in the pneumatic hall is a technical challenge. It may be necessary, for example, to install confusors in the air supply system of the hall. In the case of warm sportswear (only 0.3 clo difference) the ideal level of PMV was not achieved, although the temperature was reduced by 1°C, the relative humidity was reduced by 20% and the air speed was increased by 0.6 m/s. These were limit values or even almost a bit exceeded (air speed). Despite these changes, the thermal conditions were still warm and it might be one of the reasons that modern indoor tennis courts are constructed in other techniques than pneumatic hall. Nowadays, the most popular are the halls, in which the roof construction is supported on girders made of light plastics, glued wood or truss. This type of construction enable the side curtains being opened ensuring a constant supply of fresh air and adequate humidity, what increases the comfort of use of the object.

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