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A PERSPECTIVE NUMERICAL STEP BY STEP THERMAL MODELING FOR OVER-GROUND OUTDOOR SWIMMING POOL DESIGN OPTIMIZATION

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ABSTRACT

The prediction of heating demand for outdoor swimming pool installed over-ground was established. The step by step technique in regards to the heat losses and pool temperature variation with climate conditions were investigated. The postulated technique showed that the optimization methodology predicted a more accurate heating demand than the traditional technique which considered the pool as a lumped body. A hypothetical pool size of (100) m^3 to operate for recreational objectives at design temperature range of (24-29) °C was studied. Ambient air temperature range of (10-20) °C, (50) % relative humidity and wind speed range of (1.8-18) km/h were assigned for the design scheme. The major losses of pool operation showed that evaporation occupied the highest percentage among other components during pool usage. It was amount to (54-79) % of the total loss for the investigated environment wind speed. The results showed that the heat loss out of the pool accounted for (40-49) % of the total heat input depending on the wind speed during the preheating stage. Computer codes were built to implement the numerical scheme for the prediction of the design heating load. At specified operating strategy and pool conditions, the present technique showed the possibility to maintain the comfortable conditions for swimmers with (15-17.5) % lower heating load demand than previous published design model.

INTRODUCTION

The outdoor swimming pools design suffers from the lack of accurate available data for thermal demand prediction. Many models have been suggested to estimate the thermal demand of outdoor pool in the open literature but they are limited in their implementation. This is because these models were built for specific climate environment, location and activity. Chan and lam [1] studied the economic feasibility, thermal performance and energy savings of heat pump implementation in outdoor hotel pools operating under subtropical climates. Greyvenstein and Meyer [2] studied the feasibility of using heat pumps for heating pools in South Africa. They considered the assessment of the average monthly losses of an outdoor pool and established many correlations. Verkannah [3] 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.

Govaer and Zarmi [4] developed an analytical thermal model for open and closed swimming pool on the basis of annual values. Haaf et al. [5] established a model for outdoor pool. The model revealed an acceptable behavior within the range of (21 - 26) °C. More recently, Tarrad [6] postulated a conservative method for the thermal energy requirement for above-ground outdoor swimming pools. He imposed quite severe conditions for the operation of the swimming pool during preparation, occupancy and preheating stages. The method was also suggested to implement the sea water as a sustainable heat source for the heating purpose of the pool. Numerical (CFD) analysis has also been used for the swimming pool thermal and hydrodynamic assessments, Pochini and Strazza [7] and Li and Heiselberg [8].

In the present study, a numerical model employed the step by step scheme for pool and ambient temperatures, wind speed and running time for each operating stage of the pool. The pool was suggested to operate with a firm time strategy during each of the preparation, occupancy and preheating modes. The thermal energy and heat requirement to keep acceptable temperature range for the pool were estimated using three computer codes built for these objectives. The postulated algorithm was applied for a case study where full description of the scheme and its implementation to monitor the pool temperature, losses and heating demand was established.

METHODOLOGY

Pool During Occupancy

Figure 1 illustrates the components of heat loss and gain for the postulated model during its occupancy by swimmers. All of the expected controlling heat factors are shown in both direction, loss or gain depending on the operating temperature of the pool.

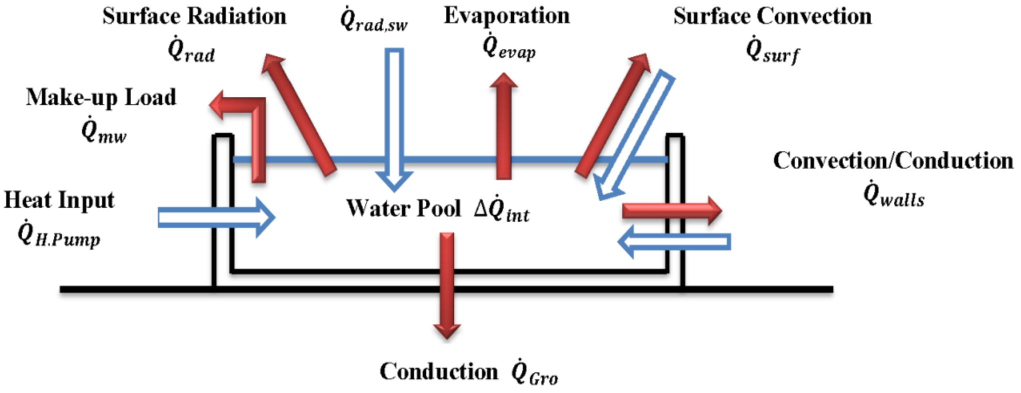

Fig. 1: The mechanism of energy balance for a swimming pool

During the heating up and usage stages of the pool, it is expected that heat may be escaped from the wall and pool water surface or gained according to the operating temperature of both domains. The first law of thermodynamic is applied for the swimming pool system with ideal mixing and steady flow is assumed throughout the control volume then:

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

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

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

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

Hence, the thermodynamic first law expression for the pool is:

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

In this expression, $\sum \dot{Q}_{out}$ represents all of the heat losses shown in Figure 1. In the present study, the heat added to the pool through the heat pump is presented by $(\dot{Q}_{H.Pump})$. The total design load to heat and maintain the pool at set point temperature during occupancy by bathers may be expressed as:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} + \dot{Q}_{evap} \mp \dot{Q}_{walls} \mp \dot{Q}_{surf} + \dot{Q}_{mw} + \dot{Q}_{Gro} + \dot{Q}_{rad} - \dot{Q}_{rad,sw} \tag{2}$$

The evaporation component is inevitable and represents a significant factor during the pool occupancy and composes almost the principal heat loss source. It is a dependent factor on the pool temperature and ambient climatic conditions such as air temperature, humidity and wind speed. This component is also a time dependent in regards to the variation of these operating conditions. Since the pool water and ambient air temperatures vary with time, hence the pool walls and water surface components could be a heat gain or loss with respect to atmosphere. 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.

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 [9], Govaer [10] and Rakopoulos [11]. For the case when the pool is firmly sitting on the ground, this component is usually ignored and($\dot{Q}_{Gro}$) =0. Outdoor pools absorb ($\dot{Q}_{rad,sw}$), which corresponds to (75–85) % of the solar energy striking the pool surface. This is an important contribution to the pool heating needs, [12]. It was neglected for the present model and accounted for the safety factor of the thermal load analysis, hence:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} + \dot{Q}_{evap} \mp \dot{Q}_{walls} \mp \dot{Q}_{surf} + \dot{Q}_{mw} + \dot{Q}_{rad} \quad (3)$$

This Equation holds for the occupied pool during the usage stage. The present study also neglected the heat rejected from the occupants to the pool water body due to its small value on the same basis of that followed by Tarrad [6].

Covered Pool Surface

Equation (3) may be simplified further for the covered or blanketed pool during the first preparation and preheating modes. This yields to the following expression:

$$\dot{Q}_{Design} = \dot{Q}_{Heat-up} \mp \dot{Q}_{walls} \mp \dot{Q}_{surf} + \dot{Q}_{rad} \quad (4)$$

During the heating up stages of the pool, the evaporation and make-up water heat losses tend to be zeros.

THERMAL MECHANISMS

The heat transfer and energy modes which control the thermal aspect of the swimming pool are shown in Figure 1. The treatment of each heat transfer mechanism is described as follows:

Evaporation Process

Evaporation Mass Loss

There are many correlations available in the open literature for the prediction of the evaporation rate from an open pool. Smith et al. [13] formulated quite a simple correlation based on experimental data to predict the amount of water evaporated from a pool in the form:

$$\dot{m}_{evap} = A_s \frac{(30.6+32.1\,u_{wind})(p_{w,sat} - p_{a,Dew})}{h_{fg}} \quad (5)$$

The pressure difference in the above equation has (mm. Hg) units.

Evaporation heat loss ($\dot{Q}_{evap}$)

The evaporation process from the pool surface represents a coupling of heat and mass transfer mechanisms.

Most of the heat required for the evaporation is taken from the water itself. The required heat supplied to cover the evaporation loss can be calculated from:

$$\dot{Q}_{evap} = \dot{m}_{evap}\, h_{fg} \quad (6)$$

The latent heat of vaporization for pool water is measured at the bulk pool temperature.

Fresh water load ($\dot{Q}_{mw}$)

Fresh water is usually supplied to maintain fixed level of water in the swimming pool. This make-up water is usually added at the available water source temperature to compensate the evaporated amount ($\dot{m}_{evap}$) from the pool surface. Heat should be provided to heat up this amount of water to the pool temperature. Hence, the heating load required for fresh water can be estimated from the following expression:

$$\dot{Q}_{mw} = \dot{m}_{evap}\, cp\, \Delta T_{FP} \quad (7)$$

The term (ΔT_{FP}) represents the temperature difference between the fresh and pool water temperatures.

Convection loss ($\dot{Q}_{surf}$)

Although this component is a well-established and described in full accurate equation but it is really hard to assess for the swimming pool. This is due to the fact that the pool-air potential temperature difference is a variable rather been a constant value. The pool water temperature varies with time during the heating up and usage stages. Even if the ambient temperature was assumed to be fixed at a specified point, the convection loss still fluctuates according to the potential temperature difference. This heat loss was estimated from the following expression, Root [14]:

$$\dot{Q}_{surf} = \alpha_s \, \Delta T_{aw} \, A_s \tag{8}$$

The heat transfer coefficient (α_s) for an outdoor pool was found by Czarnecki [15] expression:

$$\alpha_s = 3.1 + 4.1 \, u_{wind} \tag{9}$$

This component will considerably be reduced when a cover was implemented at the pool water surface because of the insulation action of the cover. In the present work, the overall thermal conductance of typical covers made of Plastipack's 400 Grade products was used. The thermal resistance of such covers is within (16.67) W/m^2 K which corresponds to ($R_{th,co}$=0.06) m² K/W, [16]. The heat loss was estimated from:

$$\dot{Q}_{surf} = U_s \, \Delta T_{aw} \, A_s \tag{10.a}$$

$$U_s = \frac{1}{R_{th,co} + R_{th,amb}} \tag{10.b}$$

$$R_{th,amb} = \frac{1}{\alpha_s} \tag{10.c}$$

Pool inertial load ($\dot{Q}_{Heat-up}$)

This represents the amount of energy rate to be added to raise the temperature of the pool from its initial to the set point value during the preparation and preheating stages, it is estimated from:

$$\dot{Q}_{Heat-up} = \frac{V \, \rho \, cp \, \Delta T_{water}}{\Delta \theta} \tag{11}$$

A considerable attention should be paid for this heat component when a swimming pool is to be designed. Longer heating up time provides lower heating load demands for the attendance of set point and vice versa. The operating philosophy of the swimming pool determines the heating up time strategy to be followed.

Pool side walls ($\dot{Q}_{walls}$)

The convection and conduction modes represent the predominate mechanisms and estimated from:

$$\dot{Q}_{walls} = U_{wall} A_{wall} \Delta T_{aw} \tag{12}$$

The overall heat transfer coefficient (U_{wall}) is determined by the material and thickness of the composite wall structure. In the present study an above-ground (1/2) in fiberglass-plastic walls supported by an open framework of wood or metal tubing was chosen to demonstrate the model idea. This wall structure has (U_{wall}) of (11) W/m^2 K measured at (11) km/h average wind speed, [14].

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:

$$\dot{Q}_{rad} = A_s \, \varepsilon \, \sigma \left\{ {T_s}^4 - {T_{sky}}^4 \right\} \tag{13.a}$$

$$\varepsilon = 0.9 \quad \text{And} \quad \sigma = 5.67 \times 10^{-8} \frac{W}{m^2K^4} \tag{13.b}$$

The sky temperature (T_{sky}) depends on the condition of the atmosphere, cloudy or clear and day or night time. 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, [14]. 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 (10) and the thermal resistance of the cover itself by:

$$T_s = T_P - \frac{\dot{Q}_{surf}\, R_{th,co}}{A_s} \tag{14}$$

MODEL ANALYSIS

The analysis of the present model implements the step by step technique for the pool temperature domain at fixed ambient conditions. The following represents a full description of the design scheme:

Preparation Process

The pool is filled with water from the source at initial temperature of (12) °C and covered by the blanket. Hence the mechanism of heating is controlled by Equation (4) for the heating load prediction of the swimming pool. The flowchart of the code (**HEATING-1**) built for this purpose is shown in appendix (A), Figure A.1. The step by step procedure was conducted as follows:

1. The physical dimensions and volume of the pool are specified according to the design requirements.
2. The design parameters such as climate condition in regards to temperature, humidity and wind speed are assigned to represent the design boarder conditions.
3. Calculate the heat losses and design heating demand for each pool temperature step of (1) °C until the set design point was achieved.
4. The heating demand was estimated from the net of heat gain and lost during each pool temperature step.
5. Taking the average of heat loss/gain for each component and design heating demand for the whole of investigated pool temperature range between (12-29) °C.
6. Repeat step (3-5) for various wind speed values by (0.5) m/s step interval until the design wind speed was obtained.
7. Repeat steps (3-6) for different ambient temperature of step interval equal to (1) °C until the set design air value was achieved.
8. All heat loss components, ambient and pool temperatures and design heating demand are stored and the design scheme was terminated.

Although the procedure resulted in much detailed data for the pool thermal concept, but it is impossible to determine the optimum heating demand needed without a full evaluation for the next stages of the pool running strategy. This is mainly due to the fact that many parameters interact and play important roles in the assessment of the heating load especially during pool occupancy. The outcomes of this procedure were mainly a single value of each of the heat components and total heating demand for each ambient temperature and wind speed steps. It also considers the direction of heat flow to or from the pool and included within the net heat loss/gain of each component. The databank represents the main source for the present analysis for the determination of the swimming pool design heating demand.

Usage Stage

This stage represents the main objectives of the thermal design of the swimming pool. Equation (3) controls the operating mechanism of this stage. The pool should be capable to handle all of heat losses and provides a comfortable environment for the bathers within the acceptable temperature range of the pool water. The flowchart of the written code (**USAGE**) to outline the design procedure is shown in appendix (A), Figure A.2. The following represents a simple description for the procedure followed for the design purposes of this stage as stated by (**USAGE**) code:

1. Select the expected ambient design operating conditions for the swimming pool, namely temperature, relative humidity and range of wind speed during occupancy.
2. Select the minimum ambient temperature for the design conditions of the pool.

3. Recall the average design heating demand from the results of (HEATING-1) at the specified conditions assigned at points (1 and 2) for the investigated wind speed range.
4. Calculate the mean design heating load needed from those estimated at the minimum and design operating ambient temperatures of the pool for the whole wind speed range.
5. Find the maximum heating load demand required for the attendance of the operating conditions from point (4). This is usually experienced at the maximum design wind speed condition.
6. The initial temperature of the pool prior to usage is usually set at (29) °C.
7. Calculate the mean heat losses for the pool temperature range between the minimum and maximum acceptable temperature limits.
8. Use the design heating load demand from point (5) as input and use Equation(3) to determine the net of heat loss/gain, in this expression the net is represented by ($\dot{Q}_{Heat-up}$).
9. Apply Equation (11) to estimate the rate of change of pool temperature difference, $\frac{\Delta T}{\Delta \theta}$ for the investigated wind speed up to the design value.
10. Continue the calculation of the pool temperature (T_{Pool}) in the transient mode to fulfill the occupancy running time of the pool to be (4-5) hr and store the data.
11. Increase the wind speed by (0.5) m/s step and repeat the procedure from point (7).
12. Store the average of all of the assessed losses, inertial loads, ambient and pool temperatures and terminate the calculation when the maximum design wind speed was achieved.

At each wind speed, the losses to the environment were estimated as a mean value for the expected temperature range for the pool to work with. This represents the acceptable range of the pool temperature by the users to be within (24-29) °C. All the factors involved in Equation (3) were calculated at each wind speed and pool temperature then the mean value was taken for this temperature range as:

$$\dot{Q}_{m,comp} = \frac{\sum_{T_P=24\,°C}^{T_P=29\,°C} \dot{Q}_{comp}\,(T_P)}{6} \tag{15}$$

The subscript (*comp*) stands for the value of each heat loss component including pool surface, radiation, walls, evaporation and make-up. These average single values were suggested to be used in the governing equation (3) to predict the pool inertia load defined as ($\dot{Q}_{Heat-up}$) at each wind speed. The pool inertia expression represented by equation (11) was used for each time step for the prediction of pool temperature variation with usage time and marching the scheme up to (5) hr occupation time.

Preheating Mode

This is the final mode to be evaluated prior to the judgment of design heating demand is decided. The heating load which was considered from the preparation stage and used in the usage stage should be checked for the preheating mode validation. In this procedure a code (**HEATING-2**) similar to that used for the first preparation stage was also built with initial temperature to be the final value obtained from the occupancy stage. Hence the final target pool temperature for this stage was to achieve the design value of (29) °C prior to the next day use. The load selected for this stage should be capable for the reheating process of the pool within a limited time.

Equation (4) was used to estimate the net load where the pool inertia load for heating up ($\dot{Q}_{Heat-up}$) was estimated. Here, the mean losses of pool surface, radiation and walls have also been suggested to be estimated for the pool temperature range of (24-29) °C similar to that used for the occupancy period, Equation (15). This is in order to consider the losses at a mean value of the pool during the heating up scheme of the pool. All the losses during this stage are a pool temperature dependent and are preferred to be assessed at each temperature step in the range (24-29) °C and taking the average as a final design values for each wind speed.

Scheme Evaluation

The model suggested predicting the design heating load demand from the full step by step numerical method implemented for the assessment of the preparation stage of the swimming pool. A three steps validation methodology was implemented for the final evaluation decision to be approached. The design heating load needed should be capable to handle the running strategies of the pool, preparation, occupancy and preheating mechanisms. Failing to fulfill any of these requirements indicates the fail of the design load value to comply with the running scheme of the pool. Hence, either the operating strategy or conditions of the swimming pool should be reconsidered again.

RESULTS AND DISCUSSION

The design procedure was implemented for the following case study:

a. A swimming pool size of (100) m^3 having (12 ×7×1.2) m installed over-ground outdoor.
b. Ambient temperature range of (10) °C to (20) °C, (50) % relative humidity and (0.5-5) m/s wind speed range.
c. Water source temperature for preparation and fresh water make-up was taken as (12) °C.
d. Design operating ambient temperature during occupancy was (15) °C and relative humidity of (50) %.
e. The pool temperature for comfortable swimming condition during occupancy lies in the range of (24-29) °C.
f. Heating up time for the first preparation process of the swimming pool was set to (3) days.
g. The pool usage time was set at (4-5) hr per day and to be preheated to the set point prior to usage on the next day.

Pool Preparation

The ambient environment temperature and wind speed interplay an important role in the design process of a swimming pool and they are more pronounced when the pool is situated outdoor. The wind speed effect is clearer at the occupancy period due to the evaporation action. Figure 2 illustrates the variation of the total heating load as predicted by equation (4). The results showed that the lower design ambient temperature (10) °C exhibited the highest load and vice versa.

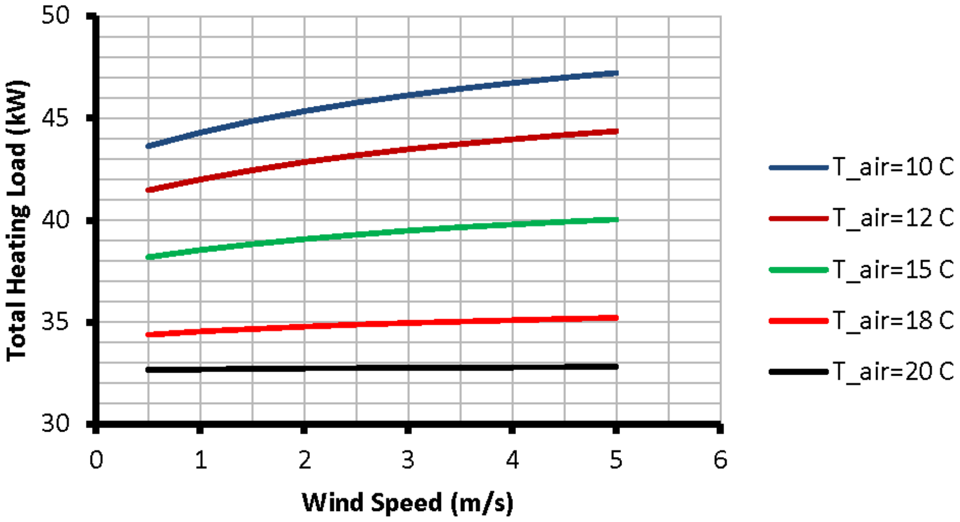

Fig. 2: Preparation heating load comparison for different ambient air temperatures

The highest heating load was ranged between (44) kW and (47) kW estimated at (10) °C for wind speeds of (0.5) m/s and (5) m/s respectively. The heat load corresponds to a constant value of (33-34) kW predicted at (18-20) °C ambient temperature regardless of wind speed. The rest of the investigated ambient temperature range occupied the zone bounded by these values. This behavior can be explained in relation to the heat loss behavior which has a strong dependency on the ambient temperature as shown in Equations (10, 12 and 13). Figure (3) shows the total heat loss due to surface convection, pool walls convection-conduction and long-wave radiation to the surrounding for a variety of ambient temperatures. The lowest heat loss was experienced when the pool worked under the higher ambient temperature of (20) °C and the maximum was achieved at (10) °C.

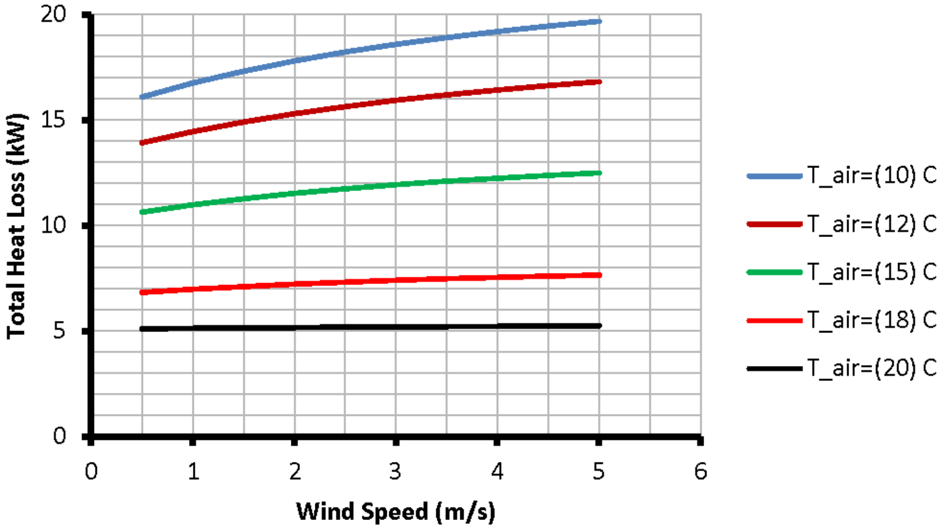

Fig. 3: A comparison for the total heat loss estimated at different ambient temperatures

Figure 4 shows the behavior of the surface convection component with wind speed and pool temperature for different ambient temperatures. It is obvious that the scheme has revealed two different heat modes; it is either heat loss from or gain to the pool.

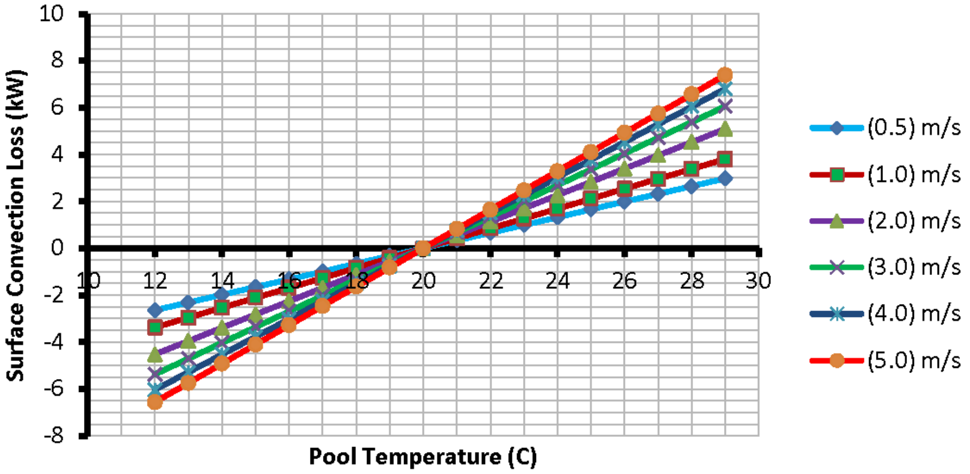

Fig. 4a: Preparation stage at (20) °C ambient temperature

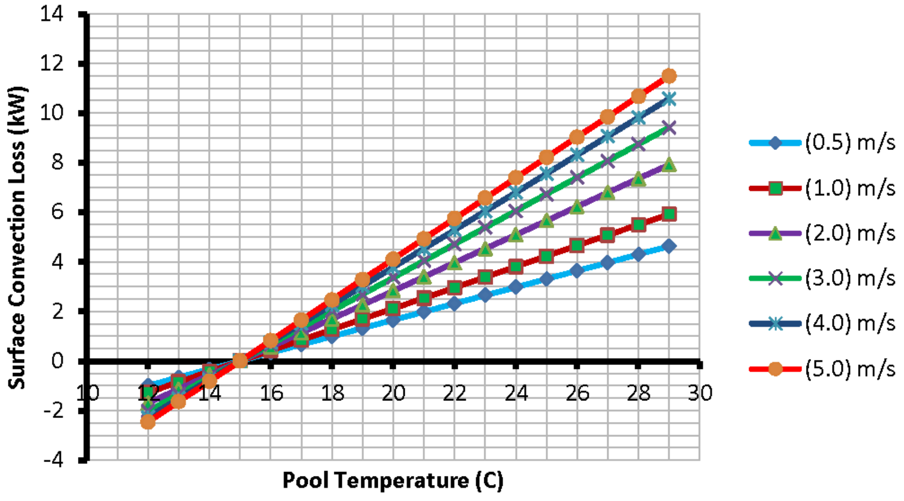

Fig. 4b: Preparation stage at (15) °C ambient temperature

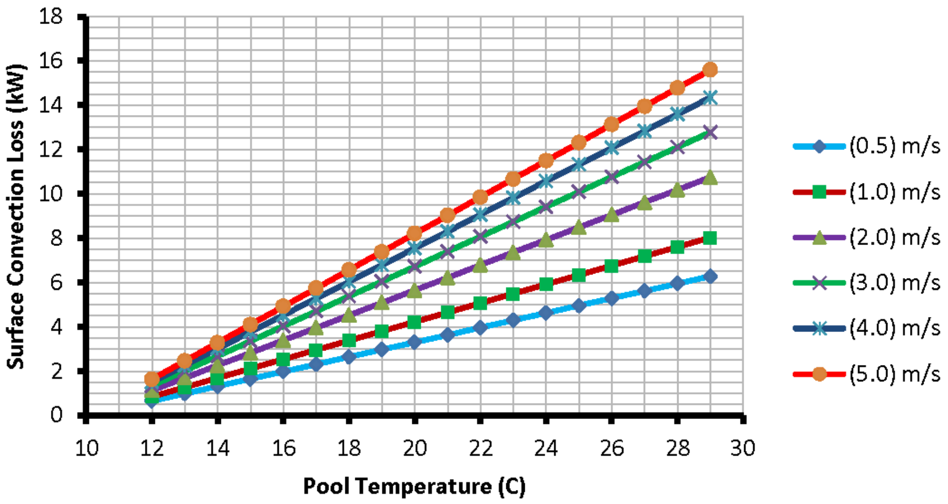

Fig. 4c: Preparation stage at (10) °C ambient temperature

Fig. 4: A comparison for the pool surface convection loss at different wind speeds and ambient temperatures during preparation stage

The highest ambient temperature of (20) °C showed cancelled loads due to direction from or to the pool body. Hence, the total loss exhibited a declination with ambient temperature rise and the lower losses was evident at the higher temperature of (20) °C and minimum at (10) °C, Figure 3.

The results also showed that the loss or gain were proportional to the wind speed, the higher was usually corresponding to the higher speed and vice versa. The trend of the heat flow was also showed a dependency on the pool temperature during the heating period. At the early stage of the heating process, the pool temperature was lower than the ambient then the heat was gained. On the contrary, heat waslost to the environment when the pool temperature approached a value higher than the surrounding. If the operating conditions of the pool experience both heat modes, then the net heat to be lost to the surrounding decreases such as the case of the (20) °C ambient temperature, Figure 4a. This trend was evident when the ambient temperature was lower than the pool water temperature and heat flows to the surrounding and lost during the heating up stages, figure 4c.

Occupancy Period Analysis

The design climate temperature, humidity and wind speed are the most important factors to be carefully considered during this stage. The design air temperature was taken as (15) °C and relative humidity was set as

(50) %. The wind speed was studied for the whole practical expected range of (1.8-18) km/h. A general value for the wind speed may be considered as (14) km/h for design purposes which corresponds to (4) m/s.

The present step by step scheme suggested using the average of total heat loss for both of the minimum ambient and design temperature from the first stage calculation of heating load demand. Figure 5 shows the mean of the average losses and the design heating load predicted at (10) °C and (15) °C for the whole investigated wind speed range.

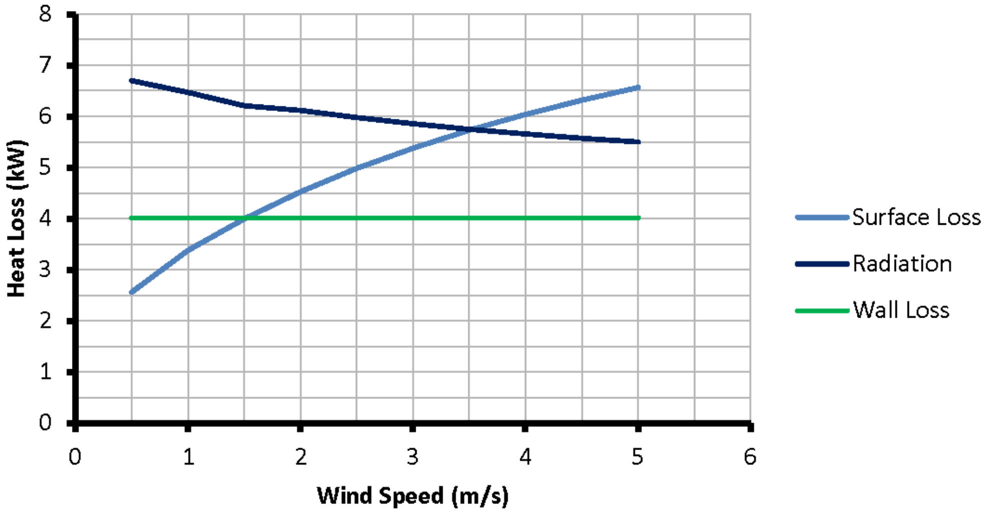

Fig. 5a: Mean heat losses to ambient calculated for (10) °C and (15) °C environment

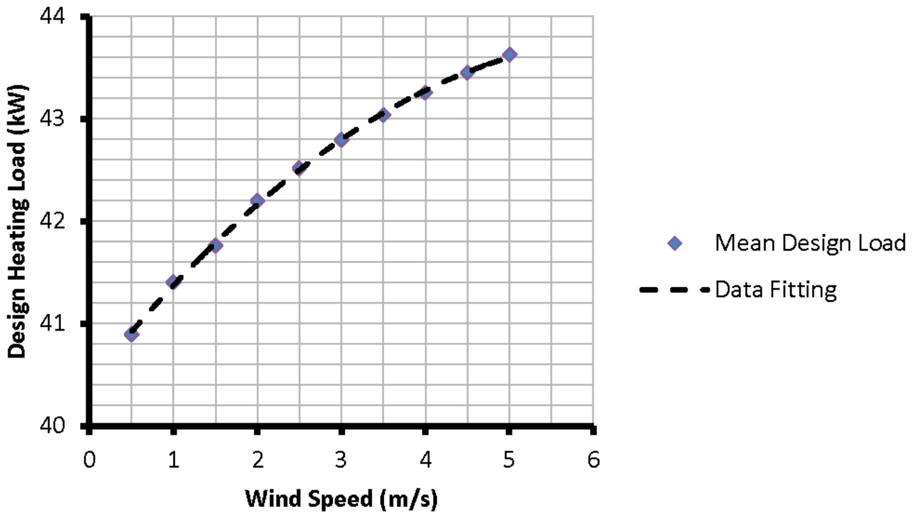

Fig. 5b: Design heating load estimated from mean heat losses at (10) °C and (15) °C ambient conditions

The scheme showed that the design heating load estimated on the basis of mean heat losses assessed at minimum and maximum design ambient temperatures of (10) °C and (15) °C respectively has the expression:

$$\dot{Q}_{Design} = -0.0778\, u_{wind}{}^{2} + 1.0226\, u_{wind} + 40.428 \tag{16}$$

It is obvious that the maximum heating load suggested by this scheme to be (43.5) kW as a design heating demand for the swimming pool. This load will be selected as the recommended value by the step by step technique and should be checked for validation.

Figure 6 represents a comparison for the pool temperature declination at different usage time. The resulted showed that the pool temperature experienced a declination as the occupancy time of the bath was increased. This behavior revealed that the heat lost away from the pool was higher than that added during occupancy.

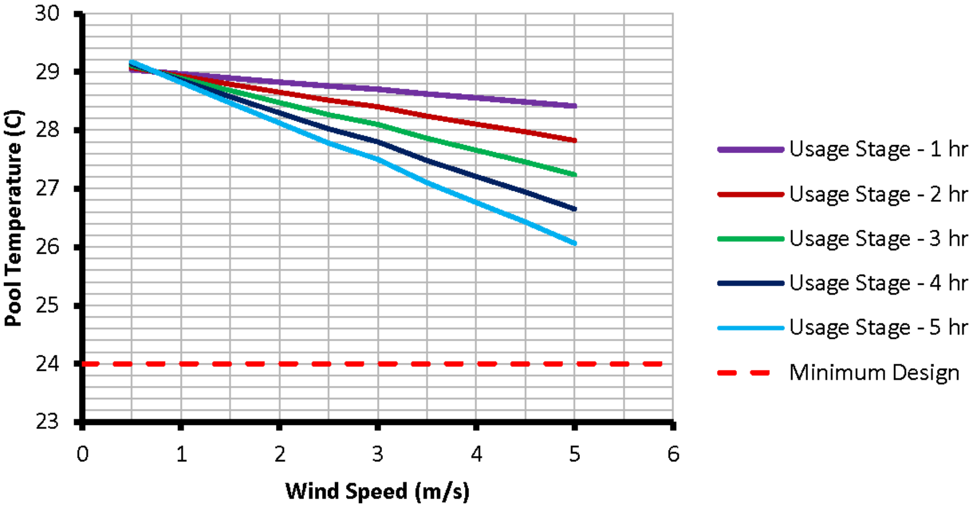

Fig. 6: Pool temperature variation comparison for different occupancy time and wind speeds at (15) °C ambient temperature

It is clear that even for (5) hr occupancy time, the pool still possess enough energy to enjoy swimming at a temperature well above the minimum design set point. The minimum temperatures approached by the pool were about (26) °C and (26.7) °C predicted after (5) hr and (4) hr of occupancy time by swimmers respectively.

Figure 7a shows the percentage of each heat loss component with respect to the total amount of heat rejected to atmosphere. The evaporation loss represents the maximum among other components; it is amount to (54-79) % of the total loss. The radiation loss corresponds to about (8-20) % of the total heat loss followed by (5-15) % for the pool wall and (10) % for the pool surface convection. The fresh water added as a make-up to compensate the evaporation rate from the pool accounts for only (1-1.5) %.

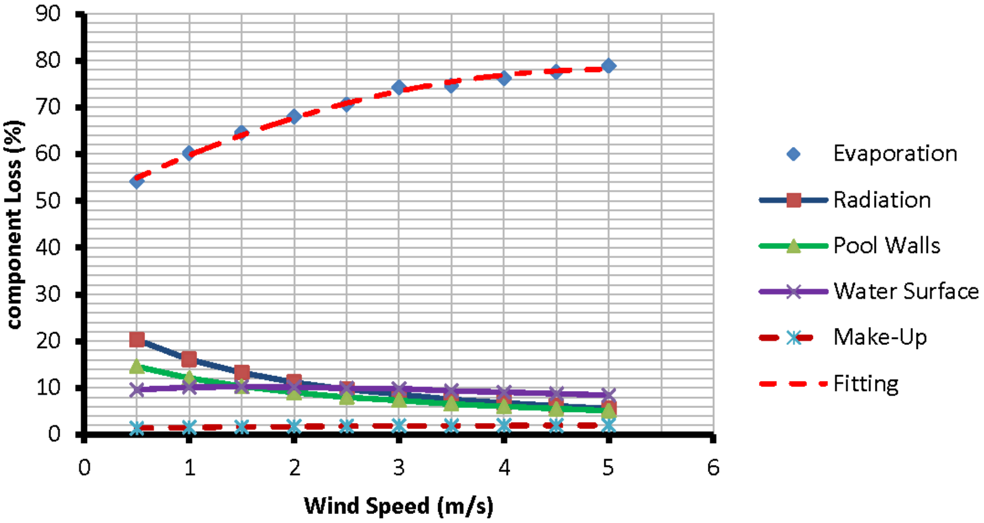

Fig. 7a: Losses components percentage comparison during occupancy at different wind speeds and (15) °C evaporated ambient temperature

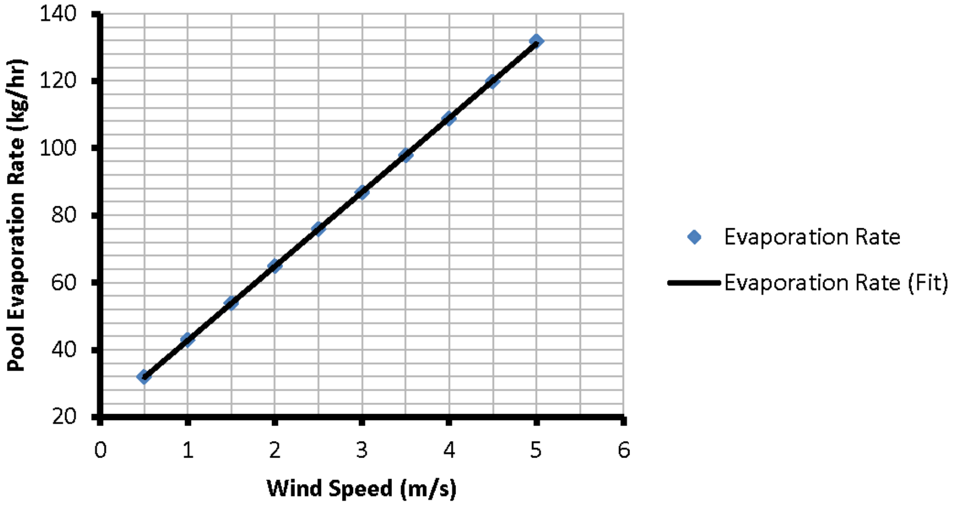

Fig. 7b: Evaporation rate comparison during occupancy at different wind speeds and (15) °C ambient temperature

The evaporation rate and hence the load lost from the pool surface showed an increase with wind speed and the highest was accompanied to (5) m/s wind speed, Figure 7b. The evaporated amount is proportional to the wind speed as shown in the following expression:

$$\dot{m} = 22.068\, u_{wind} + 20.725 \qquad (17)$$

This amount is compensated through the make-up supplied at the main source temperature. The pool will lose about (660) kg and (530) kg during the usage time of (5) hr and (4) hr respectively.

According to this argument and data collected from the present analysis; the scheme is valid and passed the design criteria for this stage.

Preheating Process

The built model for the first stage preparing of the pool is still valid but with known heating load and Equation (4) describes the process during this stage. The design heating load which was chosen from (**HEATING-1**) code and implemented for (**USAGE**) code should be capable to reheat the pool for the next day use by the bathers as well.

In a procedure similar to that suggested for the occupancy stage assessment, the calculation of the mean heat loss at the pool temperature (24-29) °C was considered. The average values of heat lost to the ambient, surface convection, pool wall and radiation were estimated for each wind speed as shown in Equations (15). The preheating process was chosen to take place at the design ambient temperature of the scheme, it was chosen as (15) °C. This was to allow the pool to lose energy to the ambient for the whole range of pool temperature after occupancy stage. Figure 8 illustrates the heat loss percentage of each component with respect to the total heat lost to surrounding.

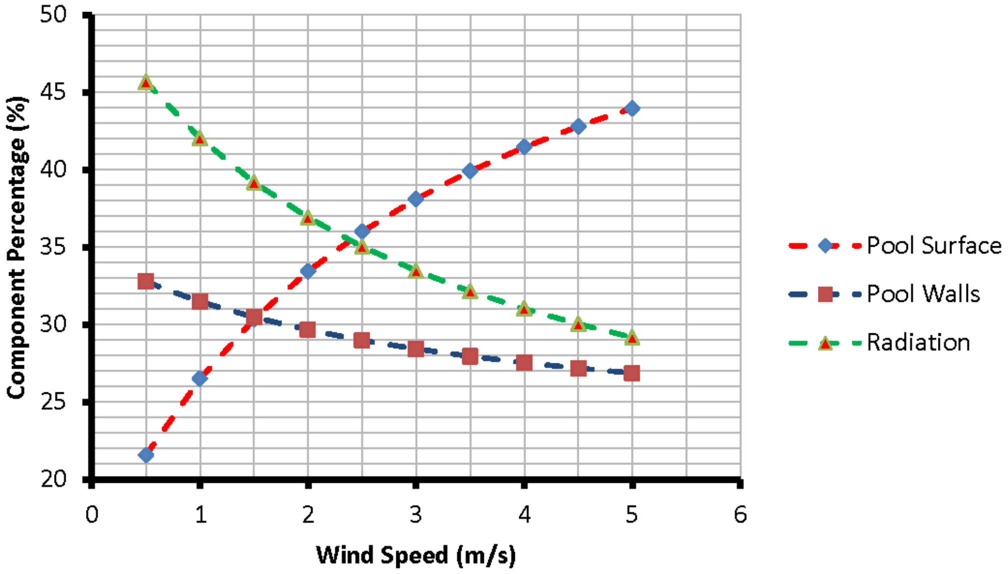

Fig. 8: Predicted losses percentage at (15) °C climate temperature for preheating stage

The surface convection loss occupied about (22-44) % of the total loss estimated at (0.5-5) m/s wind speeds. The pool walls loss due to convection-conduction fell within (27-33) % and the highest limit corresponds to the lowest wind speed and vice versa. The corresponding values for the radiation losses were within (29-46) %. Equation (11) was implemented to estimate the time required for the pool to be heated up to the design set point of (29) °C. On commencing the step by step numerical scheme, the pool was considered to be at its final temperature of the usage stage. Then the procedure took into account heating the pool up from this temperature to the highest design temperature of (29) °C.

Figure 9 shows the output of the preheating code (**HEATING-2**) implemented together with the results of (**USAGE**) in regards to the design heating load and final temperature after occupancy. The trend of the results revealed polynomial expressions for the pool temperature variation with wind speed. For the usage time of (4) hr, the expression has the following form:

$$\theta_{preh.} = 0.1413\, u_{wind}{}^{2} + 2.0362\, u_{wind} - 1.2654 \tag{18.a}$$

If the pool was used for (5) hr swimming, then:

$$\theta_{preh.} = 0.1766\, u_{wind}{}^{2} + 2.5453\, u_{wind} - 1.5818 \tag{18.b}$$

The preheating time obtained from these relations is in (hr). At common design wind speed of (4) m/s, the preheating time fell within (9.2) hr and (11.5) hr for (4) hr and (5) hr occupancy time.

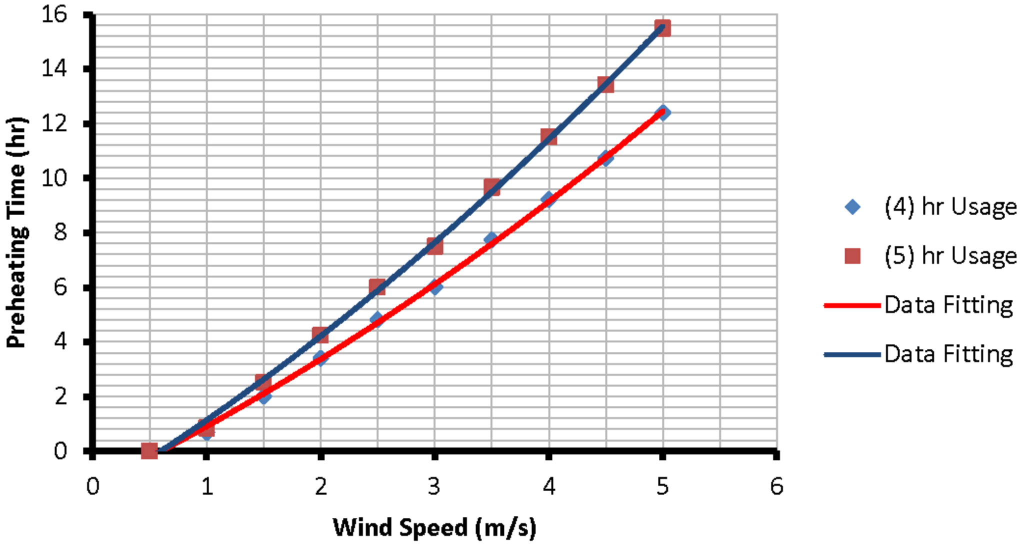

Fig. 9: Preheating time comparison for different occupancy periods at (15) °C ambient temperature

At (5) m/s wind speed, the (4) hr usage time is still feasible to be within (12.4) hr for preparing the pool for the next day use. These results show that although the pool experienced a longer usage time but the predicted design heating load was capable to handle the preheating stage. It could extend to (15.5) hr running time for the heating equipment for the case of (5) hr usage when the wind speed approaches (5) m/s. Again it looks feasible for the heating equipment to attain the set point temperature of the pool for the next day occupancy stage.

The heat loss and pool water inertia portions of the total design heating load are presented in Figure 10. As the wind speed increases, the heat loss portion increases which cause a declination for the heating up load left out of the total heat input to the pool. The results showed that the heat loss out of the pool accounted for (40-49) % of the total heat input depending on the wind speed. This is mainly due to the fact that the surface heat loss is the predominant as a result of overall heat transfer coefficient increase with wind speed as shown in Figure 8.

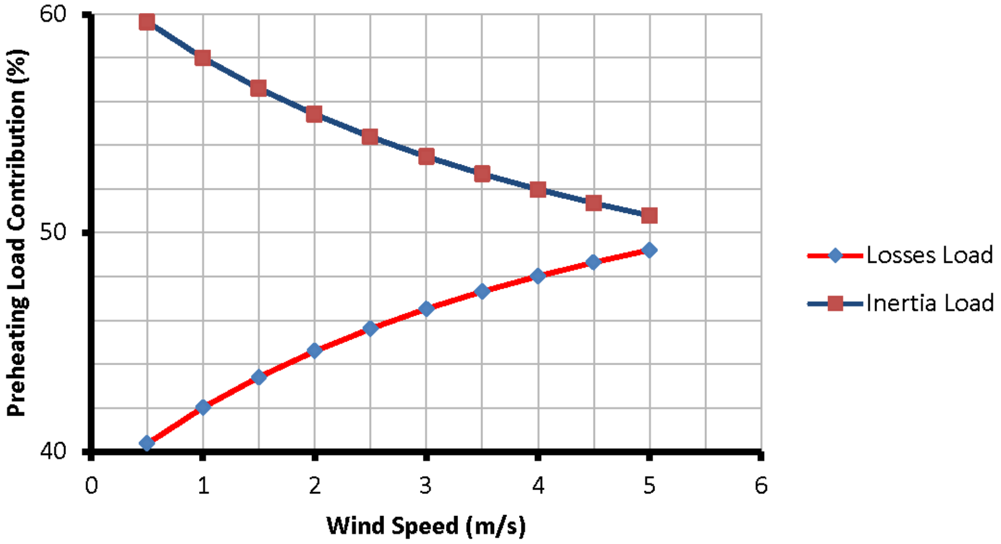

Fig. 10: Preheating load distribution with respect to the design load at (15) °C ambient temperature

MODEL COMPARISON

The present numerical model was compared to the previous work presented by Tarrad [6]. The comparison was based on the following conditions:

i- Ambient temperature was set at (15)°C and relative humidity of (50) % for the preparation, preheating and occupancy stages.
ii- The pool to be prepared to the set point temperature of (29) °C within (3) days prior to first occupancy stage.
iii- The acceptable pool temperature range of (24-29) °C for recreational comfortable objectives by swimmers.

Tarrad's [6] conservative model showed a higher design heating demand than the present work for the whole investigated wind speed range as shown in Figure 11.The deviation was estimated by:

$$\dot{Q}_{dev}\,\% = \frac{\dot{Q}_{p,Design} - \dot{Q}_{Tar,Design}}{\dot{Q}_{Tar,Design}} \tag{19}$$

The design heating load for the present work lied in the range of (15-17.5) % lower than the predicted value by the previous model for wind speed range of (0.5-5) m/s. The heating design load is usually selected at the highest design wind speed. Hence, the present model showed a design heating load of (43.5) kW compared to (52.8) kW for the previous model estimated at wind speed of (5) m/s. This design heating demand corresponds to about (82) % of that predicted by Tarrad [6] model.

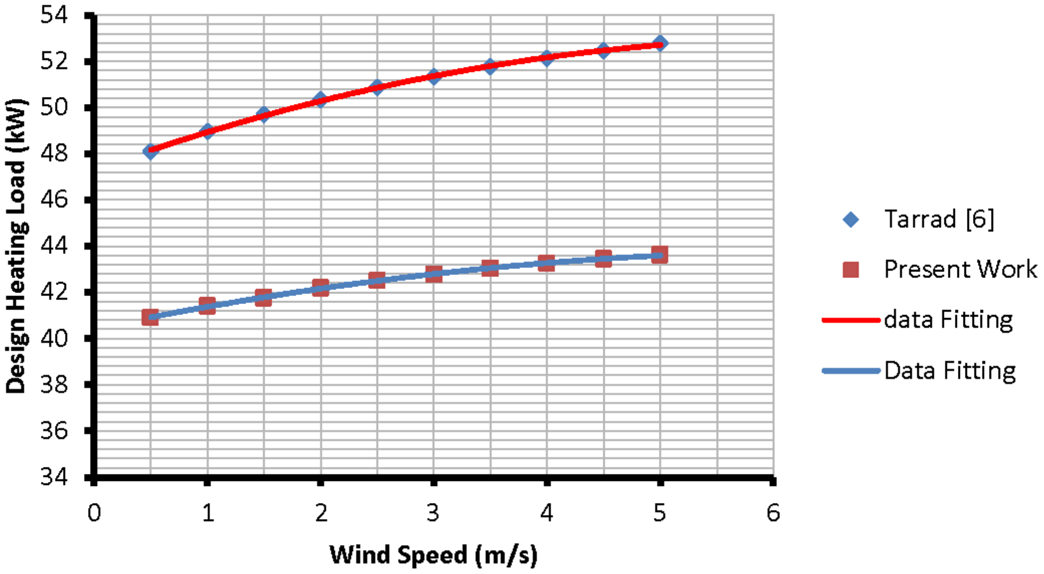

Fig. 11: Design heating load for (15) °C ambient temperature during preparation stage

The design heating load demands for both schemes were correlated in terms of the wind speed. For Tarrad [6] model, it has the form:

$$\dot{Q}_{Design} = -0.1348\, u_{wind}^{\;2} + 1.7546\, u_{wind} + 47.314 \tag{20}$$

The present work formula was presented in Equation (16).
Figure 12 illustrates a comparison for the pool temperature variation with wind speed predicted at different occupancy time for both models.

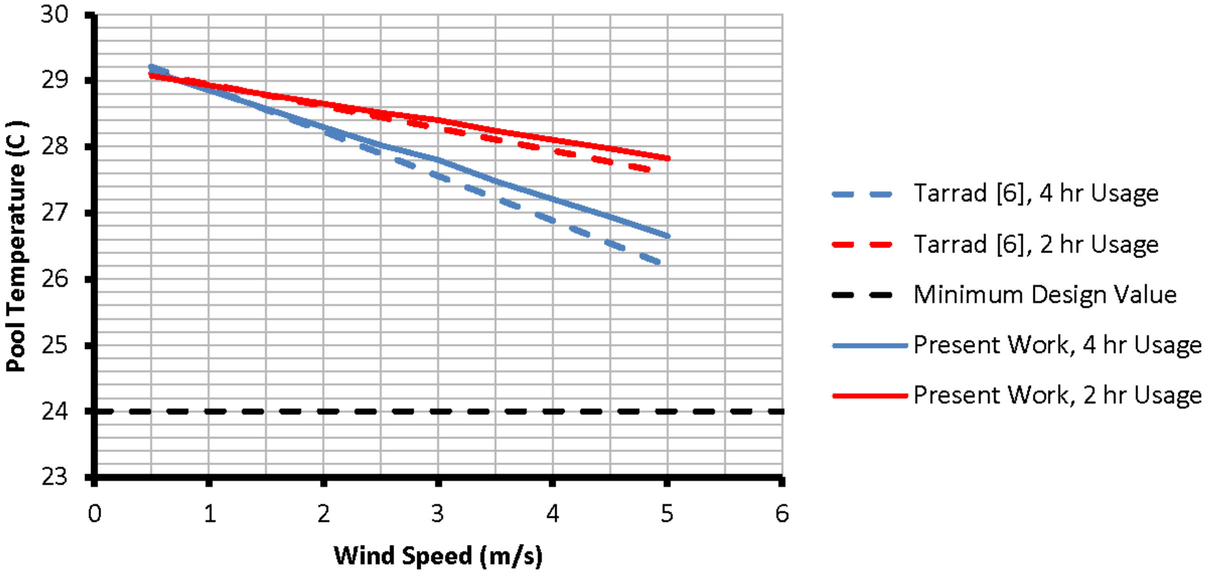

Fig. 12: Pool temperature comparison between both models at (15) °C ambient temperature during usage stage

Both schemes predicted quite good range for pool temperature within the comfortable swimming conditions. The present model revealed a temperature of about (0.5) °C higher than that of the previous model at the end of (4) hr occupancy period.

A comparison for the preheating time needed by the pool to attain the set point temperature of (29) °C for both models is shown in Figure 13. Similar trends were observed for the pool temperature variation with wind speed as predicted by both design techniques.

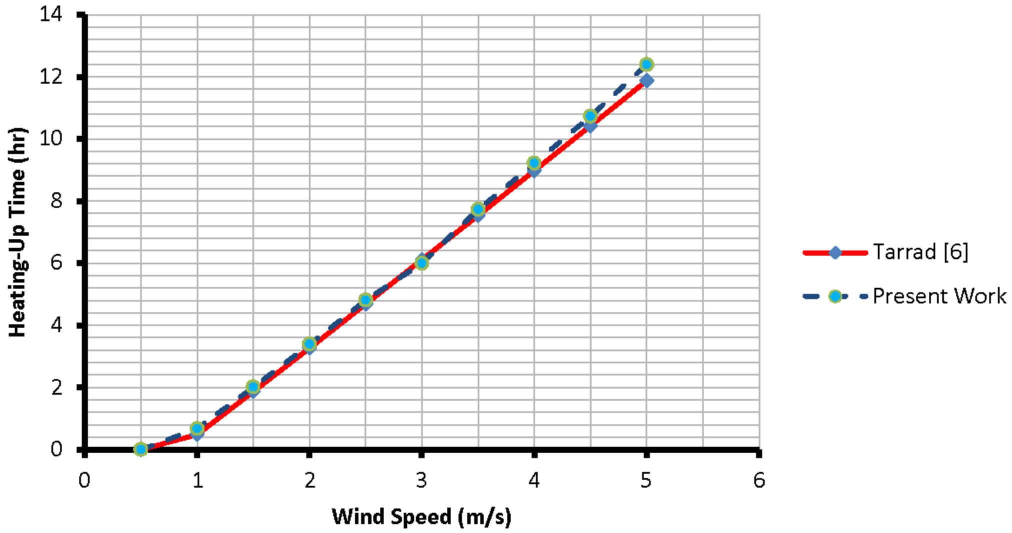

Fig. 13: Heating-up time comparison between both models at (15) °C ambient temperature during preheating stage

Although the design heating load of the present work was lower than that of the previous model by (15-17.5) %, but both models showed the same trend and final preheating time. Almost the same time was predicted to retain the set point temperature, it was within (12) hr for both design schemes. It is usually recommended to add a margin of (10-20) % for the heating load demand as a safety factor. This accounts for the uncertainty of the correlations and any approximation involved in the main work frame of the design model and climate conditions fluctuation for the pool surrounding.

CONCLUSIONS

The present investigation outlined a simple numerical step by step technique to predict the swimming pool temperature variation and design heating load demands. A proper operating strategy for the pool was also suggested to optimize the usage of energy and heating equipment within the frame of acceptable comfortable pool temperature for users. The present scheme provides the designer with a clear time dependent map of all thermal controlling aspects for the swimming pool energy modeling.

The evaporation loss represents the major component of heat rejected to the surrounding during occupancy; it was within (54-79) % of the total loss for the investigated environment wind speed. The long-wave radiation losses composed of (8-20) % of the total heat loss followed by (5-15) % for the pool wall losses and (10) % for the pool surface convection. The fresh water added as a make-up to compensate the evaporation rate from the pool accounts for only (1-1.5) %. At specified operating strategy and pool conditions, the present numerical step by step model showed the possibility to attend these conditions with (15-17.5) % lower heating load demand than previous published design model. The thermal design codes and procedure built in this work could be implemented for industrial design of over-ground outdoor pools with optimum load assessment.

NOMENCLATURE

Parameter	**Definition**	aw	Air-water
A	Surface area (m^2)	co	Cover
cp	Specific heat (kJ/kg K)	cond	Conduction
h_{fg}	Latent heat (kJ/kg)	conv	Convection
$\dot{m}$	Mass flow rate (kg/s)	evap	Evaporation
P	Pressure (kPa) or (mm. Hg)	FP	Fresh/pool value
$\dot{Q}$	Heating load (kW)	Gro	Ground
R	Resistance (m^2 K/W)	H.Pump	Heat pump
T	Temperature (°C)	int	Internal
u	Speed (m/s)	m	Mean value
U	Overall heat transfer coefficient (W/m^2 K)	mw	Make-up water
V	Pool volume (m^3)	p,Design	Present design value
W	Work rate or power consumed (kW)	P	Pool
Greek Letters		rad	Radiation
α	Heat transfer coefficient (W/m^2 K)	rad,sw	Short-wave radiation
Δ	Difference or change	s	Surface parameter value
ε	Radiation Emissivity (----)	sky	Sky value
θ	Time (sec) or (hr)	surf	Pool surface
ρ	Density (kg/m^3)	Tar,Design	Tarrad [6] design value
σ	Stefan-Boltzmann Constant (W/m^2K^4)	th, amb	Thermal for ambient

Subscripts		th,co	Thermal for cover
a	Air	w	water
a,Dew	air at dew point	w,sat	water saturation condition
amb	Ambient	walls	Pool side walls

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Appendix (A): Flowcharts of present model codes

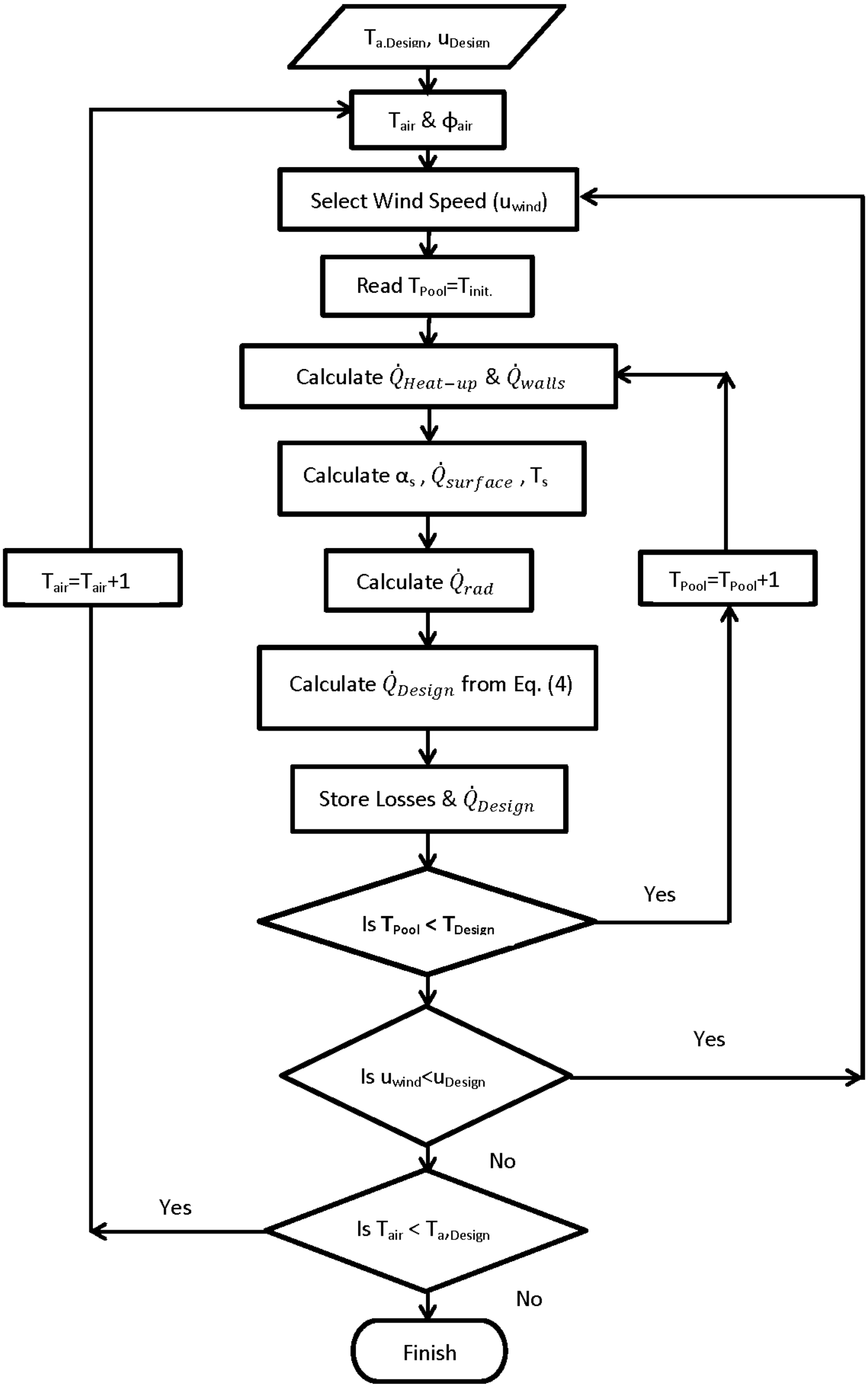

Fig. A.1: The (HEATING-1) code flowchart for the preparation mode

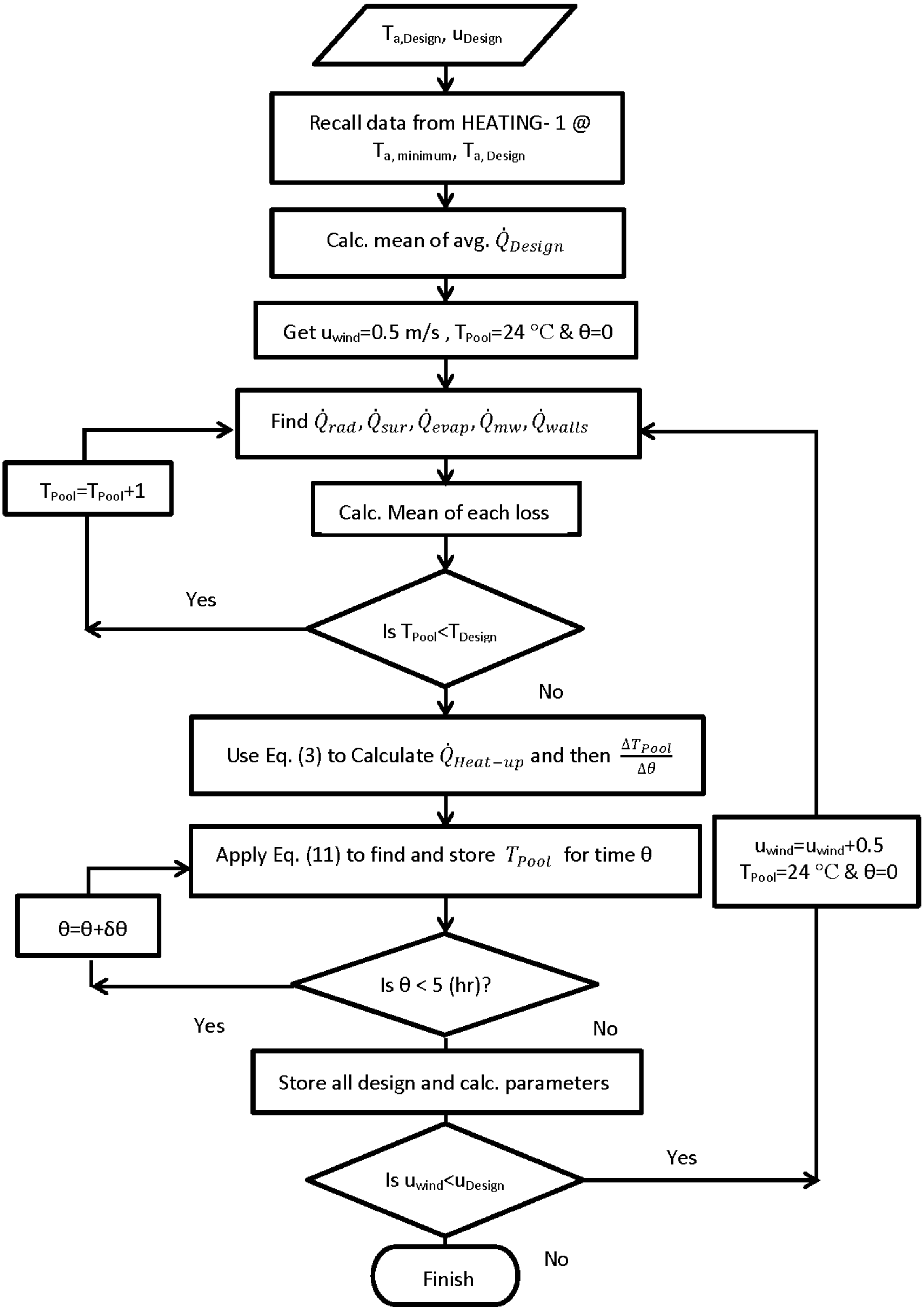

Fig. A.2: The (USAGE) code flowchart for the occupancy mode