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Water Tempering of Pools Using Air to Water Heat Pump Environmental Friendly Solution

Gábor Géczi, László Bense, Péter Korzenszky
Szent István University, Gödöllő, Hungary

1. Introduction

Renewable energy source utilization can be found in education and in practice at the Faculty of Mechanical Engineering, Szent István University (*Gödöllő, Hungary*). In 2005 a 9.6 kW photovoltaic power plant based on a 150 m^2 surface solar cell was installed. In 2012 the new multifunctional education building the Knowledge Transfer Centre was opened and supplemented with a new heat pump heating system [4, 18].

Fig. 1. Szent István University, Faculty of Mechanical Engineering, Knowledge Transfer Centre with the utilization and tuition of renewable energy sources
Rys. 1. Uniwersytet św. Stefana, Wydział Mechaniczny, Centrum Transferu Wiedzy uczące o i wykorzystujące odnawialne źródła energii

The Central European researches of the last years prove that solar systems are the most popular at individual heating systems out of other applicable renewable energy sources [11, 15, 21]. Besides the solar systems, the geothermal energy consumption is gaining more popularity for heating of houses and for hot water supplies [5, 9, 10, 15]. There are ongoing researches for waste heat utilization in mixed fuel boiler [1, 12, 20]. Those results have to be mentioned as well, which do not exclude the effective utilization of electricity. [3, 19]. Practically heat pumps can be put in this group.

Lately, renewable based researches were conducted with the examination of air to water heat pumps. We have created an experimental system for energetic measures. We conducted the measures at different weather conditions, simulating a real task with tempering water of a 10 m^3 pool. With our research we would like to prove that the utilization of air to water heat pumps is favorable in energetic aspects and a gives cost efficient and environmental friendly solution.

2. The history of heat pumps

Lately, heat pumps became more and more popular. In articles we can read about opportunities and development, and in practice we can see the popularity and spread of heat pumps. But heat pump technology is not new; its basic principle was described by Sadi Carnot, French physicist, mathematician in 1824. On the basis of this principle heat can be distracted from lower temperature medium and transmitting it to the higher temperature medium with energy investment. James Joule and William Thomson described the principle of heat pump utilized for heating in 1852. With the usage of this principle, Peter Ritter von Rittinger constructed the first industrial heat pump. It was used for drying salt in salt mines. The biggest milestone was the first application: in 1938 the wood furnaces of Zurich town hall were replaced by heat pumps. The heat source was the water of the river Limmat. Nowadays, many examples of heat pump utilization can be seen in office buildings, baths, family houses and at governmental institutions (such as the German Bundestag building) [6, 22].

The Hungarian application, the compressor heat pump was a technological breakthrough which was constructed with the help of

Heller László in 1948. The world-wide famous professor of The Budapest University of Technology and Economics and academician, defended his PhD thesis in 1948 in Zurich. The topics of his thesis were the technical and economic conditions of heat pump utilization (Heller László: Die Bedeutung der Wärmepumpe bei thermischer Elektrizitätserzeugung. Universitätsdruckerei, Budapest 1948). His conceptions were the heat pump heating of the Hungarian Parliament and the Budapest University of Technology and Economics with usage of Danube water as heat source. Nowadays, with the spread of heat pumps his thoughts are coming through [6, 7].

From the mentioned examples it can be seen that the heat pump is actually a refrigerator, because we distract heat from our medium, but the most important is that we utilize this heat. At heat pump utilization the heat distraction happens from the lower temperature place (soil, water, air). The heat is transferred to a higher temperature place. This can only be done with energy investment [2, 13, 14, 17].

Heat pump utilization was examined in Poland as well. It can be an alternative solution for family house heating, as the study in 2009 points out. But, it must be considered, that the return of investment is slow because of high investment costs [15, 16].

In the following, in our work we would like to prove that heat pump utilization can decrease costs and negative environmental effects. We present this with laboratory and realistic experiments of a Microwell type heat pump.

3. Air to water heat pumps

Air to water heat pumps utilizes the heat of environmental air (evaporator cools environmental air). On condenser side heat utilization prevails, which is used for heating water [2, 8, 14].

3.1. Definition of current COP value

The efficiency and conformance of heat pumps can be defined with the performance factor (COP). The COP is the ratio of heat performance, $\dot{Q}_h$ [W] and used electrical performance P_w, [W].

$$COP = \frac{\dot{Q}_h}{P_w} \tag{1}$$

The value of COP is defined by vaporization and condenser temperature. In our case it can be described with environmental air and pool water temperature. It is evident that at lower air temperature and/or higher pool water temperature the efficiency of the heat pump is lower as well. The proportion of this lower performance cannot be defined by COP value (mostly defined for ideal cases by the manufacturers).

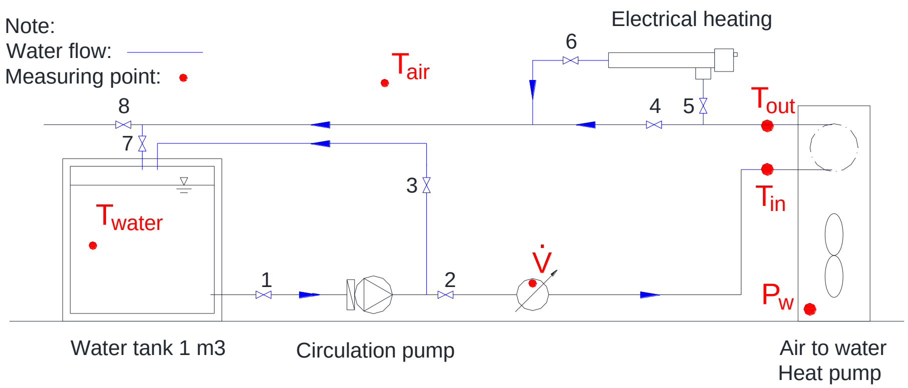

Fig. 2. Air to water heat pump measurement circle scheme
Rys. 2. Schemat obiegu pomiarowego z pompą ciepła typu powietrze woda

At Szent István University, Faculty of Mechanical Engineering we made a measurement circle which continuously records the parameters of heat pumps (Fig. 2) At the experiments we heated 1 m^3 water with HP700 (Microwell, Šaľa, Slovakia) heat pump. In the period of March-June 2013, we heated the content of the water tank from 13°C to 44°C more than 40 times at 13–27°C environmental temperature. (In summer time the initial 13°C was reached with the cooling function of the heat pump.) At the experiments we measured the inner and outer water temperature (T_{in} and T_{out} [°C]) and water tank temperature T_{water} [°C] with NiCr-Ni heat elements. The temperature of environmental air T_{air} [°C] and moisture content φ [%] FHA646-E1C (Ahlborn, Holzkirchen, Germany) was defined with a combined sensor. We adjusted the volumetric flow of water with the opening of the bypass branch to $\dot{V} = 6\text{m}^3 \cdot \text{h}^{-1}$ and we hold it on a constant value. The value of volumetric flow was measured by ARAD Woltman Silver Turbó (WST model, Arad Hungária, Miskolc, Hungary) mechanic flow meter. The electric performance was measured by an Actaris SL7000 (Ganz Mérőgyár Kft., Gödöllő, Hungary) performance measure equipment P_w, [W]. The before mentioned measurement data were collected with the ALMEMO 2590-9 measurement and data collector system (Ahlborn, Holzkirchen, Germany).

The design of measurement system of Szent István University, Faculty of Mechanical engineering can be seen on Fig. 3.

Fig. 3. Heat pump measurement circle at Szent István University, Faculty of Mechanical Engineering
Rys. 3. Obieg pomiarowy z pompą ciepła, Uniwersytet św. Stefana, Wydział Mechaniczny

With taking water temperature into consideration specific heat c_p, [J·kg^{-1}·K^{-1}] and density ρ, [kg·m^{-3}] values can be defined from specific tables. On the basis of that the current heat performance can be defined:

$$\dot{Q}_h = c_p \cdot \rho \cdot \dot{V} \cdot \left(T_{ki} - T_{be}\right) \tag{2}$$

We show the current COP values (determined by equation 1 and 2) on Fig. 4 in the function of tank water and environmental air temperature. The results state the known principle: the decrease of environmental air temperature and/or the increase of pool water temperature results in lower current COP value. However, the available current values make planning, optimization and determination of a mean COP value possible on the basis of expected weather conditions and needed water temperature.

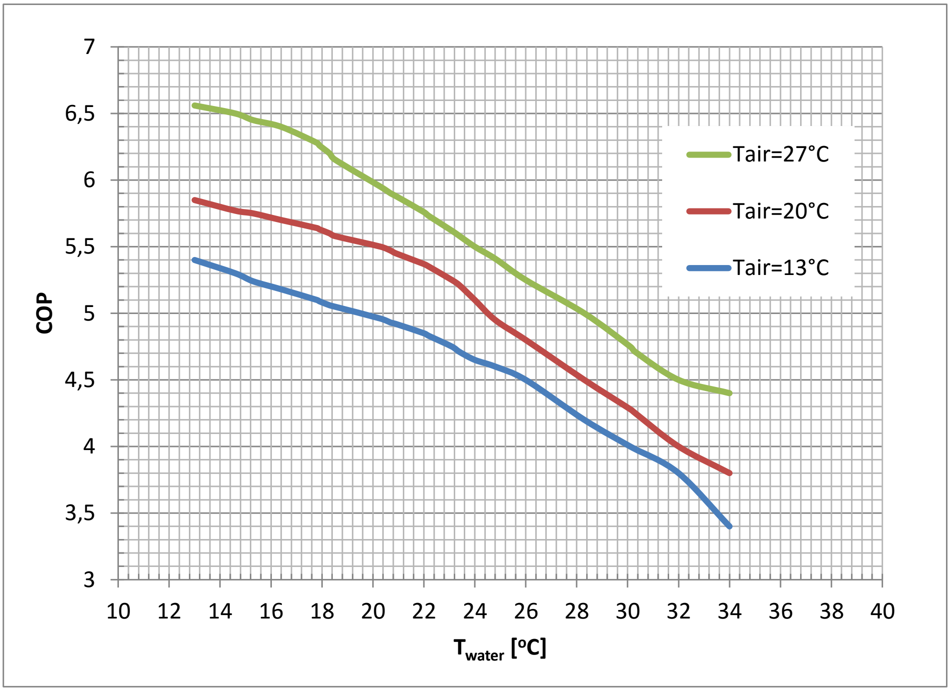

Fig. 4. Current COP value as a function of water and environmental air temperature ($\dot{V}$ = 6 $m^3 \cdot h^{-1}$=const.)
Rys. 4. Zmiany współczynnika efektywności w zależności od temperatury wody i powietrza ($\dot{V}$ = 6 $m^3 \cdot h^{-1}$=const.)

3.2. Tempering of outside pool with heat pump

At Hungarian climatic conditions the outside pools of hotels, pensions and family houses can only be comfortable with heating them in spring and autumn time. The heating of pools makes appropriate conditions for fish farming as well. In outside pools (ponds) the breeding period can be shifted, better possibilities can be provided for the fish. On the basis of the two mentioned examples in 2013 we wanted to realize the tempering of a 10 m^3 artificial pool with an air to water heat pump (Fig. 5).

During our experiments we heated 10000 l water with the before mentioned HP700 (Microwell, Šaľa, Slovakia) equipment to the desired 20°C and we sustained water temperature on this desired temperature for weeks. During the experiments we used the before mentioned ALMEMO 2590-9 (Ahlborn, Holzkirchen, Germany) measurement and data collector system and collectable sensors. Similarly to the model experiment, pool water temperature T_{water} [°C] and environmental air temperature T_{air} [°C] was continuously measured. Inner and outer water temperature T_{in} and T_{out} [°C] and water mass flow was measured as well for the description of heat pump efficiency. The mass flow was adjusted to $\dot{V}$ = 65 l/min with the closing of the returning branch. The water was kept at a constant temperature. Electric performance P_w [W] was defined and on the basis of the value heat pump operating time can be described as well.

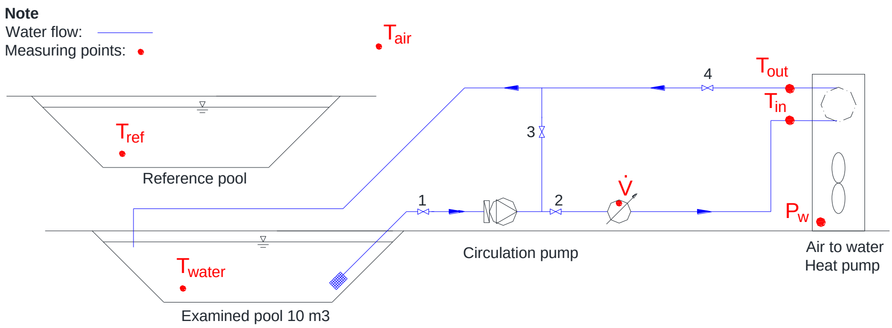

Fig. 5. Tempering of outside pool with 7 kW heat pump
Rys. 5. Utrzymywanie stałej temperatury w odkrytym basenie za pomocą pompa ciepła o mocy 7 kW

The introduced circulation system was put in operation in September, 2013. The extreme October weather helped to gather information at different outside conditions. Fig. 6 shows the situation at 9–13 October. At the first day, 9th October, night time temperature was under 10°C and the daytime temperature reached 15°C. The second day was a rainy day, and after it the weather became warmer, maximum air temperature exceeded to 20°C. Heat pump operation is shown on Fig. 6 on the basis of electricity consumption. The circulation pump was operating continuously, which meant 1.6 A current consumption. Beside the circulation pump, heat pump operation can be seen at 5.8–7.3 A current consumption. The evolved "saw" diagram shows spectacularly how many times and for what time interval heat pump operation was needed.

For the presented 4 days it can be said that pool temperature can be kept on an average mean temperature 20.0±0.3°C at 14.3°C environmental temperature. (For comparison: the temperature of the reference pool was 9.5–14.9°C) The heat pump switched on 23 times for 0.5–3.5 hours intervals, and it operated for 36 hours. This meant 49.68 kWh energy consumption by 1.38 kW mean electrical performance.

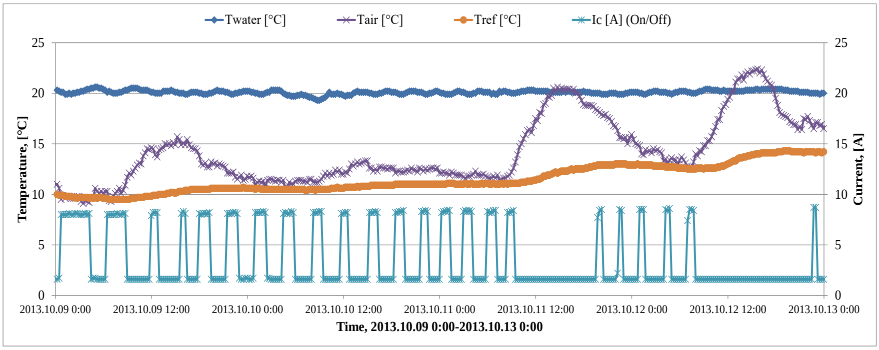

Fig. 6. Changes in water and air temperature as a function of the time
Rys. 6. Zmiany temperatury wody i powietrza w funkcji czasu

For the examination of the heat pump on Fig. 7 we introduce ashorter period of the diagram. It can be seen that on the first morning at approx. 6:14 pool temperature decreased to 20°C and the heat pump switched on. During the flow of pool water the heat pump gained a mean $\Delta T_{heat\ \mathrm{pump}}$=1.3±0.03°C temperature difference at $\dot{V}$ = 65 l/min mass flow. This temperature difference can be measured at the input and at the output side of the heat pump. On Fig. 7 it can be seen that water temperature is increasing again, whilst the temperature of the reference poll decreased onwards.

For describing COP (which shows heat pump operation) we calculated with specific heat, c_p=4.18kJ·kg^{-1}·K^{-1} and with water density, ρ=998.2 kg·m^{-3} values, taking temperature into consideration. The electric performance was P_w=1.33 kW in this period. COP was calculated with these values and with equations (1) and (2). Based on Fig. 7 the current COP value was 4.51. This value corresponds with the expected value of Fig. 4.

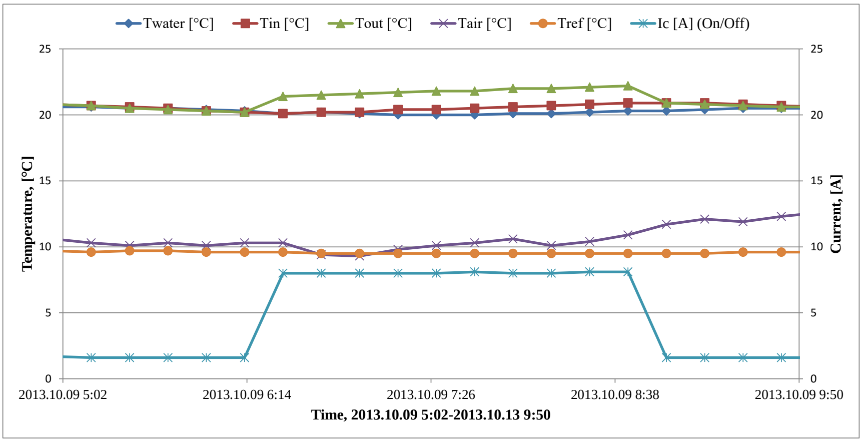

Fig. 7. Heat pump operation parameters as a function of time (detail of Fig. 6)
Rys. 7. Parametry pracy pompy ciepła w funkcji czasu (szczegóły na rys. 6)

Taking the whole fall period into consideration lower efficiency than COP=3.62 did not occur. To mention more extreme conditions, on 24th September the heat pump was not needed, but it was operating full time on 3rd October. According to experiences up to the present, it can be stated that the ideal utilization field for air to water heat pumps are fish farming systems, pool technology and water tempering. In spring and in fall time, air temperature (evaporator temperature) is already/still (T ≈ 12–20°C) and pool temperature (condenser temperature) is ideal (T ≈ 20–24°C) for heat pump application.

4. Conclusions

It is clear that the heating and tempering of pools is a surplus cost in case of the breeding and at comfort increasing. However, the larger fish production, the security or even the possibilities and comfort can be effective. In Hungary the utilization of air to water heat pumps means 30% cost saving against gas furnaces if the breeder chooses tempering. It must be mentioned that heat pump application means approx. 45% CO_2 emission decrease compared to fossil fuel usage. The usage of electric inlays is not cost efficient and it has high CO_2 emission. This mentioned information can be seen on Fig.8, which shows the specific emission during the 4 day tempering. (Calculated emissions are at 0.56 kg CO_2/kWh electric energy and at 1.96 kg CO_2/m^3 natural gas value. The heating performance of natural gas is 9.44 kWh/m^3).

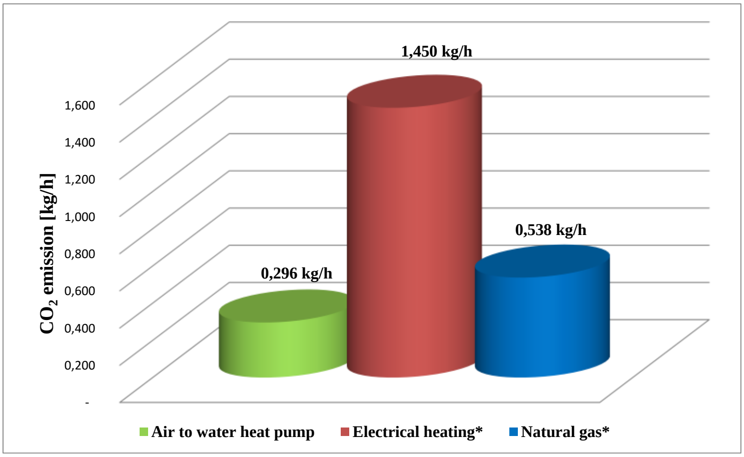

Fig. 8. Specific CO_2 emission according to measuring of October month in 2013 (*calculated values)
Rys. 8. Jednostkowa emisja CO_2 według pomiarów z października 2013 (* obliczone wartości)

5. Summary

The extension of heat pump applications is happening because we recognized the fact that it is based on a renewable energy source. At least at the COP value (*Coefficient of Performance*) it is operating at.

The air to water heat pumps require more place on the market. They are even able to heat a flat or an office building in winter time, or produce the needed amount of sanitary hot water. It is clear that the performance of air to water heat pumps is changing in the function of outside air temperature and needed water temperature. The COP can be interpreted as a current value, it cannot be considered as a continuous feature of the system. In specific cases maybe the current COP value is not that relevant; the needed energy consumption is more important.

At Hungarian climatic conditions swimming pool technology and fish farming is searching for energy sparing solutions for pool heating and tempering. Thermal water can be a good solution in both cases, but its utilization has territorial obstacles. Sun collector utilization is not a sufficient and safe solution taking the Hungarian meteorological conditions into consideration. Natural gas and electricity is available everywhere in the country, but its usage has economic aspects. In case of swimming pool technology applications the utilization is more convenient. This way the risk is decreasing at fish farming, and the breeding possibility is increasing as well at water tempering.

At Szent István University, Faculty of Mechanical Engineering (*Gödöllő, Hungary*) we stated that tempering of pools with air to water heat pumps is easy and economic. For the experiments we used Microwell HP700, 7 kW heat pumps. In the beginning the laboratory measurements focused on the determination of the current COP-value. Later the measurements were extended to the energetic monitoring of outside pool tempering. In the changing autumn weather we got a clear view of air to water heat pump operation. In spring and autumn time the air temperature (evaporator temperature) is appropriate already/still ($T \approx 12$–20°C) and the pool water (condenser) temperature is ideal ($T \approx 20$–24°C) for heat pump applications.

We proved that heat pump utilization is more cost efficient than natural gas based heating. The specific CO_2 emission is lower as well.

It can be stated that the utilization of air to water heat pumps is approx. 30% cost saving compared to gas furnaces. Water tempering with this method may result in approximately 45% reduction of CO_2 emission compared to fossil fuel utilization.

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Sterowanie temperaturą wody w basenach za pomocą pomp ciepła typu powietrze-woda jako rozwiązanie przyjazne dla środowiska

Streszczenie

Pompy ciepła są urządzeniami, które mogą być wykorzystywane do pozyskiwania energii ze źródeł odnawialnych. Osiągają wtedy przyzwoite wartości współczynnika efektywności COP (Coefficient of Performance). Bez problemu dostępne są w sprzedaży. Pompy ciepła typu powietrze-woda są szeroko stosowane do ogrzewania budynków biurowych i mieszkalnych oraz wody użytkowej. Oczywiste jest, że wydajność pomp ciepła tego typu jest funkcją temperatury powietrza panującej na zewnątrz obiektu i wymaganej temperatury wody. Współczynnik COP zmienia się w czasie, w zależności od panujących warunków a jego wartość w szczególnych przypadkach nie jest tak ważna dla danego układu, ważniejsze jest zapotrzebowanie na energię. Poszukuje się energooszczędnych technologii podgrzewania wody i utrzymywania jej stałej temperatury w basenach, zarówno pływackich jak i przeznaczonych do produkcji rybnej, które w warunkach klimatycznych Węgier zdałyby egzamin. Wykorzystanie wód termalnych mogłoby być dobrym rozwiązaniem, w obu tych przypadkach, ale nie w każdym miejscu geograficznym jest to możliwe. Zastosowanie kolektorów słonecznych nie jest wystarczająco pewnym rozwiązaniem biorąc pod uwagę węgierskie warunki meteorologiczne. Dostępne powszechnie gaz i energia elektryczna są dobrymi rozwiązaniami ale są zbyt drogie. W przypadku zastosowania w basenach pływackich są bardzo wygodne do utrzymywania stałej temperatury wody, wykorzystane w basenach rybackich zmniejszają ryzyko strat, poprawiają efektywność i możliwości hodowli.

W Uniwersytecie św. Stefana, na Wydziale Mechanicznym (Gödöllő, Węgry), stwierdzono, że podtrzymywanie temperatury wody w basenach poprzez jej ogrzewanie pompami ciepła typu powietrze-woda jest łatwe i ekonomiczne. W doświadczeniach wykorzystano pompę ciepła Microwell HP700, o mocy 7 kW. Na początku pomiary laboratoryjne koncentrowały się na określeniu wartości aktualnego współczynnika COP. Później pomiary rozszerzono na monitorowanie parametrów energetycznych utrzymywania stałej temperatury wody w zewnętrznym basenie. W czasie zmiennej pogody jesiennej otrzymano jasny obraz procesu wykorzystania pompy ciepła powietrze-woda. Można stwierdzić, że w okresie wiosennym i jesienią temperatury powietrza (temperatura w otoczeniu parownika) są już / jeszcze odpowiednie ($T \approx 12–20°C$), a temperatura wody w basenie (skraplacz) utrzymywana jest wtedy na poziomie idealnym ($T \approx 20–24°C$) w wyniku zastosowanie pompy ciepła. Udowodniono, że korzystanie z pomp ciepła jest bardziej opłacalne niż ogrzewanie gazowe. Jednostkowa emisja CO_2 jest również na niskim poziomie. Można stwierdzić, że wykorzystanie pomp ciepła powietrze-woda do ogrzewania wody w basenach jest ok. 30% oszczędniejsze w porównaniu do wykorzystania w tym celu pieców gazowych. Sterowanie temperaturą wody w basenach tą metodą może dawać w efekcie około 45% zmniejszenie emisji CO_2 w porównaniu do spalania paliw kopalnych.

Słowa kluczowe: pompa ciepła, temperatura wody w basenie, współczynnik efektywności COP, emisja CO_2
Key words: heat pump, pool water temperature, COP, CO_2 emission