technical transactions

No. 2020/001

environmental engineering

sciendo

Indoor air quality and control methods for mechanical ventilation systems inside large passive objects

Nina Szczepanik-Ścisło

nszczepanik@pk.edu.pl | Orcid 0000-0002-1473-406X

Faculty of Environmental and Power Engineering, Cracow University of Technology

Scientific Editor: Michał Zielina, Cracow University of Technology
Technical Editor: Aleksandra Urzędowska, Cracow University of Technology Press
Language Editor: Tim Churcher, Big Picture
Typesetting: Małgorzata Murat-Drożyńska, Cracow University of Technology Press

Received: November 14, 2016
Accepted: March 26, 2020

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing interests: The authors have declared that no competing interests exist.

Citation: Szczepanik-Ścisło, N. (2020). Indoor air quality and control methods for mechanical ventilation systems inside large passive objects. *Technical Transactions, e2020/001*. doi.org/ 10.37705/TechTrans/ e2020001

Abstract

This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants. This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants. This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants. This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants. This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants.

This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants. This paper summarises the indoor air quality of a sports hall built in the passive standard. The sanitary conditions within the object were measured and analysed to identify whether the standards were met and if the test object was safe for occupants.

Keywords: indoor air quality, passive sports hall

1. Introduction

The objective of lowering energy consumption in the European Union is one of the most significant issues that is been undertaken. Because the building sector consumes 40% of the worldwide energy (Baden, 2006), considerable effort is made to building energy efficient buildings, which under certain requirements, can be considered to be passive houses by the PIBP (Polish Institute of Passive Housing and Renewable Energy – PIBPiEO). This standard is gaining recognition around the world and in recent years, the number of passive objects in Poland has been growing. One of these objects is the passive sports hall described in this article and located in Krakow, Poland.

For an object to be recognised as a passive object in Central European climatic conditions, the maximum annual energy demand for heating should be less than 15 kWh per square metre per year and the rate of primary energy demand for the sum of all household purposes (heating, domestic water heating, electricity) cannot exceed 120 kWh per square metre per year (PIBPiEO). To achieve this, passive objects are built from materials providing better thermal insulation and fresh air is no longer provided by the leakages in the building envelope, as in the case of the traditional building standard, but by a mechanical ventilation system. An important issue is the air tightness of the building envelope. Airtightness is restricted to n50 = 0.6 air change/h (0.6 times the volume of the house per hour through the building envelope under 50 Pa pressure difference between the inside and outside), and on this basis, an object is admitted as a passive object (PIBPiEO). This raises questions about the quality of indoor air in such sealed structures as it can be prone to contaminant accumulation.

Additionally, contaminants inside of sports facilities may have a high impact on occupants as they have increased respiratory rates during activities and most of the air is inhaled through the mouth, bypassing the nasal area which filters the air (Carlisle, Sharp, 2001). Moreover, the capacity for pulmonary diffusion has been shown to increase with exercise (Smith, 1999). This shows that the quality of indoor air inside such objects is extremely important, which is why it is essential to maintain proper indoor air parameters within them.

2. Methods

The research object was a passive sports hall located in Krakow, the capital of the Malopolska region of Poland. It is part of the University of Agriculture in Krakow and is used by students of the university on a regular basis as well as being rented out in the evenings to private persons for sport activities. The layout of the object is shown in Fig. 1. The total area of the three story building is 18,000 m^2, out of which, the main part is the indoor sports area. The building also consists of cloakrooms, a smaller fitness hall, technical and storage rooms. The indoor sports area is divided into two main zones (Pyszczek, Stelmach, 2011). The first is the court, upon which the occupants participate in sport activities and is 23 m wide and 45 m long. The second part of the object are benches with 150 seats that rise from the level of the court to 2.5 m and at the top are connected to an open hallway. The court is equipped with special curtains that can divide it into three sectors (right, centre and left) shown in Fig. 1. The object is equipped with a mechanical ventilation system and large windows, which allows fresh air to flow inside. The windows are placed on both the east and west side of the facade and are mainly used between classes to air the room. The focus of the study was on the indoor air quality of the sports area.

To determine whether the indoor air quality and sanitary conditions are appropriate for occupants, a series of sensors were laid out within the object. The sensors constantly measured the concentration of carbon dioxide, temperature and relative humidity for a period of two weeks from the 10th to the 23rd of March. In this study, the concentration of carbon dioxide was taken into consideration

https://doi.org/ 10.37705/TechTrans/e2020001

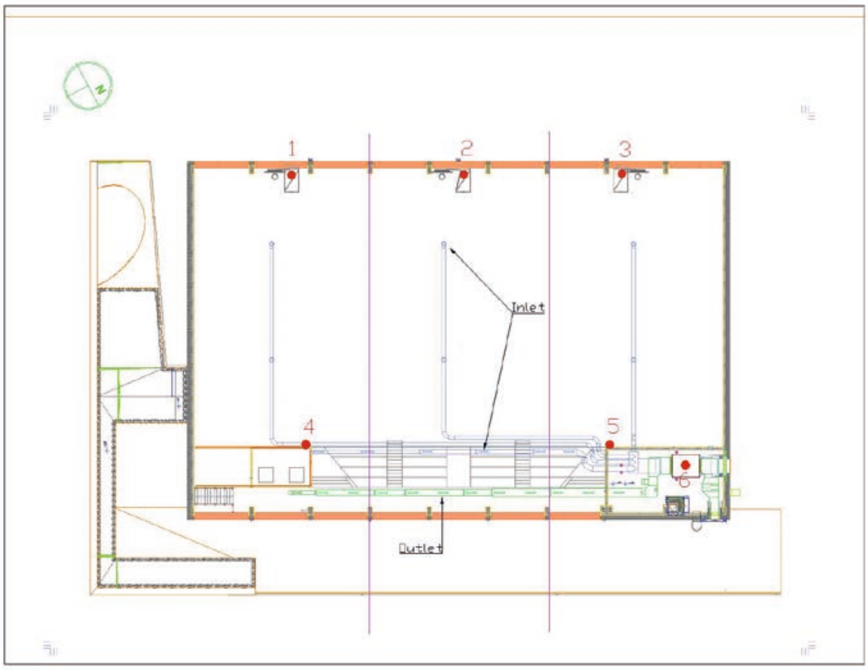


Fig. 1. Layout of the permanently placed sensors and layout of the ventilation system (created by an educational program of Autodesk)

to determine whether proper sanitary conditions were maintained. This was performed because the only indoor air source of CO_2 was human respiration, meaning that the concentration of the contaminant was strictly related to the behaviour of occupants. According to ASHRE standards (ASHRAE (1989), for an object to be considered safe for occupants, the concentration of carbon dioxide should not exceed 1,000 ppm. If this amount is exceeded, the consequences could range from dizziness and feelings of weakness to fainting and heart malfunction (Kaiser, 2010). To determine if this sanitary standard was met, six sensors were permanently placed inside of the object as shown in Fig. 1. Five of the sensors were placed on the inner walls of the sports hall, the sixth was placed in the ventilation outlet through which the air from the sports hall was discharged and located 4.6 m above the ground. Sensors 1–3 were placed 2.5 m above the ground. Sensors 4 and 5 were placed 3.5 m above the ground. Because of the characteristics of the building, it was impossible to place permanent sensors near the breathing zone of the occupants. This is why periodical measurements were taken using additional sensors, located closer to the breathing zone of the occupants. This was to determine whether the air quality in different parts of the building that were closer to the breathing zone were the same as in the areas where the permanent sensors were placed. The sensor system was equipped with a router that wirelessly transmitted the measurements to a computer where the results were processed by software. The measurements were taken every five minutes and included the concentration of carbon dioxide in the range from 0–5,000 ppm with an accuracy of ±50 ppm.

The mechanical ventilation system was not equipped with a control system to control the amount of air that flowed through it, but was manually controlled by a caretaker who had an overview of the conditions within the object. The manual control system showed the basic indoor air parameters as well as the carbon dioxide concentration and allowed the user to control whether or not the windows in the building were open and whether the ventilation system was turned on. He was also in charge of opening the windows of the sports hall between classes so that a draft would occur to remove contaminants.

3. Results

3.1. Results from the permanent sensors

As mentioned earlier, the sensors were placed in the sports hall for a period of two weeks. The results of sensors 1–4 are shown in Fig. 2 and the results form sensor 6 are shown in Fig. 3. Unfortunately, sensor 5 malfunctioned due to technical problems and was not included in the study.

From Fig. 2, it can be deducted that the concentration of carbon dioxide for the four working sensors that were installed inside of the sports hall was very similar. The similarity of the sensor readings concludes that the air inside of the building is well mixed and there is no contaminant accumulation in the zones in which the sensors

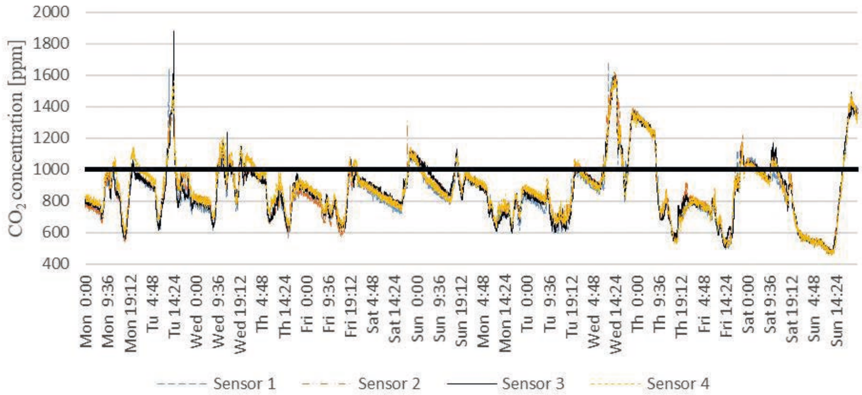
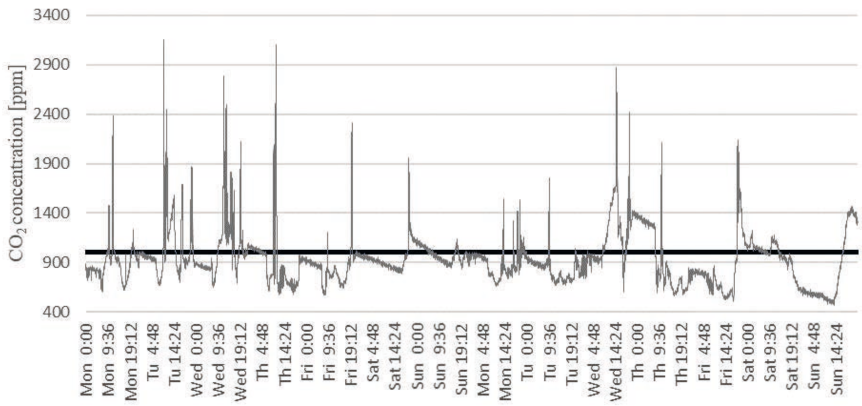


Fig. 2. Readings form sensors 1–4

are placed. However, the amount of CO_2 inside of the sports hall often exceeded the maximum level of 1,000 ppm. The concentration of the contaminant was mainly surpassed during the morning from around 10am to early afternoon and evening hours after 6pm. This phenomenon occurred daily and for every sensor, meaning that it was not the influence of an individual event in the building. The concentration of contaminants mainly lowers during the afternoon and in the night. The highest concentration of carbon dioxide was 1,881 ppm and occurred on Tuesday in the first week. This happened during a period of elevated contaminant concentration that occurred between 12pm and 3pm. Two additional peaks occurred during the second week on Wednesday and Sunday. The first occurred around the same time frame as the maximum reading, at 2pm. The time frame in which this peak occurred was during a long period of increased contaminant concentration between 10am and 6pm. The third peak occurred on the second Sunday in the evening around 9pm. The fact that peaks that occurred on week days were in a similar time frame means that it could be caused by the occupants within the sports hall and could be a reoccurring event. The peak that occurred on the second Sunday probably occurred due to a large number of people that were using the object at that time for sports activities when the sports hall was rented out to private individuals.

The maximum readings were from sensor 6 (Fig. 3). The concentration of contaminants in this area of the hall had no influence on the indoor air quality as it was located at the end of the discharge ventilation duct. The reason why this was measurement was performed was to see if the contaminants were removed by the ventilation system in a proper manner. The readings from sensor 6 are higher that the concertations recorded by sensors 1–4, which means that the carbon dioxide is removed from the building. The majority of peaks shown in Fig. 3 occurred before the peaks of contaminant concentration in Fig. 2. This means that such a system could be worth enhancing with a dedicated control systemfor the ventilation system. As it was stated earlier, the ventilation system is controlled manually by a caretaker who had an overview of the conditions within the sports hall. Because a caretaker is usually responsible for other tasks in a building, the lack of immediate response could be the cause of the high concentrations of carbon dioxide within the building. If a control system was installed, it could be possible to base it on the concertation of contaminants in the discarded air, as it was higher than the readings from within the building and could prevent peaks of contaminant concertation from occurring inside the hall.

Fig. 3. Readings from sensor no. 6



https://doi.org/ 10.37705/TechTrans/e2020001

3.2. Periodical measurements

As a result of the maximum acceptable limits of carbon dioxide concentration being exceeded during the measurements performed by the permanently placed sensors, it was decided to conduct measurements closer to the occupants breathing zone to see if standards were met.

The first measurement was taken on the 14th of March. The results of the measurements are shown in Figs. 4 and 5. Four additional sensors were placed inside of the sports hall – sensors 7 to 10. Sensors 7 and 8 were placed under sensors 4 and 5, respectively, and were placed 40 cm above the ground. Sensor 9 was placed in the centre of the benches. Sensor 10 was held by the author near the occupants. The measurements were taken in the evening from 8pm to around 10pm while the sports hall was rented out to private individuals

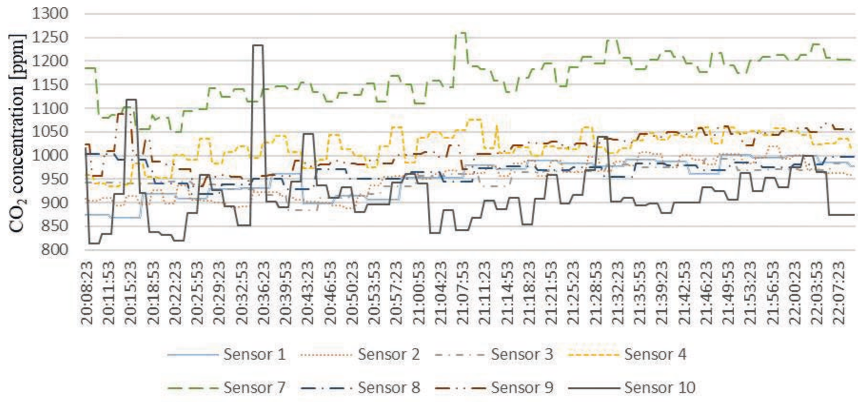


Fig. 4. Readings from sensors 1 to 10 on the 14th of March

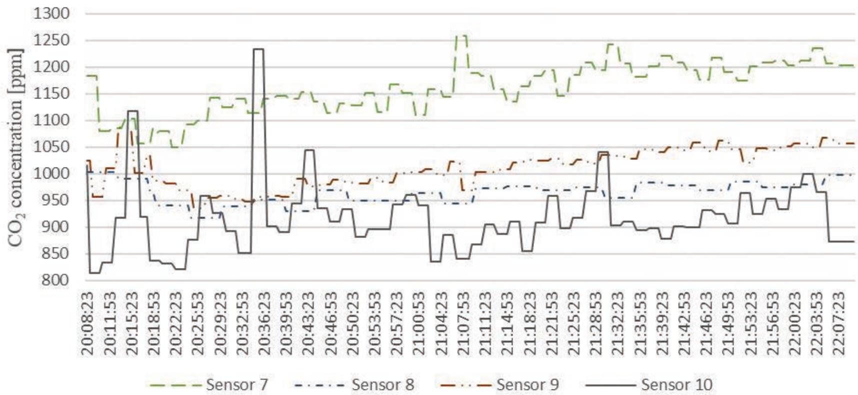


Fig. 5. Readings from sensors 7 to 10 on the 14th of March

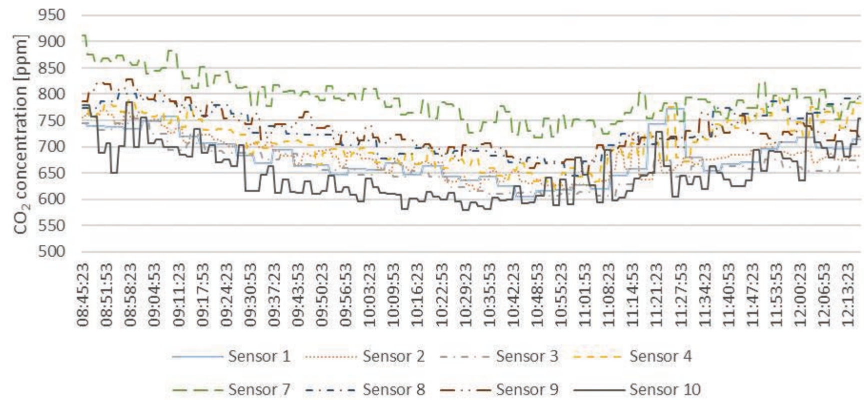


Fig. 6. Readings from sensors 1 to 10 on the 17th of March

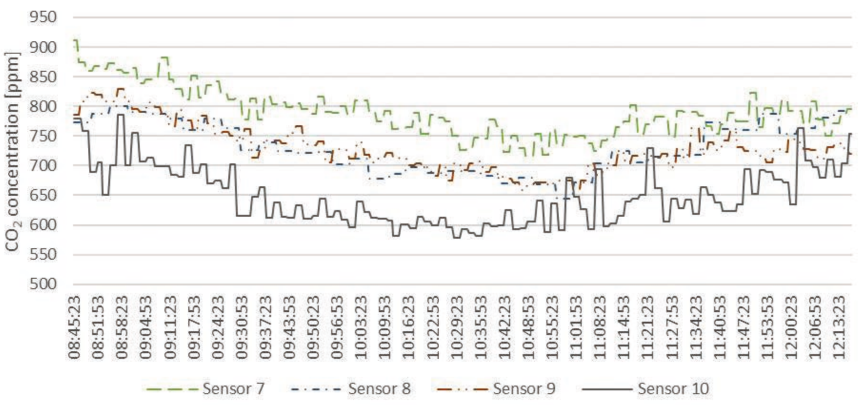


Fig. 7. Readings from sensors 7 to 10 on the 17th of March

who played volleyball. During this time, 12 people were on the right sector, 10 on the middle sector and 8 on the left sector of the object. Special division curtains were used do divided the hall into sectors as is shown in Fig. 1. With the exception of one person, all of the occupants were male. The results of the contaminant concentration measurements were similar to the readings of the rest of the sensors.

The reading from sensor 10, which was the closest to the breathing zone, shows that the concentration of CO_2 is periodically above the maximum acceptable limit of 1,000 ppm. However, the readings from sensors 7 and 9 constantly surpassed 1,000 ppm. The high readings from sensor 9 could be due to its proximity to the outlet duct and the contaminated air that could flow from the sports zone to the outlet through the benches. The readings from sensor 7 may be higher than those from sensor 8 because the sector in which it was placed had the most occupants.

The second periodical measurement was performed on the 19th of March from 8:45am to 11:45am. Four additional sensors were placed in the object. During this time, the sports hall was occupied by students during their classes and once again, division curtains were used do divide the hall into three sectors. Because of the long time frame, the number of occupants changed during this period. The occupation schedule changed as follows:

- from 8:45 to 8:50 – 21 occupants were in the sports hall, ten each in the left and right sector and one in the middle sector,
- from 9:15 to 10:10 – 5 females occupied the right sector and one was sitting,
- from 11:00 to 11:45 – 11 females were in the left sector.

Four additional sensors were placed in the sports hall during this period. Sensor 7 was paced in the centre of the object at a height of 1.6 m, sensors 8 and 9 were placed under sensors 4 and 5, respectively, at heights of 40 cm. Sensor 10 was carried by the author and placed in the immediate surroundings of the occupants. The readings presented in Figs. 6 and 7 show that the concentration of carbon dioxide from the sensors is below the maximum acceptable level of 1,000 ppm. This means that the concentration of contaminants was not harmful for the occupants.

Comparing the results presented in Figs. 5 and 7, it can be deducted that there is a large difference in contaminant concertation during these periods. This could mainly be caused by the number of occupants in each time frame. In the first periodical measurement, the amount of occupants was higher than the second periodical measurement. Also during the second measurement, there were periods of time in which the sports hall was empty. This shows how occupant behaviour influences the contaminant concentration, as the higher the number of occupants, the higher the level of carbon dioxide. This also shows that the ventilation method used to remove contaminated does not ensure appropriate indoor air quality.

4. Conclusions

Due to their specific characteristics and airtightness, passive objects may be prone to contaminant accumulation. This is why it is important that the ventilation systems installed in such objects are designed in such a way that the occupants have proper hygiene conditions.

The undertaken measurements have shown that the concentration of CO_2 inside of the sports centre is not appropriate for the occupants. The concentration exceeds the maximum amount of 1,000 ppm for various periods of time during the two weeks in which the test took place. The high levels of CO_2 may be the consequence of a lack of adequate ventilation methods. The lack of a control system may also contribute to the high contaminant level. When a system is controlled manually, it is prone to human error, especially when the operator has other tasks that he or she may need to attend, as it was in this case. The possibility for the installation of a control system should be considered. The system could be based on the concentration of CO_2 in the discharged air. The results of the measurements have shown that the concertation of the contaminant was, for the majority of the time, higher in the discharged air than the concertation within the object, meaning that the majority of contaminated air was removed though the system. If the system was to be triggered to turn on before the peaks of contamination occurred inside the object, it would be possible to prevent such events. However, to determine whether this would be possible, more detailed research would have to be carried out.

Because of their specific structure and purposes, the indoor air quality inside of passive sports halls should not be overlooked in preference of energy savings. Energy savings are essential but they should not have a negative effect on the conditions within objects as they are crucial for proper functioning indoors.

References

ASHRAE (1989). *Ventilation for acceptable Indoor Air Quality* (Standard 62-1989). Atlanta.

Baden, S., et. al. (2006). Hurdling Financial Barriers to Low Energy Buildings. Experiences from the USA and Europe on Financial Incentives and Monetizing Building Energy Savings in Private Investment Decisions. In *Proc. 2006 ACEEE Summer Study Energy Effic. Build*. (pp. 1–16). Copenhagen: Danish Energy Agency.

Carlisle, A. J., Sharp, N. C. (2001). Exercise and outdoor ambient air pollution. *Br. J. Sports Med.*, *35*(4), 214–222.

Kaiser, K. (2010). Tlenek i dwutlenek węgla w pomieszczeniach. *Rynek Instal.*, *9*, 1–7.

Polski Instytut Budownictwa Pasywnego i Energii Odnawialnej [PIBPiEO]. Retrieved from http://www.pibp.pl (date of access: 2015/07/24).

Pyszczek, S., Stelmach, J. (2011). *Architectural-building Project of Sports Hall Building in Krakow*. Kraków: Pyszczek & Stelmach Sp. J.

Smith, M., et. al. (1999). Impaired Pulmonary Diffusion during Exercise in Patients with Chronic Heart Failur. *Circulation*, *100*, 1406–1410.

Jakości powietrza wewnętrznego i metody kontroli dla systemów wentylacji mechanicznej wewnątrz większych obiektów pasywnych

Streszczenie

W artykule podsumowano jakość powietrza wewnątrz hali sportowej wybudowanej w standardzie pasywnym. Warunki sanitarne w obiekcie zostały zmierzone i przeanalizowane w celu sprawdzenia, czy normy zostały spełnione i czy badany obiekt był bezpieczny dla użytkowników.

Słowa kluczowe: jakość powietrza w pomieszczeniach, pasywna hala sportowa