Experimental assessment of thermal, humidity and flow conditions in the indoor swimming pool

Ocena warunków cieplno-wilgotnościowych i przepływowych w hali pływalni na podstawie pomiarów

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Indoor swimming pools belong to ventilated facilities in which due to the complex nature of air, heat and moisture flow there are difficulties in shaping the conditions of the indoor environment, suitable for the occupants. The aim of the presented research was to assess the thermal, humidity and flow conditions in the actual ventilated school swimming pool. The assessment was carried out based on long-term and short-term measurements of indoor air parameters: temperature, relative humidity and speed, which were carried out over different periods of the year.
Comparing the results of the research with the air parameters recommended for indoor swimming pools in the literature sources, the need to improve thermal, humidity and flow conditions in the facility by modernizing the ventilation system was indicated.
Keywords: indoor swimming pool, ventilation, air parameters, experiments, measurements

Hale pływalni należą do obiektów wentylowanych, w których ze względu na złożony charakter przepływu powietrza, ciepła i wilgoci występują trudności w kształtowaniu warunków środowiska wewnętrznego, odpowiedniego dla przebywających ludzi. Celem prezentowanych badań była ocena warunków cieplno-wilgotnościowych i przepływowych w rzeczywistej wentylowanej szkolnej hali pływalni. Została ona przeprowadzona na podstawie ciągłych i krótkotrwałych pomiarów parametrów powietrza wewnętrznego: temperatury, wilgotności względnej i szybkości, które wykonano w różnych okresach roku.
Porównując wyniki badań z wartościami parametrów zalecanymi dla pływalni w źródłach literaturowych, wskazano na potrzebę poprawy warunków cieplno-wilgotnościowych i przepływowych w obiekcie przez modernizację instalacji wentylacyjnej.
Słowa kluczowe: hala pływalni, wentylacja, parametry powietrza, pomiary, badania eksperymentalne

Introduction

In indoor swimming pools, high heat and moisture gains from both indoor and outdoor sources occur. Main sources of heat gains are lighting, radiators, occupants, evaporating water, heat penetrating through building partitions and solar radiation. Heat losses occur in the form of a heat flux transmitted by water by convection and a heat flux exchanged with the external environment and adjacent spaces. Moisture gains come from the evaporation of moisture from the surface of water in the pool basin, the surface of moistened floors, as well as from occupants and water attractions.

To reduce heat gains or losses, moisture gains and gaseous pollutants, it is necessary to provide a ventilation system, which during the winter period often acts as air heating at the same time. Proper design of the indoor swimming pool ventilation has a significant impact on the correct operation of the facility, occupant's thermal comfort, operating costs, as well as the safety of the building construction.

Lack of or improperly designed, made and operated ventilation can result in thermal discomfort of swimmers and staff, including in particular an increase in air specific humidity. This leads to many negative phenomena, such as condensation of water vapour on cold surfaces, windows fogging, and in the long term – to rusting and weakening of building's structural elements, moisture on building partitions and the formation of fungi and mould on them.

To avoid such negative phenomena during the operation of the facility, it is necessary to maintain the appropriate values of indoor air parameters shaping thermal, humidity and flow conditions in the swimming pool.

After reviewing the state of knowledge of indoor swimming pools ventilation, it was concluded that there is lack of literature results of comprehensive, long-term *in situ* research of swimming pools ventilation carried out both for the assessment of thermal, humidity and flow conditions, as well as the protection of the building structure from the effects of excessive moisture.

So far, long-term experimental research at different times of the year was not carried out to assess thermal and humidity conditions in indoor swimming pools. To assess such conditions only short-term measurements over the summer were conducted to validate the numerical model [11]. Experimental research on moisture emission from the pool water surface was also short-term. It was carried out in tropical climate only for a period of 6 days [1]. Experimental air quality research presented in [13] was aimed at determining the

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content of gaseous air pollutants emitted from pool water, only for improving the water treatment technology. Therefore, the results of this research cannot be considered universal.

The purpose of the research presented in this paper was to assess thermal, humidity and flow conditions in the actual ventilated swimming pool. It was carried out by comparing the results of experimental research at different times of the year with the values of the air parameters recommended in the literature.

The data obtained from experimental research were also used as boundary conditions to develop and validate the numerical model of the facility and carry out multi-variant research of the ventilation of the swimming pool using numerical method CFD, as presented in [3, 5, 6, 7, 15].

Research problem

Among many requirements for indoor swimming pool ventilation, particular attention should be paid to thermal protection of building partitions, indoor thermal conditions and air quality, especially disposal of gaseous air pollutants emitted from the surface of the water. These requirements at the design stage are met primarily by adopting the recommended parameters for, among others, thermal and humidity properties of building partitions, outdoor air calculation parameters, required indoor environment parameters, number and type of technical equipment, etc.

The values of air parameters in the swimming pool should be selected in such a way as to ensure thermal comfort for occupants, swimmers and staff. The required values of these parameters are not uniformly defined by Polish legislation. This issue is discussed very briefly in specifications and legal acts. Therefore, the selection of indoor air parameters (temperature, humidity and speed) must be based on design guidelines contained in the literature. Table 1 summarizes the recommended values of air parameters in an indoor swimming pool of general-purpose according to various sources.

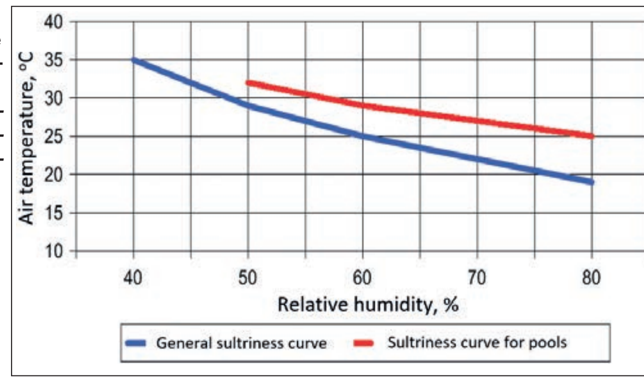
Tab. 1. Recommended values of air parameters in an indoor swimming pool of general-purpose according to different sources
Tab. 1. Zalecane wartości parametrów powietrza w hali basenowej o przeznaczeniu ogólnym według różnych źródeł

Data source	Air temperature t_i, °C	Air relative humidity ϕ_i, %	Air speed v_i, m/s
acc. [20]	t_w + (2 ÷ 4)	40 ÷ 64	no recommendation
acc. [2]	24 ÷ 29	50 ÷ 60	no recommendation
acc. [8]	28	45 ÷ 65	0,1 ÷ 0,15
acc. [9]	t_w + (3 ÷ 5)	50 ÷ 60	0,15 ÷ 0,3

where: t_w – pool water temperature

For occupants' thermal comfort, not only the values of individual air parameters but also the relationship between them is important. This is presented, for example, on the sultriness curve for swimming pools according to Lancaster-Custens-Ruge, which differs from the general sultriness curve due to a different type of clothing worn (Fig. 1). It can be concluded that as the air temperature increases, its relative humidity should decrease.

Fig. 1. Lancaster-Castens-Ruge sultriness curve, according to [8]
Rys. 1. Krzywa duszności według Lancaster-Castens-Ruge, na podstawie [8]



The relationship between air temperature and relative humidity inside the swimming pool is also important for the structural elements of the building. In case of even a slight reduction in air temperature at high air relative humidity, the air dew point temperature may be exceeded and the water vapour condensation might occur. This phenomenon occurs especially in the case of air with a higher temperature being in contact with surfaces with lower temperature, i.e. on the external partitions of the building and thermal bridges. In such a situation, in these places condensation of water vapour occurs, and as a result, favourable conditions are created for corrosion of building elements and development of mould and fungi.

After analysing the recommended air parameters in indoor swimming pools it was found that air speed values are most often adopted between 0.1 m/s and 0.2 m/s.

The adoption of appropriate ventilation air parameters allows to determine the correct value of ventilation air volume flow rate and the method of air treatment. Thus, the expectations of occupants in terms of the indoor environment should be met.

Since the main task of swimming pools ventilation in the summer is to remove excess moisture from the building, therefore, according to [14], the supply air volume flow rate $\dot{V}_N$ is determined from the formula (1), depending on moisture gains $\dot{W}$, specific humidity of supply air x_N and specific humidity of exhaust air which is approximately assumed as equal to the specific humidity of indoor air x_i.

$$\dot{V}_N = \frac{\dot{W}}{\rho_N \cdot \Delta x} = \frac{\dot{W}}{\rho_N \cdot (x_i - x_N)}, \quad m^3/h \qquad (1)$$

In summer, outdoor air is directly supplied to the swimming pool, without heat treatment. Therefore, the specific humidity of the supply air x_N is equal to its value for outdoor air x_e. Thus, the values of the supply air volume flow rate, in addition to calculated indoor air parameters, are determined by outdoor air parameters adopted for calculation.

Taking into account the sultriness curve, it can be read from Mollier's chart (Fig. 8) that in the swimming pool, irrespective of external conditions, air specific humidity value below x_i = 0,016 kg H_2O/kg dry air should be maintained and this is generally not discussed. On the other hand, there is a difference of views on the value of outdoor air specific humidity which should be adopted to calculate the supply air volume flow rate.

The value of the outdoor air specific humidity resulting from the design parameters for the conditions characteristic for Polish climate, given in the standard [16], for the Second summer climate zone, is equal to x_e = 0,012 kg H_2O/kg dry air.

However, there are opinions that the recommended value of the outdoor air specific humidity x_e = 0,009 kg H_2O/kg dry air [20] should be adopted. Proponents of such views use the argument that the duration of the value x_e > 0.009 kg H_2O/kg dry air is so short that the resulting need to increase the air volume flow rate is unjustified. This is always linked to higher investment and operating costs [19].

To illustrate the appropriateness of the different approach to this issue, in Fig. 2 the distribution of the external air specific humidity during the July-September period is presented, based on the climatic data of one of the meteorological stations in southern

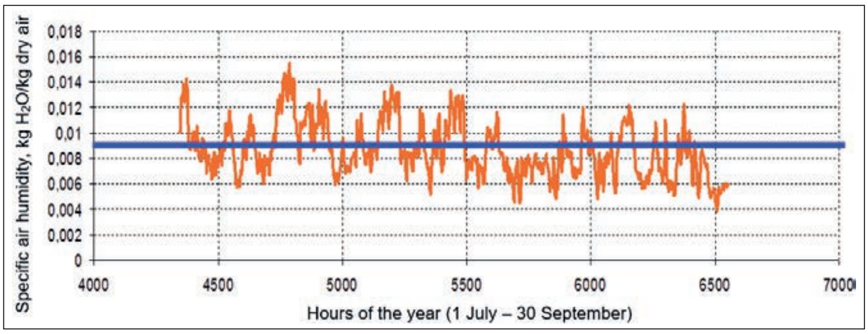


Fig. 2.
Distribution of outdoor air specific humidity according to climatic data of the selected meteorological station in southern Poland [19]
Rys. 2. Rozkład wilgotności właściwej powietrza zewnętrznego według danych klimatycznych wybranej stacji meteorologicznej na terenie Polski południowej [19]

Poland [19]. The chart indicates the value of x_e = 0.009 kgH_2O/kg dry air, recommended in the outdoor air volume flow rate calculation [20]. It can be seen that this is approximately the average outdoor air specific humidity value within the time interval considered. Therefore, the duration of the values higher than it represents about half the duration of the summer period.

With such adoption of the outdoor air specific humidity value, the air volume flow rate is determined based on the difference $\Delta x = x_i - x_e$ = (0,016 – 0,009) kg H_2O/kg dry air. This means that, while maintaining a constant supply air volume flow rate, the permissible value of indoor air specific humidity x_i = 0,016 kg H_2O/kg dry air may be exceeded for the significant part of the summer period.

Other methods for calculating the air volume flow rate in a swimming pool are based on the recommended number of air exchanges. However, there is also no consensus on the value of this parameter. According to [2], the recommended number of air exchanges in the swimming pool should range from 4 h^{-1} to 6 h^{-1}, and according to [18] – from 3 h^{-1} to 4 h^{-1}. In Poland, the number of air exchanges of 8 h^{-1} is usually adopted in the design of swimming pools ventilation.

The actual state of microclimate conditions, which is difficult to predict at the design stage, is most often assessed only during the use of the facility and may require the experimental identification of actual air parameters and even the need to modernize the ventilation system when these conditions deviate from those assumed at the design stage.

Currently, numerical research CFD is useful for assessing the conditions of thermal comfort and air quality in ventilated premises. However, the use of this method for swimming pools is difficult, due to the complex nature of air flow phenomena and a small number of literature examples of modelling of such facilities. Thus, numerical research should be preceded by a detailed diagnosis of the specificities of a swimming pool and experimental research, in order to, among others, properly select boundary conditions for their performance from *in situ* research, and to validate the results of numerical calculations.

Test object

The subject of the research was the actual school swimming pool in Gliwice (Fig. 3). The choice of the facility was dictated by the location of the swimming pool, the possibility of conducting long-term and short-term measurements during winter, spring and summer seasons, as well as access to technical documentation. In addition, this indoor swimming pool was a typical school facility.

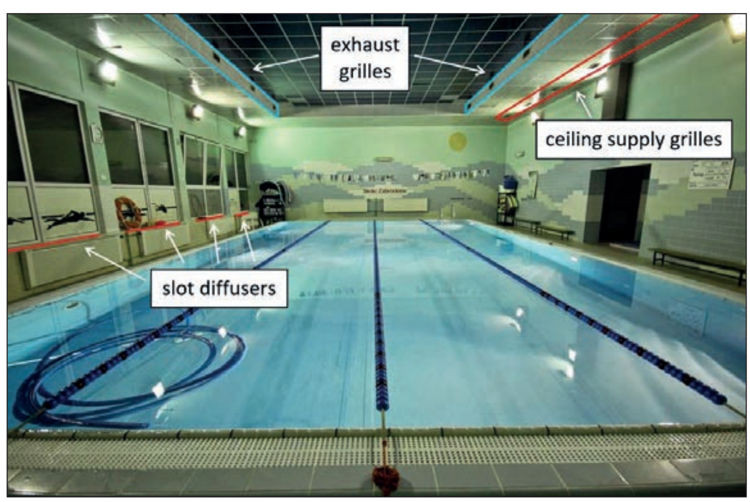


Fig. 3.
View of the interior of the school's swimming pool [21]
Rys. 3. Widok wnętrza badanej hali szkolnej pływalni [21]

The dimensions of the swimming pool were as follows: length 17.6 m, width 11.7 m, average height 4.4 m. Its volume was 906 m^3. Inside the facility, there was a pool basin with a length of 12.5 m and a width of 7 m. The pool basin was surrounded by a 40 cm high wall, therefore the water surface was at the height of 40 cm above the floor. At the north-west wall, there was an entrance to the swimming pool basin, accessed by steps. The swimming pool was used during the school year from the beginning of September to the end of June from 8:00 to 21:00 by primary school pupils and swimming schools. The swimming pool was not of a spectacular character, so only lifeguards and teachers could stay in it in addition to swimmers.

The indoor partitions of the indoor swimming pool were: north-east and south-east wall, swimming pool floor above the basement and ceiling under the attic. Other building partitions were external: a south-west wall with windows and north-west wall without windows.

Indoor heat sources in the swimming pool were: swimmers, lighting, radiators and people staying outside the pool basin. Indoor sources of moisture were people, water surface, moistened floors and supply air.

Thermal and humidity conditions inside the swimming pool were maintained using a mechanical ventilation system, which was responsible for: supplying of the required outdoor air volume flow rate, maintenance of indoor air temperature and relative humidity and removal of excessive moisture and gaseous air pollutants emitted from water. The system operated in continuous operation mode, supplying identical air volume flow rate around the clock.

The facility used a mixing ventilation system with one-sided air supply through 12 slot diffusers located along the windows. To ensure adequate air circulation in the swimming pool, on the opposite side of the building at the exit of the changing room, 7 ceiling grilles above the occupied zone were applied. Air exhaust was carried out by 12 air grilles located in the ceiling cavity above the swimming pool basin (6 grilles on each side of the cavity).

Fig. 4 shows the location of ceiling supply grilles K1÷ K7, slot diffusers N1÷ N12 and windows O1÷ O2.

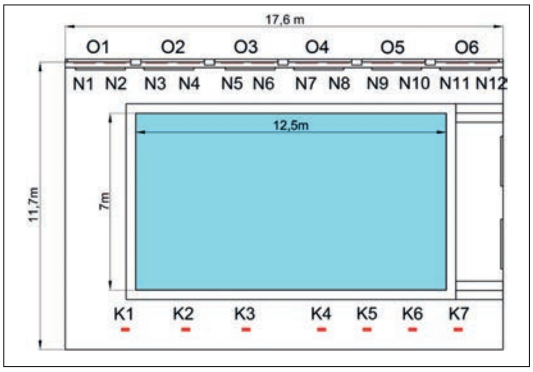


Fig. 4.
Arrangement of ceiling supply grilles, slot diffusers and windows in the swimming pool [3]
Rys. 4. Rozmieszczenie nawiewników sufitowych i szczelinowych oraz okien w hali pływalni [3]

Experimental research methodology

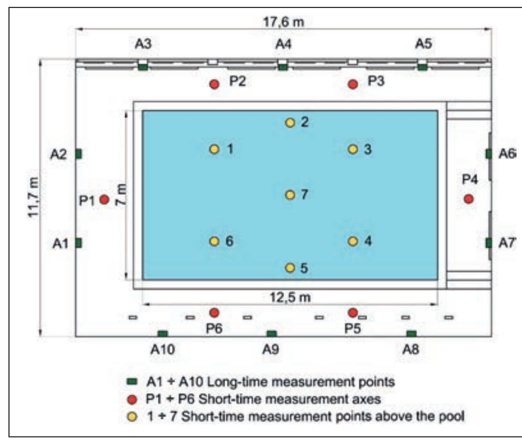
As a part of the experimental research, measurements were carried out to identify the operating conditions of ventilation in the swimming pool and to determine the distribution of air parameters in the occupied zone and above the water surface in different periods of the facility's operation during the year (winter, spring and summer).

1) Experimental research encompaslong-term measurements (conducted during the spring-summer period in 2015 and the winter period in 2016) of:
- outdoor air temperature and relative humidity,
- indoor air temperature and relative humidity at measurement points A1÷ A10 located on the walls of the swimming pool at the height of 1.7 m,

2) short-term measurements (carried out over a day without the presence of people in three measurement cases: spring – case 1, summer – case 2, winter – case 3) of:
- supply air temperature and relative humidity in the ventilation duct,
- supply air speed at the surface of air diffusers,
- indoor air temperature, relative humidity and speed above the floor around the pool's basin in measurement axes P1 ÷ P6, at four heights (0.1 m, 0.6 m, 1.1 m and 1.7 m),
- indoor air temperature, relative humidity and speed above the surface of the water at measurement points 1 ÷ 7 at a height of 0.2 m,
- water temperature in the pool's basin.

Fig. 5 shows the arrangement of measurement points and axes in the tested swimming pool. The detailed methodology of the measurements is presented in table 2.

Fig. 5.
The arrangement of measurement points and axes in the swimming pool [3]
Rys. 5. Rozmieszczenie punktów i osi pomiarowych w hali pływalni [3]



Results of experimental research

The experimental research, carried out in accordance with the methodology described in chapter 4, enabled the identification of thermal, humidity and flow conditions inside the swimming pool and obtaining data for numerical calculations, as well as for the validation of the numerical model of the swimming pool [3, 5].

Tab. 2. Measuring instruments and research methodology
Tab. 2. Zastosowane przyrządy pomiarowe i metodyka badań

No.	Measuring instrument	Measured parameter	Measuring range	Measurement accuracy	Measurement method
1.	Eight-channel thermal anemometers with HT-428 multidirectional spherical sensor with measuring system Air-DistSys 5000 [22]	Air speed	0.05 m/s ÷ 5 m/s	± (0.02 m/s + 1% of measurement value)	Short-term measurements: above the floor around the pool basin –on the rack at heights: 0.1 m, 0.6 m, 1.1 m and 1.7 m [17] above the water surface – on the rack at a height of 20 cm Measurement duration – 15 min. with averaging time 5 min. Registration of results every 1 min.
		Air temperature	-10°C ÷ 50°C	± 0.2°C	
2.	Air relative humidity and temperature recorders APAR AR235 [23]	Air relative humidity	0% ÷ 100%	± 3% (in the range 20% ÷ 80%)	Long-term measurements of air relative humidity and air temperature – on the walls around the swimming pool basin at the height of 1.7 m at A1 ÷ A10 points – a time step of 5 min. Short-term measurements of air relative humidity: above the floor around the pool basin – on a rack at four heights in measuring axes P1 ÷ P6 above the water surface – on the rack at a height of 20 cm Short-term measurements of supply air relative humidity and temperature – in the ventilation duct – measuring time 3 h, with a time step of 1 min.
		Air temperature	– 30°C ÷ 80°C	± 0.5°C (in the range 20°C ÷ 30°C) ± 0.5°C ÷ 1.8°C (in the other range)	
3.	Multifunctional measuring instrument 435-4 with wind probe [24]	Supply air speed	0.25 m/s ÷ 20 m/s	± (0.1 m/s + 1.5% of measurement value)	3-times evenly moving the probe over the surface of the supply air diffusers and averaging values in the instrument memory
4.	Thermometer DRT-10 [22]	Water temperature in swimming pool basin	-50°C ÷ 600°C	± 0.3°C	Measurement by immersion of the thermometer probe in water
5.	Davis Weather Station at the Silesian University of Technology (about 635 m from the swimming pool)	External air parameters			Continuous recording of air parameters, with a time step of 15 min.

Results of measurements of ventilation conditions and water temperature

In the course of long-term measurements carried out at different periods of the year, the following values of outdoor air parameters were obtained:

1. in the spring-summer period, the maximum outdoor air temperature was 37.6°C and the minimum – 3.4°C (in spring it varied from – 3.4°C to 27.9°C, in summer from 4.8°C to 37.6°C), while the air relative humidity was in the range of 22% to 95%,
2. during the winter period – the maximum outdoor air temperature was 15.2°C and the minimum – 1.3°C, while the air relative humidity was between 44% and 99%.

On the basis of the external air temperature and relative humidity values, it was possible to determine the specific humidity of the air supplied to the swimming pool by the ventilation system during different research periods. The values of the outdoor air temperature during the winter period were also used to determine the heat flux penetrating through the external building partitions and then they were used to determine the heat transfer coefficients of these partitions.

The measured values of air supply velocity at supply grilles ranged from 1.21 m/s to 2.84 m/s. The values of the same parameter at slot diffusers ranged from 0.41 m/s to 1.89 m/s and were lower than the recommended value of 4 m/s [10], resulting in a significant decrease in the range of the supply air jet. The measured values of air velocity at the supply openings were used to determine the volume flow rate of air supplied to the building by ceiling grilles and slot diffusers of defined effective surfaces. The number of air exchanges in the swimming pool calculated on this basis was: in winter 2.70 h^{-1}, in spring – 1.77 h^{-1}, in summer – 1.48 h^{-1}. These values were lower than the recommended range 3 ÷ 6 h^{-1} [2, 18].

The measured average water temperature in the pool basin was 31°C and was too high for school swimming pools and incompatible with [20, 9] which recommend a maximum water temperature in the pool basin at 28°C÷ 30°C. In addition, the water temperature was always higher than the air temperature in the pool. This contradicts the recommendations [20, 9] which suggest that the water temperature in the pool basin should be lower by 2°C to 5°C than the indoor air temperature.

Thermal and humidity conditions assessment in the swimming pool

As a result of ventilation air being supplied to the indoor swimming pool, the distribution of air parameters: speed, temperature and relative humidity were formed in the facility.

Table 3 shows the results of measurements of air temperature, relative humidity and speed in the occupied zone in the swimming pool. Measured values were compared with those recommended in the literature.

Tab. 3. The results of air parameters measurements in the swimming pool [4]
Tab. 3. Wyniki pomiarów parametrów powietrza w hali pływalni [4]

Measured value	Value for air above the floor	Value for air above the water	Recommended values
Temperature (°C) – winter period – spring period – summer period	26.1 ÷ 28.1 25.6 ÷ 28.1 25.1 ÷ 28.3	27.8 26.7 ÷ 27.8 25.2 ÷ 26.0	acc. [20]: t_w + (2 ÷ 4) acc. [2]: 24 ÷ 29 acc. [8]: 28 acc. [9]: t_w + (3 ÷ 5)
Relative humidity (%) – winter period – spring period – summer period	37 ÷ 77 49 ÷ 83 52 ÷ 83	48 ÷ 51 55 63 ÷ 64	acc. [20]: 40 ÷ 64 acc. [2]: 50 ÷ 60 acc. [8]: 45 ÷ 65 acc. [9]: 50 ÷ 60 (< 70)
Speed (m/s) – winter period – spring period – summer period	0.06 ÷ 0.20 0.03 ÷ 0.15 0.03 ÷ 0.17	0.18 ÷ 0.20 0.09 ÷ 0.15 0.10 ÷ 0.20	acc. [8]: 0.1 ÷ 0.15 acc. [9]: 0.15 ÷ 0.3

where: t_w – pool water temperature

The distribution of air temperature in the swimming pool was even. All air temperature values ranged from 24°C to 29°C as recommended by [2]. However, the mean values were lower than 28°C as recommended by [8]. In addition, the indoor air temperature was lower by a maximum of about 5°C than the temperature of the water in the pool, which was not in line with the recommendations [20, 9] which determine indoor air temperature from the temperature of water in the pool basin. Such situation had a negative impact, in particular, on swimmers who, coming out of the water of a temperature higher than the indoor air, experienced a cooling of the body and a feeling of thermal discomfort.

In the case of air relative humidity, the measurement cases differed in value of this parameter. Maximum values were about 15 ÷ 20% higher than the recommended ones, and the minimum values only for winter period were 3 ÷ 13% lower than the recommended ones [20, 2, 8, 9]. Above the water surface, the air relative humidity values were in accordance with the recommendations [20, 8, 9]. Only in summer, they were 4% higher than the recommended ones [2].

In most of the occupied zone, the minimum air speed condition was not met. The approximate value was equal to 0.03 m/s and therefore about 0.07 m/s lower than the recommended one [8]. In general, values smaller than those recommended accounted for as much as 46% of all measurement values. Higher speed values than in the rest of the occupied zone occurred mainly in the area where the air was supplied by ceiling grilles. On the basis of maximum and minimum values, it could be concluded that there were both draught and air stagnation zones in the swimming pool which resulted in the deterioration of thermal comfort and the feeling of shortness of breath of people around the pool basin. In the case of an area above the water surface of the pool basin, the minimum air speed values were equal to or close to the lower limit of the recommended range and the maximum values were lower than the maximum values in the occupied zone around it. Only above the part of the pool basin, near the area under the influence of air supplied by ceiling grilles, a local increase in the air speed above the water surface occurred and the recommended limit values were exceeded. This may result in the feeling of draught in this area of the pool basin experienced by swimmers.

Fig. 6 shows the indoor and outdoor air temperature distribution for both long-term measurement periods. It can be seen that throughout the whole measurement period the indoor air temperature remained stable despite the changing outdoor temperature. This means that the indoor air temperature was properly adjusted.

Fig. 7 shows dependence of indoor air temperature on indoor air relative humidity for both long-term measurement periods along with the sultriness curve for swimming pools. It can be seen that in the spring-summer period a large part of the results was located on the right of the sultriness curve. In the early part of the spring-summer period, the exceedance of the air relative humidity value in relation to the sultriness curve was less frequent (11% of

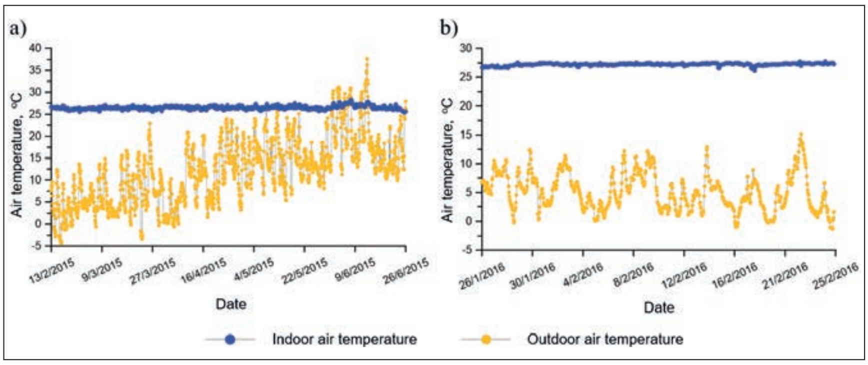


Fig. 6.
Indoor and outdoor air temperature distribution for long-term measurement periods: a) spring-summer period, b) winter period
Rys. 6. Rozkład temperatury powietrza w hali pływalni i temperatury powietrza zewnętrznego dla okresów pomiarów ciągłych: a) okres wiosenno-letni, b) okres zimowy

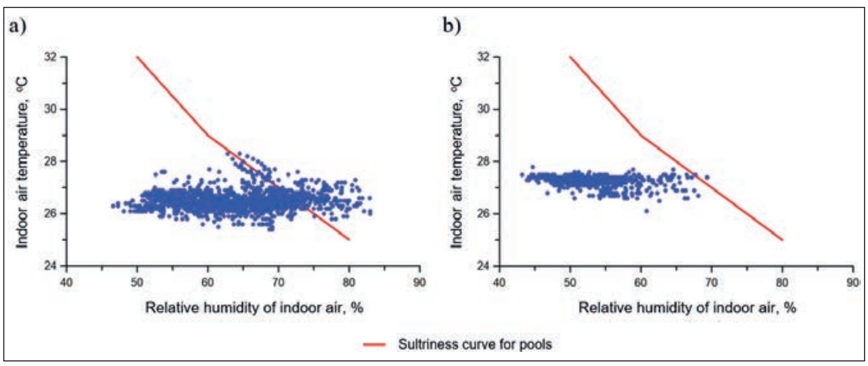


Fig. 7.
Indoor air temperature and relative humidity values: a) in the spring-summer period, b) in the winter period
Rys. 7. Temperatura i wilgotność względna powietrza w hali pływalni: a) w okresie wiosenno-letnim, b) w okresie zimowym

the measurement results) and mainly related to the afternoon or evening, while in May and June these exceedances related to longer periods, even several days (in May this condition covered 42% of the values and in June as much as 55% of the values). The required air parameters were not always preserved. During the winter period, this situation occurred only in 0.2% of the measurement results and the exceedance of the air relative humidity value in relation to the limit one resulting from the sultriness curve was negligible, which can be considered as meeting the requirements throughout the whole measurement period.

The measured values of air temperature and relative humidity were used to determine, using the *h-x* chart, the specific humidity of the air in the swimming pool. The *h-x* chart (Fig. 8) shows the area of the identified air conditions in the facility during the measurements. On this basis, it was claimed that a substantial part of them exceeded the acceptable area limited by the sultriness curve for swimming pools. This contributed to the feeling of discomfort by the occupants. In addition, it confirmed the subjective assessment of thermal and humidity conditions by those who conducted the measurements and experienced excessive shortness of breath, dizziness, weakness of the body and drowsiness during them. It was also the result of the previously mentioned not a big enough number of air exchanges in the swimming pool.

Conclusions

1. As a result of air parameters measurements in the indoor swimming pool, it was found that in a large part of the occupied zone thermal and humidity conditions and air speed values differed from those recommended in the literature sources.
2. The main problem was the failure to meet the criterion of the recommended value of air speed in the facility. There were both draught and air stagnation zones. The air speed values lower than the recommended ones covered almost 50% of all measurement results. In the case of air temperature and relative humidity values, their distribution was even in the building, and they were in line with some recommendations, but not all. For example, the recommendation that the air temperature in the indoor swimming pool should be higher than the pool water temperature was not met. It was related to, among others, exceeded recommended maximum temperature of water in the pool basin.
3. The air volume flow rate (calculated on the basis of the measured air supply velocity at slot diffusers and ceiling grilles and their surface area) may

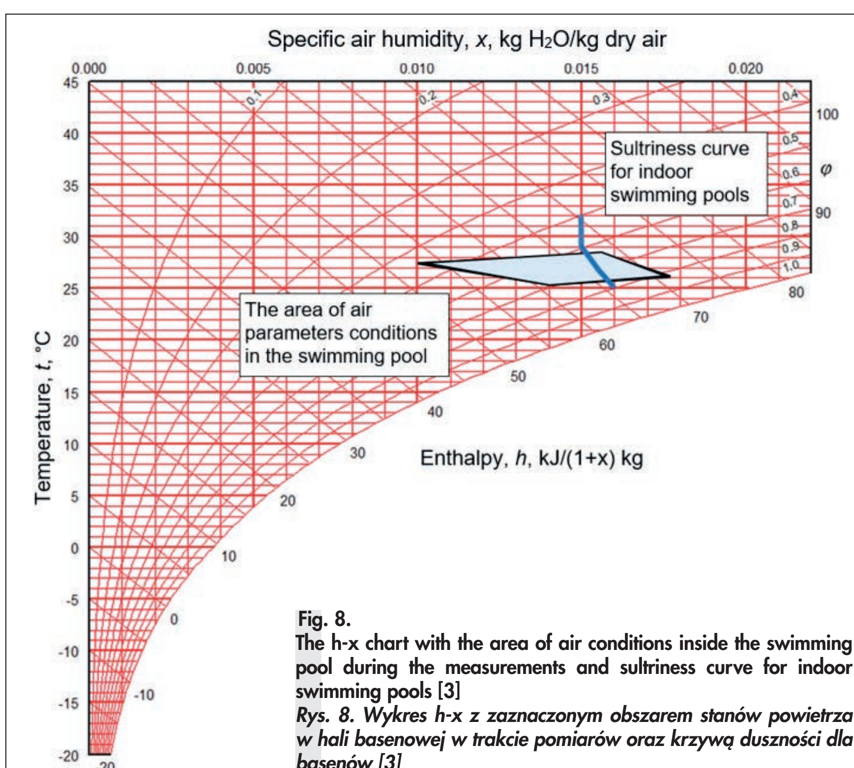


Fig. 8.
The h-x chart with the area of air conditions inside the swimming pool during the measurements and sultriness curve for indoor swimming pools [3]
Rys. 8. Wykres h-x z zaznaczonym obszarem stanów powietrza w hali basenowej w trakcie pomiarów oraz krzywą duszności dla basenów [3]

have been subject to some error related to the possibility of a slight clogging of the slot diffusers with crushed debris. The number of air exchanges calculated on this basis was significantly lower than the recommended values for indoor swimming pools. In the spring and summer periods, the values of air exchanges, 1.77 h^{-1} and 1.48 h^{-1} respectively, were significantly lower than the recommended minimum value of 3 h^{-1} [18]. In winter, the air exchange ratio of 2.7 h^{-1} was only slightly lower than the recommended one. This probably also had an impact on the fact that in winter there were more favourable thermal and humidity conditions in the swimming pool than in the rest of the year and only in a small period of time the sultriness curve for swimming pools was exceeded.

4. To ensure the thermal comfort of occupants, swimmers and staff, the thermal and humidity conditions in the indoor swimming pool should be improved. This can be achieved by increasing the supply air volume flow rate, increasing the speed of air supplied by slot diffusers and increasing the air temperature in the facility. Increasing the supply air volume flow rate will improve the range of the air jets supplied by the diffusers and grilles, although then there may occur a feeling of draught, especially at ankle height, among the occupants. Therefore, it is proposed to redirect most of the supply air volume flow rate to slot diffusers, which currently supply the air with the speed of less than 0.8 m/s, while the recommended supply air speed of such diffusers is 4 m/s. In addition, an increased air volume flow rate supplied by slot diffusers could effectively protect the windows against moisture condensation and induce air from inside the building. Thus, it would be possible to reduce the supply air volume flow rate of ceiling grilles, which would lead to a reduction in the mixing of moist exhaust air with the air supplied to the occupied zone and reduce the process of water evaporation from the surface of the pool basin.
5. In order to see the impact of the planned changes on the thermal-humidity and flow conditions in the indoor swimming pool before the modernisation of the ventilation system, it would be advisable to perform numerical calculations CFD of air, heat and humidity flow under the new conditions. In such simulations, the results of *in situ* measurements presented in this paper can be used to develop boundary conditions and validate the calculation results.

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