Daria Plotnikova

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COMPARISON OF INTERNATIONAL AND RUSSIAN NORMS AND GUIDELINES FOR THE INDOOR CLIMATE AND AIR CONDITIONING OF SWIMMING HALLS

Bachelor's Thesis
Degree programme in Building Services Engineering

January 2014

MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

Description

MIKKELIN AMMATTIKORKEAKOULU Mikkeli University of Applied Sciences	**Date of the bachelor's thesis** 15.01.2014
Author(s) Daria Plotnikova	**Degree programme and option** Double Degree Programme in Building Services Engineering

Name of the bachelor's thesis

Comparison of the international and Russian norms and guidelines for the indoor climate and air conditioning of swimming halls

Abstract

Swimming pool is a place where people go in for sports or spend time with their family, so indoor climate should be as comfortable as possible for visitors. Russian and international standards and guidelines offer a variety of solutions for indoor climate. Therefore, the main aim of this thesis is to find out and to compare the differences between international and Russian standards and guidelines for swimming pools. In the beginning common problems of swimming pools will be determined. Also monitoring of air temperature and relative humidity will be carried out. It is necessary for comparing of the measured results to international and Russian standards and guidelines.

In this thesis literature review, analysis of Russian, Finnish and The USA standards and guidelines, calculations absolute humidity and air flow rate and measurement in swimming halls were carried out. Finally, the differences between values that will be obtained as a result of measurements and the recommended values will be written.

According to comparison international and Russian standards and guidelines for swimming halls, it can be concluded that there are some differences. All of regulations and guidelines don't give specific value of indoor air temperature; it depends on water temperature of pools. But and Russian and Finnish recommendations limits maximum air temperature (it should be less than 31°C). Level of air humidity also differs in regulations. The highest differences between lower and upper limits of relative humidity are in Russian recommendations. All recommendations that are given in guidelines are needed to achieve the acceptable indoor climate in swimming pools to avoid health hazard effect or damage of building envelope.

Subject headings, (keywords)

Swimming pools, indoor climate, absolute and relative humidity, common problems in swimming halls

Pages	**Language**	**URN**
65	English	

Remarks, notes on appendices

Tutor	**Employer of the bachelor's thesis**
Marianna Luoma	

CONTENTS

1 INTRODUCTION

Many people have used swimming pools since ancient time, because it has hygiene and relaxing effects. In ancient Rome there were public baths, which people visited for hygiene, sports, and entertainment purposes. These baths can be considered as the founders of today's pools. So, why do we go to the pools today?

Swimming is very useful as well for children as for adults. The children's muscular system will be harmoniously formed, because when person swims, he uses all muscle groups. Swimming for adults is well too, as the load is removed from the spine. The uniqueness of training in the water is that you can get exactly the result what you want: to relax or vice versa to cheer up.

As we can see, swimming pool is a place where people go in for sports or spend time with their family, so indoor climate should be as comfortable as possible for visitors. Russian and international standards and guidelines offer a variety of solutions for indoor climate. But each standard or guideline have their opinion about good indoor air in the pool area. Therefore, the aim of this thesis is to find out and to compare the differences between international and Russian standards and guidelines for swimming pools.

In this thesis public pools without spectator's places will be studied. Air-conditioning of swimming halls is a task which requires a special approach. The target of the engineer is not just to provide fresh air into the pool's space, his target is to create a comfortable environment for swimmers and personnel. Pool water temperature is higher than air temperature, so it causes increased evaporation. Thus, vapour condensation occurs on cold surfaces, leading to corrosion and decay of materials. In addition, there can be fogging of windows and mould in swimming halls, creating uncomfortable conditions. Another problem is the insufficient supply of fresh air. Fresh air is needed for the removal of stagnant smells for wellbeing.

When we are aware of these problems, we can design the optimal air conditioning systems for swimming pools. It can be simple ventilation system, with only supply and exhaust air systems. Or it can be air-conditioning system with dehumidifier or with heat recovery depending on the case.

There are common solutions that are described in the standards and guidelines for designing swimming pools. The application of these norms and guidelines is mandatory, otherwise indoor climate will not match hygiene standards, and possibly will harm the health of visitors. This thesis will review the standards and recommendations of three countries: Russia, Finland and the USA.

In the background section, it will be explained why air temperature and air humidity are so important for indoor conditions of swimming halls. Then, necessary equipment for providing fresh air and for drying moisture air will be considered. In the next part of this thesis such standards for the construction of pools as “Russian designing and building code 31-113-2004. Swimming pools”, ASHRAE standards and Finnish recommendation for swimming pools will be analyzed. Common themes will be found and analyzed. In the second part of the thesis most important factors for indoor climate such as air flow rate and absolute humidity will be calculated. In the final part of this thesis measurements in the Russian and Finnish swimming halls will be reported. Then the measured results will be compared with the international and Russian standards and guidelines.

2 AIMS AND METHODS

2.1 Aims

The main aim of this Bachelor's thesis is to find the differences between International and Russian standards and guidelines for swimming halls.

This thesis also contains some other research questions. At first it will be determined what common problems exist in indoor climate of swimming halls. These problems will be associated with insufficient supply fresh air, relative humidity and temperature of air and surrounding surfaces.

The second research question is to understand how air temperature and air humidity influence the indoor climate of swimming pools and swimmers.

The third research question is to describe the necessary equipment of air-conditioning systems in the swimming pools for the achieving good indoor climate.

The fourth question is to compare calculated parameters of indoor climate such as absolute air humidity and air flow rate to Russian and Finnish standards and guidelines. This is necessary in order to determine how the real meanings of these parameters different from calculations.

In Russian and Finnish swimming halls monitoring of air temperature and relative humidity will be carried out. It is necessary for the fifth research question comparing of the measured results to international and Russian standards and guidelines.

2.2 Methods

The first method which will be used in this Bachelor's thesis is the studying literature sources. Main problems of the indoor climate in pools will be determined. Articles and books where significance of air temperature and air humidity is written will be studied mainly. After reviewing main problems necessary equipment allowing to remove these problems will be selected. In this case, the manufacturer information will be used. After that it is important to study standards and guidelines of other countries for comparing their differences.

The second method is analysis of Russian, Finnish and The USA standards and guidelines. There the main criteria for swimming halls climate will be described.

The third method of thesis is the calculations. There are differences between the standards and guidelines of Russia, Finland and the USA. Absolute air humidity and air flow rates will be calculated all the ways that these standards and recommendations offer. It is necessary to see the differences between the real values in swimming halls and calculated values.

The fourth method is the measurement. It will be carried out measurements of air temperature, air humidity and carbon dioxide levels in swimming halls of Russia and Finland. Air conditioning systems will be described in order to determine how to conform to recommended values.

The last method is the comparison. In this part of this thesis differences between Russian and International standards and guidelines will be showed, also differences depending upon calculations will be determined. Finally, the differences between values that will be obtained as a result of measurements and the recommended values will be written.

3 THEORETICAL BACKGROUND

Types of pools vary in purpose and location. In this Bachelor's thesis public swimming halls without spectator's place will be considered. So what is the pool? Some norms define it (sometimes, swimming halls are called in American articles as natatorium) how:

- An artificial structure, and its appurtenances, which contains water more than two feet (600mm) deep which is expressly designated or which is used with the knowledge and consent of the owner or operator for swimming or recreational bathing and which is for the use of any segment of the public. /1, p.3/

- The swimming pool is year-round, such physical activity sports facilities are for swimming sport, which it is primarily reflected in the teaching of swimming, fitness swimming, swimming, sports, and visitors with special needs. Swimming pools also serve a number of swimming sport and physical arts training and competition locations. /2, p.1/

Depending on the objectives and the type of pools appropriate design solutions is developed at the design stage. It is important to remember that pools provide difficult environment for the conventional HVAC system. The continuous moisture load generates challenges the air-conditional system and creates other opportunities for building envelope damage. An efficient HVAC system must function properly during all seasons and should be capable of taking all indoor and outdoor air conditions. /3, p.7-8./

3.1 Common problems in the Indoor climate of swimming halls

As practice shows, the following problems exist: low temperatures, high or low air velocities, air impurities, high or low relative humidity and poor air distribution /4/. So, look at all these challenges in detail.

First of all the challenge caused by relative humidity will be considered. Enclosed swimming pools in winter climates have the possibility to safe high relative humidities and low temperature of building materials. These elements can contribute to condensation and damages of building envelopes. Buildings with high indoor relative humidities during the year do not have the opportunities to dry out. /3, p.1./

Moisture migration through the building envelope to outdoors in cold weather should be stopped. Process of migration is based on vapor pressure differences. There is effectively a 10” water column pressure difference between indoors and outdoors during cold winter days. The building envelope must be designed to adequately deal with condensation by placing vapor barrier in appropriate locations of building envelope. /5/

Therefore, it is important to start with the proper envelope construction to avoid damages during the life of the building. A vapor barrier is needed to keep moisture from the buildings walls and roof. Additionally the window quantity, design and installation, as well as the wall construction detail and its insulation should be correctly designed. Condensation on building elements during low outdoor air temperatures should be carefully prevented. When the surface of the interior insulation becomes cold enough condensation occurs. Therefore vapor barrier should be installed on the interior side of the building envelope. It prevents water from reaching the cold insulation, where condensation will form. /6, p.3./ Example of the building envelope you can see in figure 1.

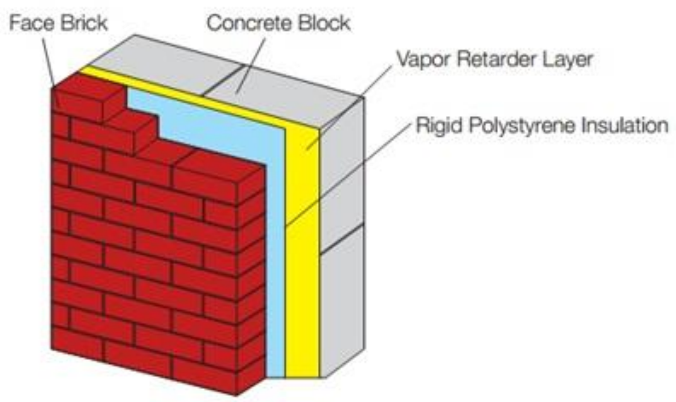


FIGURE 1. Building envelope with vapour barrier /6, p.3/

The relationship between relative humidity and indoor air quality is well described in various recommendations and articles. High relative humidity level in the space is well-known for destructive effects on building components and can pose serious health effects. It promotes the mold growth and mildew which at first are unsightly, than can attack wall, floor and ceiling. Spores of it negatively impact the air quality. Comfort levels of visitors and personnel are very sensitive to relative humidity. Fluctuation of relative humidity more than the 40% - 60% range can result in increased levels of bacteria, viruses, fungi and other factors that reduce air quality. Also it leads to respiratory problems. /7, p.3./ In figure 2 you can see how health factors vary with relative humidity.

High relative humidity level is can be uncomfortable for swimmers and personnel, because in swimming pool condensation through the skin decreases. It reduces the regulation possibility of organisms to maintain defined level of temperature. Humans may feel stuffiness. /4, p.7./ But for visitor's health low relative humidity is adverse as high relative humidity. The low relative humidity can cause the freezing of skin especially when outdoor air contains small amount of moisture. Also low level of relative humidity can cause the excess evaporation from water surface. So it can lead to the additional load on the air-conditioning system. /4, p.8./

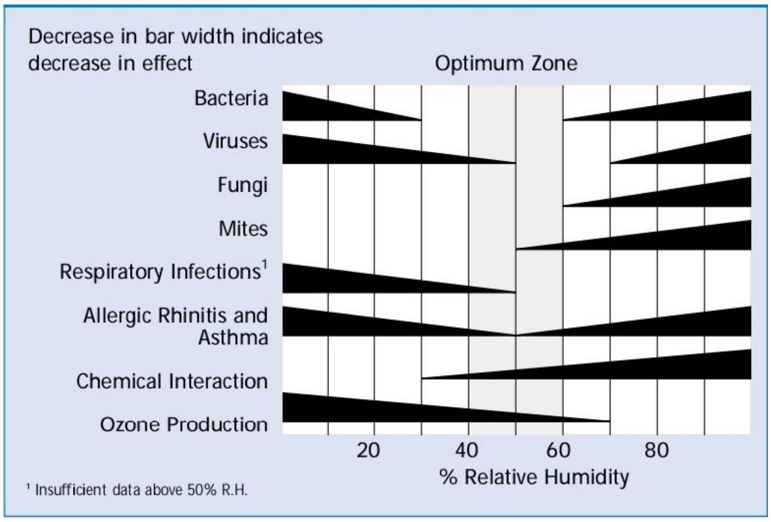


FIGURE 2. Health factors vary with relative humidity /7, p.4/

Feature of swimming hall's microclimate is that the moisture in the pools area is distributed unevenly depending on pool's height. Humid air is lighter than dry air, therefore it moves to the upper area of the space. The danger is that, if the room has surfaces with temperatures below the dew point, it will condensate on such surfaces. It can be air ducts and translucent structures with a thermal resistance less than $0{,}5 m^2 \cdot °C/W$. Moisture which appears on these surfaces can be intense and form fungi and mold at the interface to the wall. /13, p.5-6./

The next challenge of indoor climate in swimming halls is the low and high air temperatures. It effects to swimmer conditions. Swimmers and personnel lose more radiation heat and the sensation of draft appears in swimming pool even there is no air moving /4/. But the problems with the indoor climate may occur even when the air temperature is high. However, the increasing of temperatures is also undesirable because it creates number of problems:

- Microorganisms will multiply faster.
- Pool users will swim more actively so it increases water pollution through sweat and body oil contamination in the water.
- There will be more moisture in the pool atmosphere, even when relative humidity will be controlled at the same level. Risk of condensation and also corrosion and deterioration of the building, structure and equipment appear.
- Chloramines will form more rapidly.

Nowadays it is difficult to select a single appropriate or optimum operating temperature for any particular pool. The large volumes of water do not allow to change water temperatures rapidly in a pool. This means that the selection and proper control of the optimum water temperature for each pool is essential to maintain efficiency and customer satisfaction. /6, p.63./

The next challenge of swimming halls is the air impurities. The unpleasant smell is always an indication that the air contains any impurities. It is known that the air quality is directly affected by the water quality.

Many people often complain about a strong “chlorine” odor which is found in pool rooms. Actually, this odor is not chlorine. Chlorine cannot be smelled by humans until it is above toxic levels. In the pool room people smell intermediate compound of chlorine which is formed during the disinfection process. This odor is produced by the combination of chlorine and sweat, oils and urine in water. It is called chloramines, which are volatile. These substances can be detectable by humans at low concentrations. The formation of chloramines occurs only when there is not enough free chlorine in the pool. In order to get rid of chloramines, it must be “shocked”. It means seven times the presented amount of combined chlorine should be added to the water.

When people smell "chlorine," the pool water chemistry should be changed by increasing chlorine level in the water. Proper ventilation can assist with maintaining water quality by the removing airborne chloramines. /5./

A proper HVAC design will adequately remove these chemicals and provide good indoor air quality. Typically, HVAC-engineer designs air-conditioning system which supplies extra air in order to control any potential odor problems. /5./

Air quality in swimming pools depends on the amount of fresh air that is introduced into the space every hour. In other words, it depends upon adequate quantity and velocity of supply air. Therefore poor air distribution can cause discomfort for visitors too. Fogged or wet windows are leading indicators of airflow problems.

Ventilation is important in indoor swimming pools since it provides humidity control and swimmer comfort. But there is the classic conflict. On the one hand, air movement above the water surface is good, because it assists to remove of chloramines and to protect the swimmer's breathing zone. But on the other hand, air movement is bad, because it increases energy consumption and relative humidity in the pool through increased evaporation rates. Also it can produce a "cold" effect on swimmers.

Relationship between air velocity and evaporation rate varies. The air velocity above pool water surface increases the evaporation rate. A balance should be controlled in order to maintain desirable air quality while it will not generate too much load to the dehumidification system. /7, p.4./

Excessive air movement around the swimmers should be avoided. High air velocity level will increase the amount of heat transferred from human body as a result of convection. Generally heat emissions from human body decrease and the overheat zones appear along with the cold zones. These overheat zones cause the sensation of draught. /4, p.8./

The air distribution system should be designed to minimize stagnation zones in the building. The airflow should moves in the correct direction. It ensures that humidity and odors will not transfer into adjacent spaces, and also minimizes the potential for condensation. Supply air should be covered windows and other surfaces which can have low temperatures in cold weather. It assists to prevent condensation. Exhaust and return air inlets should be located as high as need to take heated and humid air. /8, p.3./

For proper IAQ, a natatorium must have synergy between the building envelope, the air distribution (ductwork), mechanical dehumidification equipment and water chemistry. If any of these important components break down, the facility will not function properly /9./

3.2 The necessary equipment of air-conditioning systems

Choice of necessary equipment for swimming halls is a complex issue. It is generally recommended that air is covered the whole area, and that air movement in the occupied zone is maintained with acceptable conditions for swimmers and stuff comfort. Air-conditioning systems is designed for the solving problem as contaminants removal from the air. It also controls pool air quality, temperature, humidity, evaporation from the water surface and condensation to maintain comfortable environmental conditions. /6, p.64./

The main problems in indoor climate can arise due to inappropriate design or incorrect equipment selection. This chapter is therefore called “the necessary equipment” to prevent the problems described above, but do not overspend energy.

In this Bachelor’s thesis three common ways of achieving good indoor climate in swimming halls will be considered.

3.2.1 Air-conditioning systems with dehumidifier

Air-conditioning system with dehumidifier is one of the most effective systems for providing good indoor climate in swimming halls. This method is optimal for maintaining the relative humidity of the pool. Air is supplied to the pool with the necessary air flow rate and dehumidifier will dehumidify the air to the required level, which will be comfortable for visitors and staff.

This system does not create draft and works even with a hundred percent humidity outside. This is radical difference from a simple ventilation system where supply and exhaust system operate separately. If a simple system is used, then humidity control in the pool is not possible in the summer after rain.

There are two kinds of air-conditionings systems with dehumidifier:

1. Air-conditioning system with separate dehumidifier.

It means that there are separately mounted supply and exhaust systems that operate at one time. Supply system produces air intake, filters it, regulates the temperature and humidity, and then provides air flow into the room with fan. Exhaust system collects air with the exhaust fan and gives it completely to outdoor.

2. Air-conditioning system with dehumidification function.

Such systems are used for large pools or water parks. Most often, it includes features such as dehumidification, filtration, heating, cooling, ventilation and heat recovery. Purified fresh air is supplied to the pool through the duct system. Special automation devices allow you to switch on or switch off the system depending on the temperature and humidity levels in the pool.

As in the first and in the second cases the principle of dehumidifier's operation is the same.

3.2.2 Air-conditioning systems with heat recovery

The next air-conditioning system which is used in swimming halls is air-conditioning system with heat recovery.

There are two main functions that air-conditioning system should perform:

1. Removal of carbon dioxide and odors;
2. Correction of humidity-level to remove condensate.

Air-conditioning system with heat recovery is the most efficient and economical system for creating good indoor climate in the pools. Its advantage is that such system allows and maintain the recommended indoor climate and minimize power consumption.

Recovery is a process when part of the energy is returned for re-use. It means heat is transferred from the extract air to supply air, but these streams are separated in the heat recovery unit. If the temperature of the exhaust air is not sufficient, the heater is switched into to operate. Such systems also include features such as dehumidification, filtration, heating, cooling and ventilation. But, as mentioned above, such system for pools saves from 60 to 92% of the thermal energy. It depends on the type of heat exchanger.

3.3 Research results of case studies in swimming halls

In this chapter two case studies will be considered. The first is based on Martha G. VanGeem's, Kami Farahmandpour's and John Gajda's studies about building material problems caused by condensation at an enclosed swimming pool and an enclosed ice rink /3/.

As authors have written, enclosed swimming pools in winter climates have high indoor relative humidities which can contribute to condensation and premature damages of building materials. Therefore good indoor climate conditions into the pools should be provided.

The authors have investigated swimming hall after roof leaks and around some skylights were noted. After preliminary inspection, it was determined that the reported leaks were related to building moisture problems. Water streaks were visible on the exterior walls below the cornices and under windows. The evaluation included a visual inspection, fourier transforminfrared spectrometry (FTIR) analysis on water stains on the masonry walls, borescope inspection through roof and wall assemblies, measurements of interior relative humidities and temperatures, measurement of interior-exterior pressure differentials, and exploratory openings made through the roof assembly. Analyses were performed to evaluate condensation potential through the roof and wall at actual and design conditions.

As a result authors have got that the roof and walls were constructed in accordance with design plans. The noted leaks in the skylights area were related to condensation in the roof assembly. The brown stains at the exterior walls were also related to this condensation. It's possible, water condensed on the ventilated deck boards and leaked to the interior through skylight openings. Condensation at the skylights was further deteriorated by the presence of steel support angles around the perimeter of the skylights. These steel angles are thermal bridges that resulted in their low surface temperatures. Humid indoor air condensed as it contacted with the cooler steel surfaces. The condensation in the roof assembly was caused by lack of an effective vapor barrier on the interior surfaces of the roof assembly. It is possible that continued condensation has caused damage to the ventilated deck boards or other roof assembly components. In the absence of an effective vapor barrier, heated and humid air from the pool area penetrated the building envelope. As it reached the colder surfaces of the exterior brick, it condensed. It was caused by pressure differences. As air passed through the porous structure, it dissolved water-soluble salts such as calcium carbonate and brought these salts to the outside surfaces of the brick.

The only effective method to prevent condensation in such building is to provide a continuous vapor barrier on the interior surfaces of the pool area. For long-term prevention of moisture problems, authors have recommended to install the vapor barrier in the walls between the pool area and the workout room, offices, and second floor lounge. Also rough surfaces should be smoothed to prevent cuts on the vapor barrier. A layer of moisture-resistant wallboard or cement plaster can be installed over the vapor barrier. The interior surfaces of the wallboards should be finished and painted with a vapor retarding paint. Vapor barrier in the roof assembly and exterior walls should be continuous. /3, p.1-5./

The next five paragraphs are based on Randy C. Baxter's studies about designing for IAQ in natatoriums /10/.

In the last 10 to 15 years research has shown that poor air quality in indoor swimming pools has a negative impact on the health of swimmers, coaches and pool workers. Therefore author in her article would like to review the literature concerning the effects of disinfectant by products on indoor swimming pool air quality and to propose practical methods for reducing their impact in conventional pools.

For the purpose of this article, only the inorganic chloramines will be considered. Monochloramine is always present in chlorine-disinfected water and is frequently used by public water systems. Dichloramine is more volatile and more irritating substance to breathing than monochloramine but it is related with unpleasant taste and odor of water. Trichloramine, on the other hand, is a potent respiratory irritant. It effects on the respiratory system and eyes the same as chlorine gas. Many experts think that trichloramine is the compound most responsible for the indoor pool air quality problem. It can exist as a vapor and it is quite toxic.

In the past all proposals to achieving good indoor environment have focused on such areas as watertight pool buildings and equipment, dilution of the bad pool air with outside air and UV treatment to reduce combined chlorine levels in pool water.

But as practice shows these systems are not total solutions to the problem. It is known that modern indoor pools using these technologies have periodic air quality crises that raise health problems. It occurs because the modern pools have HVAC systems are designed to limit air velocity across the pool surface. If air velocity is increased enough to delete the trichloramine, then swimmer freezes. The increased rate of pool water evaporation, the increased rate of trichloramine release becomes problems. If the air velocity is not sufficient to remove trichloramine at a rate which exceed the formation rate, then air circulation and dilution will only succeed in continuously circulating trichloramine in the HVAC system.

Based on the information presented in this article author have recommended to take advantage of the high density of trichloramine vapor to keep it separate from HVAC room air circulation. Also exhaust trichloramine vapor should be taken out to the outside from a level close to the waterline. It shouldn't have a chance to diffuse into the pool space. One more solution is to design of air circulation system for setting up a careful air movement across the pool water surface /10/.

4 DEVELOPMENT OF THE RESEARCH TOPIC

4.1 Survey of the standards and recommendations

4.1.1 Russian norms and guidelines

This chapter is based on “Russian designing and building code 31-113-2004. Swimming pools.” /11/ and “Energy and HVAC environmental guidelines for the design of indoor swimming pools” of ABOK (Heating, Ventilation, Air Conditioning, District Heating, Building Physics Journal) /8/.

The swimming hall is a construction which consists of one or more pools, facilities and equipment to service the involved people, the visitors, as well as for the technical operation. Covered swimming hall is the building, where there is pool with ancillary facilities.

There are some tasks, which air-conditioning systems, ventilation and dehumidification of swimming pool must perform:

- The providing requirement parameters of indoor air;
- The providing parameters of air near building envelope, which need to prevent condensation in order to maintain their bearing capacity and appearance;
- Optimization of energy consumption depending upon the changes of microclimate /8, p.2./

For swimming pools it is necessary to provide separate supply and exhaust ventilation systems in accordance with SanPin 2.1.2.1188 /12/.

The temperature of water in the pool depends on the type of swimming pool. For the training pool, it is from 24 to 28°C. The temperature into the pool’s space is generally selected 1-2°C higher than the temperature of water. The maximum temperature doesn’t exceed 31 °C. The relative humidity is recommended to vary from 40 to 65 in the pools and absolute humidity should not exceed 14 g/kg. /8, p.4./ For the calculation of heat losses relative humidity should be taken 67% and the temperature is 27 °C. /11, p.48./ In the halls of the swimming baths with seats for spectators calculation of ventilation of pools should be performed for the two modes: firstly, it is with the audience (if it exists), secondly, it is without spectators.

Air handling unit should be placed in the basement and ground floors (on the ground) so that the length of the air ducts is as short as possible. In rooms that are designed for air-supply systems, the input of heat carrier, boilers and water pumping is allowed. The air handling unit is recommended to be chosen on the basis of their work in two ways: the first is as an independent supply and exhaust units intended only for non-work pool, the second is as additional installations which together with the first should provide air exchange for the duration of the pools.

Distribution of fresh air in the pool area is performed in such way that based on the location of visitors, as well as the design features of the building, translucent structures, slabs, etc. The priority task is to provide the required parameters of microclimate.

It is necessary to maintain a negative imbalance in relation to the surrounding premises to prevent the ingress more humid air and odors of chemically active substances from the pool into adjacent spaces. Excess of exhaust air above the supply should not be more than 10-15%, otherwise it is possible to get other types of discomfort, for example, drafts through insufficiently tight door or the smell of locker rooms, etc.

Arrangement of supply air with the mobility of air jets less than 0.15 m/s is recommended to prevent drafts. For this, it is advisable to use air diffusers with automatic air throw with adjustable guide vanes /11, p.48./

Height of pool’s hall is usually more than 4 meters. If you place the low-speed air supply diffusers under the ceiling, there may be difficulties with the organization of the air supply downstairs. To avoid a complicated adjustment, the air supply is performed at floor level so that air covers the coldest surface. This solution is recommended when ventilation and air heating are used both in cold climates.

Exhaust grids are not recommended to be placed at the level of distribution of fresh air, because dry outside air will go directly to the exhaust grids, it will not mix with the air of conditioned space. If there are jacuzzi-bath or children’s pool you should put extract grids close to these sources of increased water evaporation.

In pools the combined system of central air-or water heating can be used. Air heating systems, combined with the systems of ventilation are recommended. Such systems allow the use of recirculated air. The volume of fresh air supplied must not be lower than 80 m^3/h of outdoor air for a swimmer or not less than 20 m^3/h for spectators. /11, p.46./

In order to avoid the cold air flows from the windows heat emitters should be placed under them and near exterior walls. Internal surfaces of building envelope should have temperature higher than the dew point of exhaust air (normally 16°C). It is recommended that the coldest surface has a 3°C higher temperature than the dew point temperature. /11, p.48./ Special attention should be paid to translucent constructions. To avoid condensation on these surfaces it is necessary to increase their temperature or to decrease humidity in contact with the cold glass and translucent surfaces. The simplest solution is the local heating of air in the area of windows, for example, by conventional radiators. But this method applies only for a small glass area (less than 20%). The alternative is the organization of the distribution heated fresh air by compact jets, especially in buildings with large areas of glazing (20%). In the area of cold ceilings it is possible to distribute air by jets toward ceiling with a maximum coverage area. It is allowed to use jets of air recirculation. /8, p.5./

For the protection of building envelope from over moistening and premature destruction the organization monitoring temperatures of the surfaces and the air near the ceiling is recommended. If there are conditions for condensation it is necessary to include independent system airflow of ceilings. This airflow of ceilings also recommended to protect them after work days in the presence of water vaporization from the pool water /17, 18./

4.1.2 Finnish standard and guidelines

This chapter is based on D2 Regulations and guidelines 2003 “Indoor climate and ventilation of building” /13/ and Finnish recommendation 06–10451 “Swimming halls. HVAC design” /2/.

D2 Regulations and guidelines 2003 "Indoor climate and ventilation of building" gives some information concerning swimming pool area except the general recommendation about the acceptable indoor climate. Indoor climate of swimming pool area has to be designed and calculated in such a way that air movement, surface temperatures and other indoor factors don't cause discomfort to the visitors. At the same time there shouldn't be such internal conditions which can cause damage of building construction.

So, outdoor air flow which D2 recommends is 2 $(dm^3/s)/m^2$, air velocity is 0,40 m/s and moisture removal is a design factor, which should be calculated separately in each case.

As you can see in this guideline there is not sufficient basis for designing air flow rates according to the number of occupants. In this case the design should be based on the surface areas in question. Also these guidelines don't give the exactly recommendations about the acceptable moisture level in swimming pools /13, p.35./

Next, Finnish recommendation 06–10451 "Swimming halls. HVAC design" will be presented /2/.

The task of the air-conditioning system in the pool is creation of a comfortable and healthy environment for swimmers, as well as protection against moisture damage to building envelope. After swimming skin and swimsuits of swimmers are wetted, therefore water evaporates quickly from these surfaces, causing the skin to freeze rapidly. Swimmers may feel cold when they come out from the water. If the temperature and humidity control will be high enough that the evaporation from the skin surface will decrease and the conditions for pleasurable sensations will appear. Staff working in the room feels discomfort associated with high temperature and high relative humidity.

The temperature of water in the pool depends on the type of swimming pool. For the basic pool, fitness pool and sports swimming it is from 26 to 28°C. The temperature in the pool's space is generally selected 1,5-2,5 °C higher than the temperature of water. The maximum temperature doesn't exceed 31 °C. Most of the heat loss occurs through windows in the walls, then, windows should be blown with air warmer than it is served in the pool, or to arrange electroheating of glass. If the temperature in the pool is less than required, stuff will feel uncomfortable.

To reduce the evaporation from the skin surface of swimmers and from pool's space it is necessary to establish the relative humidity as high as possible, ranging from 45 to 55%. Relative humidity should not exceed 60%, because it promotes the growth of bacteria. The maximum moisture content of dry air is 14,3 g /kg (0,0143 kg /kg dry air), which corresponds to the internal conditions of 28°C temperature and 60% relative humidity.

Maximum permissible air velocity is 0,4 m/s. Ventilation in the pool is calculated by air exchange rate, and the value should be at least 4-5 1/h.

It is important to arrange the distribution of air. In order to remove impurities from air, the air velocity should be more than 0,2 m/s over the water. However, removal of impurities from the air exhaust chamber degrades correct operation. Exhaust air containing impurities is removed over a roof of the swimming hall. Supply and exhaust grids should be set in such way that it can be adjusted to provide air of pool area, corridor and ceiling.

Pool's heating often is combined with air heating because humidity control always requires large flows of air. Good technical design of heating and blown windows completes air heating. Different types of pools require their own air heating systems. Comfortable temperature for air heating will be 3-5°C higher than the temperature of the pool water.

Traditional radiators are not recommended for wet conditions pool heating system. Traditional radiators can be used only for specific purposes, for example, for compensating the heat loss from the windows /2, p.1-13./

4.1.3 The USA standards

The following chapter is based on ASHRAE standard 62.1-2004 "Ventilation for acceptable indoor air quality" /14/ and article "Systems of climatology" /15/.

The main problem of swimming halls is the high relative humidity. For sports pools optimal air temperature is 27-28 °C or slightly lower. This is due to the recommendations of the doctors to keep the air temperature by about 1°C above the water temperature. Evaporation from water surfaces is minimal and swimmers feel comfortable. If there is high water temperatures it causes big temperature difference between air and water, resulting in increase the rate of evaporation from the surface of the pool. It is necessary to combine the most comfortable temperatures of air and water with the help of the proper selection of equipment, which adjusts relative humidity to the required level.

Relative humidity in the pool area should be 50-60% to maintain a comfortable environment and an adequate level of water evaporation. In this case, when the air temperature is 28-30°C dew point temperature will be between 16°C and 21°C. In public pools absolute humidity of air can be 3/4 higher than normal moisture content in the air-conditioned rooms. The designer should take this into account and to reduce condensation on the surfaces of walling. The constant formation of evaporation decreases while the pool is unoccupied. While pool is unoccupied water evaporation is formed by 25-35% lower than in working time, the load on the equipment for reducing the moisture still retains. Constant air circulation should be maintained 24 hours a day /15, p.57./

In addition to maintaining a constant level of relative humidity, the designer should think about the air quality. Therefore, to maintain acceptable conditions in the pool ventilation should operate, ensuring the assimilation of chemicals from the water surface, in addition to ordinary human secretions. To provide acceptable indoor air quality recommended ventilation rate is 2,4 l/s per 1 m^2 of swimming pools, including floor area /14, p.243./

Optimal air exchange ranges is from 4 to 8. Such wide range of recommended values is due to differences in the intensity of pool’s using, it attendance and type of equipment /14, p.240./

The main task of the air distribution system is achieving effective reduction of relative humidity and acceptable air quality in the pool. Simple increasing of air flow through the equipment should not solve the problem of condensation and formation stagnant zones, which accumulates “bad” air. In the pool there are many places where it is necessary to create sufficient air flow to maintain the quality of air or to prevent condensation.

Air flow above the water surface should be minimized to avoid the excess of its mobility in the area of swimming. Moreover, it allows to reduce the evaporation, which increases with the increasing of air velocity. The velocity of the air should not be zero because various gases will accumulate above the pool’s water surface. Then, swimmers will have irritating of eyes and respiratory problems. Location of supply air grills at the high 4,5-9 m. can prevent formation of the flow above the water /15, p.56./

To avoid complicated adjustment of direction supply air grills are often installed at floor level. But there are some mistakes that should not be allowed. For example, exhaust grills should not have the same level as the supply air grills. This leads to the fact that the supply air directly comes into the exhaust system and it is not mixed with air of conditioning space. Another common mistake is wrong size of exhaust grilles. Air moves through the small exhaust grids with a higher rate, and the noise is only getting stronger.

Because of excess relative humidity and temperature in swimming pool heat load of heating system or dehumidifying system will be increased. If we have about +29 °C of indoor temperature in swimming pool and intake air flow with temperature less than +29 °C, this cold flow reduces indoor temperature and increase heat load of the heating equipment. But if relative humidity of outdoor air is less than this one of indoor air, it helps to reduce the humidity /15, p.58./

In the children’s pool or jacuzzi air grille should be installed near the water to reduce the effect of increased evaporation. Sometimes these areas should use extra exhaust fan.

Proper air distribution also depends on the quality of air ducts mounting. It should be mounted in such way that there is no condensation. All joints of supply and exhaust air ducts shall be tightly sealed. If the ducts are laid outside the conditioned space, it should be placed in the insulation. Ducts for pools are made of materials which are resistant to corrosion by chlorides and their connection should be sealed, wrapped and covered with mastic.

If any surface is cooled to a temperature below the dew point of ambient air, condensation begins. Cold surfaces are northern exterior walls, windows, frames of windows and doors and skylights. Single glazed windows, metal windows and door frames create thermal bridges between the cold air outside and humid air inside. Skylights are the same as the windows, but it is located near unfavorable areas in terms of availability of condensate. Warm and humid air rises to the ceilings, where the air flow is usually very weak. Therefore, the humidity level around the skylight is higher than elsewhere.

The key parameter is the dew point temperature. Dew point temperature of the air in the pool is high because of the specificity of buildings. The coldest surface temperature should be at least 3°C higher than the dew point of the air in the pool. When the dew point of the outside air is low, equipment that uses 100% outside air is installed. In such AHU, heat recuperators are used to ensure efficient heat transfer between the supply and exhaust air. Heat pipes or type of heat exchangers “air-to-air” are used as heat recuperators. If the dew point temperature of the outside air higher than 15-20°C, then, as a rule, it requires additional dehumidification. If the outdoor temperature is higher than 24°C, air cooling is required, and in the winter additional heating is required /14, 15./

4.2 Calculations

4.2.1 Calculation of absolute humidity

Equation for absolute humidity /8/ is

$$AH = 0{,}622 \cdot \frac{p_w}{P - p_w} \tag{1}$$

where p_w is the partial pressure of water vapour, kPa

P is the total pressure of dry air (=101,325 kPa)

Formula of the partial pressure of water vapour /8/

$$p_w = \varphi \cdot p_{ws} \tag{2}$$

where φ is relative humidity, %

p_{ws} is the pressure of saturated water vapour, kPa

Based on equations (1) and (2) formula for absolute humidity is

$$AH = 0{,}622 \cdot \frac{\varphi \cdot p_{ws}}{101{,}325 - \varphi \cdot p_{ws}} \tag{3}$$

Formula of the pressure of saturated water vapour /8/ is:

$$p_{ws} = \frac{\exp\left(77{,}345 + 0{,}0057 \cdot (t + 273{,}15) - \dfrac{7235}{t + 273{,}15}\right)}{(t + 273{,}15)^{8,2}} \tag{4}$$

where t is the temperature of air.

4.2.2 Calculation of air flow rate according to Russian standards and guidelines

In this chapter amount of outdoor air which is required for the providing of recommended relative humidity level in the pool will be determined according to Russian standard and guideline. Method of calculation is based on “Energy and HVAC environmental guidelines for the design of indoor swimming pools” of ABOK (Heating, Ventilation, Air Conditioning, District Heating, Building Physics Journal) /8/.

It is known that the evaporation rate is determined by the velocity of water vapour which crosses through a thin boundary layer of air immediately adjacent the surface of the water. Quantity of evaporated moisture depends on the difference between partial pressure of water vapor in the boundary layer and partial pressure of air in the space. It also depends on linearly the water surface area. The amount of moisture coming into the room much increases with the number of visitors.

When water evaporation is calculated, it is necessary to take into consideration evaporation from floor. Area of water evaporation is equal to area of pool. The values of evaporation rates from the surface of water are given in the table 1.

TABLE 1. Evaporation rates /11/

Type of swimming pools	Evaporation rates, m/h	
	After work day β_u	During the work day β_b

Public swimming pool: • depth of pool is less than 1,35 m.	7	28
• depth of pool is more than 1,35 m.	7	40

At first, water evaporation from the surface of water should be calculated with formula 5 /8/ twice: firstly, it is for the time of work day and secondly, it is for the time after work day.

$$M_{D.B.b(u)} = \frac{\beta_{b(u)}}{R_D \cdot T} \cdot \left(p_{D.W} - p_{D.L}\right) \cdot A_B \qquad (5)$$

where $\beta_{b(u)}$ – the evaporation rate at work (after work) day, which is given in the table 1, m/h;

R_D is the gas constant (=461,52 J/kg·K);

T is average temperature of the water T_w and air T_R, K;

A_B is area of water surface, m^2;

$p_{D.W}$ is pressure of saturated water vapour, which is given in the table 2, Pa;

TABLE 2. Pressure of saturated water vapour /11/

t_w, °C	$p_{D.W}$, Pa
23	2809
24	2984
25	3168
26	3363
27	3567
28	3782
29	4005
30	4246

$p_{D.L}$ is partial water vapor pressure for specific temperature and relative humidity in the pool, Pa. It is determined with formula 6 /8/.

$$p_{D.L} = \frac{\varphi \cdot p_{D.W}}{100\%} \tag{6}$$

where φ is relative humidity of air, %.

Secondly, water evaporation from floors (kg/h) can be determined with formula 7 /8/.

$$M_{D.p.} = 0{,}006 \cdot (t_R - t_{WW}) \cdot A_p \tag{7}$$

where t_R is temperature of air, °C;

t_{WW} is the temperature of floor, °C;

A_p is the area of wet surfaces around pool, m^2. Usually it is accepted that wetted perimeter of the floor around pool is at a distance of 1,5 – 2,0 m. from its edge.

After that, mass flow of outdoor air (kg/h) which required for the providing of recommended relative humidity level in the pool will be calculated with formula 8 /8/.

$$M_{A.S.} = \frac{M_{D.B.b} + M_{D.p.}}{X_{DL} - X_{DA}} \cdot 10^3 \tag{8}$$

where $M_{D.B.b}$ is water evaporation from the surface of water, kg/h;

$M_{D.p.}$ is water evaporation from walkways, kg/h;

X_{DL} is the maximum water content in the pool's air, g/kg (=14 g/kg)

X_{DA} is the water content of outdoor air, g/kg. It is found out with formula 9 /8/.

$$X_{DA} = 0{,}622 \cdot \frac{p_{DA}}{p_B - p_{DA}} \cdot 10^3 \tag{9}$$

where p_{DA} is the partial pressure of water vapor in the outside air, Pa.

p_B is the barometric pressure, Pa. Values for these pressure are given in the table 5a and table 2 of SNiP 23-01-99* "Building climatology".

Usually volume air flow rate is used. Mass flow rate can be converted to a volume flow rate by dividing it the density of air (formula 10) /8/.

$$L = \frac{M_{A.S.}}{\rho_{air}} \tag{10}$$

4.2.3 Calculation of air flow rate according to Finnish guidelines

In this chapter amount of outdoor air which is required for the providing of recommended relative humidity level in the pool will be determined according to Finnish guideline. Method of calculation is based on Finnish recommendation 06–10451 “Swimming halls. HVAC design” /2/.

The amount of water that evaporates in the pool can be calculated using several formulas. The resulting values will be different, because in these formulas there are some various empirical coefficients. Mass flow rate of evaporated water (formula 11) /2/ is calculated using the method of the German calculation VDI 2089. Mathematical coefficients include evaporation from the water surface, from the wet floor, from swimmer’s skin and their wet swimsuits.

$$q_{VM} = A \cdot \frac{B_p}{R \cdot T} \cdot (p_v - p_i) \qquad (11)$$

where q_{VM} is the mass flow rate of evaporated water, kg/s;

p_i is the partial water vapor pressure for specific temperature and relative humidity in the pool, Pa;

p_v is the pressure of saturated water vapour, Pa;

B_p is the empirical coefficient of evaporation is given in the table 3, m/h;

A is the area of water evaporation, m^2;

R is the gas constant (=461,52 J/kg·K);

T is the average temperature of water and air, K.

TABLE 3. Coefficient of evaporation /2/

Type of swimming pools	B_p, m/h
Public swimming pool:	
• depth of pool is less than 1,35 m.	28
• depth of pool is more than 1,35 m.	40

Below there is equation (formula 12 /2/) based on the original formula of VDI 2089, but which uses the absolute air humidity difference instead of the difference of the partial pressures of water vapor.

The partial pressure values, and compares the absolute humidity, so that when the absolute humidity is calculated, there is a slight error. For indoor pools error ranges from 1 to 4%. At higher temperatures, the water in the pool, the error increases. For example, if the pool water temperature 36 ° C, then the error is about 8%. Evaporation rate B_x converted into the original equation coefficient.

$$q_{VM} = A \cdot B_x \cdot (X_v - X_i) \qquad (12)$$

where q_{VM} is the mass flow rate of evaporated water, kg/s;

X_i is absolute humidity of air, which calculated with formula 3, kg/kg dry air

X_v is water content of air at 100% humidity, kg/kg;

B_x is the empirical coefficient of evaporation is given in the table 4, kg/m^{2}s;

A is the area of water evaporation, m^2.

TABLE 4. Coefficient of evaporation /2/

Type of swimming pools	B_x, kg/m^{2}s
Public swimming pool:	
• depth of pool is less than 1,35 m.	0,0087
• depth of pool is more than 1,35 m.	0,0125

Then, mass flow of outdoor air (kg/s) which required for the providing of recommended relative humidity level in the pool will be calculated with formula 13 /2/.

$$q_{MI} = \frac{\sum q_{VM}}{(X_p - X_t)} \qquad (13)$$

where q_{VI} is mass flow of outdoor air, kg/s;

$\sum q_{VM}$ is the mass flow rate of evaporated water, kg/s;

X_p is the absolute humidity at exhaust temperature kg/kg dry air;

X_t is the absolute humidity at exhaust temperature kg/kg dry air.

4.2.4 Calculation of volume flow rate according to ASHRAE standards

In this chapter amount of outdoor air which is required for the providing of recommended relative humidity level in the pool will be determined according to ASHRAE

Applications Handbook 1989 /16/. Calculation of outside air flow rate to maintain a given level of relative humidity in the swimming hall is performed in two stages. At the first stage the water evaporation from the surface of water should be calculated with formula 14 /16/.

$$W_p = 0{,}1 \cdot A \cdot \left(P_w - P_a\right) \tag{14}$$

where W_p is the water evaporation from the surface of water, kg/s;

A is the area of water evaporation, m^2;

P_w is the pressure of saturated water vapour at the water temperature, Pa;

P_a is the pressure of saturated water vapour at dew point temperature of space, Pa.

The second phase is the calculation of outdoor air which is required for the assimilation of water evaporation. Minimum amount of outdoor supply air is determined with the formula 15 /16/.

$$Q = \frac{W_p}{60 \cdot r \cdot \left(W_i - W_0\right)} \tag{15}$$

where Q is the volume flow of outdoor air, l/s;

W_p is water evaporation from the surface of water, kg/s;

r is the air density at the normal conditions (=1,204 kg/m^3);

W_i is the calculated water content of space air, kg/kg;

W_0 is the calculated water content of outdoor air, kg/kg.

The equations were written for pools with normal conditions of ambient air where the air velocity above the water surface is in range of 0,05-0,15 m/s, and the latent heat of vaporization at the temperature of pool's water is about 2330 kJ/kg.

4.3 Measurements

Measurements have been carried out in Russian and Finnish swimming halls. The building envelope and it properties will be described in each case.

All of measurements have been carried out with temperature and humidity dataloggers CEM DT-172 which is presented in figure 3. Temperature range for device is from -40 to 70°C, where temperature accuracy is ±1°C. Humidity range is from 0 to 100% RH, where humidity accuracy is ±2 % RH.

FIGURE 3. Temperature and humidity datalogger CEM DT-172

Additional measurements of CO_2 level were carried out in Finnish swimming hall. Data logger Tinytag TGE-0010-SPK was used. You can see it in figure 4. Measuring range for device is from 0 to 2,000 ppm, where accuracy is ± (50ppm +2% of measuring value).

FIGURE 4. CO_2 logger Tinytag TGE-0010-SPK

Measurements were carried out for one day. Devices were reading the air temperature, relative humidity and CO_2 level every minute during the whole period of experiment. Devices were set in such way that the best reflects the parameters of area where staff and people coming out from the pool were located.

The results were converted into Excel-table. In this thesis average values for every ten minutes will be considered and analyzed. All of measurements will be shown on the diagrams.

4.3.1 Measurements in a Russian swimming hall

The indoor swimming pool facility is located in Saint-Petersburg. Construction of pool was completed in fall 1987. Detached pool building has brick exterior walls, inside the room walls were decorated with ceramic tiles.

The building was reconstructed in 2009. Floor beams and pool deck were tested. The heating system has been replaced in 2011. Temperature and air exchange rate inside the pool is measured twice a year. Measurements are carried out by a specialized company in order to determine their compliance to the standards. Also there is checking how adequate ventilation system works. In figure 5 you can see the current state of swimming hall.

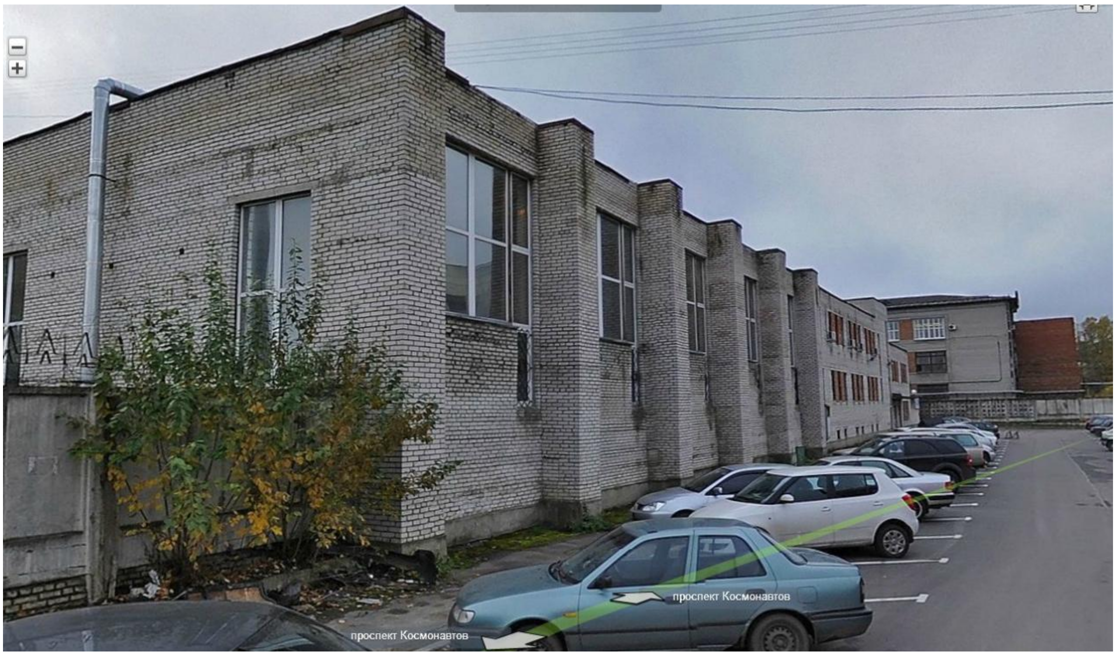


FIGURE 5. Russian swimming hall

The building includes public swimming pool area, workout room, offices. This pool is a training pool which is designed for training of swimming, fitness classes, workouts, as well as for the local competition without spectators or with limited number of spectators. Pool length is 25 meters, the width of each track is 1,8 meters. Swimming pool area also includes two water slides. But during the measurements the slides were not working, so the pool will be considered as a public swimming pool for swimming training, not a water park. The pool is presented in figure 6.

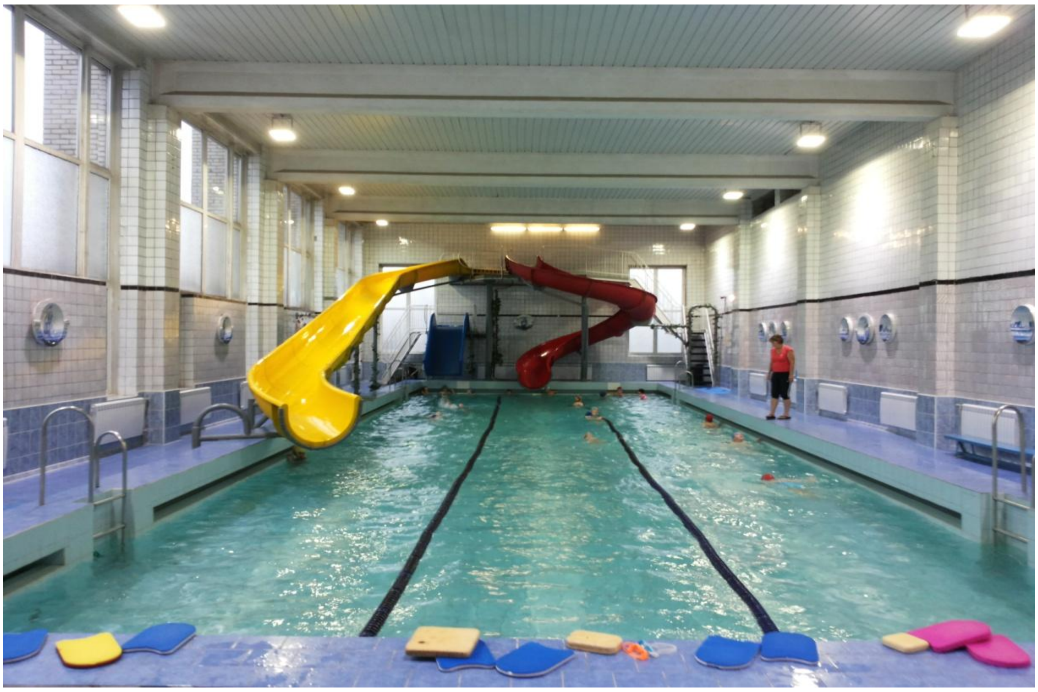


FIGURE 6. Space of swimming pool

Swimming starts at 8 a.m. and operates for 12 hours. The average number of visitors is 23,1 per hour, therefore 277,2 person visit the pool per the day. The highest activity comes at a time from 10 a.m. to 1 p.m. of the day, as it is time for swimming training of children groups, and from 6 p.m. to 8 p.m., because at this time is aqua aerobics classes are held for adults. Water slides operate once a week from five to eight in the evening.

The ventilation system in the pool is a simple mechanical ventilation system. This is separate supply and exhaust air systems, which work simultaneously. There are 2 supply and 1 exhaust systems, at that one of supply systems is reserve, it begins to work, when first system fails. Exhaust system operates continuously. In figure 7 you can see the location of supply and exhaust chambers for the pool.

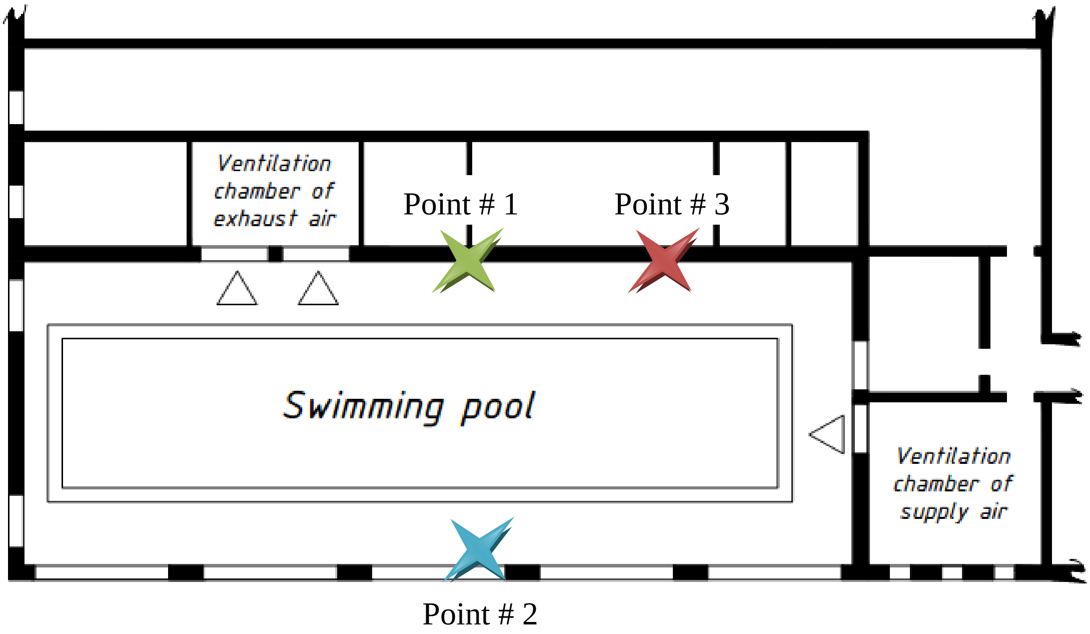


FIGURE 7. Location of supply and exhaust ventilation chambers. Sampling location 1-3

Measurements were carried out from 24th to 25th of October 2013. Start of measurements was recorded with instruments at 8 a.m. Location all of dataloggers you can see in figure 7. Dataloggers #1 and #2 were installed in points as it is shown in figure 8. These points are closest to the walkway (floor around the pool). Visitors do not have to feel uncomfortable (freezing, draft) coming out of the pool, so it is important to control the temperature, humidity and air velocity in this area. Also, points # 1 and # 2 is located at the level of human height, you can see it in figure 8. It will determine the most accurate temperature which swimmers, wait staff or, for example, the coaches feel.

The devices were installed on wall decor, as it was seen in figure 9. The points were arranged so that there were no external influences, such as penetration of water. And also data loggers were mounted quite distant from the heating device to not sense the excessive temperature.

FIGURE 8. Points #1 and #2 for measurements with dataloggers

FIGURE 9. Location of the first datalogger

The third point was located on the same wall as the first, but the datalogger values are more interesting for the analysis, as this point is closer to the exit from the pool. This is the place where temperature difference of water and air is highly noticeable. You can see the location of point #3 in figure 10.

FIGURE 10. Point # 1 and point # 3 for measurements

4.3.2 Measurements in a Finnish swimming hall

The public swimming pool facility is located 4,2 kilometers from the center of Mikkeli. Construction of pool was completed in 1992. Detached pool building has brick exterior walls and translucent constructions, inside the building walls were decorated with ceramic tiles and wood panels. The building was reconstructed in 2000. New part of the building was constructed, in which at the moment there are 3 pools: for children, multifunctional pool and pool with slides. You can see in figure 11 the current state of swimming hall.

FIGURE 11. Finnish swimming hall

The building includes public swimming pool area, gyms, café and offices. Studied swimming pool area includes two pools. First pool has length 25 meters, and width 10 meters. This pool is a training pool which is designed for training of swimming, fitness classes. Second pool has length 10 meters, and width 5 meters, and it was designed for children training of swimming. In this thesis big pool will be considered and it is presented in figure 12.

FIGURE 12. Space of swimming pool

Pool is open from 1.00 p.m. to 9.00 p.m. for Monday to Friday, from 8.00 a.m. to 10.00 a.m. on Tuesdays, from 11.00 a.m. to 6.00 p.m. on Saturday. The air-conditioning system of pool's area is controlled by a special automated program. It is schematically presented in figure 13.

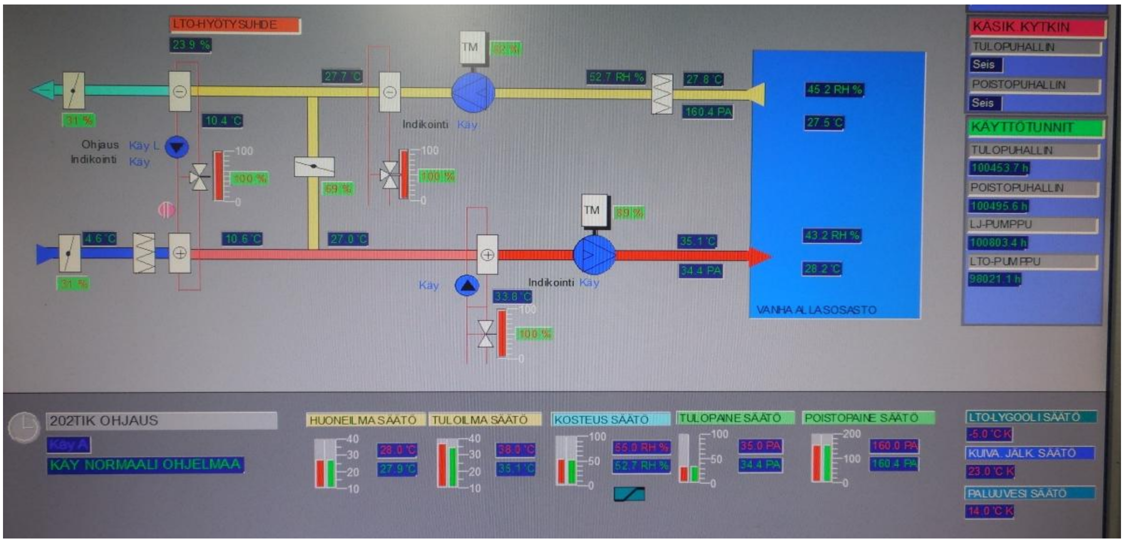
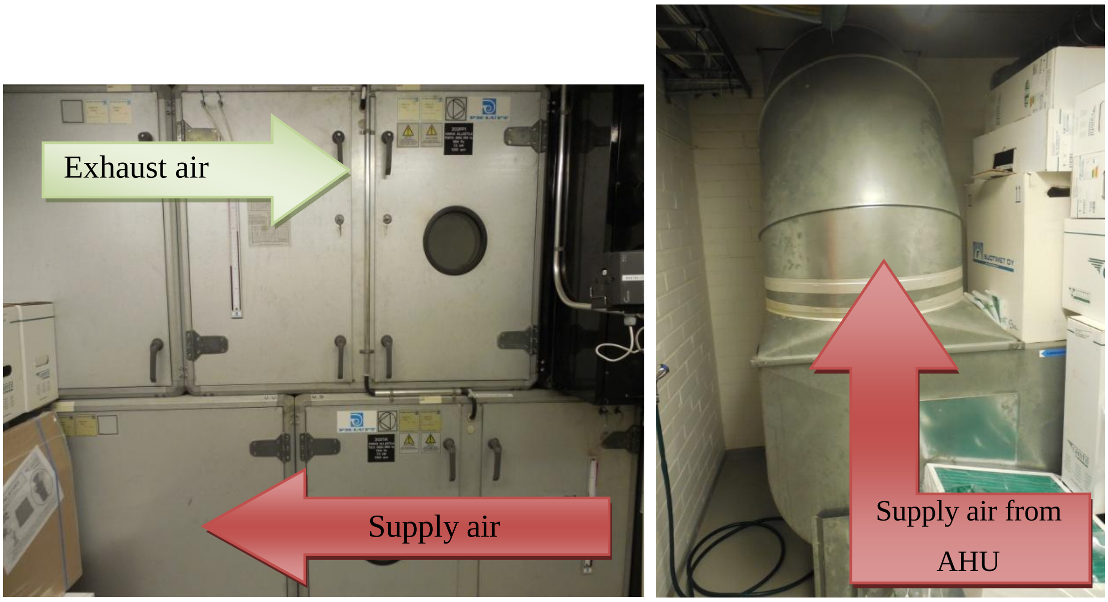
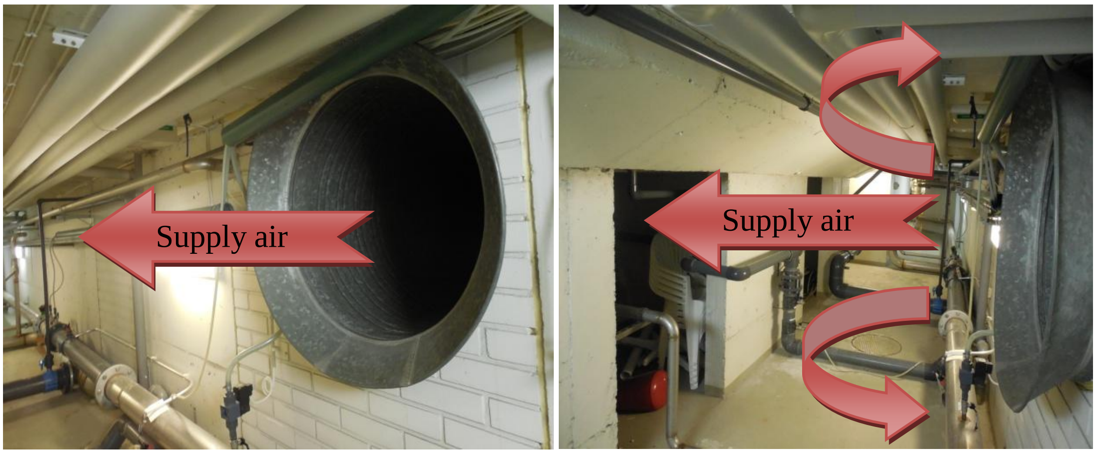


FIGURE 13. Drawing of pool's air-conditioning system

The air intake was located above the roof of the building, and then cold outdoor air passes through the two heaters, how it I shown in figure 14, where it is heated to the required temperature and after that it is supplied to the space under the pool by duct with diameter 800 mm. You can see it in figure 15 and 16. Heated air coming out from this duct goes to the chamber under the pool. It is shown in figure 17. After that it passes through holes in the ceiling, as it is shown in figure 18. Into the pool's space heated air comes through grids between windows and floors, you can see it in figures 19 and 20. Then, air is distributed throughout the pool area. Exhaust air goes into the two exhaust grids, which are located on the interior wall, as it is shown in figure 21. Part of the exhaust air passes through the bypass and mixes with air which was heated in the first heater. This mixture will have temperature higher than temperature of air after the first heater, therefore it allows to use less energy on reheating. The remainder of the air goes out, as it is shown in figure 13.



FIGURES 14-15. AHU for big swimming pool's area. Duct of supply air



FIGURES 16-17. Supply air duct. Chamber under the pool's area

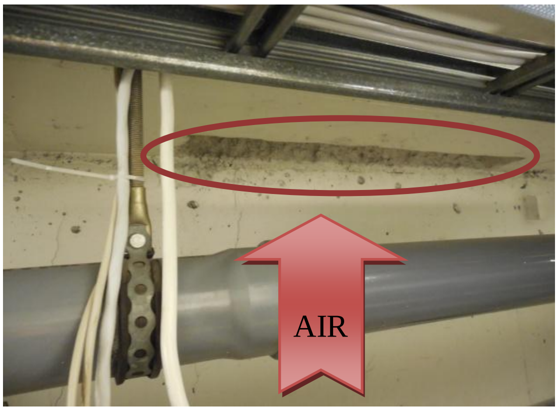


FIGURE 18. Intake grill in the ceiling of chamber under pool

FIGURES 19-20. Supply heated air from grids in the pool's space

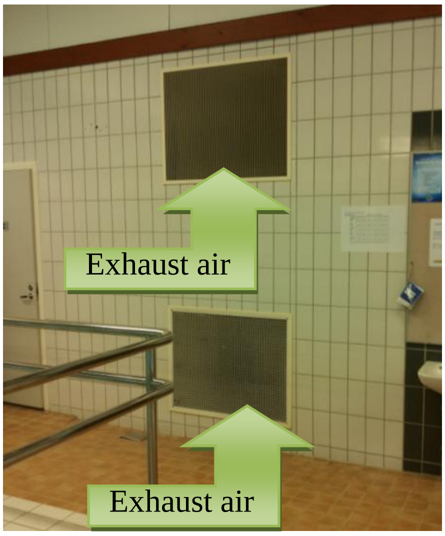


FIGURE 21. Exhaust grids in the interior wall

Measurements were carried out from 21st to 22nd of November 2013. Start of measurements was recorded with instruments at 8 a.m. Location all of dataloggers you can see in figure 22. Datalogger #1 and device for measuring CO_2 were set such way to obtain more sensible values of temperature, relative humidity and CO_2 concentrations for personnel or swimmers. It is shown in figure 23. Dataloggers #2 and #3 were installed in points as it is shown in figure 24. This is an important area, because visitors do not have to feel uncomfortable (freezing, draft) coming out of the pool. Also, points # 2 and # 3 is located at the level of human health (1,7 m.). It will determine the most accurate temperature which swimmers, wait staff or, for example, the coaches feel.

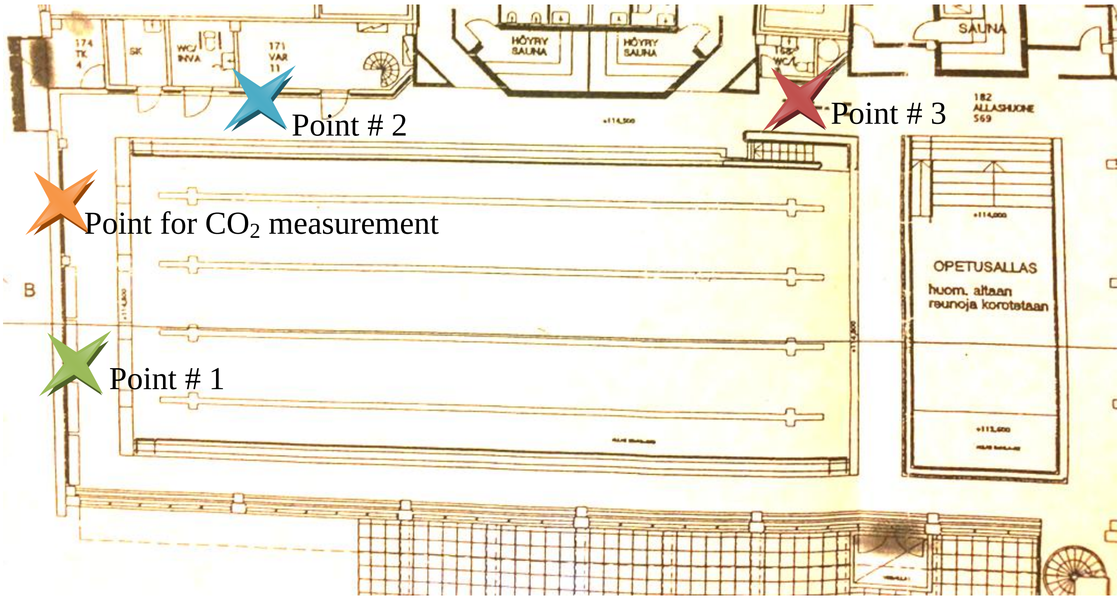


FIGURE 22. Sampling location 1-3 and CO_2

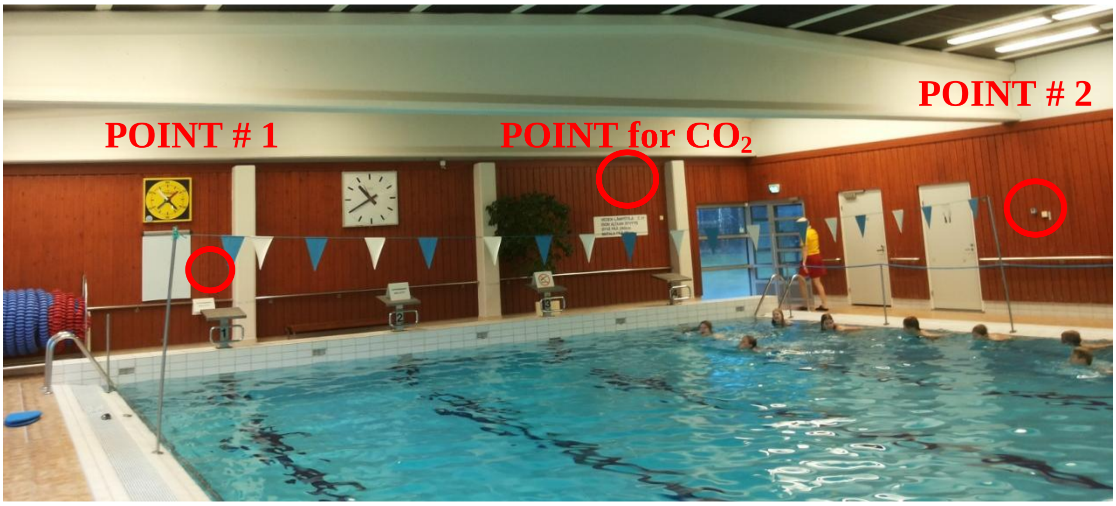


FIGURE 23. Location of points # 1, # 2 and point for CO_2 measuring

The devices in the points #1 and #2 and CO_2-logger were installed on wood panels of walls, as it was seen in figure 25. Point # 3 is located on the exhaust grill. This makes it possible to measure temperature and relative humidity of the exhaust air. The points were arranged so that there were no external influences, such as penetration of water. And also data loggers were mounted quite distant from the windows to not sense the low temperature.

FIGURE 24. Location of points # 2 and # 3

FIGURE 25. Location of dataloggers #1, #3 and CO_2-logger

Now, it is possible to study results of measurements and analyze it.

5 RESULTS AND ANALYSIS

5.1 Analysis of differences between international and Russian standards and guidelines

In this chapter requirement parameters of indoor climate of swimming pools will be resulted. You can see all required meanings in table 5.

TABLE 5. Requirement parameters according to Russian and international standards and guidelines

	Water tem-pera-ture	Air tempe-rature	Max. air tem-pe-rature	Rela-tive humi-dity	Absolute humidity	Air flow rate	Air velo-city
RUSSIA (training pool)	24-28°C	1-2°C higher than water temperature	31°C	40-65%	Less than 14 g/kg dry air	At least 80 m^3/h per person	Less than 0,15 m/s
FINLAND (basic, fitness pool)	26-28°C	1,5-2,5°C higher than water temperature	31°C	45-55%	Less than 14,3 g/kg dry air	2 $dm^3/s/m^2$ or air exchange rate is 4-5	Less than 0,2 m/s
The USA (sport pool)	27-28°C	1°C higher than water temperature	-	50-60%	Can be ¾ higer than AH in the air-conditioned rooms	2,4 l/s per 1 m^2 or air exchange rate is 4-8	Less than 0,15 m/s

Outdoor air flow rate is recommended at least 2.4 l/s per one square meter by the USA standards, at least 80 m^3/h for each swimmers by “Russian building code” 31-113-2004 and 2,0 l/s by D2 regulations.

Russian standards give 24-28°C for water temperature for training pool and for air it should be 1-2°C higher. Finnish guidelines give 26-28°C for basic and fitness pool and for air temperature should be higher on 1,5-2,5°C. USA standards "ASHRAE" recommend air temperature higher water temperature on 1°C.

Level of air humidity in Russian recommendations is from 40 to 65%, Finnish guideline gives value from 45 to 55% RH and ASHRAE gives 50-60% RH.

All recommendations that are given in guidelines are needed to achieve the acceptable indoor climate in swimming pools to avoid health hazard effect or damage of building envelope.

5.2 Results of measurements, analysis and comparison of results to standards and guidelines

5.2.1 Results, analysis and comparison of results to Russian standards and guidelines

We assumed that the value of indoor temperature would be from 30 to 33˚C according to "Russian designing and building code 31-113-2004. Swimming pools." /11/ and also we expected that relative humidity would be from 40 to 65 %, and absolute humidity would be less than 14 g/kg. Besides we assumed, there are fairly straight lines on the temperature and relative humidity diagram, because of ventilation system worked during the whole day.

You can see the data from all dataloggers in figure 26. Values in points #1 and point #3 are the most close to each other. Temperature curve of point #2 much differ from the two other. Perhaps it depends on the fact that this point was located on the outside wall and under the window; it indicates there are large heat losses in this area. Also, you can see that during the day the temperature was not constant and slightly increased.

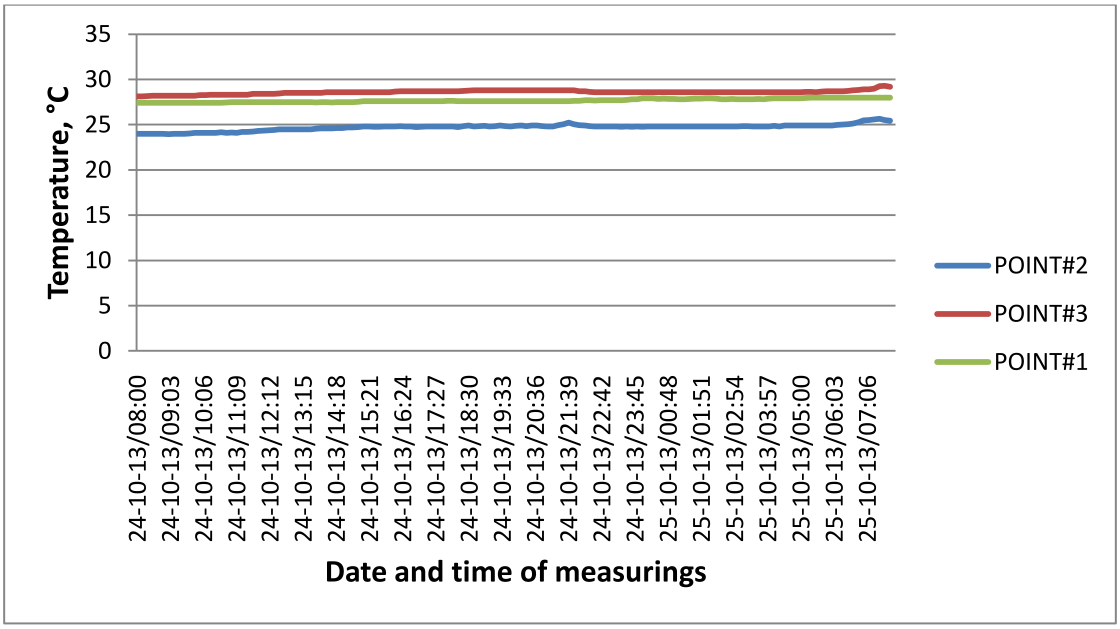


FIGURE 26. Temperature measurements

Now each measurement point will be considered in more detail. You can see the data from the point #1 of the swimming pool in figure 27.

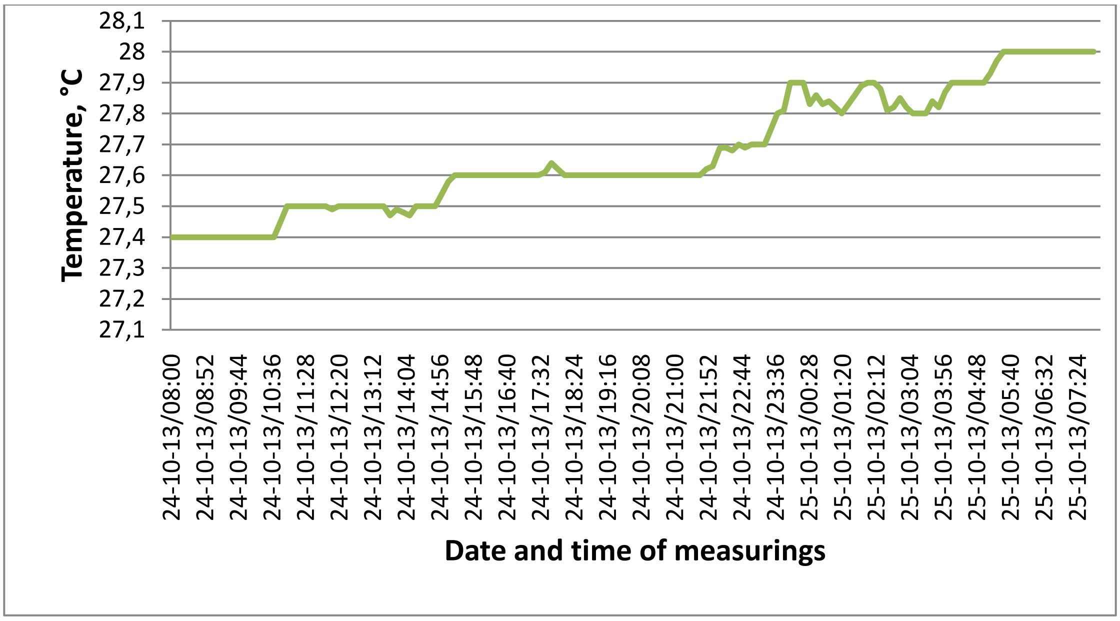


FIGURE 27. Temperature measurements in the point # 1

The minimum value of the temperature which sensor showed was founded at 8.00 a.m. and was equal to 27.4°C. It is assumed, such temperature depends on operation of exhaust ventilation system. Swimming hall is opened for visitors from 8 a.m., but exhaust ventilation system is switched on half an hour before it. The average temperature was 27.5°C and the highest temperature was 27.6°C during the whole work day.

The air temperature begins to increase from 9.54 p.m. and it maximum value which sensor showed was achieved by 5.17 a.m. and was equal to 28°C. We can assume that such temperatures were associated with the fact that during the night time exhaust ventilation system doesn’t work, so indoor air is not moving and warms. We can see on the diagram that after 10.40 a.m. and 5.40 p.m. the temperature curve gradually rises up, supposedly it depends upon activity of swimmers. During the day the air was warmed by 0.6°C.

The figure 28 illustrates temperature measurements in the point # 2. This curve has the same dynamics as the temperature curve of first point, but there are some differences. At first, datalogger have showed much lower temperature than in the point #1. For example, minimum value was registered in the beginning of pool’s work at 8 a.m. was 24°C (in the first case temperature was 27.4°C). The reason may be, as mentioned above, that point was located on the outer wall near the window; it caused heat losses. Further, the temperature increases during the day. There was no such period of time as in the first case when the temperature was constant. Perhaps it depends on the fact that in this area there was not enough air exchange rates; stagnant air existed, which was heated during the day. Average temperature during work day was 24.5°C and the highest temperature was 24.9 °C. The maximum value of the temperature which sensor showed was achieved to 7.25 a.m. and was equal to 25.7 °C.

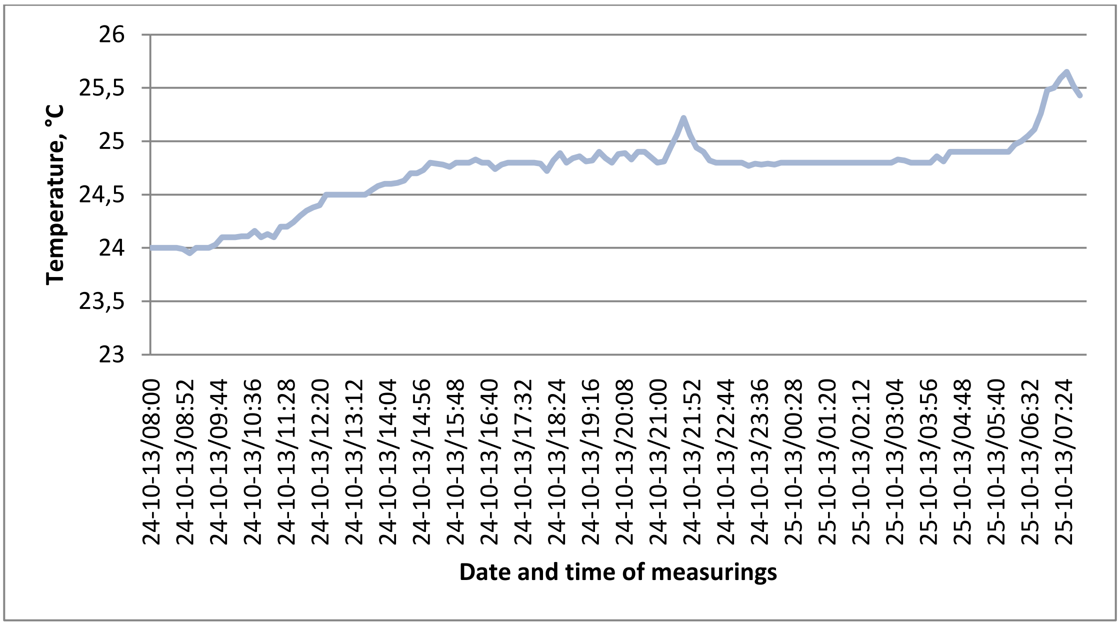


FIGURE 28. Temperature measurements in the point # 2

The last point where the measurements were carried our will be considered in figure 29. Third datalogger was installed nearly the first point on the internal wall. This curve has the same dynamics as the first two temperature curves. But there are some differences. For example, temperature in the beginning of pool's work was higher, then temperatures in the points #1 and #2 (at 8.00 a.m. temperature was equal 28.1°C). Further, the average temperature during work day was 28.5°C and temperature was growing up smoothly. Then, from 08.00 a.m. to 9.00 p.m. the temperature was changing from 28.1 to 28.8°C. The last number is the highest temperature during the work day, but it was not the highest the whole day. The maximum value of the temperature which datalogger showed was achieved by 7.24 a.m. and was equal to 29.3°C. Temperature was constant from 10.40 p.m. to 4.40 a.m., it depends on location of third points. This point was installed on internal wall, where there was no heat losses, and also quite far away from the exhaust grating. So, in this area there was no active air flow rate, and temperature could rise up.

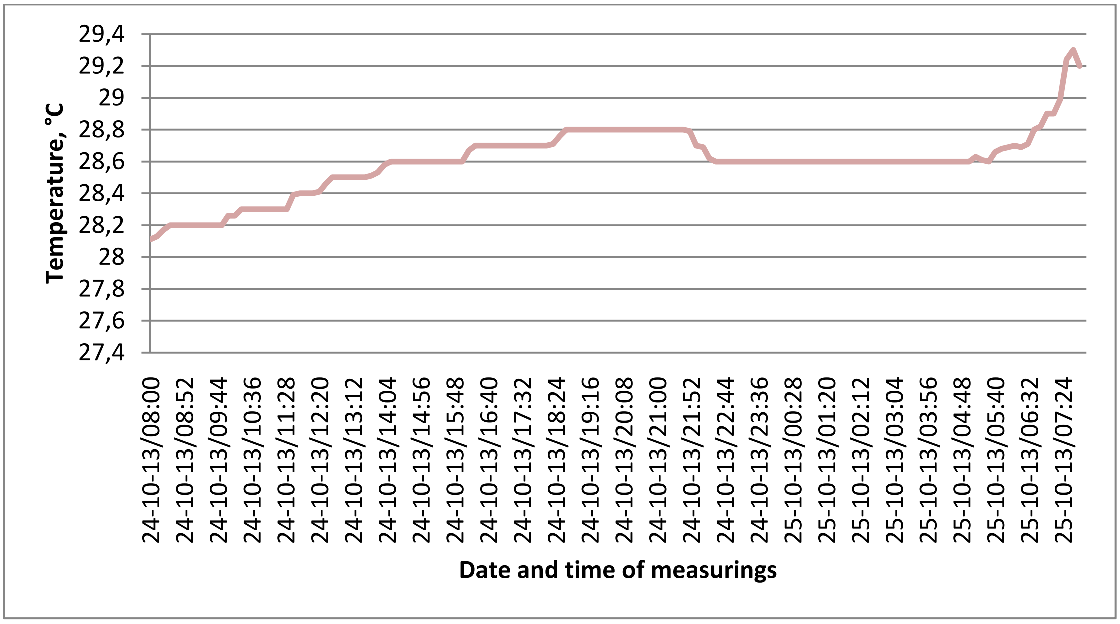


FIGURE 29. Temperature measurements in the point # 3

By comparing the data all of the dataloggers, we can conclude that there were no points where expected temperature was reached. Maximum temperature for point #1 was 27.6°C, for point #2 was 24.9°C and for point #3 was 28.8°C, but expected temperature was from 30 to 33°C. This means that, firstly, the air supplied into the space was not enough heated, secondly, heating system operates inefficiently. Third, it can be assumed that the exhaust ventilation operates so much that indoor air is constantly being replaced and has no time to reheat. According to the temperature measurements, we can conclude that visitors coming from the swimming pools will be frozen, maybe they will feel draft.

But in order to make conclusion about the ventilation system work as a whole, it is necessary to consider the relative and absolute humidity curves. You can see the data of relative humidity from all dataloggers in figure 30. Curves from point #2 and point #3 have similar dynamics and are most close to each other. Relative humidity curve of point #1 much differ from the two other and dynamic and values. Perhaps it depends on the fact that this point was located nearly than others to the grid of exhaust ventilation system. The air does not stagnate in this area and constantly updates, so the relative humidity is low enough. During the day the relative humidity increases, this is due to the fact that there is active water vaporization from the surface of the water where people swim. After working hours values of relative humidity decrease as the water is stationary.

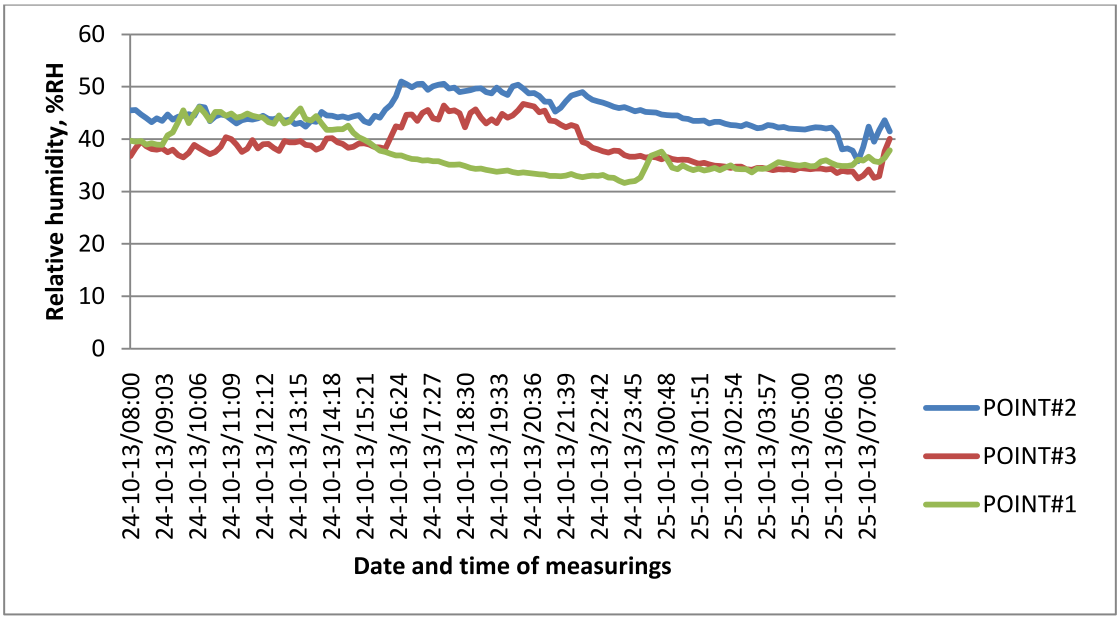


FIGURE 30. Relative humidity measurements

Now each measurement point will be considered in more detail. You can see the data from the point #1 of the swimming pool in figure 31.

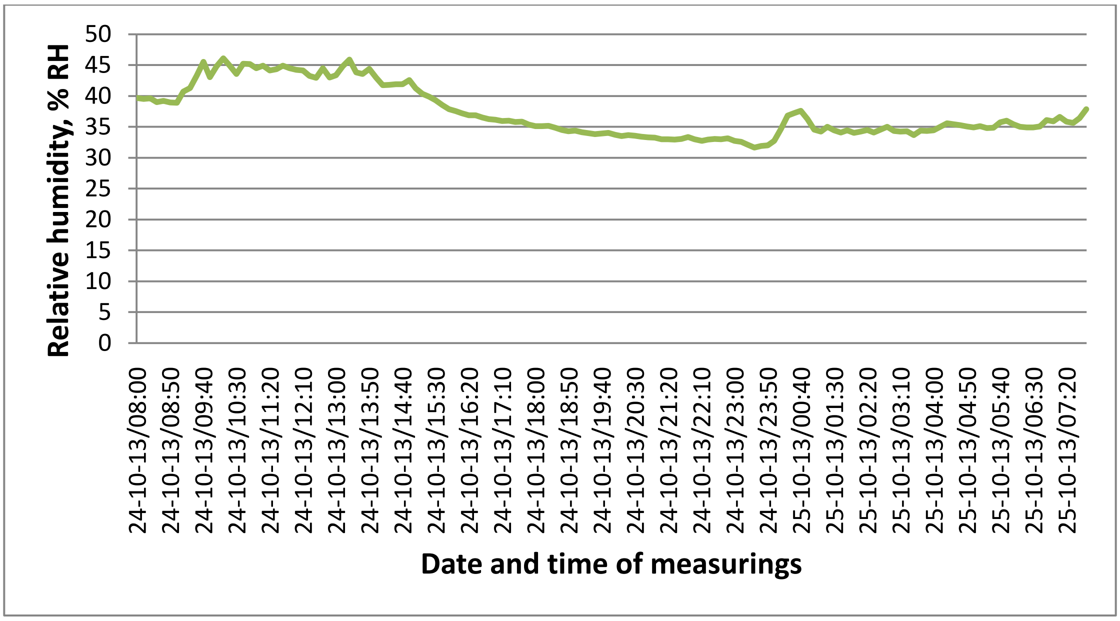


FIGURE 31. Relative humidity measurements in the point # 1

The curve of relative humidity doesn't have the same dynamics as the temperature curve of this point. The minimum value was showed 32.9 % RH at 8.55 p.m. and the maximum value was 46.6 % RH at 9.32 a.m.; these values are explained by the activity of visitors. During the day there was active water vaporization from the surface of the moving water, workarounds lanes and the visitors themselves. The more active is water vaporization, the more active the exhaust system. This is most noticeable at that point, because it is nearest to the exhaust system. From 8.00 am to 01.00 p.m. water vaporization is the most active, because at this time there were training groups of children in swimming. At night, the relative humidity values are almost constant. It changed slightly from 34.9 to 35.2 %RH, but there was leap of curve from 11.50 p.m. to 1.40 a.m.

The next point which will be considered is point # 2 in figure 32. This point was located on the opposite wall from the first, it can be assumed that the values are quite different.

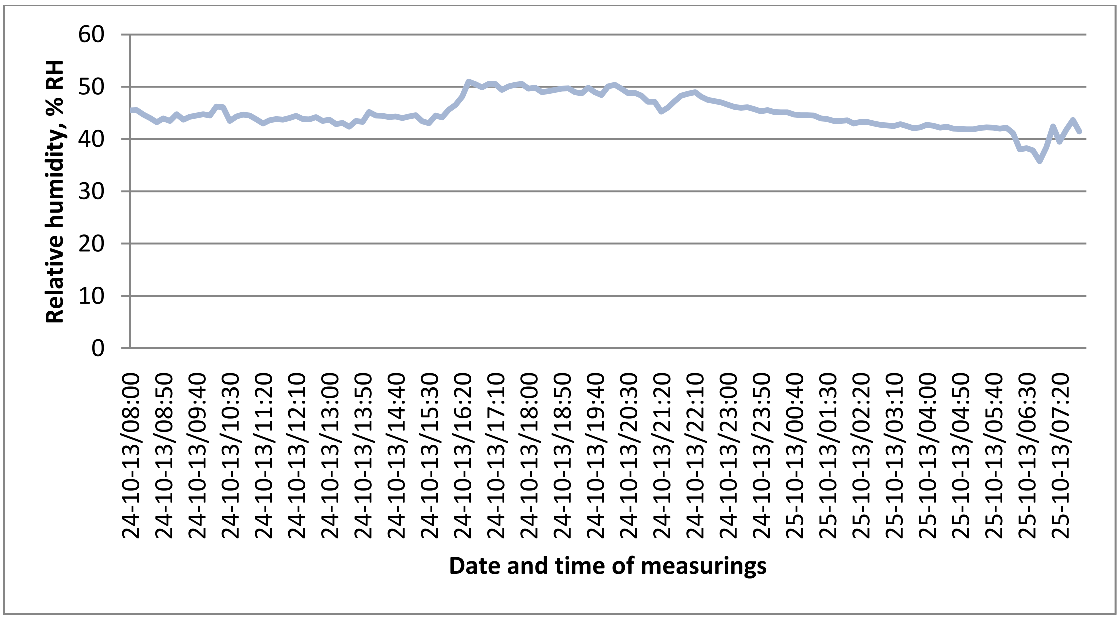


FIGURE 32. Relative humidity measurements in the point # 2

This curve doesn't have the same dynamics as the curve of point # 1. In the beginning of work day the value of relative humidity was higher than in the first point (45.5 % RH opposite 39.7 % RH). The following seven hours curve changed quite slightly, but at 3.30 p.m. you can see leap of curve from 42.3 to 51.1 % RH. Then the curve changed quite slightly again. It was a time of active training in the pool. These values are shown in the diagram, the air was replaced in this field, but it wasn't so much that the relative humidity may decrease. The minimum value of work day was showed 42.3 % RH at 1.05 p.m. and the maximum value was 51.1 % RH at 9.32 a.m. During the night, the relative humidity values decreased (from 49.8 to 36.7 %RH), this is due to stillness water, thus, it was decreased evaporation.

The last point which will be considered is point # 3 in figure 33. This point was located on the same wall that the first, but values are different because of these points have different distance to the exhaust grid. Therefore, the air flow rate can be varied, and thus also relative humidity can differ.

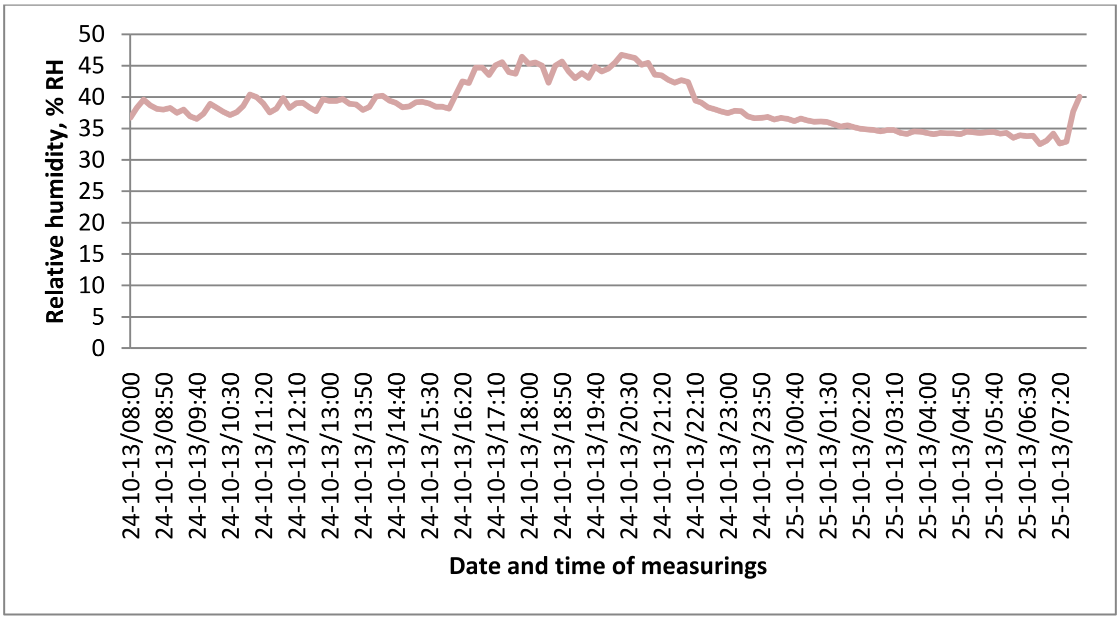


FIGURE 33. Relative humidity measurements in the point # 3

This curve dynamic is similar of the curve of point # 2 despite the fact that the points were on different walls and different distances to the exhaust grid. In the beginning of work day the value of relative humidity was 35.5 % RH, this is the smallest value of third points. The following seven hours, as in last case, curve changed quite slightly, but at 3.30 p.m. you can see leap of curve from 38.3 to 46.7 % RH. Then the curve begins to decrease all time to minimum value 33.7 % RH. The minimum value of work day was showed 42.3 % RH at 09.40 a.m. and the maximum value was 46.7 % RH at 8.25 p.m. During the night, the relative humidity values decreased to 33.7 % RH.

We can conclude that there was one point where expected relative humidity was reached. Expected relative humidity was from 40 to 65 % RH and average relative humidity during the work day in the point #2 was 46.1 % RH. Values in other two points did not reached required relative humidity. In point #1 required relative humidity is kept from the beginning of the working day to 3.00 p.m. of the day. After that it drops below the lower limit of the required relative humidity. In point #3 the situation is reversed. Recommended relative humidity is reached only by 3.40 p.m. and retains its value throughout the remainder of the day, however, the values are low in the morning. In the results of data analysis, we can confirm our opinion that exhaust ventilation operates more than necessary. The air is too dry in the pool, water from the visitor's skin will evaporate quickly, and then the feeling of freezing will become stronger.

And the last point that we need to check is the maximum value of the absolute humidity. After that we will be able to make a final conclusion on the ventilation system of the pool. You can see curves of calculated absolute humidity for all of the points in figure 34. Formula by which the diagram of absolute humidity was constructed is given in the chapter 5.2.1. Absolute humidity indicates the maximum amount of vapor per 1 m^3 of air (or per 1 kg) depending on the temperature at a given time.

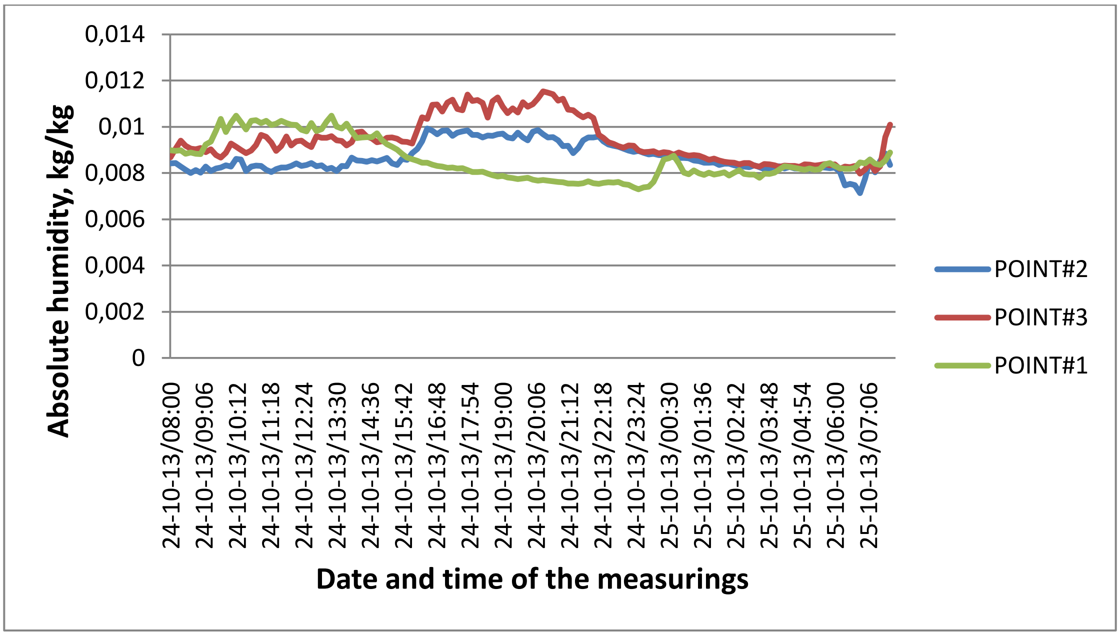


FIGURE 34. Values of absolute humidity

The curves of relative and absolute humidity in all cases have the same shape and the same trend. Maximum value was reached at 8.05 p.m. and was equal 11.5 g/kg in the point # 3. Neither of the curves does not have a values greater than the standards recommends (14 g/kg).

As a result we get the values of air temperature and relative humidity that are quite different from recommended values. Only values of absolute humidity matched to required levels. We can conclude that exhaust ventilation system was inefficient. The air which are supplied into the pool was not enough heated. It is known, the air colder in the pool the visitors feel the freezing and draft. Furthermore, the air in the pool was too dry, it showed, system operated more than necessary. Perhaps air change rate is so high that the air is not enough time to moisten. The high air velocity combined with low air temperatures and low relative humidity and gives a feeling of cold and draft pick.

5.2.2 Results, analysis and comparison of results to Finnish recommendations

We assumed that the value of indoor temperature would be from 27,5 to 28,5˚C according to D2 Regulations and guidelines 2003 “Indoor climate and ventilation of building” /13/ and Finnish recommendation 06–10451 “Swimming halls. HVAC design” /2/. And also we expected that relative humidity would be from 45 to 55 %. Besides we assumed, there are fairly straight lines on the temperature and relative humidity diagram, because of ventilation system worked during the whole day and adjusted automatically.

You can see the data from all dataloggers in figure 35. Values in points #1 and point #2 are the most close to each other. Temperature curve of point #3 much differ from the two other.

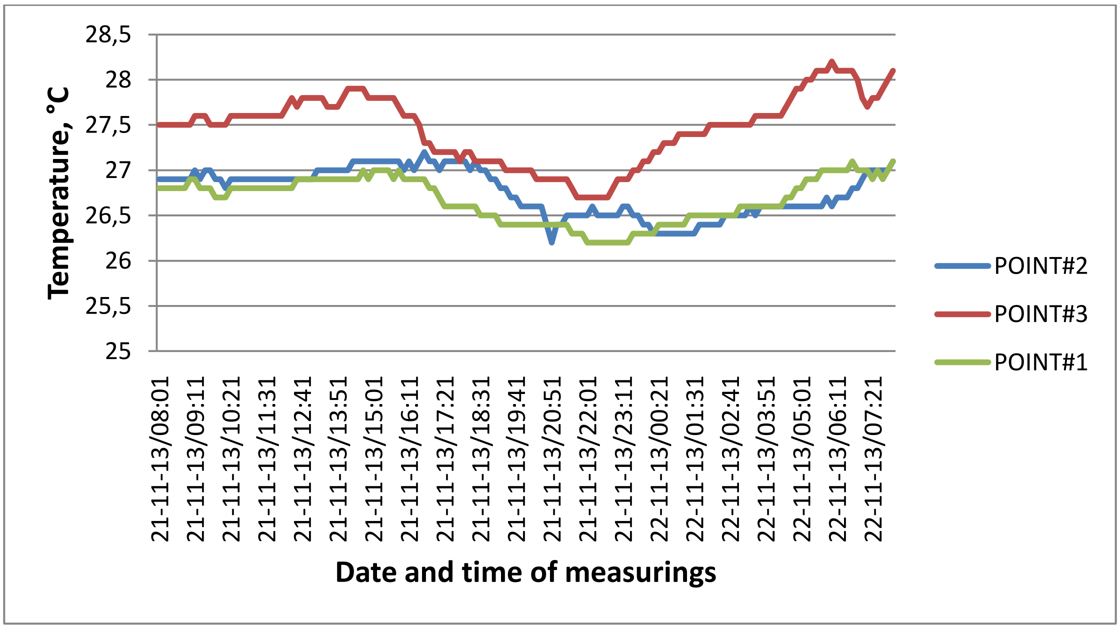


FIGURE 35. Temperature measurements

Perhaps it depends on the fact that this point was located on the exhaust grill; it indicates there are no factors which can affect on temperature as in two first cases. Also, you can see that during the day the temperature was not constant and sometimes it slightly increased or fallen down.

Now each measurement point will be considered in more detail. You can see the data from the point #1 of the swimming pool in figure 36.

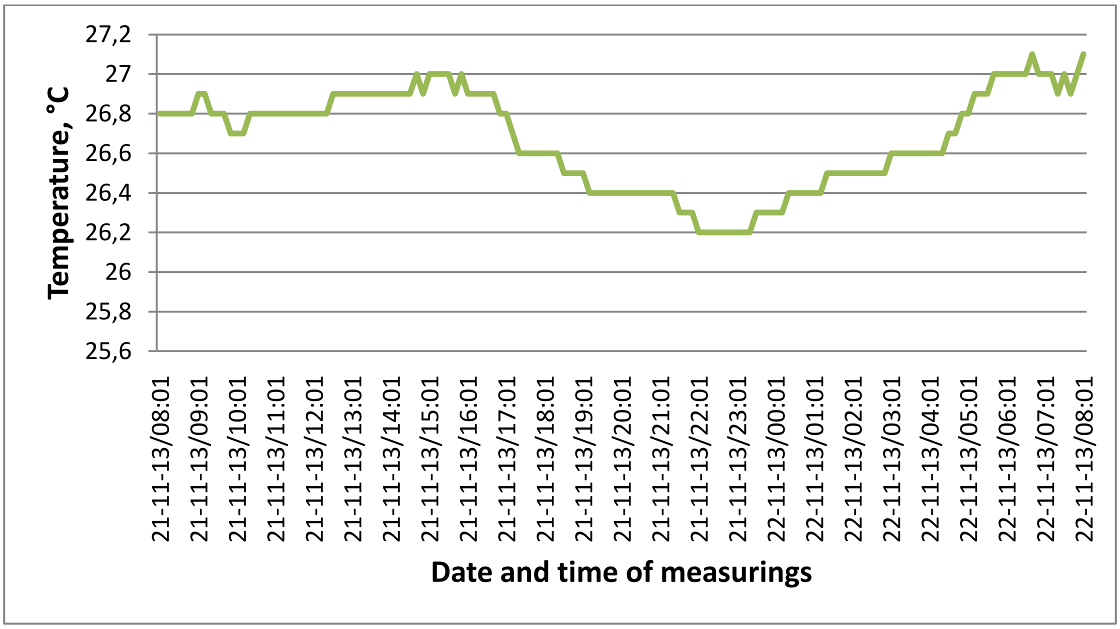


FIGURE 36. Temperature measurements in the point # 1

The minimum value of the temperature which sensor showed was founded at 10.00 p.m. and was equal to 26.2°C. The average temperature was 26.6°C. The air temperature begins to increase from 10.00 p.m. and it maximum value which sensor showed was achieved by 6.01 a.m. and was equal to 27.1°C. It is assumed that such temperatures were associated with the fact that during the night time supply and exhaust ventilation system work, so indoor air in the poll warms a little (0.8°C). During the work day, temperature at first slightly increases (from 26.7 to 27°C), then it falls down to 26.2°C.

The figure 37 illustrates temperature measurements in the point # 2. This curve has the same dynamics as the temperature curve of first point, but there are some differences. At first, temperature begins to decrease at 6.00 p.m. and it minimum value was registered in the end of pool's work at 9 p.m. and was equaled 26.2°C (as in the first case). The reason may be, that point was located nearly window and surroundings rooms, where temperature is known for us. Secondly, temperature differences during the day a little more, than in first case. It is 1°C, but in the point #1was 0.9°C. Further, the temperature begins to increases from 9 p.m. to 11 p.m. and has achieved value 26.6°C.

After that temperature falls down again to value 26.3°C at midnight. There was no period of time when the temperature was constant. As in the last case temperature rises all night and at 8 a.m. it is equal 27.1°C. Average temperature during work day was 26.7°C and the highest temperature was 27.2°C. All of maximum and minimum values of the temperature which sensor showed were achieved during the work day.

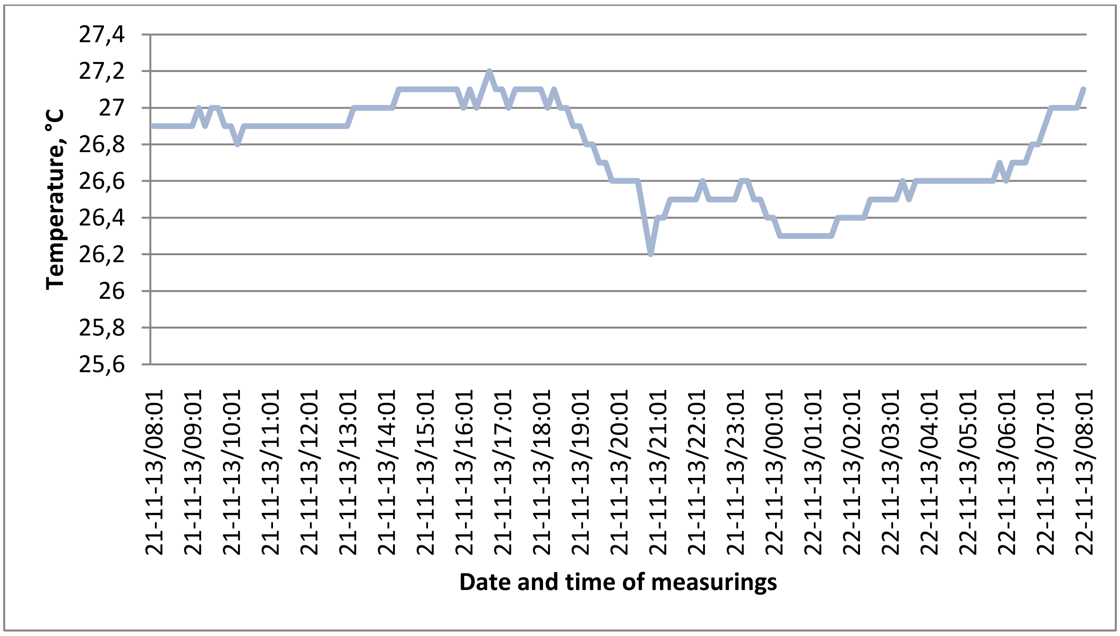


FIGURE 37. Temperature measurements in the point # 2

The last point where the measurements were carried our will be considered in figure 38. Third datalogger was installed on exhaust grill. This curve has the same dynamics as the first two temperature curves but has other values. For example, temperature differences during the day is more than in the first and second cases (1,5°C opposite 0.9 and 1°C). Further, the average temperature during work day was 27.5°C. As in the two first cases temperature begins to increase from 8 a.m. and to 2 p.m. it reached 27.8°C, than temperature curve falls down to value 26.7°C (this is minimum value for point # 3) and further, temperature was growing up during all night. The maximum value of the temperature which datalogger showed was achieved by 6 a.m. and was equal 28.2°C but the maximum temperature during the work day was 27.8°C.

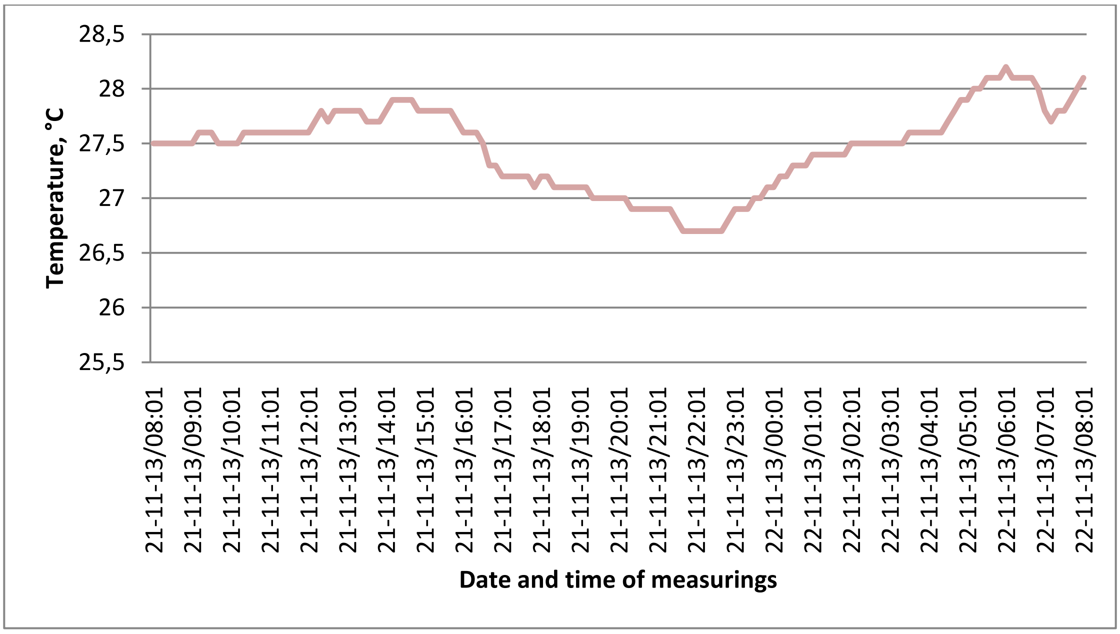


FIGURE 38. Temperature measurements in the point # 3

By comparing the data all of the dataloggers, it can be concluded that there were no points where expected temperature was reached during the whole day. Maximum temperature for point #1 was 27.1°C, for point #2 was 27.2°C, but expected temperature was from 27,5 to 28,5°C. Temperature in the point #3 sometimes reached expected values, for example, from 8 a.m. to 4 p.m. and from 2 p.m. to 8 p.m., but it is not enough to consider this point as appropriate. This means that, firstly, the air supplied into the space not enough heated, secondly, it can be assumed that the exhaust ventilation operates so much that indoor air is constantly being replaced and has no time to reheat. According to the temperature measurements, we can conclude that visitors coming from the swimming pools will feel cold, maybe they will feel draft.

But in order to make conclusion about the ventilation system work as a whole, it is necessary to consider the relative humidity curves. In figure 39 you can see the data of relative humidity from all dataloggers. Curves from point #1 and point #3 have similar dynamics and exist the most close to each other. Relative humidity curve of point #2 differ from the two other with dynamic. During the work day the relative humidity decreases, but sometimes leaps appear, this is due to the fact that there is active water evaporation from the surface of pool's water where people swim. After working hours values of relative humidity are almost constant as the water is stationary and there are no swimmers and personnel.

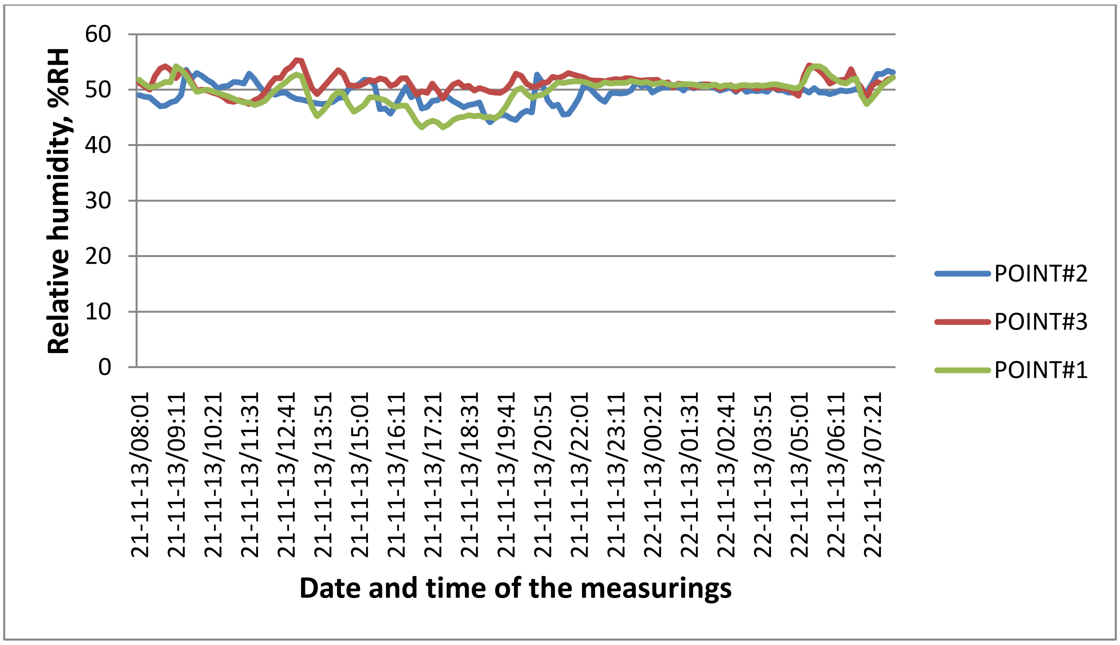


FIGURE 39. Relative humidity measurements

Now each measurement point will be considered in more detail. You can see the data from the point #1 of the swimming pool in figure 40.

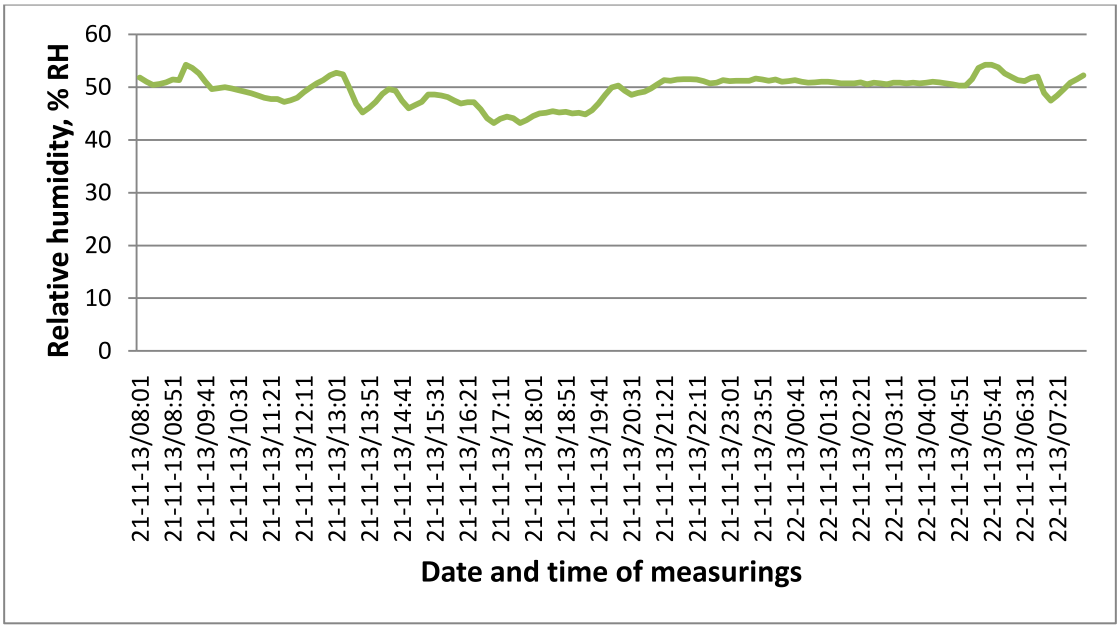


FIGURE 40. Relative humidity measurements in the point # 1

The curve of relative humidity doesn’t have the same dynamic as the temperature curve of this point. The minimum value was showed 43.2 % RH at 6 p.m. and the maximum value was 54.2 % RH at 9.10 a.m. During the work day relative humidity curve went down to 47% RH (at 11.23 a.m.), 45% RH (at 1.48 p.m.), 46 %RH (at 2.41 p.m.) and 42% RH (at 4.56 p.m.), also curve rises to 54.2% (at 9.10 a.m.), 52% (at

1.30 p.m.), 50% (at 2.02 p.m.) and 49% (at 3.30 p.m.) values. These values are explained by the activity of visitors. During the day there was active water evaporation from the surface of the moving water, floor and the visitors themselves. From 1.00 p.m. to 9.00 p.m. water evaporation is the most active, because at this time there were training groups of children or ordinary swimmers in swimming pool. At night, the relative humidity values are almost constant. It changed slightly from 49.5 to 51 % RH, but there was leap of curve from 5.20 a.m. to 6.31 a.m.

The next point which will be considered is point # 2 as it is shown in figure 41.

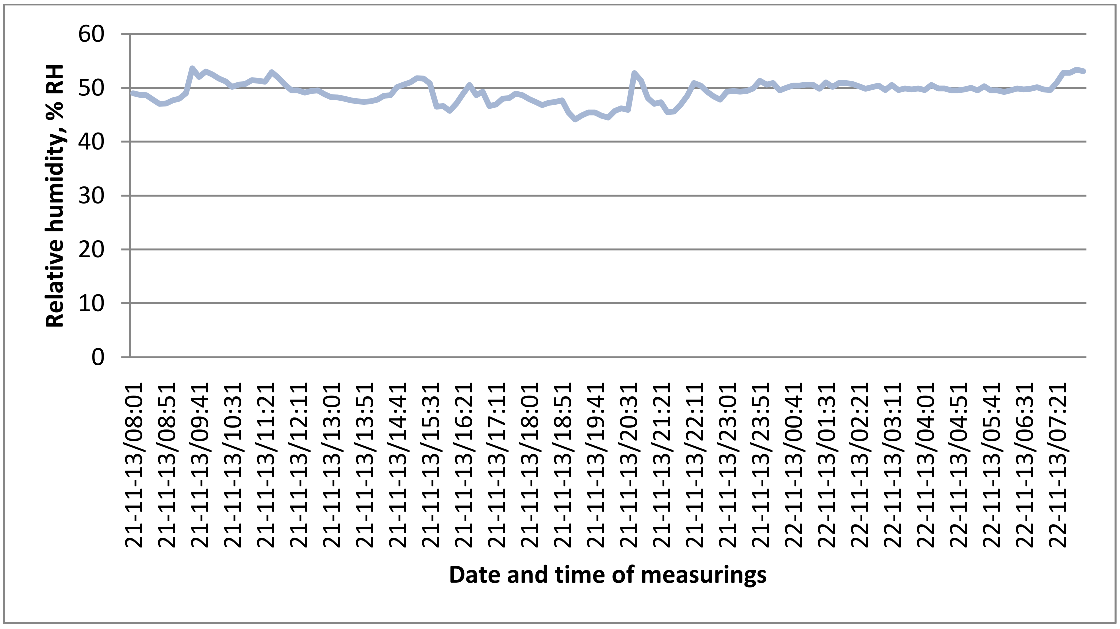


FIGURE 41. Relative humidity measurements in the point # 2

This curve doesn’t have the same dynamics as the curve of point # 1. In the beginning of work day the value of relative humidity was lower than in the first point (48.3 % RH opposite 52.7% RH). The curve changes quite much, for example, at 1.51 p.m. value is 47.4% RH, then curve rises to 51.8% RH at 2.52 p.m., then curve fell down again to value 46.2%RH at 3.28 p.m. It was a time of active training in the pool. The minimum value of work day was shown 44.1 % RH at 6 p.m. and the maximum value was 53.6 % RH at 9.31 a.m. During the night, the relative humidity values are constant.

The last point which will be considered is point # 3. It is shown in figure 42. This point was located on the exhaust grill, therefore, the air flow rate can be varied, and thus also relative humidity can differ. The more active is water vaporization, the more active the exhaust system. This is most noticeable at that point, because it is nearest to the exhaust system.

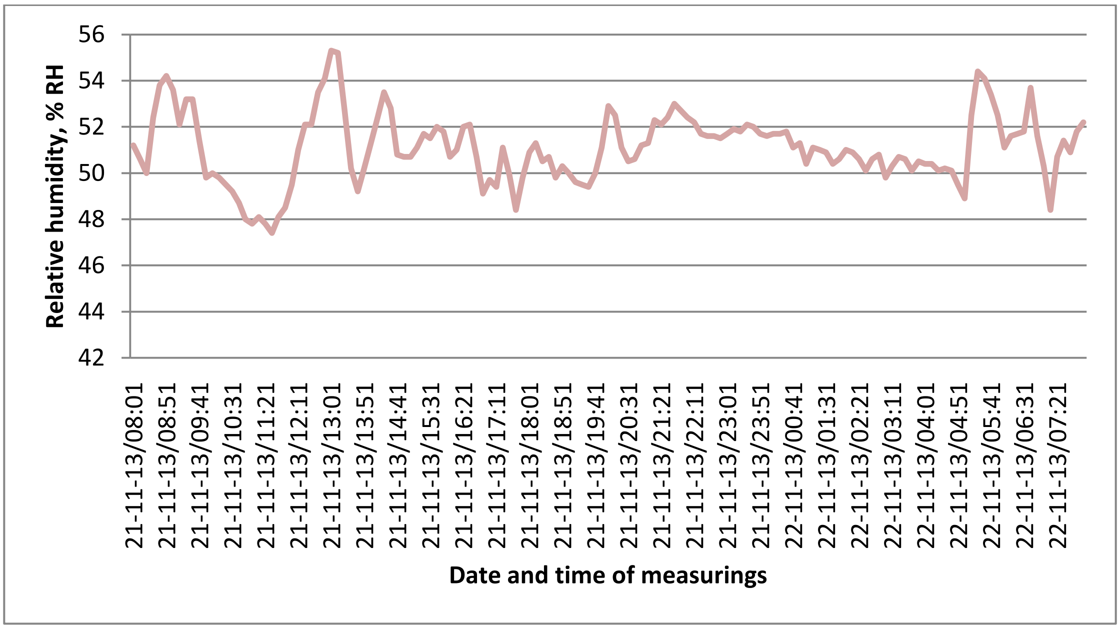


FIGURE 42. Relative humidity measurements in the point # 3

This curve of relative humidity quite much differs from two other curves. In the beginning of work day the value of relative humidity was 55.3 % RH, this is the highest value of third points. Values of relative humidity changes very much. For example, at 11.21 a.m. value was 47.5%RH, then relative humidity stars to rise up to value 55.4%RH by 1.05 p.m., then curve decreases to 47.2%RH by 1.54 p.m. and after that it rises again. The minimum value of work day was shown 47.4 % RH at 11.31 a.m. and the maximum value was 55.3 % RH at 10 a.m. During the night, the relative humidity values are reduced stepwise to 4.51 a.m. and after that it stars to increase and decrease periodically.

It can be concluded that in all of points expected relative humidity was reached. Expected relative humidity was from 45 to 55 % RH and average relative humidity during the work day in the point #1 was 49.5 % RH, in the point #2 was 49.23 % RH and in the point #3 was 51.1 % RH. Values in the point # 1 from 4.50 p.m. to 6 p.m. are a little low than 45%, but it can not be considered significant.

The next thing that we need to check is the maximum value of the absolute humidity. In figure 43 you can see curves of calculated absolute humidity for all of the points. Formula by which the diagram of absolute humidity was constructed is given in the chapter 5.2.1.

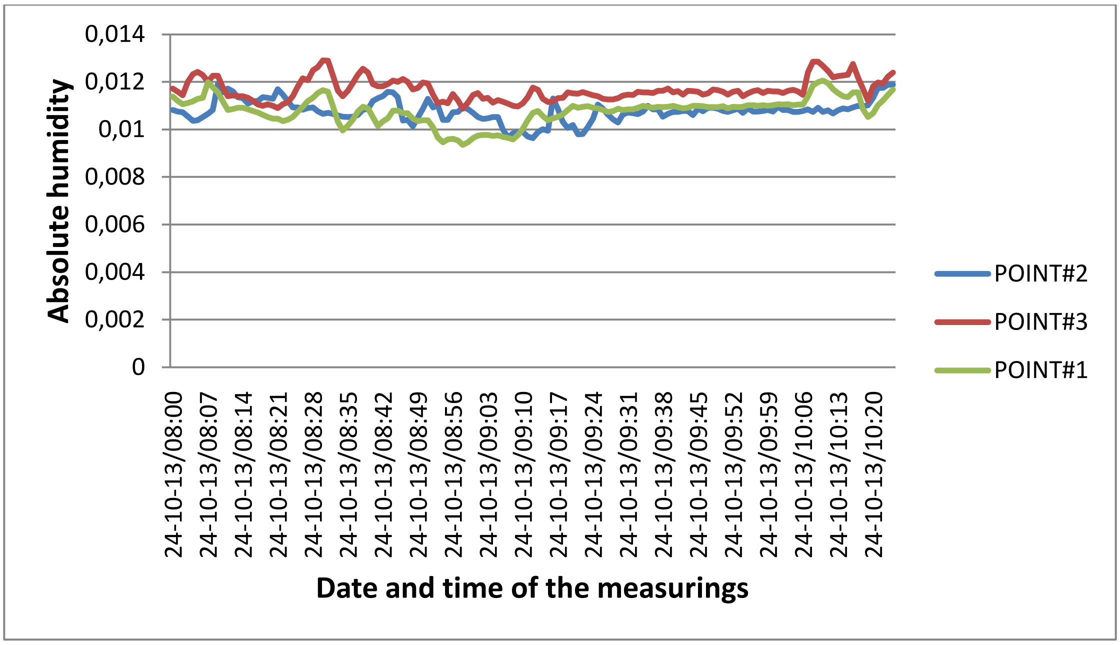


FIGURE 43. Values of absolute humidity

The curves of relative and absolute humidity in all cases have the same shape and the same trend. Maximum value was reached at 0.50 p.m. and was equal 12.9 g/kg in the point # 3. Neither of the curves does not have a values greater than the standards recommends 14 g/kg.

And the last point that we need to check is the point where CO_2 level is measures. After that final conclusion about operation of pool's air-conditioning system will be got. In figure 44 you can see curves of measured CO_2 concentrations in the specific point. At the beginning of work day CO_2 level was 677 ppm (parts per million), then curve starts to increase and reached value 704 ppm by 1.41 p.m. After that CO_2 concentration decreases to 615 ppm at 3.11 p.m., and then it rises again to 685.2 ppm by 3.51 p.m., then it fell down to 670 ppm at 4.21 p.m. and curve started to increase to 728 ppm by 4.41 p.m.. Maximum value of CO_2 concentration was equaled 730.9 ppm and was reached at 5.31 p.m. Then CO_2 concentration starts to decrease and reach minimum value 500 ppm at 10.01 p.m., during the night values change slightly.

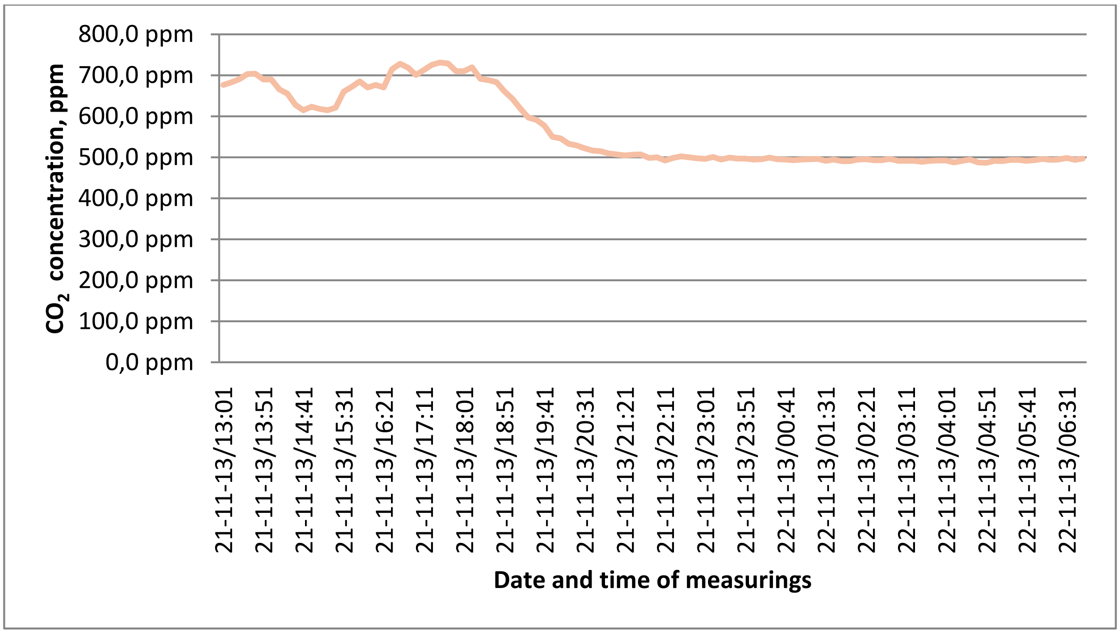


FIGURE 44. Values of CO_2 measurements

It can be concluded, that during the work day CO_2 concentration changes stepway: at first it grows, then it falls down, then it grows again. Values of CO_2 depend on amount of visitors and their activity as well as the air flow rate per person. The maximum permissible indoor air carbon dioxide content in usual weather conditions and during occupancy is 1200 ppm. Measured values don't exceed recommended value, so exhaust system operates well.

As a result we get the values of air temperature that are quite different from recommended values. Values of relative humidity, absolute humidity and CO_2 concentrations matched to requirements. It can be concluded that exhaust system was efficient, but the air which are supplied into the pool was not enough heated. It is known, the air colder in the pool the visitors feel the freezing and draft.

5.3 Calculations

5.3.1 Calculated absolute humidity

Absolute humidity will be calculated for temperature 24°C and relative humidity 45,47% RH. For that we need to know the pressure of saturated water vapour.
According to formula 4 we will calculate it.

$$p_{ws} = \frac{\exp\left(77{,}345 + 0{,}0057 \cdot (24 + 273{,}15) - \frac{7235}{24 + 273{,}15}\right)}{(24 + 273{,}15)^{8{,}2}} = 2.975 \ kPa$$

Than we calculate absolute humidity value based on formula 3.

$$AH = 0{,}622 \cdot \frac{\varphi \cdot p_{ws}}{101{,}325 - \varphi \cdot p_{ws}} = 0{,}622 \cdot \frac{0{,}4547 \cdot 2{,}975}{101{,}325 - 0{,}4547 \cdot 2{,}975} = 0{,}008417 \ kg/kg$$

5.3.2 Calculated air flow rate according to Russian standards and guidelines

Water evaporation and maximum air flow should be calculated for the swimming pool which located in St. Petersburg. Area of water surface is 135 m^2. Pool water temperature is 28°C. Temperature of the indoor air is 26,86°C and relative humidity is 42,17%. Evaporation from the water surface is calculated to determine the size of ventilation ducts and grills.

For calculating of water evaporation from the surface of water, pressure of saturated water vapour and partial water vapor pressure should be known. Pressure of saturated water vapour $p_{D.W}$ is taken from table 2 by interpolation and equaled 3538,44 Pa. Then, partial water vapor pressure $p_{D.L}$ is calculated according to formula 6.

$$p_{D.L} = \frac{42{,}17\% \cdot 3538{,}44 Pa}{100\%} = 1492{,}16 \ Pa$$

The values of evaporation rates from the surface of water are taken from the table 1. It equal β_b= 40 and β_u = 7 for type of swimming pools with depth of pool is more than 1,35 m. Now water evaporation from the surface of water for the time of work day should be calculated with formula 5.

$$M_{D.B.b} = \frac{40}{461{,}52 \cdot \left(\frac{28 + 26{,}86}{2} + 273\right)} \cdot (3538{,}44 - 1492{,}16) \cdot 135 = 79{,}69 \ kg/h$$

Secondly, water evaporation from floors (kg/h) can be determined with formula 7.

$$M_{D.p.} = 0{,}006 \cdot (26{,}86 - 22) \cdot 64{,}8 = 1{,}89 \ kg/h$$

where t_{WW} is the temperature of floor (=22°C) and A_p is the area of wet floor surfaces around pool (=64,8 m^2).

After that, water evaporation from the surface of water after work day should be calculated with formula 5.

$$M_{D.B.u} = \frac{7}{461{,}52 \cdot \left(\frac{28 + 26{,}86}{2} + 273 \right)} \cdot (3538{,}44 - 1492{,}16) \cdot 135 = 13{,}95 \ \ kg/h$$

Finally, mass flow of outdoor air (kg/h) which required for the providing of recommended relative humidity level in the pool will be calculated with formula 8.

$$M_{A.S.} = \frac{79{,}69 + 1{,}89}{14 - 9{,}12} \cdot 10^3 = 16717{,}2 \ \ kg/h$$

where X_{DL} is the maximum water content in the pool's air, g/kg (=14 g/kg) and X_{DA} is found out with formula 9.

$$X_{DA} = 0{,}622 \cdot \frac{1460}{101000 - 1460} \cdot 10^3 = 9{,}12 \ \ g/kg$$

where value for the partial pressure of water vapor in the outside air for Saint-Petersburg (p_{DA} =1460 Pa) is given in the table 5a of SNiP 23-01-99* "Building climatology". Also, value for barometric pressure (p_B =101000 Pa) is given in the table 2 of the same standard.

Mass flow rate can be converted to a volume flow rate with formula 10.

$$L = \frac{16717{,}2}{1{,}21} = 13815{,}9 \ \ m^3/h$$

- Calculated values of air flow rate are L= 108, 4 m^3/h per person
- Designed values of air flow rate are L= 90 m^3/h per person
- Required values of air flow rate are L= 80 m^3/h per person

5.3.3 Calculated air flow rate according to Finnish guidelines

Water evaporation and air flow which required for the providing of recommended relative humidity level should be calculated for the swimming pool located in Mikkeli. Area of water surface is 250 m^2. Pool water temperature is 26°C. Temperature of the indoor air is 26,96°C and relative humidity is 49,94%.

Mass flow rate of evaporated water is calculated using the formula 11.

$$q_{VM} = 250 \cdot \frac{40}{461{,}52 \cdot \left(\frac{26 + 26{,}96}{2} + 273 \right)} \cdot (3547{,}58 - 1771{,}7) = 128{,}49 \text{ kg/h } = 0{,}036 \text{ kg/s}$$

where p_i is calculated with formula 2 and it is 1771,1 Pa;

p_v is calculated with formula 4 and it is equal 3547,58 Pa at the t_{air}=26,96°C;

B_p is 40 m/h from the table 1, m/h;

A is the area of water evaporation and it is 250 m^2;

R is the gas constant (=461,52 J/kg·K);

T is the average temperature of water and air, K.

Mass flow rate of evaporated water can be calculated in other way which uses the absolute air humidity difference. It is shown below and calculated with formula 12.

$$q_{VM} = 250 \cdot 0{,}0125 \cdot (0{,}023 - 0{,}011) = 0{,}038 \text{ kg/s}$$

where X_v is 0,023 kg/kg according formula 3 at 100% relative humidity and constant temperature;

X_i is 0,011 kg/kg dry air which calculated with formula 3;

B_x is 0,0125 kg/m^{2}s from the table 2;

A is the area of water evaporation and it is 250 m^2.

Finally, mass flow of outdoor air (kg/s) which required for the providing of recommended relative humidity level in the pool will be calculated with formula 13.

$$q_{MI} = \frac{0{,}037}{(0{,}011671 - 0{,}010279)} = 26{,}58 \text{ kg/s}$$

where $\sum q_{VM}$ is 0,037 kg/s as calculated above;

X_p is 0,011671 at the exhaust temperature t_{exh} = 27,46°C

X_t is 0,010279 at the supply temperature t_{sup} = 28,2°C

Mass flow rate can be converted to a volume flow.

$$L = \frac{26{,}58 \cdot 3600}{1{,}21} = 79740 \ \ m^3 / h = 22150 \ \ l / s$$

- Calculated value of air flow rate are qv = 22150 l/s
- Designed value of air flow rate are qv = 3000 l/s
- Measured value of air flow rate are qv = 3177 l/s.

Calculated value is so much than designed and measured values. Perhaps, meanings of absolute humidity differ, so results differ.

6 DISCUSSION

According to studying international and Russian standards and guidelines for swimming halls, it can be concluded that there are some differences. Outdoor air flow rate is recommended at least 2.5 l/s per one square meter by ASHRAE standard 62.1-2004, at least 80 m^3/h for each swimmers by “Russian building code” 31-113-2004 and 2,0 l/s by D2 regulations. All of regulations and guidelines don’t give specific value of indoor air temperature. It depends on water temperature of pools. Russian standards give 24-28°C for water temperature for training pool and for air it should be 1-2°C higher. Finnish guidelines give 26-28°C for basic and fitness pool and for air temperature should be higher on 1,5-2,5°C. And Russian and Finnish recommendations limits maximum air temperature, it should be less than 31°C. USA standards “ASHRAE” recommend air temperature higher water temperature on 1°C (water temperature should be for sport pool 27-28°C or slightly lower). Level of air humidity also differs in regulations. For example, the highest differences between lower and upper limits of relative humidity exist in Russian recommendations (RH is from 40 to 65%), Finnish guideline gives value from 45 to 55% RH and ASHRAE gives 50-60% RH. All recommendations that are given in guidelines are needed to achieve the acceptable indoor climate in swimming pools to avoid health hazard effect or damage of building envelope.

Some articles about common problems of pools were studied. First of all challenge caused by relative humidity will be considered. Moisture migration through the building envelope to outdoors in cold weather should be stopped. It is important to start with the correct envelope construction to avoid significant problems during the life of the building. Also high relative humidity level facilitates the grows the mould and mildew which, in addition to being unsightly, can attack wall, floor and ceiling coverings, while their spores can adversely impact the air quality. The danger is that, if the room has a surface temperature below the dew point temperature, it will condensate on such surfaces as air ducts and some translucent structures. Low and high air temperatures effect to swimmer condition. The next challenge of swimming halls which was considered is the air impurities. It is known the air quality is directly affected by the water quality. Proper ventilation can assist with maintaining water quality by removing the airborne chloramines. Also air quality in swimming pools depends on air distribution. The air distribution system should be designed in such a way as to minimize stagnation in the building envelope. The airflow should move in the correct direction. So, for proper IAQ all of described challenges should be prevented.

For minimizing some problems, for example, low or higher relative humidity or poor air distribution, air-conditioning systems with dehumidifier and heat recovery are used. These systems do not create drafts and works even with a hundred percent humidity outside. Air-conditionings systems with dehumidifier can differ. It may be with separate dehumidifier or it is system with dehumidification function. Both of systems include such features as dehumidification, filtration, heating, cooling, ventilation and sometimes heat recovery. Air-conditioning system with heat recovery also is the most suitable for creating good indoor air quality. Such systems allow maintain the recommended indoor climate and minimize power consumption.

In Russian and Finnish swimming halls monitoring of air temperature, relative humidity and CO_2 level were carried out. For Russian measurements we have got values that are quite different from recommended values. It can be concluded that exhaust ventilation system was inefficiently. The air which are supplied into the pool was not enough heated. Furthermore, the air in the pool was too dry, it showed, system operated more than necessary. The high air velocity combined with low air temperatures and low relative humidity and gives a feeling of cold and draft pick.

For Finnish measurements we have got the values of air temperature that are quite different from recommended values. It can be because personnel try to save energy. Values of relative humidity, absolute humidity and CO_2 concentrations matched to required meanings. But it is necessary to note, the relative humidity is carry to maintain at this time of the year even without a dehumidifier. On the Mollier diagram you can see, that absolute humidity of outside air in the summer is higher than in the autumn or winter period. It can be concluded that exhaust system was efficiently in autumn time, but it is unknown how air-conditioning system will operate in the summer. It is interesting research question for following investigations.

According to Russian and Finnish measurements and recommendations, calculations of absolute humidity and air flow rate were performed. These values were compared to recommended values. It can be concluded that calculated amount of outdoor air which needs for the providing of recommended relative humidity is the similar as designed and required values. But Finnish calculations are so differ designed value. It can be related with differences of AH-calculations or with temperature, which is used for calculations.

Finally, all parameters which are needed for providing good indoor climate in swimming halls are considered. But there are many interesting topics related with swimming halls, which could be studied in future.

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