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Heating Mechanism and Energy Analyses for Over-Ground Outdoor Swimming Pool Technology

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ABSTRACT

The transient temperature dependency and heating load requirements were assessed for a hypothetical swimming pool size of (100) m^3 prepared at a temperature of (28) °C. The pool first preparation stage occupied quite a long running time of heat pump to raise the pool water from initial temperature of (12) °C prior to its usage. Wind speed lied in the range of (1.8-18) km/h and air temperatures of (15 and 20) °C at (50) % relative humidity. The analysis showed that the evaporation heat loss was within the range of (54-69) % depending on the wind speed. The surface convection loss occupied the range of (15-21) % at (1.8-18) km/h wind speed range. It was followed by the radiation component of (7-21) % and the lowest was the convection-conduction component of (3-8) % range through the pool walls. Correlations for the design heat load, surface evaporation rate and heating up temperature of the pool in terms of the wind speed and time were accomplished. The heating load is either extracted from a ground or sea water for maintaining the thermal aspects of the pool. This heat source was integrated with the swimming pool for the purpose of water temperature control.

Keywords: Over-Ground Pool, Thermal Analysis, Heating Load, Outdoor Swimming Pool

1. INTRODUCTION

Scientists focused their research on developing efficient systems to extend swimming seasons in countries with colder months at acceptable economic feasibility. There are a number of free natural clean energy sources available at a variety of temperature levels to be implemented for the heating objectives at different modern life needs. These sources have motivated scientists to develop technologies to make advantages of the natural available energy. Advanced technologies were developed to obtain energy through unconventional methods and thermoregulation techniques that reduce heat loss from the pool and heating up philosophy.

Solar energy has received a great intention to be used for heating purposes of swimming pools. Szeicz and McMonagle [1] investigate the thermal aspects of outdoor swimming pools in Toronto, Canada. Their outcomes showed that pool covers reduced the heat loss by evaporation during the day and the radiation heat loss during the night. Chan and lam [2] studied the thermal performance, energy savings and economic feasibility of heat pump implementation in outdoor hotel pools operating under subtropical climates.

Greyvenstein and Meyer [3] studied the feasibility of using heat pumps for heating pools in South Africa. They assessed the average monthly losses of an outdoor pool and established many correlations. Cunio and Sproul [4] investigated the theoretical and experimental performance of solar collectors for pool heating without glazing at low flow rates. They have found that efficiency for 60 l/min was about 15% of that obtained for 140 l/min.

Verkannah [5] proposed operating and pool preparing strategies for saving energy and reducing greenhouse gasses. He considered a methodology depends on selecting a sequence of heating for a pool based on usage time and other relevant parameters. Yucra [6] rated and analyzed the equipment necessary for heating up of an outdoor swimming pool. Facão and Oliveira [7] analyzed a hybrid system composed of solar-gas technologies of micro-power generation and heating for a swimming pool complex and office space. Govaer and Zarmi [8] developed an analytical thermal model for open and closed swimming pool on the basis of annual values. Muñoz [9] postulated a scheme for the design of a pool heating system composed of a solar collector and a storage tank; he compared its efficiency with the standard conventional systems. Losses in the reservoir and the walls of the pool were assumed to be negligible, and the overall coefficient of loss was calculated using the ASHRAE criteria.

Asdrubali [10] calculated experimentally the evaporation rate of water from pool surface in indoor pools under various temperature, relative humidity, and air speed conditions. Luminosu and De Sabata [11] investigated the feasibility of an outdoor pool with showers, solar heaters, and classic heaters. They proposed an algorithm to determine the energy gains and losses of the pool and estimate the efficiency of a solar-heated outdoor swimming pool. Haaf et al. [12] established a model for outdoor. The results showed that the model revealed an acceptable behavior within the range of (21 - 26) °C, with a maximum error of (1) °C.

The methodology and results of the thermal and hydraulic design for a solar heating field of an elementary school's pool was presented by Dorantes et al. [13]. Improved flat solar collectors with copper tube and aluminum fins were used. For this heating system a water volume/solar collection area relation of (1.45) m^3/m^2 was obtained. Shah [14] derived a number of correlations to predict the evaporation rate from many types of water pools and vessels. These included indoor and outdoor swimming pools (occupied and unoccupied), spent nuclear fuel pools, decorative pools, water tanks, and spills. The developed methods were based on theory, physical phenomena, and test data. A number of look-up tables were provided for easy manual calculations. Woolley et al. [15] validated a model that uses meteorological data to predict the hourly temperature variation of a swimming pool to within (1.1) C maximum error over the period of observation. Comparison of predicted and observed pool temperature for all hours over a (56) day experimental period shows an R-squared relatedness of (0.967).

In the present work, a preliminary thermal design assessment for an over-ground outdoor swimming pool was investigated. A simple procedure was suggested for the estimation of heat load demand to maintain a proper pool temperature for occupants. The heating load evaluation and temperature variation under the transient conditions were considered. The pool temperature variation with time during the occupancy and preheating stages were predicted for a variety of wind speeds. The investigation took into account the environmental and climatic changes in regards to temperature and wind speed. The heating load needed for the heating up of a swimming pool was suggested to be extracted from a sea water or ground sources with the aid of a heat pump.

2. METHODOLOGY

The energy and load assessment of a swimming pool is quite a difficult task to be handled in full details due to several different parameters which should be considered in their design. These variables experience a time dependent fluctuation during the day and night time. The heat balance is also being affected by the place of pool installation whether it is indoor or outdoor and over-ground or underground. For outdoor pools, the heat balance of the pool is governed by the weather conditions such as solar radiation, air and sky temperatures, humidity and wind speed. Accordingly, the investigation outlines a rough assessment for the energy demand of the above-ground swimming pool with a margin of accuracy depends on the available correlations. Figure 1 shows a schematic diagram for the suggested system layout implemented for the heating purposes of the over-ground swimming pool.

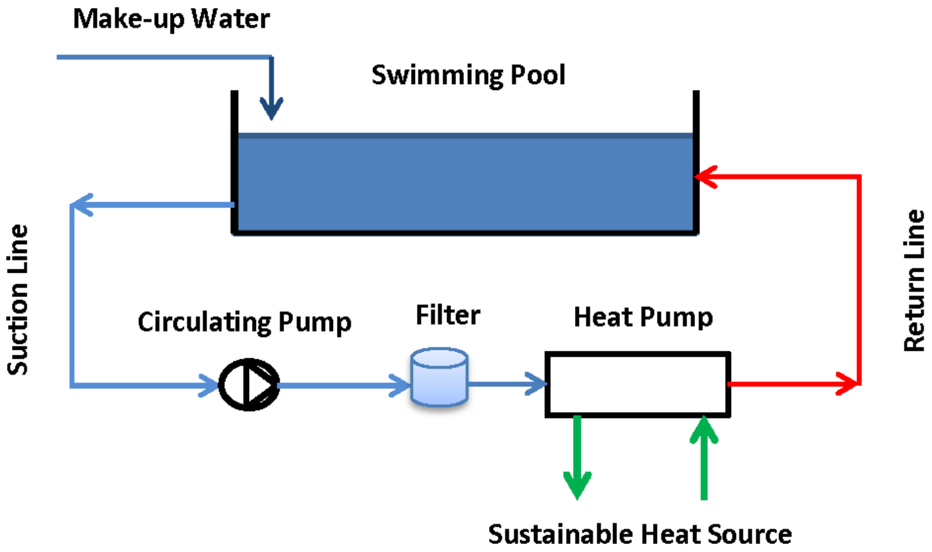
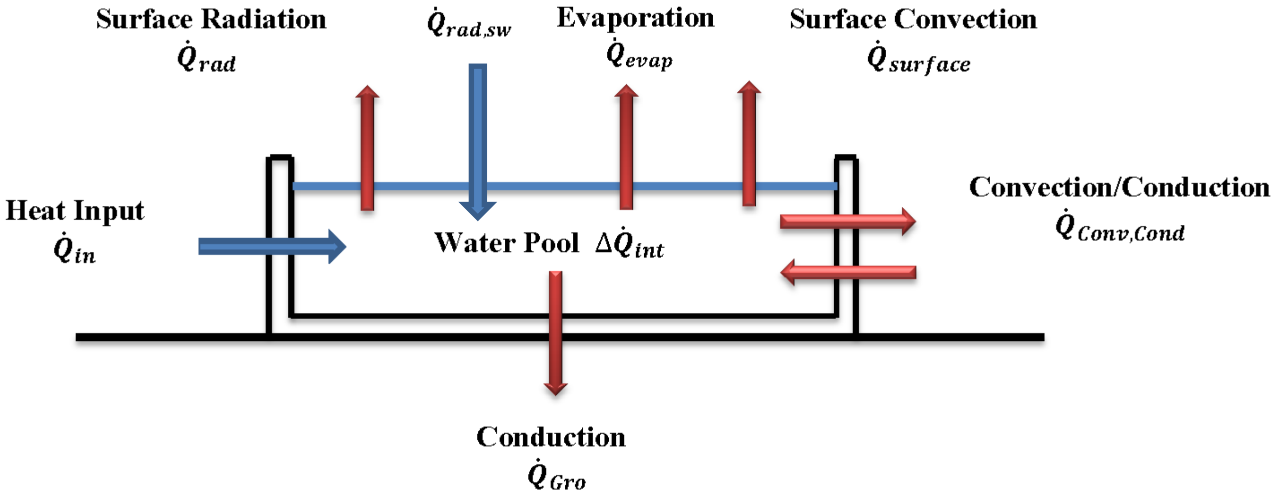


Fig. 1. A schematic diagram of swimming pool integration with the sustainable heat source

A (100) m^3 pool size having dimensions of about (12×7×1.2) m at initial temperature of (12) °C was selected for this study. The optimum pool water temperature during its occupancy was considered to be within the range of (24-28) °C. The design heating load demand was investigated at wind velocity range of (0.5-5) m/s.

3. POTENTIAL LOADS

A general view for the energy demands of the swimming pool is shown in Figure 2. The heat dissipated or absorbed by the pool is greatly influenced by its position, environment condition and day or night time.



The first law of thermodynamic is applied for the swimming pool system when an ideal mixing is considered as:

$$m\ cp\ \frac{dT}{d\theta} = \dot{Q}_{net} - W \tag{1.a}$$

There is no net work done in the pool, hence $W = 0$. This yields to:

$$m\ cp\ \frac{dT}{d\theta} = \dot{Q}_{net} \tag{1.b}$$

And

$$\dot{Q}_{net} = \sum\{\dot{Q}_{in} - \dot{Q}_{out}\} \tag{1.c}$$

Then

$$m\ cp\ \frac{dT}{d\theta} = \sum\{\dot{Q}_{in} - \dot{Q}_{out}\} \tag{1.d}$$

In this expression, $\sum \dot{Q}_{out}$ represents all of the heat losses shown in Figure 2. The left hand side of Equation (1.d) corresponds to the change of internal energy of the water pool. In the present study, the heat added to the pool through the heat pump is presented by($\dot{Q}_{in}$). This formula will be used in the present study for the thermal analysis of the swimming pool.

3.1 Evaporation Process

3.1.1 Evaporation Mass Loss

Many evaporation rate empirical correlations are available with margin of errors, which depends on the range of the implemented experimental data in their formulation. The evaporation rate represents the principal component of the predicted heating load that is required for the swimming pool, it composes about (65-70) % of total heat loss from a pool. Hence, a careful consideration has to be presented in the selection of such correlations for the design needs. Pools typically lose more than (50 %) of the heat placed in the pool by the heater. The amount of evaporated water can be predicted from available empirical equation, Smith et al. [16]:

$$\dot{m} = A_s\ \frac{(30.6+32.1\ u_{wind})\ (p_{w,sat} - p_{a,Dew})}{h_{fg}} \tag{2}$$

The pressure difference in the above equation has (mm. Hg) units. It is obvious that the evaporation rate is proportional to the environment and climate conditions such as temperature, humidity and wind speed.

3.1.2 Evaporation Heat Loss ($\dot{Q}_{evap}$)

The heat load supplied to the pool is required to compensate among others the heat rejected away from the surface due to evaporation. Most of the heat required for the evaporation is taken from the water itself. To maintain the water temperature heat must be supplied. The required heat supplied to cover the evaporation loss can be calculated from:

$$\dot{Q}_{evap} = \dot{m}\ h_{fg} \tag{3}$$

Evaporation latent heat of water was taken at the pool temperature.

3.2 Convection Loss ($\dot{Q}_{surface}$)

The heat loss from water surface due to convection should also be compensated as a part of the total design requirements. It mainly depends on the ambient air heat transfer coefficient and potential temperature difference between the ambient climate and pool value. The temperature difference is a time dependent variable, but for conservative steady state heat loss estimation, it may be considered at its highest possible value to maximize the losses. This heat loss was estimated from the following expression, Root [17]:

$$\dot{Q}_{surface} = \alpha_s \, \Delta T_{aw} \, A_s \tag{4}$$

The heat transfer coefficient (α_s) for an outdoor pool was found by Czarnecki [18] expression:

$$\alpha_s = 3.1 + 4.1 \, u_{wind} \tag{5}$$

For blanketed pool, the heat lost by convection from the pool will be minimized due to the insulation action of the cover. The overall thermal conductance of typical covers made of Plastipack's 400 Grade products of thermal resistance is (16.67) W/m^2 K which corresponds to ($R_{th,co}$=0.06) m² K/W, [19]. The heat loss due to convection from the pool during the heating up stages was estimated from:

$$\dot{Q}_{surface} = U_s \, \Delta T_{aw} \, A_s \tag{6.a}$$

And

$$U_s = \frac{1}{R_{th,co} + R_{th,amb}} \tag{6.b}$$

$$R_{th,amb} = \frac{1}{\alpha_s} \tag{6.c}$$

3.3 Inertia Heating-up Load ($\dot{Q}_{Heat-up}$)

This component of total heat load represents the amount of energy rate to be added to raise the temperature of the pool from its initial to the set point value. This load can be calculated from:

$$\dot{Q}_{Heat-up} = \frac{V \, \rho \, cp \, \Delta T_{water}}{\Delta\theta} \tag{7}$$

The heating-up time (Δθ) is a major factor which controls the amount of energy required for the swimming pool during occupancy and preheating for the next day. Hence, a considerable attention should be paid for this part of the design load demand when a swimming pool is to be designed.

3.4 Side Walls Convection-Conduction ($\dot{Q}_{Conv,Cond}$)

The heat loss through the walls of the pool is composed of two heat transfer modes. The convection and conduction modes are the predominant and estimated from:

$$\dot{Q}_{Conv,Cond} = U_{wall} \, A_{wall} \, \Delta T_{aw} \tag{8}$$

The overall heat transfer coefficient U_{wall} is determined by the material and thickness of the composite wall structure. For above-ground (1/2) in fiberglass-plastic walls supported by an open framework of wood or metal tubing, U_{wall} = 11 W/m^2 K measured at (11) km/h average wind speed, [17].

3.5 Ground Conduction ($\dot{Q}_{Gro}$)

Conduction between the swimming pool and ground is in most circumstances accounts for less than (1) % of the total energy loss from the pool Hahne [20], Govaer [21] and Rakopoulos [22]. This component is usually ignored when the pool is sitting firmly on the ground due to the small temperature difference between the pool bottom and ground, hence ($\dot{Q}_{Gro}$) =0.

3.6 Radiation Heat Loss ($\dot{Q}_{rad}$)

The long-wave radiation heat lost from the pool water surface is usually estimated from the general radiation formula as:

$$\dot{Q}_{rad} = A_s \, \varepsilon \, \sigma \left\{ T_s{}^4 - T_{sky}{}^4 \right\} \tag{9.a}$$

$$\varepsilon = 0.9 \tag{9.b}$$

$$\sigma = 5.67 \times 10^{-8} \, \frac{W}{m^2 \, K^4} \tag{9.c}$$

The sky temperature (T_{sky}) depends on the condition of the atmosphere, cloudy or clear and day or night time. On a cloudy night the clouds may be only about (5) °C below the air temperature and the effective sky temperature may be as much as (44) °C below the ambient air one [17]. It is difficult to guess a proper value for sky temperature, but it may be taken as (11) °C below the air temperature for a mean estimated value to predict the radiant load component.

During the heating-up stages, the surface temperature of cover will be used to assess the radiation from the pool surface. It was estimated from Equation (6) and the thermal resistance of the cover itself by:

$$T_s = T_P - \frac{\dot{Q}_{surface} \, R_{th,co}}{A_s} \tag{10}$$

4. THERMAL DEMAND ASSESSMENT

There are many design schemes and procedure philosophies available in the open literature to estimate the energy management of a swimming pool with a scatter of accuracy limits. Numerical analysis has also been used for the swimming pool thermal and hydrodynamic assessments, Pochini and Strazza [23] and Li and Heiselberg [24]. A simple procedure was suggested at the present work for preliminary heating load estimation for an over-ground outdoor swimming pool.

The evaporation process reduces the temperature of the pool surface due to the latent heat of vaporization drawn from the pool water body. The convective process cools or warms the liquid surface according to value of the ambient air. It cools if the air temperature is lower and warms if the air temperature is higher. Therefore, it depends mainly on the direction of heat flow, in or out of the swimming pool. The possible minimum temperature that the water surface can attain is the wet-bulb temperature of the ambient air due to equilibrium conditions.

The total design load to heat and maintain the pool at set point temperature may be expressed as:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} + \dot{Q}_{evap} + \dot{Q}_{Conv,Cond} + \dot{Q}_{surface} + \dot{Q}_{rad} - \dot{Q}_{rad,sw} \quad (11)$$

The evaporation component is the predominant among other losses mechanisms. It is inevitable and significant during the pool occupancy and composes almost the principal heat loss source.

Since the pool water and ambient air temperatures vary with time, hence the convection-conduction component could be a heat gain or loss with respect to atmosphere. This adds another complication to the assessment task of thermal mechanism during heating up of the pool. During night time the ambient temperature falls below the pool and heat loss is evident to the ambient. During the initial heating up, the pool temperature passes through both modes of loss and gain with time. For conservative heating load evaluation, the heat transfer through the pool walls was considered as a heat loss to the ambient and measured at the maximum pool temperature of (28) °C. Further, the short-wave heat gain ($\dot{Q}_{rad,sw}$) due to radiation was neglected to be within the safety factor for the conservative thermal load analysis, hence:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} + \dot{Q}_{evap} + \dot{Q}_{Conv,Cond} + \dot{Q}_{surface} + \dot{Q}_{rad} \quad (12)$$

It should be pointed out that other factor such as swimmers effect on both evaporation loss and energy addition are difficult tasks to be. Molineaux [25] assumed a heat addition of approximately (400) cal/h per swimmer, which would have a measurable impact on water temperature in a pool with heavy use. However, this was assessed for the present case study on the basis of (3) m^2 per swimmer according to the guides for safe bathing load, EUSA [26]. The load added by the (28) occupants of the swimming pool for (4) hr of occupancy time was negligible.

4.1 Initial Thermal Conditions

The following initial temperature distribution was considered:

a- A temperature of (12) °C was implemented for the first heating period, where the pool was just filled with fresh water from the source.
b- A value of (28) °C was assigned for the initial pool temperature prior to its usage.
c- At the second preheating mode, the pool was considered to be at its last recorded temperature of the usage stage prior to heating up process.

4.2 Pool Operation Conditions

Pools have a turnover of between (4 – 8) hours as recommended by EUSA [26] depending on their use. The turnover rate was set at (8) hr to achieve (12.5) m^3/hr of water to recirculate the full pool capacity through the filtration device and heat pump unit. The heat transfer and energy exchange modes which control the operation conditions of the pool are shown in Figure 2. The following operating conditions were considered:

i- The mean ambient air temperature was assumed to be (15) °C and (20) °C for the heating up and usage stages respectively.
ii- The overall heat transfer coefficient of (11) W/m^2 K was used for the conduction and convection heat transfer modes from the walls of the pool.
iii- The evaporation heat loss from the water surface during occupancy was estimated at a reference ambient conditions of (20) °C and (50%) relative humidity and a pool temperature of (28) °C.

5. RESULTS AND DISCUSSION

The heating load estimation for a swimming pool depends mainly on the philosophy of its use. The limitations of its usage are in regard of outdoor or indoor, private or public, number of bathers and size, sheltered or in open area, season and mostly the climate condition. Our case study was related to the energy analysis for heating of an over-ground outdoor swimming pool during summer in a climate like that of Denmark and most of Europe.

5.1 Preparing Stage

The acceptable pool temperature range falls within (24-28) °C for active swimming of users. Hence, the assigned usage temperature was selected to be (28) °C on commencing of bathers occupancy for the pool. The first heating period for the preparing process of the pool was taken to be (4) days with blanketed pool water surface. Therefore, the major components of heating load will be controlled by:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} + \dot{Q}_{Conv,Cond} + \dot{Q}_{surface} + \dot{Q}_{rad} \quad (13)$$

Since the pool is installed over the ground and outdoor, then ambient air condition and wind speed play vital roles in the assessment of convection and radiation heat losses. Figure 3 illustrates the design heating load required to run the swimming pool for the first preparation prior to usage. It is obvious that the heating load is proportional to the local wind speed value and it is higher for higher speed range according to:

$$\dot{Q}_{Design} = -0.1257\ u_{wind}^{\ 2} + 1.6347\ u_{wind} + 38.262 \quad (14)$$

A design heating load was estimated to be (43) kW when the wind speed approaches (5) m/s. The water temperature lift (ΔT_{water}) will be about (3.0) °C as it passes through the heat pump to absorb a load of (43) kW. This represents the maximum load as estimated to keep the pool within the acceptable temperature limit for the (4) hr of occupancy.

A high speed values are uncommon and may occur under abnormal conditions where swimming outdoor is unlikely to be favored. A mean wind speed of (4) m/s which corresponds to (14.4) km/h is a common climate design value.

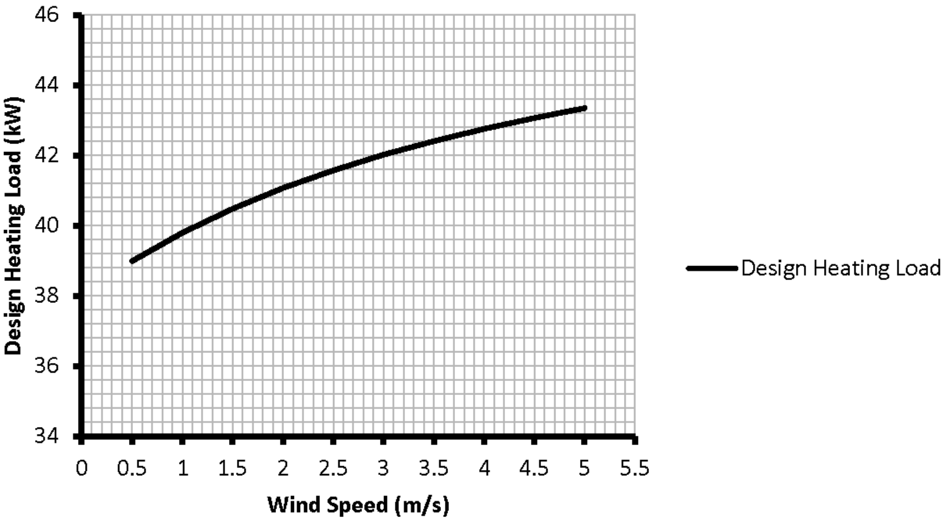


Fig. 3. Design heating load required for the investigated swimming pool

Figure 4 illustrates the load percentage of each heating design component variation with ambient wind speed. The heating up load for the pool to raise its temperature from (12) °C to (28) °C occupied the highest among other factors. It was in the range of (44-50) % followed by the surface convection and radiation to be within (11-27) % and (13-21) % respectively.

The convection-conduction load through the pool wall was the lowest component; it was within (15-17) %. The surface convection loss showed an increase as the wind speed increased. This is mainly due to the increase of the ambient air convective heat transfer coefficient with velocity. The convection-conduction load revealed almost a constant value regardless of the wind speed due to the constant overall heat transfer coefficient employed for its assessment.

This load percentage distribution reveals that reducing of the first preparation heating-up time increases the load required considerably to attain the design temperature of (28) °C. It also reduces the heating up time for the preheating stage and increases the occupancy time of the swimming pool during the usage stage. The present operating philosophy didn’t require imposing severe judgment for the amount of heat load to be added to the swimming pool. The pool was intended to be used for only (4) hr a day and there was enough time for the preheating mechanism to attain the temperature set point.

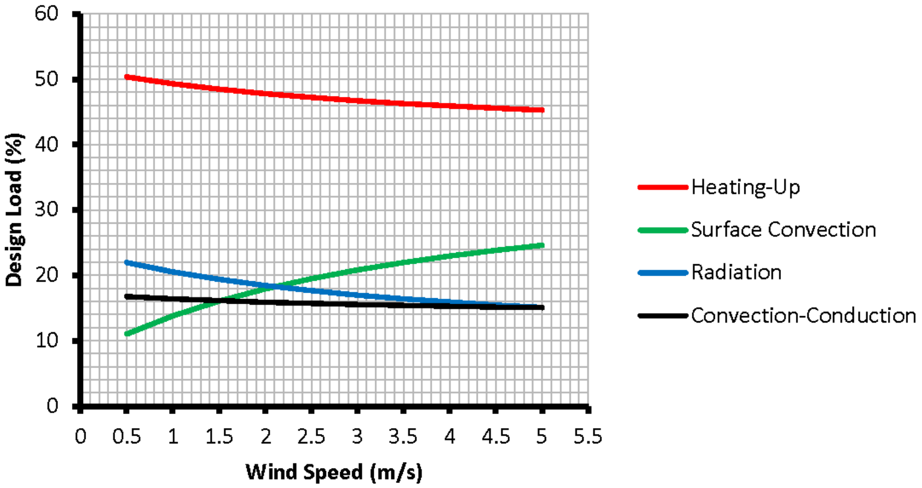


Fig. 4. Design load percentage distribution for the investigated pool

5.2 Usage Stage

This is the controlling stage for the swimming pool operation philosophy and represents the critical thermal design of the pool. In fact, this stage determines the validity of the design for a comfort operation for the users. Further, the heat pump should be capable to prepare the pool for the next day and compensating its thermal loss. Hence, the heating mechanism should be capable to prepare the pool at its optimum usage temperature of (28) °C.

The major component of this stage is the evaporation heat lost from the surface of the water; this in effect cools the water body from its set point. Comfort conditions for the users should exist during the occupancy period and the optimum temperature range should be handled. Equation (12) governs the thermal mechanism of the pool during usage. The present scheme showed that the pool still possess enough energy to allow the occupants to enjoy swimming with temperature higher than the minimum design value after (4) hr occupancy as shown in Figure 5. The results exhibited linear variation with wind speed and the drop of temperature still lies within the comfortable set point for all of wind speeds.

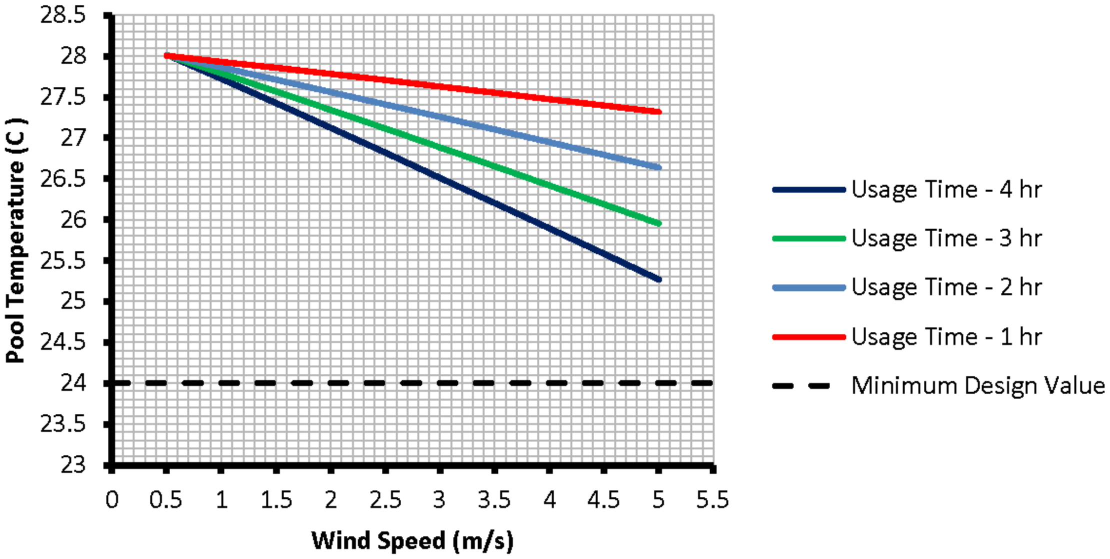


Fig. 5. Pool temperature variation with time during the usage stage

For wind speed of (4) m/s, the temperature variation with time is illustrated in Figure 6. It revealed the following expression:

$$T_P = -0.5272 \times \theta + 28 \quad (15)$$

Here the heating-up time is measured in hour.

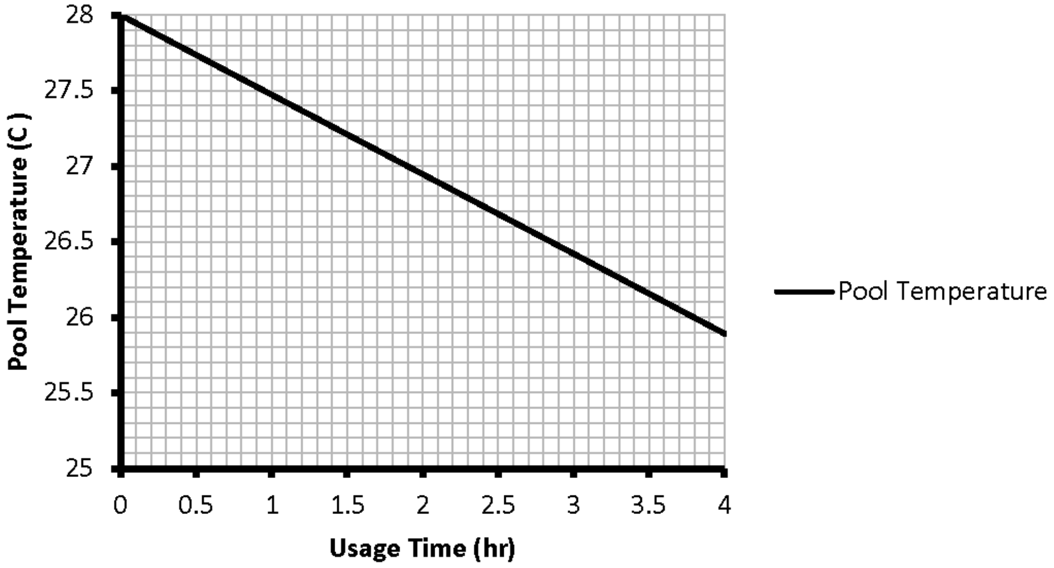


Fig. 6. Pool temperature variation with time during usage stage at (4) m/s wind speed

The variation of heat loss percentage distribution with wind speed is shown in Figure 7. The evaporation heat loss was within the expectation and agreed well with the published work in the field, it was within the range of (54-69) % depending on the wind speed. The maximum evaporation heat loss (66-69) % was experienced at (3-5) m/s wind speed. The surface convection loss occupied the range of (15-21) % at the studied wind speed range. It was followed by the radiation component (7-21) and the lowest was the convection-conduction (3-8) % range through the pool walls.

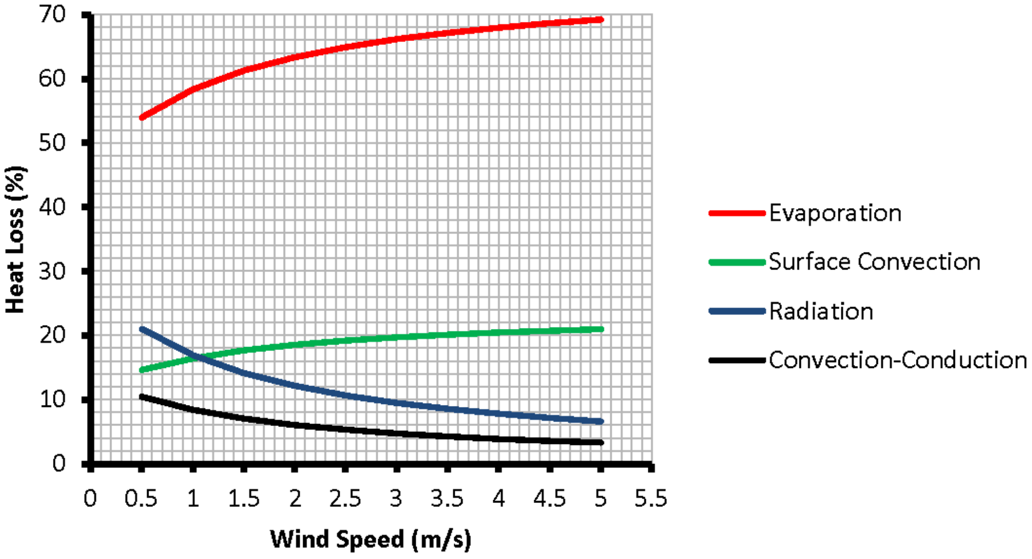


Fig. 7. Heat loss percent during usage of different components

5.3 Preheating Stage

This stage occupies the heat transfer mechanism to preheat the pool for the next day use. During this stage, the heating system should be capable to heat up the bath to the assigned maximum comfortable temperature of (28) °C prior to the next occupancy. Figure 8 shows that the heating up time for this stage is increasing with wind speed increase.

It is obvious that the installed design demand for the pool is capable to handle the preheating process within acceptable time prior to next use for the whole range of wind speed. It approaches a maximum running time of (16) hr for (5) m/s wind speed and falling to zero at (0.5) m/s. At the low wind speeds, the pool needs only about half the total load to maintain the pool temperature at the set point prior to the next occupancy. This indicates that the pool at lower wind velocities didn't lose much energy when compared to the higher speed range. This is mainly due to the reduction of convection losses to ambient.

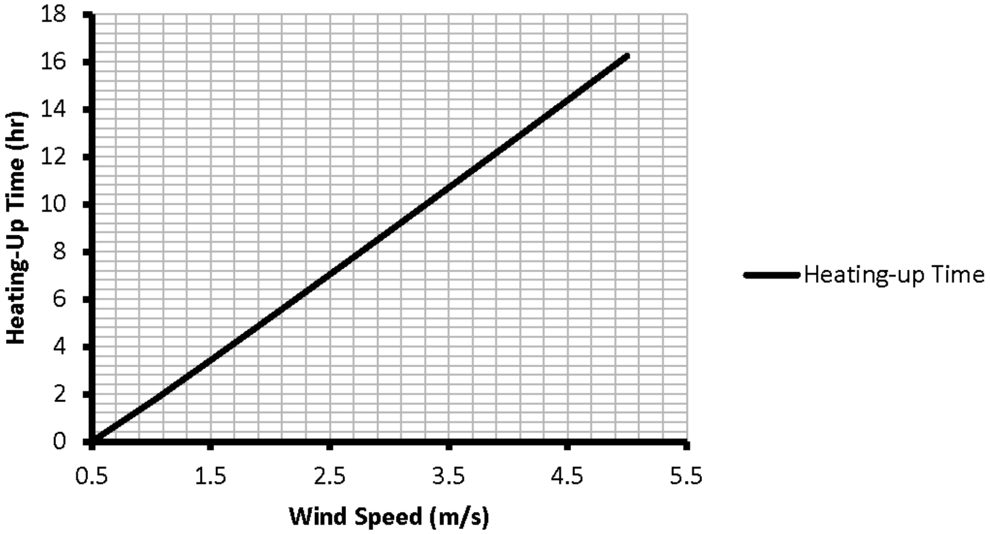


Fig. 8. Heating-up time required for the preheating stage at a variety of wind speeds

Figure 9 shows the pool temperature variation with time at typical wind speed of (4) m/s. The heating process mechanism showed a linear variation for pool temperature with time in the form:

$$T_P = 0.1682 \times \theta + 25.891 \qquad (16)$$

The heating-up time is measured in hour in this relation. The results showed that the pool could be prepared to the next usage stage within (13) hr of heating process by the heat pump for the case where (4) m/s and it was lower for lower wind speeds.

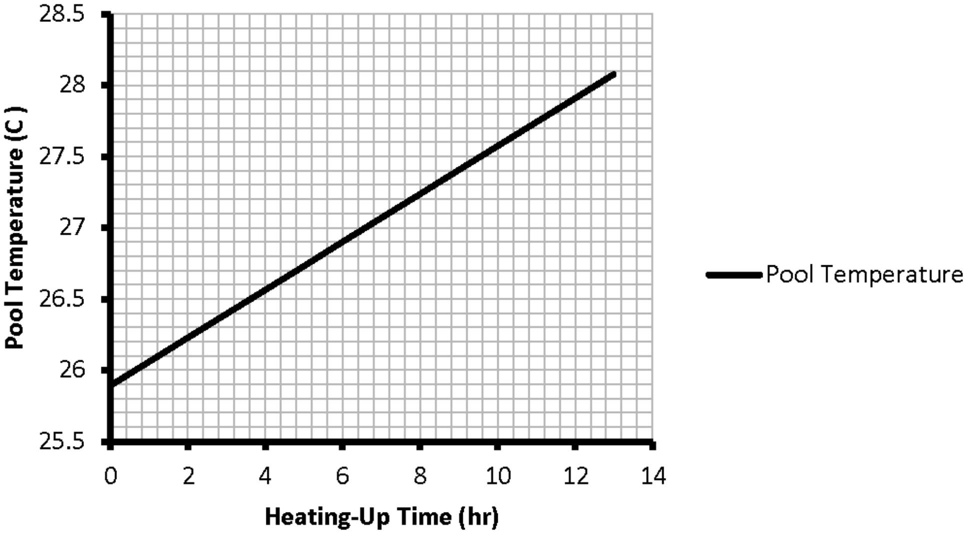


Fig. 9. Pool Temperature variation during the preheating stage at 4 m/s wind speed

5.4 Evaporation Effect

5.4.1 Temperature Trend

Figure 10 illustrates a comparison for the pool temperature variation with time for both of the usage and preheating stages at wind speed of (4) m/s. The trend of these mechanisms reveals that the evaporation heat loss from the swimming pool has a great impact on pool temperature declination with time. The curve of the usage stage shows that it is much steeper than that of the preheating mode, it drops (2.0) °C in only (4) hr of occupancy. The preheating stage showed that the corresponding temperature rise at the same time was only (0.7) °C. In other words, the rate of pool water cooling during the occupancy stage was about (3) times that of the preheating mode.

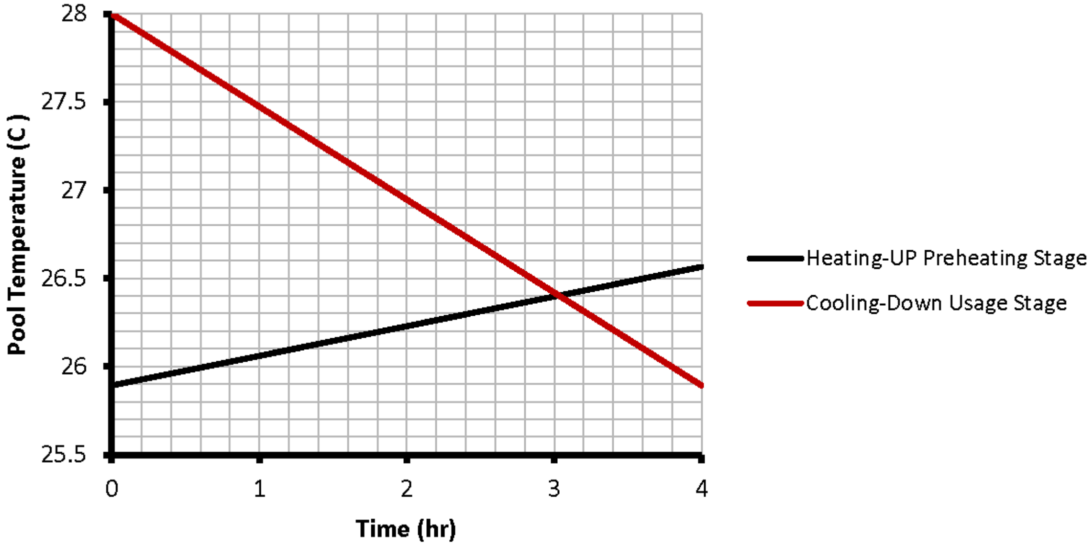


Fig. 10. Pool temperature variation during preheating and usage cooling down mechanisms at 4 m/s Wind speed

5.4.2 Evaporation Heat Loss

The evaporation heat loss during the occupancy stage represents the major source for heat losses from the swimming pool to ambient. Figure 11 shows the percentage of this heat loss with respect to the total load lost to the ambient. It is ranged between (54) % and (69) % for the test wind speed and climate conditions at temperature of (20) °C and (50) % relative humidity. It showed a gradual increase with wind speed and approached maximum at (5) m/s.

The behavior of the evaporation load percent revealed a sort of power trend in the form:

$$\dot{Q}_{evap}\% = 58.453 \times u_{wind}{}^{0.1093} \quad (17)$$

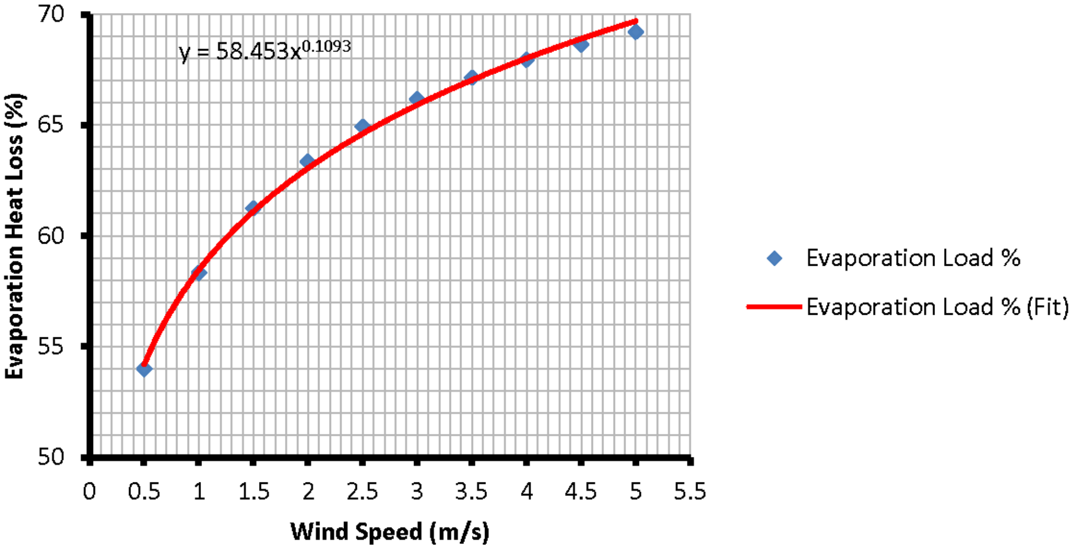


Fig. 11. Evaporation load percentage for the swimming pool during occupancy

The amount of water lost from the pool due to evaporation at a variety of pool temperature was estimated for the investigated range of wind speed is shown in Figure 12. The evaporating rate from the pool surface showed an increase with pool temperature and wind speed. This amount of water evaporated from the pool was reflected on the water level in the bath, Figure 13.

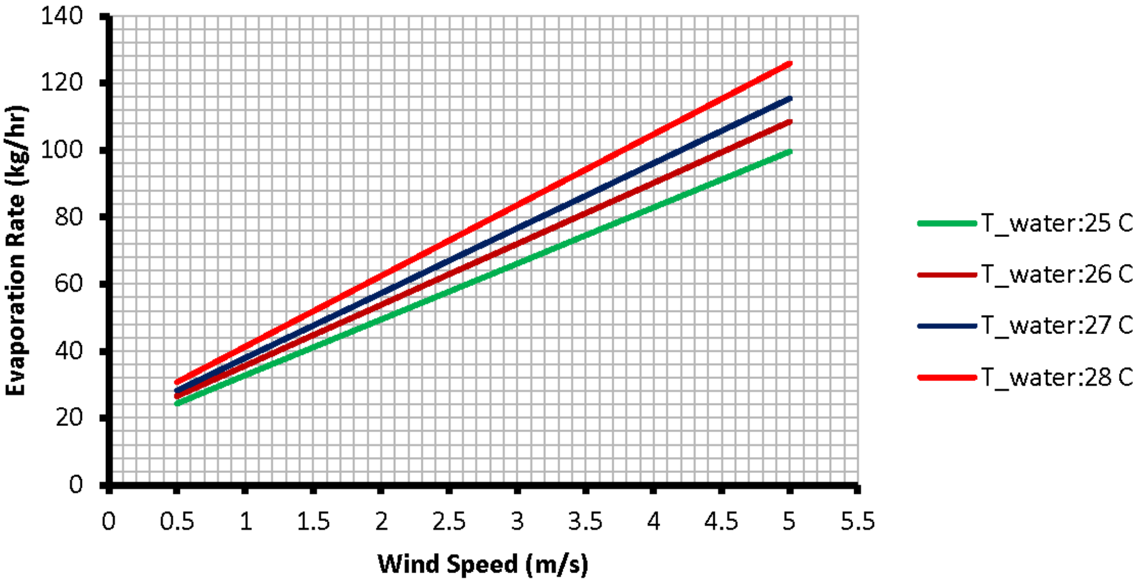


Fig. 12. Evaporation rate at different pool temperatures and wind speeds during occupancy

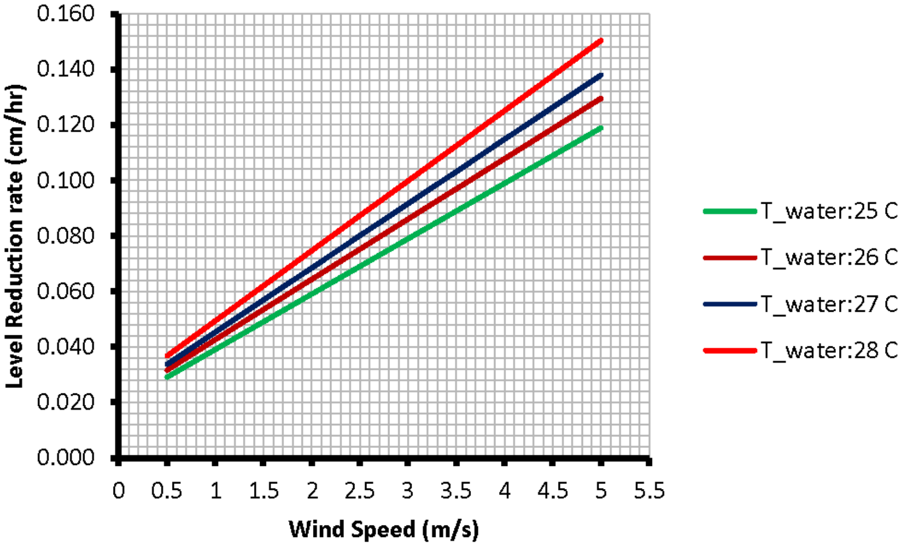


Fig. 13. The pool water level reduction rate variation with wind speed for different pool temperatures

Make-up fresh water to compensate the evaporation rate is usually added at the normal available water source temperature. This adds another load to be compensated by the heating facility such as the heat pump.

A rough estimation at wind speed of (4) m/s showed that the pool loses water at a mean rate of (94) kg/hr for pool temperature range of (25-28) °C, Figure 12. If this water was added at (12) °C, then a load of (1.7) kW should be added to the total design value, the load corresponds to (4) % of the total value to heat the make-up water up to (28) °C.

6. HEAT PUMP DESIGN

The heat pump extracts energy from the low temperature source through a thermal fluid such as (30) % ethylene glycol –water or (20) % propylene glycol-water mixtures. This thermal fluid heat carrier is selected according to the low temperature energy source, Tarrad [27-30]. A (43) kW heat pump may be implemented to extract energy from a sea water through the ethylene glycol-water solution to meet the heating load demand at highest investigated wind speed of (5) m/s.

A friendly environment refrigerant (R410A) was selected to be as the circulated refrigerant for the heat pump due to its zero ODP, low GWP and excellent heat transfer properties.

Figure 14 illustrates a schematic diagram for a heat pump and p-h diagram of the process.

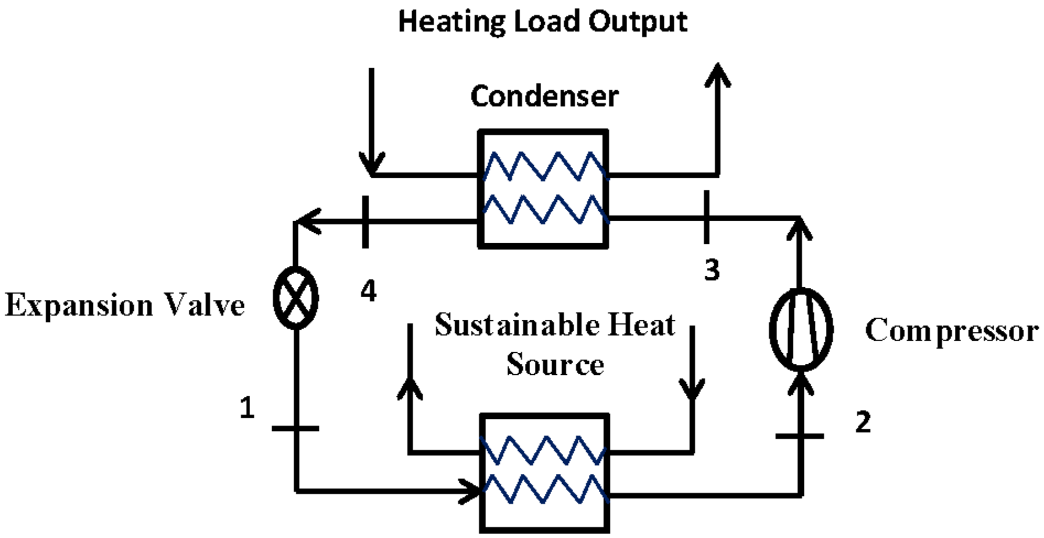


Fig. 14.a. A schematic diagram for a heat pump

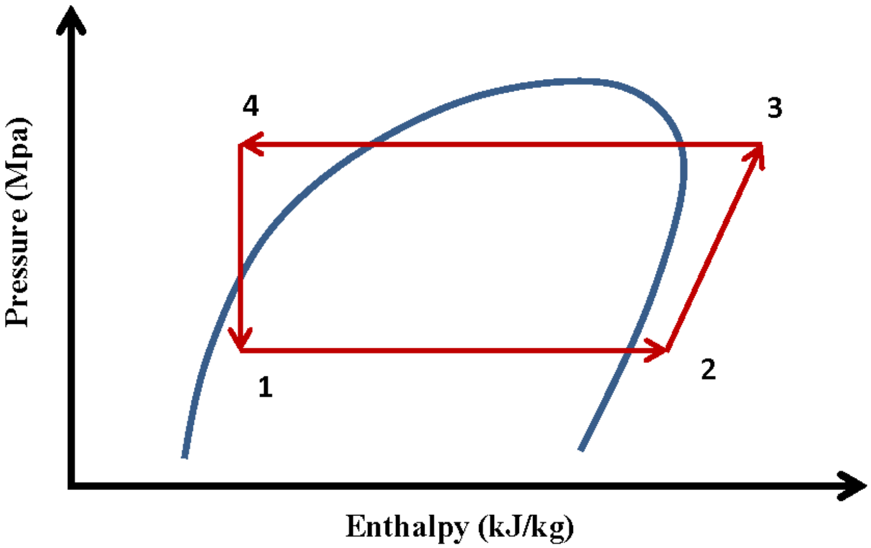


Fig. 14.b.The (p-h) diagram for a heat pump

The extracted sustainable heat load from the source such as sea water is estimated from:

$$\dot{Q}_{Sus,evap} = \dot{m}_{ref}\,(h_2 - h_1) \tag{18}$$

The power consumed by the compressor to raise the pressure up to the condenser one is estimated from the following expression:

$$W_{Sys} = \dot{m}_{ref}\,(h_3 - h_2) \tag{19}$$

The heat extracted by the evaporator and power consumed by compressor should be rejected at the condenser, this amount is calculated by:

$$\dot{Q}_{rej,cond} = \dot{m}_{ref}\,(h_3 - h_4) \tag{20}$$

This is the heat pump capacity for heating purposes of the swimming pool, it corresponds to (1.25) times the extracted heat load from the sustainable source. The capability measure of the heat pump to move the energy from the low temperature region to the higher one is represented by the heating coefficient of performance (COP) as:

$$COP_{H.Pump}=\frac{\dot{Q}_{rej,cond}}{W_{Sys}} \tag{21}$$

The following are the operating conditions and design demands for the heat pump to provide the swimming pool with heating load necessary to attain design temperature at wind speed of (5) m/s:

- i- Extracted heat load from the low temperature sustainable heat source was (34.5) kW at the evaporator temperature of (-7) °C and (5) °C superheat.
- ii- The condenser operated at saturation temperature and subcooling of (40) °C and (2) °C respectively.
- iii- The compressor isentropic and volumetric efficiencies were (90) % and (80) % respectively.
- iv- The output heating load, compressor power consumption and heating (COP) were (43) kW, (9.3) kW and (4.65) respectively.

The pool water is either to be passed directly through the heat pump or heated indirectly by an external heat exchanger. The operating philosophy of the heat pump is controlled by the pool temperature.

7. CLOSURE STATEMENT

It is important to point out that the evaluated thermal requirement in this work represents a conservative scheme in regards to the heat loss estimation and expected wind speed during operation. The following factors were considered:

1- The evaporation lose $\dot{Q}_{evap.}$ from the water surface was evaluated at the maximum pool comfortable temperature of (28) °C, this achieved the maximum possible heat loss.

2- The convection-conduction heat loss $\dot{\boldsymbol{Q}}_{\boldsymbol{Conv,Cond}}$ through walls was based on severe hypothetical climate conditions in regards to the potential temperature difference.

3- The short-wave thermal gain ($\dot{Q}_{rad,sw}$) from total solar radiation on a horizontal surface for an outdoor pool was neglected for open and blanketed pool surface. Outdoor pools absorb (75–85) % of the solar energy striking the pool surface. This is an important contribution to the pool heating needs, [31].

8. CONCLUSIONS

The present analysis revealed a conservative load assessment for above ground outside swimming pool. The outlined scheme showed that the evaporation loss during occupancy and heating-up load prior to usage are the controlling components of the selected heat pump load. The analysis showed that the evaporation heat loss was within the range of (54-69) % depending on the wind speed. The maximum heat loss percentage (66-69) % was experienced at (3-5) m/s wind speed. The surface convection loss occupied the range of (15-21) % at (1.8) km/h to (18) km/h wind speed respectively. It was followed by the radiation component (7-21) % and the lowest was the convection-conduction (3-8) % range through the pool walls. Reducing of the heating up time for the first preparation of the pool can increase the design heating demand considerably which could be just wasting of its economic feasibility. However, the purpose of the pool operating philosophy should also be considered for the load assessment.

9. NOMENCLATURE

Parameter	**Definition**
A	Surface area (m^2)
COP	Coefficient of performance (----)
cp	Specific heat (kJ/kg K)
h_{fg}	Latent heat (kJ/kg)
$\dot{m}$	Mass flow rate (kg/s)
p	Pressure (kPa) or (mm. Hg)
$\dot{Q}$	Heating load (kW)
R	Resistance (m^2 K/W)
T	Temperature (°C)
u	Speed (m/s)
U	Overall heat transfer coefficient (W/m^2 K)
V	Pool volume (m^3)
W	Work rate or power consumed (kW)
Greek Letters	
α	Heat transfer coefficient (W/m^2 K)
Δ	Difference or change
ε	Radiation Emissivity (----)

amb	Ambient
aw	Air-water
co	Cover
cond	Conduction
conv	Convection
evap	Evaporation
Gro	Ground
H.Pump	Heat pump
int	Internal
P	Pool
rad	Radiation
rad,sw	Short-wave radiation
ref	Refrigerant
rej, cond	Rejected at condenser
s	Surface
sky	Sky value
Sus,evap	Sustainable at evaporator
Sys	System

θ	Time (sec) or (hr)
ρ	Density (kg/m^3)
σ	Stefan-Boltzmann Constant (W/m^2K^4)
Subscripts	
a	Air
a,Dew	air at dew point
th, amb	Thermal for ambient
th,co	Thermal for cover
w	water
w,sat	water saturation condition

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