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Evaporation Rate in Indoor Swimming Pools – Monitoring of Evaporation at a Swimming Pool Facility and the Impact of Bathers on Evaporation

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Abstract

Ventilation system for the swimming pool is design based on evaporation rate. If the air stream based on the evaporation rate is too low it can cause moisture condensation on the building envelope and to destruction of the construction of the building. If it is to high it leads to oversizing of the ventilation system. It causes high operating costs.

There are many formulas to calculate the evaporation rate in the literature. Finding the right formula is very hard, because these relation give different results, which are significantly different from each other. The appropriate formula can help in the proper design of the ventilation system, especially in designing right size of an air handling unit. In finding appropriate formula monitoring of air handling unit in the real facility can be very helpful.

The article presents the results of monitoring of water evaporation in the swimming pool facility located in Poznan, Poland, based on the measurements of the parameters of supply and exhaust air in their handling unit and the parameters of the water and the air in the pool hall. The results show that the evaporation rate, according to the literature gives much higher values than those measured. Selection of a proper correlation will lead to correct selection of air handling unit (smaller size), which causes that the HVAC installation for the pool will operate more optimally and effectively.

Key words- evaporation; ventilation; swimming pool

1. Introduction

swimming pools are facilities with high operating costs, primarily related to the costs of preparing and handling of swimming pool water and heating and ventilation systems in the pool hall. The operating costs associated with hall ventilation arise from the need to remove moisture gains accumulated as the result of water evaporation as well as harmful chemical compounds generated by the presence of disinfection by-products in the air above the pool basin area. What is more, swimming pool halls are heated by the air heating system. In order to meet those requirements, it is necessary to select the correct air handling unit.

This paper focuses on the selection of the right formula to calculate the amount of the evaporation of water, which in the case of swimming pools is very important and often determines the size of the air handling unit. Monitoring of the air handling unit in an existing swimming facility can help to choose the right equation.

2. Air and Water Parameters in Swimming Pool Facility

The parameters of air and water have a large impact on both the proper feelings of the users and on the power consumption of the ventilation system. [6] The most important of these parameters is the temperature of the pool water. It is a determinant of the selection of air temperature. It is also important to pay attention to the proper selection of the relative air humidity in the pool hall and its speed in the occupied zone [6]. Those parameters have a significant impact on the rate of water evaporation.

The recommended temperature for different countries is shown in Table 1 and the values for the air are shown in Table 2 below.

Table 1. Water temperature recommended by different countries regulations

Recommendations		Water temperature [^oC]
FINA [5]	Lap swimming	25–28
	Diving	>26
	Water polo	26±1
	Synchronized swimming	27±1
ASHRAE [1]	Lap swimming	24÷29
	Swimming competition	24÷28
	Diving	27÷32
	Hotel pool	28÷30
	Therapeutic pool	29÷35
VDI [9]	General use	24÷28
	For children	30÷34
	Therapeutic pool	30÷34

Table 2. Indoor air parameters recommended by different countries regulations

Recommendations		Air temperature [^oC]	Air humidity [%]	Air velocity over water surface [m/s]
FINA [5]	No regulations	-	-	-
ASHRAE [1]	In general	$t_a = t_W + 1 \div 2K$	50÷60	≤0,13
VDI [9]	In general	$t_a = t_W + 2 \div 4K$	40÷65	0,15

The selection of water temperature, as shown in Table 1, is adjusted depending on the use of the facility. the higher the intensity of users' exercise , the lower the water temperature. As for the elderly and children, whose body temperature regulation system may not sometimes work efficiently , the water temperature should be higher. Table 2 shows the air parameters that should be chosen depending on the usage of the pool. The higher the temperature of air (with the same relative humidity of the air and temperature of water), the intensity of evaporation of the water decreases. It leads to reduction of energy consumed in the air drying process [6].

3. Air and Water Parameters in an Existing Facility

In the second point of this paper, the recommended parameters of the water and the air have been presented. In existing facilities these values may sometimes be different. This may be caused by the poor regulation of the heating or ventilation system.

In order to conduct research on water evaporation, measurements have been taken in an existing facility. The analyzed ventilation system in the researched facility is a decentralized ventilation with a separate pool basin zone.

For research purposes, ALMEMO 2890-9 recorder and meter, type FHA 646-E1C, with sensors for relative humidity and temperature measurements in the supply duct and exhaust have been installed. The measuring range of sensors in the range of relative humidity is 0 ÷ 100% ± 2% at nominal temperature of 25°C, while for the temperature range of 0 to 70°C, the measurement accuracy is ± 0,1°C.

The BMS system of the building has also been used to define the air flow.

The designed parameters of the water, air and the measurements taken in the pool hall are summarized in Table 3.

Table 3. Measured parameters in an existing facility

Parameter		Designed	Measured
Water temperature	t_w [^{o}C]	28	28
Air temperature in swimming pool hall	t_a [^{o}C]	30	28
Air humidity	φ_a [%]	60	60
Moisture content in exhaust air (average)	x_{ex} [g/kg]	16	14
Moisture content in supply air (average)	x_{su} [g/kg]	11	11
Velocity of the air	v [m/s]	0,2	0,2
Number of people at the pool (average)	N [peopel]	120	45
Water Surface	A_{pool} [m^2]	2150	2150
Supply air stream at daytime	V_{su} [m^3/h]	64000	54000
Supply air stream at nighttime	$V_{su,night}$ [m^3/h]	-	40000

Due to the fact that evaporation is also affected by the number of bathers, the observation of the number of bathers in two periods - in the morning and in the afternoon at a 5minute rate has been performed. Owing to the nature of the facility, where people have the ability to move around, visit different parts of the building at any time, there are some variations in the number of people. The observed number of people is presented in Fig. 1.

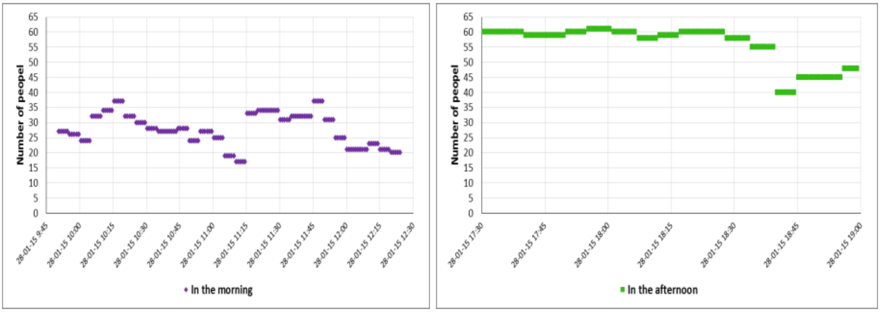

Fig.1. Number of people swimming at the pool in an existing facility in the morning (violet) and in the afternoon (green)

Analyzing the results obtained from the measurements conducted, it has been discovered that in an existing facility there were discrepancies between the set values and the values designed. .

4. Air Stream for Swimming Pool Facility

The criterion for selection of the air stream for a swimming pool hall should be the criterion of removing moisture gains, while ensuring the proper flow of fresh air for the users. It is the most appropriate criterion, especially for buildings with decentralized ventilation, in which case the ventilation is not intended to cover the losses of heat in the entire pool hall .

The equation for determining the air flow resulting from the removal of moisture gains is (1) [7]:

$$m_{su}=m_{evap}/(x_{ex}-x_{su})\ [kg/h] \qquad (1)$$

The equation (1) takes into account the stream of evaporating water m_{evap} and the difference of moisture content in the exhaust air from the pool hall x_{ex} and in the supply air x_{su}. The difference in moisture content should be small and amount to about 4÷5 g/kg [1].

5. Formulas for Calculating Water Evaporation

In order to determine the air flow, the amount of evaporating water should be known. The basic equation has the form of (2):

$$m_{evap}= \beta \cdot \Delta\pi \cdot A_{pool}\ [kg/h] \qquad (2)$$

It takes into account the surface of a swimming pool basin (area of contact between water and air) A_{pool}, the drive unit of the evaporation process $\Delta\pi$ and the evaporation factor β , which is referenced to the water surface.

In the professional literature, one can find several formulas for the calculation of evaporation . They are divided into those for inactive pools, with undisturbed water surface and active ones attended by swimmers , with disturbed water surface . All these equations contain components specified in (2). In addition, in the equations for the swimming pools in active use, the turbulent factor is used to increase the rate of evaporation. The equations are shown in Tables 4 and 5, in relation to 1 m^2 of pool water.

Table 4. Formulas for calculating evaporation from inactive pools

Formula by	Evaporation rate [$kg/h/m^2_P$]	
Carrier [6]	$(42{,}6+37{,}6\cdot v)\cdot(p''_w-p_w)/r$	(3)
Shah [8]	$35\cdot\rho_{a/w}\cdot(\rho_a-\rho_{a/w})^{0{,}333}\cdot(x_{a/w}-x_a)$	(4)
VDI [9]	$7/(R_D\cdot T\cdot 1000)\cdot(p''_w-p_w)$	(5)
Smith [2]	$(70+0{,}35\cdot v)\cdot \Delta p/r$	(6)
Sprenger [4]	$(25+19\cdot v)\cdot\Delta x$	(7)
Recknagel [4]	$7\cdot\Delta x$	(8)

Table 5. Formulas for calculating evaporation from pools in active use

Formula by	Evaporation rate [$kg/h/m^2_P$]	
Carrier [6]	$1{,}5\cdot(42{,}6+37{,}6\cdot v)\cdot(p''_w-p_w)/r$	(9)
Shah [8]	$(1+14{,}85\cdot N/A_P)\cdot 35\cdot\rho_{a/w}\cdot(\rho_a-\rho_{a/w})^{0{,}333}\cdot(x_{a/w}-x_a)$	(10)
VDI [9]	$28/(R_D\cdot T\cdot 1000)\cdot(\ (p''_w-p_w)$	(11)
Biasin&Krumme [3]	$0{,}118+0{,}01995\cdot F_u\cdot(p''_w-p_w)/$	(12)
Recknagel [6]	$28\cdot\Delta x$	

v – air velocity [m/s]; p''_w – saturation pressure of water vapor [Pa]; p_w – vapor pressure [Pa]; ρ – air density [kg/m^3]; r – heat of evaporation [kJ/kg]; x – moisture content in the air[kg/kg]; R_D- vapor gas constant 461,52 [J/kg K]; T- arithmetic average temperature of pool water and air [K]; N – number of swimmers [people]; A_{pool} – water surface [m^2]; $Fu=N/A_{pool}$ [people/m^2];

All factors have been selected according to the recommendations given in the literature for lap swimming, where occupancy is rarely the highest .

In order to compare the results of the calculations using the equations listed in Tables 2 and 3, the assumptions summarized in Table 3 have been made. A bar graph shown in Fig.2 presents the results of the calculations of the evaporating amount of water in relation to the designed parameters for air and the number of people. , The graph in Fig. 3 presents the measured and observed parameters.

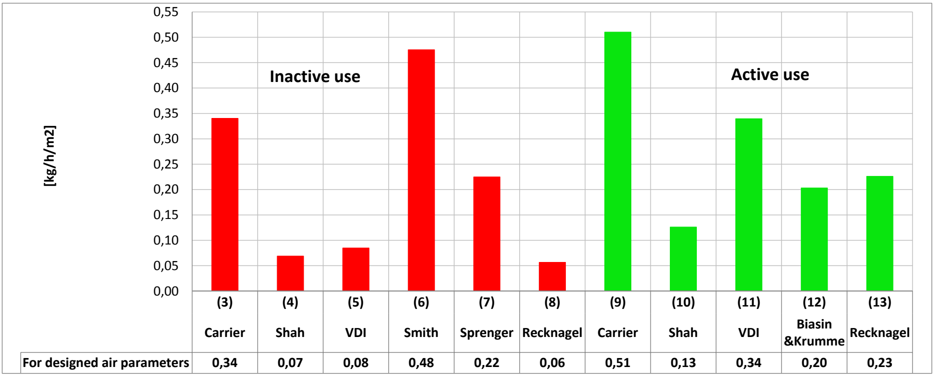

Fig.2. Evaporation rate from pools with an inactive (red) and active use (green) for designed air parameters

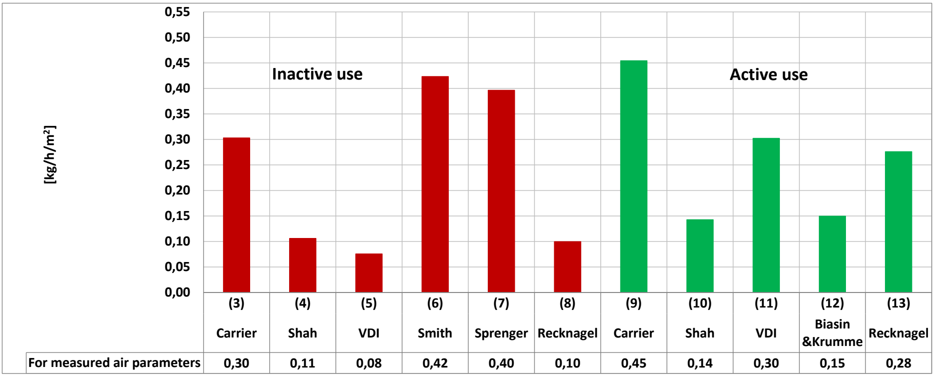

Fig.3. Evaporation rate from pools with an inactive (red) and active use (green) for measured air parameters

6. Evaporation Rate in Existing Facility

In order to compare the results obtained for the design parameters with the parameters based on the monitoring, equation (1) has been used. Monitoring has been carried out for the period of one month. The calculations have been performed for two selected periods of time: 28-31.01.2015 and 22-25.05.2015 The results are shown on graphs below (Fig.4 and Fig.5).

In addition, the graphs show values established by recommendations of the authors [6]. Namely, Shah relation, which gives the smallest value, to VDI equation, which gives a close approximation to the average value (for active use). As a result, it was possible to conduct comparison analysis.. The measurements were conducted while the facility was in use from 6:00 to 22:00 and was out of use from 22:00 to 6:00.

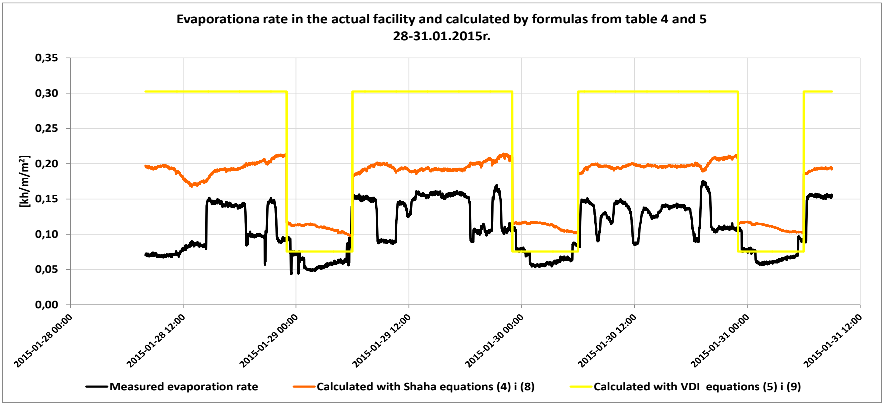

Fig.4. Evaporationa rate in an existing facility and calculated on the basis of formulas from Table 4 and 5 with parameters from Table 3 – 28-31.01.2015

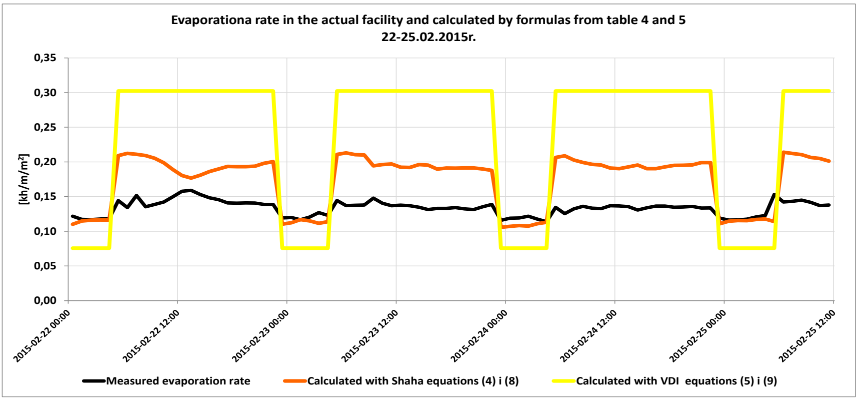

Fig.5. Evaporationa rate in an existing facility and calculated on the basis of formulas from Table 4 and 5 with parameters from Table 3 – 22-25.02.2015

The graph below (Fig. 6) shows the results based on the author's own observation of the number of people in water (Fig.1) and the equations which also take into account the number of people parameter to calculate water evaporation ((10) and (12)).

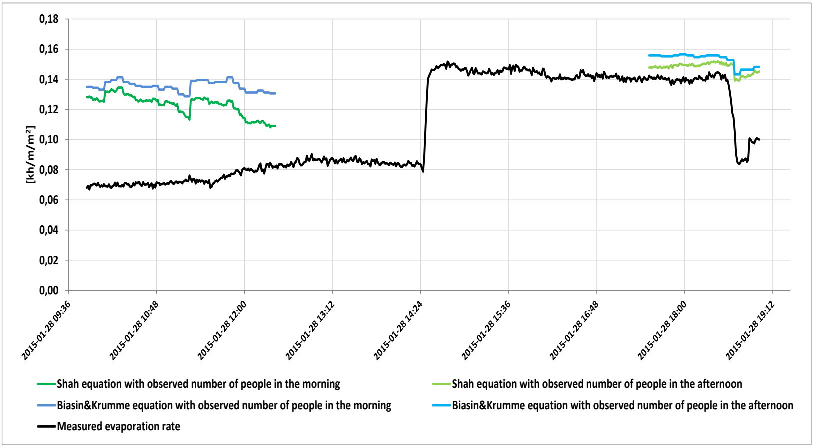

Fig. 6. Evaporation rate measured in an existing facility, including the calculation of the observed number of bathers

Analyzing the graph, it can be stated that the calculation using equations (10) and (12) give values similar to those obtained by calculation based on the monitoring of the air handling unit.

It is very important to consider here the relevant number of users. The equation (12) is recommended by the producer of air handling units installed in the existing facility on the basis of which the manufacturer selects a given air handling unit.

In the afternoons, the values calculated taking into account the actual number of people (green and blue), and the values obtained from the monitoring (black) are similar.

This is mainly due to the fact that the pool was used by a larger number of people and their intensity of swimming was greater in the morning because of the fact that between 14:30-18:30 the training of competition swimmers was held .

7. Conclusions

The presented analyses of various formulas used to calculate the evaporation of water at swimming pools show that there are significant differences between the results obtained using different relations . The discrepancies range up to 80%. Formulas used for calculations assume that the pool does not have overflow channels. Currently public pools, as the facility used for research, have overflow channels, which may result in increased evaporation of the water by the fact of large water surface, as well as the higher turbulence. The evaporation rate obtained in research give values lower than those from calculation methods, therefore the present study omitted the presence or absence of overflow channels. Accordingly, there is a high probability that the application of improper equation may result in a greatly oversizedair handling unit and thus, the operating costs are increased. It is unlikely to undersize the ventilation unit due to the fact that the equation applied gives lower rate of evaporation as the measurements show that evaporation rate in the existing facility is much lower than any rate calculated on the basis of formulas recommended in literature. This may be caused by the fact that the number of people at the pool was significantly lower than the projected one. However, even values calculated with formulas that take into account the number of bathers, which is in line with the observed number of people, give inflated values. However, these results are more comparable with the values measured for the existing facility.

The values observed in the existing facility and the values calculated with literature formulas approach each other during the nighttime, so at the time when there is not disturbance to water surface. It is a condition easier to obtain in a laboratory, thus it can be assumed that equations from (3) to (8) give results close to reality, which is confirmed by the values assigned to the existing facility on the basis of monitoring of air parameters in the air handling unit.

In the case of the calculation of the amount of evaporation of water when the water surface is disturbed, the differences are significant. It can therefore be concluded that in the design process the equations taking into account the number of bathers must be used. The pool facilities are often not fully occupied, so commonly used equations lead to oversizing of the ventilation system.

Additionally it should be mentioned that the formulas used for calculations assumed that the pool does not have overflow channels. Currently public pools, as the facility used for research, have overflow channels, which may result in increased evaporation of the water by the fact of large water surface, as well as the higher turbulence. The evaporation rate obtained in research give values lower than those from calculation methods, therefore the present study omitted the presence or absence of overflow channels.

To verify the authenticity of the claim that the calculations should be conducted on the basis of formulas taking into account the number of bathers, a longer observation combined with the monitoring of air parameters in more than one swimming facility should be performed.

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