Experimental evaluation of a heat pump for the water-supply heating of a public swimming pool

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Abstract. In this work the analysis of the thermodynamic behavior of heat pumps (HP) which supply the energy needed in the public pool at the Aquatic Center of Azcapotzalco was performed. There are 18 installed HP’s but only those needed to provide the energy required are alternately activated. The evaluation was conducted during May and June of 2015. We selected one of the HP to implement temperature and pressure gauges at the inlet and outlet of the compressor. The measurements were made every day at three times, 6:30, 13:00 and 18:00 hours. In a period of 24 hours, 1 000 L evaporated, there was no variation registered overnight, since the pool was covered with plastic to avoid loss of the fluid. The heat pump provided 150 kW to maintain the water temperature at the right level of operation, namely 28 °C. The coefficients of performance (COP) of the HP were 6.39 at 6:30, 7.42 at 13:00 and 7:32 at 18:00 hrs., values which are very close to the one provided by the manufacturer.

1 Introduction
The supply of hot water in Mexico is part of services requiring considerable amounts of energy both in households and buildings intended for commercial and recreational use. This supply requires the consumption of fossil fuels (natural and LP gas or diesel) and is used in private and public pools (sports, hotels and houses); the need of this hot water is essential both for the pool itself and the bath services. In other countries electric power is used to achieve this goal [1], with electric heaters and other elements such as heat pumps, which are significantly more efficient than traditional systems [2]. Other sources of energy have also been used such as solar energy in combination with other transformation processes in order to improve the thermal efficiency, an example of these devices are heat pumps [2-6]. Currently, mechanical vapor compression heat pumps are extensively applied in many manufacturing industries, the efficiency has improved considerably, primarily in four areas: compressor performance, new multistage cycles, new refrigerants, and combined ejector compression [4]. Many of the commercial heat pump systems comprise a single-stage vapor compression cycle, only one evaporator is used for cooling and dehumidifying, and recovering the heat from a heat source [7]. A compound system consists of two or more compression stages connected in series. It may have one high-stage and one low-stage compressor or several compressors connected in series, a multistage one has a smaller compression ratio and higher compression efficiency for each stage of compression, greater refrigeration effect, lower discharge temperature at the high-stage compressor, and greater flexibility [8]. A compound multi-stage HP system is a favorable option to improve system COP (coefficients of performance). The most recent refrigeration compressor is known as ‘Revolving Vane (RV) compressor’, the principal feature of this innovative design involves the use of a rotating cylinder that moves together with the compressing mechanism to cut down on energy loss, consequently, frictional and leakage losses are effectively reduced [9]. The use of refrigerant mixtures in heat pumps and air conditioning systems constantly poses new challenges to engineers, the occurrence of glide during the phase change present problems to heat transfer engineers, among which incomplete condensation is considered the most relevant one [10]. Recently, the performance of the R410A refrigerant in an air conditioning unit was evaluated, resulting in about 12% higher efficiency
than that of R22 unit, R410A refrigerant absorbs and releases heat more efficiently which means systems using it will require less electricity and therefore will operate more efficiently [11]. An ejector-compression heat pump employs low-grade thermal energy to provide space cooling and heating, and depends on the geometrical, aero-dynamical, and mechanical design of the ejector; a theoretical study has shown that COP of an ejector-compression heat pump can yield improved performance of up to 21% over the vapor compression standard cycle [12].

With reference to the commitment made in Europe in terms of energy consumption which states that by the 2020 year, 20% of the current should be saved [13], the energy consumed in all places was calculated and the pools and ice skating tracks were found to occupy the first consumption places [14]. There are some studies on the energy analyses of indoor swimming pools, where the open-cycle absorption heat pump system was compared to the mechanical heat pump, the absorption system operated by chemical dehumidification on the exhausted air of the swimming pool was analyzed; although considerable energy saving effect was demonstrated, the promotion of this technology was restricted by the product maturity and reliability [15]. The objective of the present work was to experimentally evaluate the thermodynamic behavior of a heat pump by mechanical compression which operates to provide hot water to a public pool.

2 System description.

The public pool is located at Aquatic Center of Azcapotzalco (19° 30' 01.2" N, 99° 10' 59.4" W and 2240 meters above sea level). This is a swimming school with a pool of Olympic dimensions, which offers daily service to 450 users, on a schedule from 6:00 to 21:00 hours, in shifts of 50 min-classes and 10 min-recess, from Monday to Saturday. The design of the pool was regulated in compliance with the Mexican regulations (namely, Norma Oficial Mexicana NOM-245-SSA1-2010) [16]. The dimensions of the pool and its operating conditions are recorded in table 1, its photograph is presented in fig. 1.

| Table 1. Pool characteristics |
|--------------------------------|
| Length                      | 50 m |
| Width                       | 25 m |
| Number of lanes             | 10   |
| Lane width                  | 2.5 m |
| Minimum depth               | 1.55 m |
| Maximum depth               | 1.90 m |
| Water temperature           | 25-28 °C |
| Environment temperature     | 26-27 °C |
| Relative humidity           | 50-60 % |

The pool water should be between 25 and 28 °C according to the existing standards, [17]; the ASHRAE Handbook [18], recommends that the temperature of the space of the pool should remain close to 28 °C, and the fluctuation range of relative humidity should be 50-60 %, this is in order to reduce the evaporation of water from the pool. The evaluation was conducted between the months of
May and June, 2015, the average recorded temperature of the environment was between 24 and 25 °C and relative humidity at this period was 50 %.

3 Heat pump energy

For the supply of hot water, the Azcapotzalco Aquatic Center has 18 C5HP3-model Heat Siphon-brand heat pumps. They are air-water type, i.e., they take energy from the environment and together with the energy of the air compressor, it is transferred to water. Only the necessary number of HPs to provide energy to the water are activated, in this assessment we used up to 8 units alternately. To keep the water flowing through the HP a centrifugal pump which distributes it among the heat pumps that are required is used; water is turned back to the pool at operation temperature (30 °C), R 410A is the refrigerant and the theoretical coefficient of performance (COP) is 7.6 (manufacturer data). The distribution of HPs in the machine room can be observed in fig. 2. The amount of energy required was calculated as follow.

\[
\text{Total heat which must be supplied to the pool shall be equal to the observed loss of heat, which is:} \\
Q = Q_s + Q_t + Q_f + Q_{\text{conv}}
\]

(1)

where \( Q_s \) is the loss of heat by conduction in solid surface that surrounds the pool; \( Q_t \) is the loss of heat by evaporation of the water; \( Q_f \) is the energy of the water replenishment; \( Q_{\text{conv}} \) are the losses by convection on the free surface of the water.

Heat losses by conduction of water from the pool to the walls and the floor forming it, are usually small, they are calculated as,

\[
Q_s = U_p A_p (T_w - T_{\text{wg}})
\]

(2)

where \( U_p \) is the overall pool wall heat transfer coefficient; \( A_p \) is the overall pool wall and bottom surface area; \( T_w \) and \( T_{\text{wg}} \) are the pool water temperature and the ground temperature, respectively. The heat loss by evaporation is given by:

\[
Q_t = W Y
\]

(3)

where \( W \) is the rate of evaporation at water surface, and \( Y \) is the latent heat of water evaporation at the water surface. The most widely used correlation for water evaporation rate is reported in the ASHRAE Application Handbook as follows [17],

\[
W = (0.089 + 0.782 v_a)(p_w - p_a) \frac{A P}{Y}
\]

(4)
where \( v_a \) is the air velocity above the water surface; \( P_w \) is the saturated vapor pressure at the water surface temperature; \( P_a \) is the vapor pressure at the indoor air dew point; \( A_p \) is the total area of the pool water surface.

The rate of energy for daily renovated feed water heating depends on the pool volume, feed water temperature and the designed pool water temperature. This can be calculated by taking the 24-h average, i.e.

\[
Q_f = C_w \eta d \rho (T_w - T_f) / 24
\]  

where \( C_w \) is the specific heat of water; \( \eta d \) is the daily feed water flow rate (is generally 3 % of the total pool volume, it was used in this study); \( T_f \) is the supplementary feed water temperature. The heat flow rate by convection can be calculated with the Newton’s formula, i.e.

\[
Q_{conv} = h_{conv} A_p (T_w - T_a)
\]  

where \( h_{conv} \) is the convective heat transfer coefficient, and \( T_a \) is the indoor air temperature.

The heating capacity of the condenser can be calculated by,

\[
Q_{cond} = \dot{m}_r (h_o - h_i)
\]  

where \( \dot{m}_r \) is the mass flow rate of refrigerant; \( h_o \) and \( h_i \) are the refrigerant specific enthalpy at the outlet and inlet of the condenser. This heat is equal to the heat transfer to water is determined by,

\[
Q_w = \dot{m}_w C_w (T_{wi} - T_{wo})
\]  

where \( \dot{m}_w \) is the mass flow rate of hot water; \( T_{wi} \) and \( T_{wo} \) are the inlet and outlet hot water temperatures. The energy consumption \( Q_{hp} \) of the heat pump unit is the total energy consumed by the compressor, the fans, the water pumps and the controller during the period, i.e.

\[
Q_{hp} = \sum (P_c + P_f + P_p)
\]  

where \( P_c \), \( P_f \), \( P_p \) are is the power consumptions of the compressor, the fan and the water pumps respectively. The coefficient of performance (COP) of the overall heating system is defined as

\[
CO_{P_{sys}} = Q_{cond}/Q_{hp}
\]

### 4 Experimental measurements.

Some modifications were carried out to the studied heat pump with the aim of obtaining its experimental evaluation; the points at which the measuring devices were installed are presented in fig. 3. The temperature was measured at the entrance of the compressor (T1), condenser (T2), expansion (T3) and the evaporator valves (T4); pressure at the inlet (p1) and outlet (p2) of the compressor; capacitor the water supply to the pool entrances to the condenser at temperature (T5) and exhausts at temperature (T6); in the evaporator the flow mass of used air coming out at temperature (T7) was measured; and the temperature of the air in the environment (T8). The consumption of electrical energy used by the compressor, fan and water recirculation pump was also evaluated. The mean values of the temperatures in the heat pump for an average day of work for the month of June 2015 at three times are listed in table 2, the first line corresponds to 6:30 a.m., he second to 13:00 hrs., and third to 18:00 hrs.
Table 2. Temperatures measured at points considered in °C, at 6:30, 13:00 and 18:00 hrs. $T$ (°C) and $P$ (MPa).

|   | $T_1$ (p1) | $T_2$ (p2) | T3 | T4 | T5 | T6 | T7 | T8 |
|---|------------|------------|----|----|----|----|----|----|
| 8.8| 88.1       | 36.9       |    |    |    |    |    |    |
|    | (0.85)     | (4.5)      |    |    |    |    |    |    |
| 9.5| 87.3       | 35.8       |    |    |    |    |    |    |
|    | (0.85)     | (4.5)      |    |    |    |    |    |    |
| 9.1| 87.4       | 36.1       |    |    |    |    |    |    |
|    | (0.85)     | (4.5)      |    |    |    |    |    |    |

Figure 3. Diagram of the heat pump and the places where the measurements were made.

5 Results

The amount of water evaporated in the 15 hours of service by the pool was 990 L, in the first hours 85 liters per hour evaporated and at the end only 60 liters every hour, fig. 4. This amount of water is replaced from the municipal service, a portion is dragged by air entering the interior of building as moisture coming out at the other end and the rest stays inside the premises. To the extent that the temperature difference between the pool water and the interior air is less, the amount of evaporated water will diminish. During the night the free surface of the water of the pool is covered with a plastic canvas to prevent both heat losses from water and the evaporation of part of it. Also from the graph presented in fig. 4 we can obtain the speed at which the water evaporates, it is simply the volume of the water evaporated over time.

The amount of heat that is required to supply to the water is approximately 150 kW per day, its distribution can be observed in the graph of fig. 5. In the first four hours a supply of 13 kW of heat (with 8 working HPs) is needed, this is due to the temperature difference between the pool water and the environment which is high; then this demand diminishes to a value of approximately 8 kW (with 5 working HPs), finally it increases slightly towards the end of the day to a value of 9.6 kW (with 6 working HPs).

Fig. 4. Evaporated water per day.

Fig. 5. Supplied heat to hot water per day.
The electrical energy consumed during this period of time by the HP compressor, the evaporator fan and the water recirculation pump motor is presented in graph of fig. 6. The total consumption was 25 kW in the 15 hours service-period of the pool. The compressor consumed 50% of the energy, 30% was consumed by the pump motor and the remaining 20% corresponded to the drive of the fan motor.

Using data from the intermediate line of table 2, as well as those of the pressure at the entrance, namely 0.85 MPa, at the exit of the compressor, 4.5 MPa and using the thermodynamic diagram of R-410A refrigerant (Fig 7), enthalpy values were obtained to determine with the help of the equations provided above. The COP of heat pump at 6:30 was 6.39; at 13:00 was 7.42 and finally 7.32 at 18:00 hrs. These values are within a very close range of the one provided by the manufacturer of the HP which is 7.6.

6 Conclusions.
In this work the analysis of the thermodynamic behavior of heat pumps that supply the energy needed in the public pool at the Aquatic Center of Azcapotzalco was performed. The values used corresponded to the months of May and June of the year 2015. We selected one of the HP to implement temperature and pressure gauges at the inlet and outlet of the compressor. The measurements were made every day at three times, 6:30, 13:00 and 18:00 hours. During 24 hours, almost 1 000 L evaporated, there was no variation overnight since the pool is completely covered with a plastic canvas to avoid loss of the fluid. The HP provided 150 kW to maintain the water temperature at the right level of operation, i. e., 28 °C. The consumption of required electrical energy turned out to be 25 kW. The COP of the HP was 6.39 at 6:30, 7.42 at 13:00 and 7.32 at 18:00 hs., very close values to the one provided by the manufacturer.
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