SIMULATION OF HEATING AND VENTILATION SYSTEM OF INDOOR SWIMMING POOLS

SIMULACIJA SISTEMA ZA GREJANJE I VENTILACIJU ZATVORENIH PLIVAČKIH BAZENA

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Systems for heating indoor swimming pools consume a lot of energy, with their specific energy consumption per unit of surface typically above than that of outdoor swimming pools. The swimming pool hall is considered to be the greatest energy consumer of such buildings, since evaporation from the free water surface increases air humidity in the swimming pool hall, affecting energy consumption for heating and ventilation on the one hand side, and energy for heating swimming pool water on the other hand side. In this paper, simulation of annual performance of indoor swimming pool hall is done in order to determine energy consumption for heating swimming pool water. Simulations are done using TRNSYS software. Desired temperature of swimming pool water and desired temperature of ambient air are varied in the modeled heating and ventilation control system to investigate the impact of the given control strategy on energy consumption. For the chosen range of the varied parameters, it the simulations indicated a possibility of reduction of energy consumption for heating and ventilation of the swimming pool hall up to 10%, by adapting the control strategy.

Key words: *Indoor swimming pool hall, annual simulations, energy consumption, control strategy;*

Sistemi za grejanje zatvorenih plivačkih bazena su veliki potrošači energije, a njihova specifična potrošnja energije po jedinici površine obično prevazilazi potrošnju sportskih hala i otvorenih plivačkih bazena. Najveći potrošač energije je bazenska hala gde isparavanje sa slobodne površine vode bazena povećava vlažnost vazduha u hali tj. potrošnju energije za grejanje i ventilaciju sa jedne strane, I utiče na dovod sveže vode povećavajući potrošnju energije za zagrevanje bazenske vode sa druge strane. U ovom radu je izvršena simulacija godišnjeg ponašanja hale zatvorenog plivačkog bazena kako bi se utvrdila potrošnja energije za zagrevanje bazenske vode i grejanje i ventilaciju bazenske hale, pri čemu je uzet u obzir uticaj ishlapljivanja sa površine bazenske vode. Simulacije su rađene pomoću TRNSYS softvera. Kako bi se ispitao uticaj na potrošnju energije, u simulacijama su varirani parametri modela sistema za upravljanje, i to: željena temperatura bazenske vode i željena temperatura vazduha u hali. Za odabrani opseg ovih temperatura, moguće je smanjiti potrošnju energije za grejanje i ventilaciju bazenske hale do 10%, promenom parametara sistema upravljanja.

Ključne reči: *Zatvoreni plivački bazeni, godišnja simulacija, potrošnaj energije, strategija upravljanja*

I. Introduction

Indoor swimming pool buildings have a large energy footprint. Energy in swimming pool halls is used for maintaining thermal comfort conditions in the hall and the pool water at desired temperature. Breakdown of energy consumption in indoor swimming pool buildings showed that: 45% of energy is used for pool hall ventilation, 33% for heating pool water, 10% for heating and ventilation of the rest of the building, 9% for lighting and equipment and 3% sanitary hot water [1]. Pool hall, together with the swimming pools can be considered as a greatest energy consumer, and may account for up to 60% of total energy use [2,3]. There are many swimming pool buildings, most of them are parts of large public sport centers in Serbia, maintained and operated by local authorities or parts of hotel and leisure facilities. Swimming pool buildings generally consume vast amounts of energy [1], with significant waste of energy and thus possibilities for energy efficiency improvements.

In indoor swimming pool halls, air temperature and humidity should be maintained at a predetermined level. Evaporation from the pool water surface to indoor air increases relative humidity of indoor air. This implies dehumidification applications and additional energy consumption for heating cold fresh air. Energy consumption in sport centers, but for buildings in continental climate it ranges from 600-6000 kWh/m^2 annually [1]. Heat required for heating indoor swimming pools is lower than that of the outdoor swimming pool, since the temperature difference with the ambient air ranges between 1-3 ^{o}C. Additional heating increases water evaporation, which further raises energy demands for water heating and maintaining thermal comfort in the pool hall. Careful design and control of the HVAC system is needed to maintain water and air temperatures and air humidity at optimal levels for efficient operation.

In order to estimate energy demands of indoor swimming pools and analyze methods for improving their energy efficiency , it is important to create a physical model of both pool hall and the pool. Mathematical models of indoor swimming pools are important for analyzing energy supply systems and addressing their energy performances. Energy balance models of swimming pools are usually a starting point of such processes [5,6,10]. The highest thermal loads in indoor swimming pool buildings, often originates from water evaporation from the pool water surface [7]. Therefore, special attention was brought to mathematical modeling of water evaporation from water surfaces of the pool. Robustness of the models is determined by the level of detail relevant to the researched problem. In this paper, a mathematical model of the swimming pool is created and used in TRNSYS software to investigate energy saving opportunities for heating and ventilation of the pool hall.

Heating, air conditioning and ventilation systems in indoor swimming pool buildings are designed to provide suitable thermal comfort conditions for pool users in the pool hall areas. Indoor temperature is kept at relatively high levels (24- 29^{o}C), which creates conditions for significant evaporation rates from pool water surface. Relative humidity should be kept below recommended values not only for occupant comfort reasons, but also to prevent corrosion and condensation problems in the facility. In order to achieve lower energy consumption for heating in the building, it is important to determine and maintain an optimal ratio between air temperature, pool water temperature, and air velocity in the pool hall.

In this paper, indoor swimming pool hall of the Sport and Recreation Center "Dubocica" in Leskovac was modeled and simulated using TRNSYS software. Speciall attention was brought to modeling of its heating and ventilation system and its performance. Desired indoor temperature and swimming pool water temperature, defined in the modeled controllers of the heating and ventilation system, represent parameters whose impact on energy consumption of the swimming pool hall was analyzed in the paper. Desired values of these parameters were varied in several simulations, and their impact on annual energy consumption is compared.

II. MODELING AND SIMULATION OF THE SWIMMING POOL HALL

Heating, air conditioning and ventilation systems in indoor swimming pool buildings are designed to provide suitable thermal comfort conditions for pool users in the pool hall areas. Indoor temperature kept at relatively high levels (24- 29^{o}C) creates conditions for significant evaporation rates from pool water surface. Relative humidity should be kept below recommended values not only for occupant comfort reasons, but also to prevent corrosion and condensation problems in the facility.

Conduction through the pool walls (in the basement) is usually negligibly small, unless the pool is above ground or in direct contact with cold groundwater, which is rarely the case. The convection from the pool surface is a function of temperature of the air in the pool hall and air speed above the water surface. Radiation losses are more important for outdoor swimming pools [3], but can also occur as a consequence of long wave radiation exchange with indoor walls [8]. Evaporation heat losses contribute to as much as 50-60% to the total het losses [8]. Evaporation rate is a function of air velocity and partial pressure difference of water vapor slightly above the water surface and water vapor partial pressure in the pool hall. Pool water is heated and kept on temperatures ranging from 24-29^{o}C in recreational and competition pools [8], or even at higher temperatures in spa centers and therapeutic pools, which results in heat demand for pool water heating even in summer periods. In swimming pool buildings, besides the evident heat loss due to evaporation, it is also important avoid moisture problems. Hence, evaporation rates should be kept at a reasonably low level, while maintaining thermal comfort for the swimmers in both water and pool hall space. Pool hall heating and ventilation equipment design guides [8] recommend 2-3°C higher pool hall air temperature compared to the water temperature. With increase of pool water and decrease of pool hall air relative humidity, evaporation rate from the pool water surface increases. Due to its large contribution to energy demands of the indoor swimming pool building, modeling of evaporation rates from swimming pool surfaces will be analyzed with more detail in this paper.

Energy balance of an outdoor swimming pools [2,3] are used to simulate performance of different heating applications. The energy balance of indoor swimming pool presented in this paper is tailored to be coupled to TYPE 56 multi-zone building model, found in TRNSYS 17 component model library. It is assumed that pool water is ideally mixed and that the fluid is incompressible. Water density and conductivity are considered constant. Presented equation is a function of pool area *A*.

Evaporation from occupied swimming pools is much higher than that of unoccupied swimming pools [9]. There are several approaches and efforts aimed to account for the difference in evaporation rate of occupied pools. ASHRAE handbook [9]proposes to calculate evaporation rates using the Carrier formula multiplied by a correction factor, which depends on pool type. Carrier formula, proposed by ASHRAE is used for obtaining results for the purpose of simulation in this paper.

In this paper, a case study of Indoor swimming pools of Sport and Recreation Center (SRC) "Dubočica" is analyzed. There are three swimming pools located in SRC „Dubočica“, with total water surface areas of 1050 m^2, 330 m^2 and 100 m^2, and depths of 2 m, 1,45 m and 0,5 m respectively. Total water surface of the pool area is 1480 m^2. For the purpose of fulfillment of indoor thermal comfort conditions in the pool hall and auxiliary rooms, an energy system with heat exchangers rated at around 3,35 MW in total, is installed (tab.1).Users of the swimming pools are adults, children and sportsmen, accounting for 55000 visitors annually. Pool’s open hours are divided in two daily shifts and a night shift lasting for four hours each.

The building was modeled as multi-zone in TRNSYS software, with the following envelope properties: outside walls based on masonry (19cm) with 5cm mineral wool insulation covered by mortar; rooftop steel plate construction with 10cm mineral wool insulation; and, outside windows and doors with double glazing and metal frame.

According to the installed capacities of heat exchangers, it can be seen that the greatest ratio of energy demand was predicted for pool water heating and air heating and pool hall ventilation (table 1) in the design phase.

Table 1 – Installed capacity of the heat exchangers

Radiator heating (90/70 °C)	276,153 kW	8,24 %
Convective heating for demisting of the hall’s glass surfaces (90/70 °C)	261,625 kW	7,81 %
Floor heating of the pool hall (35/45 °C)	87,457 kW	2,61 %
Sanitary hot water heating (60 °C)	145,100 kW	4,33 %
Pool water heating (24 do 26 °C)	1510,000 kW	45,08 %
Air heating and ventilation	1069,510 kW	31,93 %
- Ventilation chamber for demisting of the pool hall glass surfaces	518,180 kW	15,47%
- Ventilation chamber for the pool hall stands	403,100 kW	12,03%
- Ventilation chamber for ventilation of lobbies	96,800 kW	2,89%
- Ventilation chamber for ventilation of cloakrooms	51,430 kW	1,54%

The values of the relevant parameters for the evaporation models are found:

- Pool water temperature ranges between 24-30°C;
- Air temperature is 1-3 °C higher than the pool water temperature;
- Relative humidity ranges from 50% up to 80%;
- Average air velocity ranges between 0,05 - 0,2 m/s.

In order to achieve lower energy consumption for heating in the building, it is important to determine and maintain an optimal ratio between air temperature, pool water temperature, and air velocity in the pool hall. Evaporation rate is a function of air velocity and partial pressure difference of water vapor slightly above the water surface and water vapor partial pressure in the pool hall. Pool hall heating and ventilation equipment design guides [14] recommend 2-3^{o}C higher pool hall air temperature compared to the water temperature.

Main contributors to the energy balance of indoor swimming pools are:

- Conduction through the pool walls Q_{cond};
- Convection from the pool surface Q_{conv},
- Radiation from the pool surface Q_{rad};
- Evaporation from the pool surface Q_{E};
- Heat loss due to fresh water flow $\dot{\boldsymbol{Q}}_{\boldsymbol{fw}}$ for water loss compensation;
- Heat flow rate from a heating system $\boldsymbol{Q}_{\boldsymbol{aux}}$.

Temperature change of pool water over time can then be calculated as:

$$\rho_{w} c_{pw} V_{pool} \frac{dT}{d\tau} = \dot{Q}_{aux} - \left(\dot{m}_{fw} c_{pw} \left(t_{w} - t_{fw} \right) + A_{p} \dot{E} r + Q_{conv} + \alpha \left(t_{w} - t_{a} \right) + Q_{rad} \right) \tag{1}$$

Where:

$\dot{E}$ is the mass flow rate of evaporated water and r is the latent heat of evaporation; α is the heat transfer coefficient; T_{w} is temperature of the pool water; T_{a} is the indoor air temperature in the pool hall, Q_{rad} are radiation losses, which can be neglected for indoor swimming pools, m_{fw} and t_{fw} are mass-flow rate and temperature of the supplied fresh water for keeping a constant pool water level, respectively.

Convective heat transfer coefficient can be expressed as [10]:

$$\alpha = 2.8 + 3.0 V_{a} \tag{2}$$

Where $\boldsymbol{V}_{\boldsymbol{a}}$ stands for air velocity above the water surface.

In order to account for such disturbances, a pool occupancy factor can be introduced [8]:

$$F = \frac{A_{max}}{A_{p} / N} \tag{3}$$

Where *N* is the number of occupants, and *Amax* is the pool area per person at maximum pool occupancy. Factor of occupancy for unoccupied swimming pools is equal to 0.

Water evaporation rate is estimated as a function of the occupancy factor F, according to the Shah formula for occupied swimming pools [8]:

$$E_{o} = \begin{cases} E\left(3.3F + 1\right), F < 0.1 \\ E\left(1.3F + 1.2\right), 0.1 \leq F \leq 1 \end{cases}; \tag{4}$$

Desired temperature in the modeled control system of the pool was set to 24-26°C for heating, and desired temperature of the pool hall air was defined as equal to or up to 2 ^{o}C higher than the desired temperature of the swimming pool hall. It is assumed that the heating and ventilation system operates with 30% outside ambient air. The air temperature in the pool hall changed during the simulation with one set of the analyzed parameters is presented in Fig. 1. Simulation showed that there was a demand for heating even in summer period, as shown in Fig 2. Although the boiler load drops to 0% frequently in the summer period, there is a heating demand in the summer period, which can be related to the highest number of visitors, leading to higher SHW demands, but also pool hall and pool water losses (Fig.2.). Consequently, existence of heating demands in the summer imply good opportunities for solar thermal applications.

The heating system transfers heat produced by the boiler to the swimming pool heating loop, sanitary hot water loop, and heating and ventilation loop using separate heat exchangers. The heating and ventilation system is modeled using a heating coil, and the swimming pool heating loop and the sanitary hot water heating loop are equipped with two separate heat exchangers. The heat exchanger transferring heat to the swimming pool heating loop is followed by the heat exchanger responsible for heat transfer for the sanitary hot water loop. The controllers of the system are configured to give priority to heating the swimming pool over the sanitary hot water heating loop.

The sanitary hot water system is equipped with $5m^3$ heat storage tank, equipped with two electric heaters. When the temperature in the sanitary hot water heat storage tank below the defined thermostat temperature, electric heaters heat the sanitary hot water. Annual sanitary hot water consumption profile is modeled as a function of swimming pool occupancy factor *F*. When the temperature of the swimming pool is within controller preset values, entire energy flow from the solar system is directed to the heat exchanger of the sanitary hot water tank. After heat exchange with the pool heating loop, sanitary hot water tank is heated using solar energy. Water from the $5m^3$ SHW boiler is supplied to the showers, where it is mixed with water from the mains. The temperature of mixing, i.e. output shower temperature was assumed 40 °C, with 5° dead band.

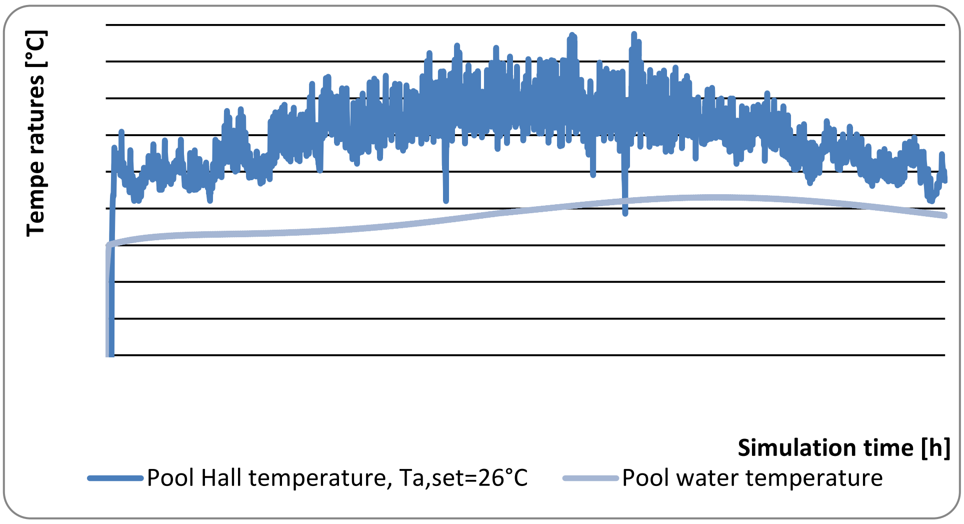

Fig 1. Annual change of pool hall air temperature and pool water temperature

Energy demand of SRC Dubočica consists of space heating demand, pool water heating demand and SHW demand. Change of in the demand profile is affected by weather conditions change, but also by pool occupancy. According to questioner data, the pool operates with full capacity of 650 swimmers only in the summer months, which is gradually decreased and drops to one tenth of nominal capacity in winter months. Pool occupancy was used to generate annual profiles of SHW water demand, and evaporation loss using the pool occupancy factor. Increase in occupancy leads to more frequent water treatment, increased fresh water supply, increased free water surface where evaporation takes place, and hence increased energy demands.

When pool water reaches the set point temperature, a controller turns of hot water flow through to swimming pool loop, so that hot water from the collector array would be used to heat SHW. SHW boiler is equipped by an auxiliary heat exchanger, which heats the water to a set point temperature. Water from the $5m^3$ SHW boiler is supplied to the showers, where it is mixed with water from the mains. The temperature of mixing, i.e. output shower temperature was assumed 40 °C, with 5° dead band. Figures 3 shows temperature of water supply from the SHW boiler to the showers and shower water temperature.

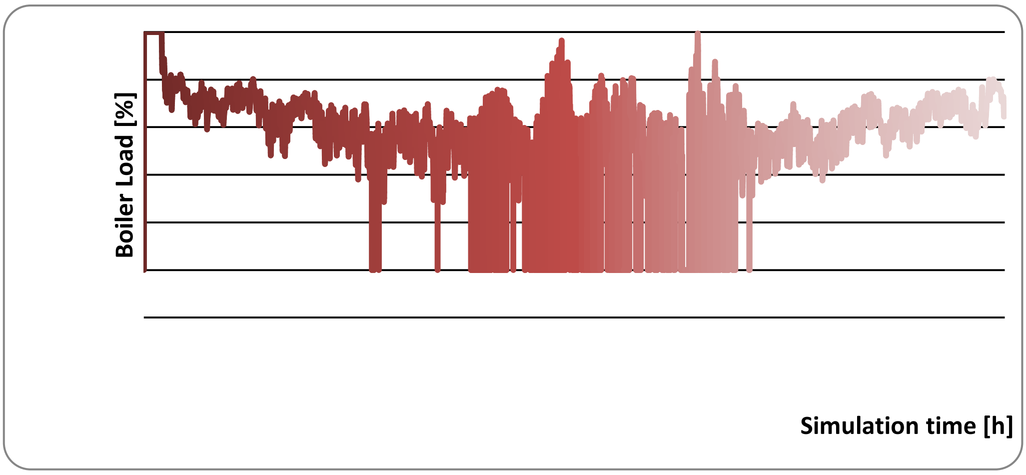

Fig. 2. Part load ratio of the boiler used for heating

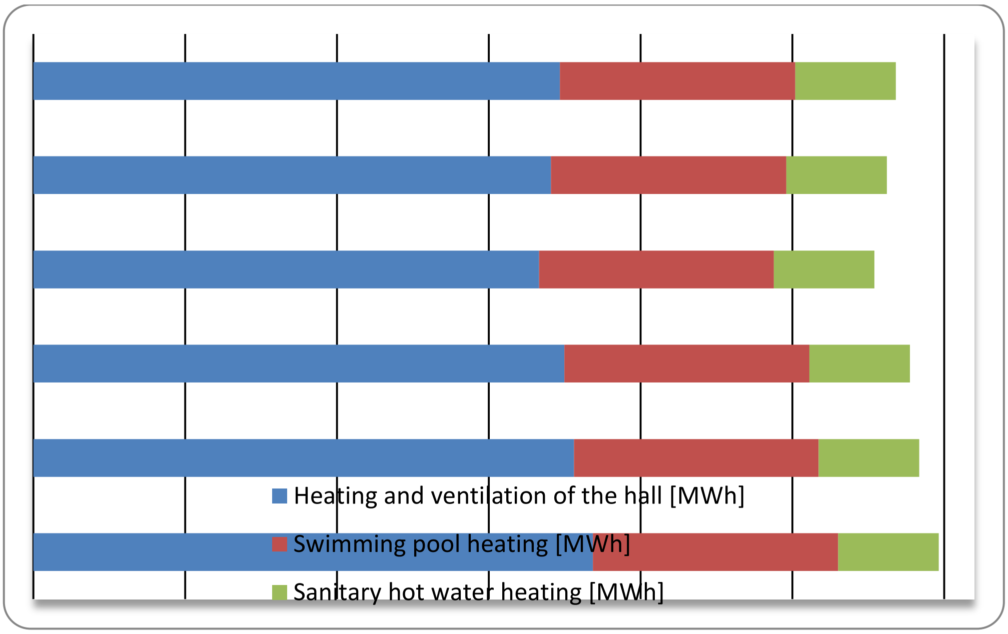

Fig. 3. Simulated energy consumption for heating and ventilation of the swimming pool hall, swimming pool heating and sanitary hot water heating using considered controller strategies

Energy consumption of the swimming pool hall is affected by water evaporation from the surface of the swimming pool into the air of the pool hall. Therefore, it is important to maintain the water and air temperature at optimal values to ensure that thermal comfort conditions are met, with minimum energy consumption. To determine impact of pool losses and pool water surface evaporation, pool hall air temperature in the modeled controller (Tair) was 26°C and 28°C, where as pool water controller temperature was kept 1-4 °C lower, i.e. varied from 24°C to 26°C. Change of temperature of both air and swimming pool water is presented in figure 1. for ambient air temperature set to 26°C, and water temperature set to 25 °C. Energy consumption for heating and ventilation, swimming pool heating and sanitary hot water for each of the analyzed parameter scenarios is presented on Fig 3. The results show slight change in energy consumed for heating and ventilation and swimming pool water heating, while energy demand for heating sanitary hot water is approximately the same in all scenarios. All of the analyzed scenarios were simulated using the exact same sanitary hot water consumption profile.

Table 2. Energy consumption per unit of swimming pool surface obtained by simulation by variation of controller parameters

Controler parameters	Tair=28°C; Tw= 24°C	Tair=28°C; Tw= 25°C	Tair=28°C; Tw= 26°C	Tair=26°C; Tw= 24°C	Tair=26°C; Tw= 25°C	Tair=26°C; Tw= 26°C
Heating and Ventilation (kWh/m^2)	1245.18	1203.10	1182.06	1125.20	1151.53	1172.08
Swimming pool heating (kWh/m^2)	546.03	544.65	544.65	522.93	524.40	523.42
Sanitary hot water (kWh/m^2)	316.07	316.07	316.07	316.06	316.07	316.06
Total (kWh/m^2)	2015.02	1971.56	1950.52	1871.95	1899.74	1919.30

It is important to note here, that energy consumption of indoor swimming pools significantly depends on the heat and mass transfer between the water surface of the swimming pool and the air above it. Here, apart from convection and conduction, one of the significant factors is the evaporation rate from the swimming pool water into air above it. The evaporation rate from the surface of the water of the swimming pool is proportional to the partial pressure difference of water vapor in air at water surface and in air above it, and the velocity of air flow caused by the ventilation system. In addition, part of the swimming pool water is lost during the water treatment process, which is modeled as proportional to the swimming pool occupancy factor in this paper. The greatest contributor to the energy demand for heating the swimming pool water is caused by evaporation swimming pool loss, followed by the convection loss. Radiation heat transfer between indoor swimming pool and walls can be considered negligibly small.

The results in Table 2 are given per square meter of swimming pool water surface per year. It can be observed that minimum energy for heating and ventilation of the swimming pool hall is obtained in the simulation where desired controller air temperature was set to *Tair*=26°C, which is 9.6% lower than the simulated energy consumption with desired air temperature set in the controller to Tair=28°C. The simulations showed the lowest energy consumption for swimming pool heating when the desired swimming pool temperature in the controller was set to *Tw*= 24°C, which 4.2% lower than the maximum simulated energy consumption. The simulations showed that total energy consumption for heating the swimming pool can be lowered by up to 7%, by adopting an adequate control strategy.

III. CONCLUSION

In this paper, modeling and simulation of indoor swimming pool building of the Sport and recreation center "Dubocica", was done using Trnsys software. The building was modeled as multi-zone, but only the results related to the swimming pool hall zone were analyzed. Special attention was brought to modeling and simulation of the performance of the heating and ventilation system responsible for keeping thermal comfort conditions in the swimming pool hall, swimming pool water heating and heating of sanitary hot water for the showers. Parameters which define the desired temperatures in the swimming pool hall and swimming pool water in the modeled control system are varied between simulation runs, to determine their impact on the energy consumption of indoor swimming pool. The values of these parameters were chosen according to literature, as the values which are typically used in the public swimming pool buildings, or are recommended in engineering design handbooks. The intention was to keep the ambient air temperature equal to or slightly above the water temperature level, whereas the water temperature level was set according to values recommended for public swimming pools. Literature review showed that simulation results could be significantly influenced by the chosen evaporation model, since evaporation rate from the swimming pool has a large share in the swimming pool energy balance. For the purpose of this analysis, Carrier evaporation rate formula recommended by ASHRAE was used..The simulation results showed that by careful choice of desired temperatures defined in the controllers, energy savings of up to 10 % for heating and ventilation of the swimming pool hall, energy savings of around 4% for heating the swimming pool can be achieved, resulting in total energy savings for heating the swimming pool and its hall up to 7% are achievable. Due to large influence of the chosen evaporation rate model to the energy balance model of the swimming pool, more precise results could be obtained using an evaporation correlation obtained by measured results in the real building.

IV. Literature

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