THE OPTIMIZATION AND THE INCORPORATION OF GREEN ENGINEERING INTO HEAT TRANSFER USING SPREADSHEETS

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Abstract

Excel was used to optimize the solution to an undergraduate heat transfer design project that incorporated three San Destin Green Engineering Principles. The students were required to find the optimum time of day to turn on a heater to an in-ground swimming pool so as to maximize the comfort of the swimmer while minimizing energy consumption. A family of solutions was developed that accounted for variation in air temperature over a 24 hour period, wind conditions, and a user specified set point for the desired pool temperature. Experimentation with the model showed the student that energy consumption could vary by as much as 40% for a given set of specifications, depending on the time of day when the heater was turned on. Excel was chosen as the computational tool because of the familiarity of the students with the basics of the program, the programs ease of use as well as its widespread use in industry, and its graphic user interface.

Introduction

The focus of this work is to demonstrate how the packaged software, Excel, may be used to optimize a design-oriented heat transfer computer project that was developed for an undergraduate heat transfer course that had green engineering concepts incorporated into it. Green engineering has been described as the incorporation of environmentally conscious attitudes, values, and principles into engineering design toward a goal of improving local and global environmental quality[1,2]. The greening process of the heat transfer course incorporated many of the green engineering concepts found in *Green Engineering – Environmentally Conscious Design of Chemical Processes* by Allen and Shonnard with key heat transfer design concepts found in the textbook, *Fundamentals of Heat and Mass Transfer* by Incropera and DeWit[3,4]. The computer project problem statement developed for the greened course and the analysis of the solution are presented here.

The following question was posed to an undergraduate chemical engineering, heat transfer class:

"What is the optimum time of day to turn on the heater for an in-ground swimming pool?"

While the answers varied greatly, most students thought that the pool heater should be turned on at night – when the pool was not in use. From a green engineering perspective, the nighttime would appear to be the *least* efficient time to turn on the pool heater simply because the temperature driving force between the warm pool, T_{pool} and the surroundings, T_{air}, is greatest at night when the air is coolest. As a result, the amount of heat input to the system (the pool) that is actually retained is at a *minimum* at night when the heat lost to the surroundings is a *maximum*. In other words, the pool heater is being used to heat the air surrounding the pool. Other students suggested that the heater should be turned on "whenever it was needed." Clearly, an optimum time of day exists that maximizes the comfort of the swimmers while minimizes the energy lost from the pool heater to the surroundings. In addition, of the nine San Destin Green Engineering Principles, the following (listed according to their number) were addressed by the solution[5]:

#5. Minimize depletion of natural resources.
#6. Strive to prevent waste.
#9. Actively engage communities and stakeholders in development of engineering solutions.

The solution to this unsteady state problem revolved around an energy balance between the heat input to the pool by the heater, the heat retained by the pool, and the heat lost from the pool due to convection, radiation, and evaporation. The solution required the use of a robust, computational software package such as Excel. Excel was chosen for the following reasons: familiarity of the students with the basics of the program, the programs ease of use as well as its widespread use in industry, and the graphic user interface. Note should be taken that this is not a computer project that is used to examine or further the programming skills of the student, but rather a heat transfer project that utilizes readily available software as a tool to develop an optimized solution that would be otherwise impossible.

The problem had the option of being presented in three formats, each format offering a different level of difficulty:

Level 1: Model the temperature of the water in the heated pool as a function of time, assuming a constant air temperature and then determine the optimum time of day to manually turn the heat *off* and *on* by trial and error.

Level 2: Model the temperature of the water in the heated pool as a function of time, assuming a variation in the temperature of the air (based on a 24 hour cycle) and then determine the optimum time of day to manually turn the heat *off* and *on* by trial and error.

Level 3: Model the temperature of the water in the heated pool as a function of time, assuming a variation in the temperature of the air (based on a 24 hour cycle) while the heater is turned *off* and *on* automatically by use of a thermostat.

The problem statement and solution to the level 2 and level 3 versions of the project are presented here and the results are compared.

Problem Statement

Heated swimming pools can extend the swimming season well beyond the summer. It is required to determine the optimum time of day to turn on the swimming pool heater such that:

1. The bulk temperature of the pool, T_{pool}, remains at approximately 80°F between the hours of 12PM and 8PM.

2. The energy consumption is minimized.

Model T_{pool} as a function of time using Excel. Note that T_{pool} and the temperature of the water at the surface, T_s, are considered equal and the terms may be used interchangeably. The temperature very far from the pool, $T_{sur} = 490$ R is considered constant. The swimming pool volume and its free surface area (surface exposed to air) are approximately 35,000 gal (4679 ft^3) and 1300 ft^2, respectively. The power of the pool heater is 333,000 BTU/hr. The pool loses heat to the outside air via three mechanisms: radiation, surface evaporation and natural convection.

Problem Solution and Analysis

McQuiston et al. has presented a graphical representation for the variation of air temperature over a twenty four hour period.[6] The variation of air temperature, T_∞, is curve fitted and a simple trigonometric function is obtained:
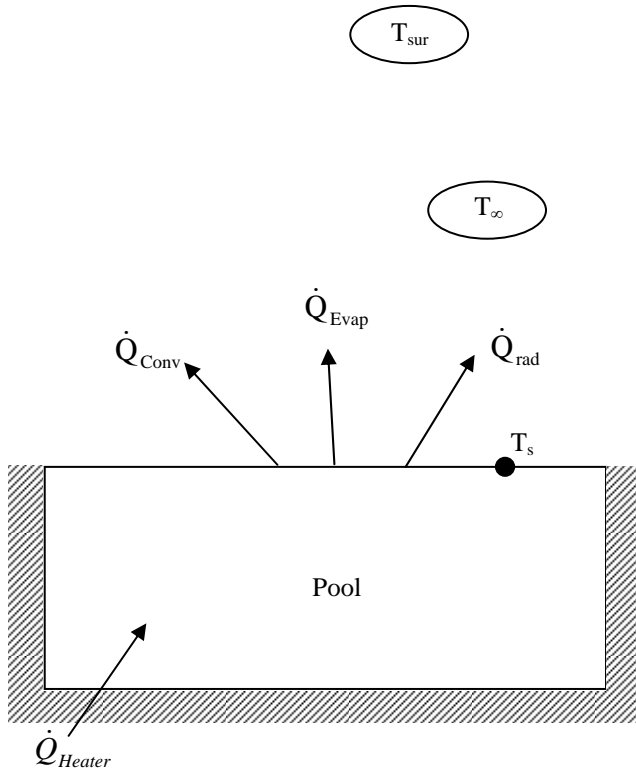
Figure 1: Heat Loss from In-Ground Heated Swimming Pool.

$$T_\infty = T_D - 0.5\,DR\left[\sin\left(\frac{\pi}{12}t + \frac{\pi}{4}\right) + 1\right] \qquad (1)$$

where T_D is the maximum daily temperature and DR is the daily range (the difference between the highest and the lowest temperature). The function seen in equation (1) is expressed graphically in Figure 2. Note should be taken that the maximum temperature is 60°F, the daily range is 20°F, the highest temperature is at 3PM and the lowest is at 3AM.

The energy balance for the pool is given by:

$$\rho_{water}VC_p\frac{dT}{dt} = \dot{Q} - (\dot{Q}_{conv} + \dot{Q}_{rad} + \dot{Q}_{evp}) \qquad (2)$$

where ρ_{water} is the density of the water, V is the volume of the pool, C_p is the heat capacity of the water in the pool, T is the changing temperature of the pool, $\dot{Q}$ is the heater energy, $\dot{Q}_{conv}$ is the heat loss due to convection, $\dot{Q}_{rad}$ is the heat loss due to radiation, and $\dot{Q}_{evp}$ is the heat loss due to evaporation. Each type of heat loss will be explained separately and the above expression will be rearranged to solve for the temperature of the pool explicitly.
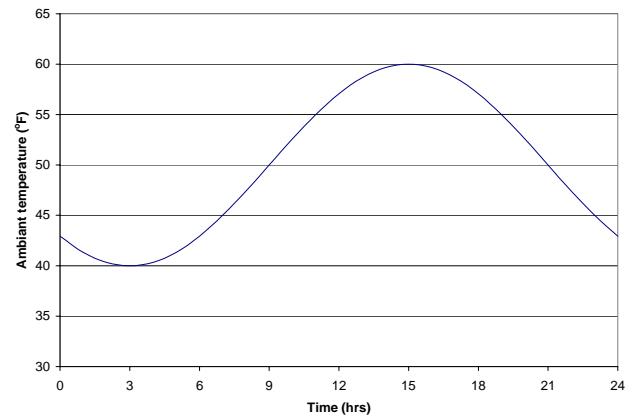

Figure 2: Variation of ambient temperature when the maximum daily temperature is 60°F and daily range is 20 °F.

Radiation Heat Loss

The heat loss from the pool via radiation is given by the following expression:

$$\dot{Q}_{rad} = \varepsilon A\sigma\left(T_s^4 - T_{sur}^4\right) \qquad (3)$$

where ε, the emissivity of the water at the surface is 0.95, A is the exposed surface area of the pool, σ is the Stefan-Boltzmann constant, T_s is the temperature of the surface of the pool, and T_{sur} is the temperature of the surroundings very far from the pool.

Evaporative Heat Loss

Heat loss due to surface evaporation can be evaluated using the following equation:

$$\dot{Q}_{evap} = \dot{m}_v h_{fg} \qquad (4)$$

where h_{fg} is the latent heat of vaporization. The parameter, $\dot{m}_v$, is the evaporation rate of water and may be evaluated in the following manner:

$$\dot{m}_v = h_{mass}A(\rho_{v,s} - \rho_{v,\infty}) \qquad (5)$$

The mass transfer coefficient, h_{mass} can be evaluated using the following expression:

$$h_{mass} = \frac{ShD_{H_2o-air}}{L} \qquad (6)$$

The correlation for the Sherwood (Sh) number for natural convection (no wind condition) is given in terms of the Grashoff (Gr) number and Schmidt (Sc) number.

$$Sh = 0.15(GrSc)^{1/3} \qquad (7)$$

where,

$$Sc = \frac{\nu}{D_{H_2O-air}} \qquad (8)$$

and,

$$D_{H_2o-air} = 2.013E - 09 \cdot T_{ave}^{2.072} \qquad (9)$$

T_{ave} is the arithmetic average of T_s and T_∞. The Grashoff number, Gr, is defined as

$$Gr = \frac{g(\rho_\infty - \rho_s)L^3}{\rho_{ave}\nu^2} \qquad (10)$$

where the subscripts ∞ and s denote conditions at the air temperature, T_∞, and the pool surface, T_s, respectively. The characteristic length L can be taken as $\sqrt{A}$. The kinematic viscosity of air, ν, may be taken as 1.86E-04 ft^2/s and g is the acceleration due to gravity. The parameter ρ_{ave} in Equation (10) is the arithmetic average of ρ_∞ and ρ_s, the densities of air with entrained water vapor at the respective conditions. They are calculated in the following manner:

$$\rho_\infty = \rho_{air,\infty} + \rho_{v,\infty}, \qquad (11a,b)$$
$$\rho_s = \rho_{air,s} + \rho_{v,s}$$

The parameters $\rho_{v,\infty}$ and $\rho_{v,s}$ are the densities of the water vapor at the air temperature and at the pool surface, T_s, respectively. The densities are calculated using the ideal gas law in the following fashion:

$$\rho_{v,\infty} = \frac{P_v}{RT_\infty}, \quad \rho_{v,s} = \frac{P_v}{RT_s} \qquad (12a,b)$$

The water vapor pressure as a function of temperature can be evaluated using the following expression which was obtained by correlating vapor pressure data in the literature:[7]

$$P_v = 4.034E - 49 \cdot T^{17.605} \qquad (13)$$

Note that T is in Rankin and P_v is in psi in equation (13). This equation can be used for calculating vapor pressure at the surface or air. Expressions for $\rho_{air,s}$ and $\rho_{air,\infty}$ are as follows:

$$\rho_{air,s} = \frac{14.7 - P_v}{0.37 \cdot T_s}, \qquad (14a,b)$$

$$\rho_{air,\infty} = \frac{14.7 - P_v}{0.37 \cdot T_\infty}$$

Convective Heat Transfer

The heat loss due to convection may be calculated in the following manner:

$$\dot{Q}_{conv} = hA(T_s - T_\infty) \qquad (15)$$

The parameter h, the heat transfer coefficient, can be evaluated using the following expression:

$$h = \frac{Nu\,D}{k} \qquad (16)$$

The diameter of the pool, D, may be replaced by the characteristic length, L and k is the thermal conductivity of the air in the above expression. For natural convection, the correlation for the Nusselt (Nu) number is given in terms of the Grashoff (Gr) number and Prandtl (Pr) number:

$$Nu = 0.15(GrPr)^{1/3} \qquad (17)$$

where the Prandtl number, Pr, may be assumed fixed at Pr = 0.71. Equations (7) and (17) evaluate the convection heat transfer coefficient when there is no wind condition (natural convection). However, for windy conditions, the following forced convection correlations may be used to replace equations (7) and (17):[7]

$$Sh = 0.0296Re^{0.8}Sc^{1/3}, \ Nu = 0.0296Re^{0.8}Pr^{1/3} \qquad (18a,b)$$

The Reynolds (Re) number is expressed as:

$$Re = \frac{D \ V}{\nu} \qquad (19)$$

In the above expression, the diameter of the pool, D, may be replaced by the characteristic length, L, ν is the kinematic viscosity of the air, and V is the wind velocity.

Since all heat losses are functions of temperature and time, a finite difference scheme is used to solve equation (2). Using a time increment, Δt, the temperature of the pool may be obtained from the following expression:

$$T_{i+1} = T_i + \frac{\Delta t \left[\dot{Q} - (\dot{Q}_{conv,i} + \dot{Q}_{rad,i} + \dot{Q}_{evp,i}) \right]}{(\rho_{water} V C_p)} \qquad (20)$$

Equation (20) can now be used in an Excel program to model the temperature variation of the heated swimming pool as a function of time.

Excel Programming

An Excel spreadsheet for evaluating the variation of pool temperature as a function of the variables discussed in the previous section is generated. Since a large number of variables are involved in the analysis, the spreadsheet is quite wide and covers columns A through X. Representative portions of the spreadsheet will be depicted by Figure 3 – Figure 5.

Dimensions of the pool along with water and air properties are entered in Excel cells as shown in Figure 3. The time increment in equation (20) is set to dt = 0.1 hr.

Figure 3: Excel cells outlining swimming pool dimensions, water and air properties along with miscellaneous variables needed for the analysis.

The next step is to generate a calculation table within the Excel spreadsheet to simulate the pool temperature over a twenty four hour period. The upper portions of this table are shown in Figure 4 and Figure 5. A brief descriptions of the various calculations performed in each cell are presented below.

Figure 4: The upper left portion of calculation table.

Figure 5: The upper right portion of the calculation table.

The first column of the calculation table (column A) is the time in hours. The time starts at 0 (midnight), increases by dt = 0.1 hr (the time increment which is given in cell B11) and ends with 24 (midnight of the next night). The entry of cell A14 is zero and cell A15 is A15+$B$11. Cell A15 is then copied and pasted into cells A15 through A254. This results in a column of times which starts with 0 and ends with 24.

The pool temperature for all time steps is calculated in column B (cells B14 through B254). It should be noted that the pool temperature at t=0 is equal to that of t=24 hr. Hence, cell B14 should be set to =B254.

Cell B15 is set to:

$$=B14+\$B\$11/(\$B\$8*\$B\$7*\$B\$4)*(X14-C14)$$

which is the Excel form of equation (20). The equation in cell B15 is then copied and pasted into cells B16 through B254. This may invoke a circular reference error message. To eliminate this, the message iteration box must be checked in the calculation options (see Figure 6). The calculation Option dialog box can be accessed via Tools in the menu bar and then by selecting Options.
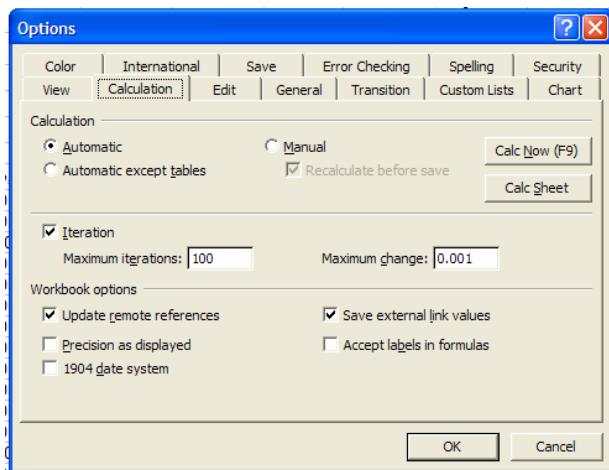
Figure 6: Calculation option dialog box showing checked Iteration box.

Other cells on the first row of the calculation table are filled with following statements:

The total heat loss from the pool is calculated in column C.

Cell C14: =K14+Q14+R14

The Excel format of equation (13) is used to calculate vapor pressure in column D.

Cell D14: =4.033713477E-49*B14^17.60510173

Equation (12b) is used in column E to calculate the vapor density at the surface of the swimming pool.

Cell E14: =D14/$F$4/B14

Equation (14a) is used in column F to calculate the air density at the surface of the pool.

Cell F14: =($F$6-D14)/$F$5/B14

Equation (11b) is used in column G to calculate the density of air and vapor mixture at the surface of the pool.

Cell G14: =E14+F14

Equation (10) is used in column H to calculate the Grashoff number and equation (17) is used in column I to calculate the Nusselt number.

Cell H14:

=$J$7*(W14-G14)*$J$6^3/((G14+W14)/2*$J$8^2)

Cell I14: =0.15*(H14*$J$9)^(1/3)

Note that for the case of forced convection, the Reynolds number is calculated in cell H14 using equation (19) and the Nusselt number is calculated using equation (18b).

The convective heat transfer coefficient and the heat loss from the pool via convection are calculated in columns J and K, respectively.

Cell J14:

=I14*$J$10/$J$6

Cell K14:

=J14*$B$6*(B14-T14)

The diffusion coefficient between water and air is calculated in column L using equation (9).

Cell L14:

=0.000000002013*((B14+T14)/2*5/9)^2.072

The Schmidt number is calculated in column M using equation (8) and the Sherwood number is calculated in column N using equation (7).

Cell M14:

=$J$8/L14

Cell N14:

=0.15*(H14*M14)^(1/3)

The mass transfer coefficient is calculated in column O using equation (6) and the mass rate of water evaporated from the pool is calculated in column P using equation (5).

Cell O14:

=N14*L14/$J$6

Cell P14:

=O14*$B$6*(F14-U14)

The heat loss from the pool due to evaporation is calculated in column Q using equation (4).

Cell Q14:

=P14*$J$11

The heat loss from the pool due to radiation heat transfer is calculated in column R using equation (3).

Cell R14:

=$J$5*$J$4*$B$6*(B14^4-$B$5^4)

If necessary, solar radiation can be calculated in Cell S14. However, in this problem it is set to, assuming a cloudy day. The ambient temperature as a function of time is calculated in column T using equation (1).

Cell T14:

=$B$9-0.5*$B$10*(SIN(PI()/12*A14+PI()/4)+1)

The vapor density based on the ambient temperature is calculated in column U using equation (12a) and the air density based on the ambient temperature is calculated in column V using equation (14b).

Cell U14:

=4.033713477E-49*T14^17.60510173/$F$4/T14

Cell V14:

=($F$6-4.033713477E-49*T14^17.60510173)/$F$5/T14

The combined air and vapor density based on the ambient temperature is calculated in column W using equation (11a).

Cell W14:

=U14+V14

Cell X14 is the heat supplied to the pool by the heater. Since the heater is tuned off at t = 0 hr, its value is set to zero. To fill the remaining cells in the calculation table, row 14 from column B through column X is copied and pasted into rows 15 through 254. Through the use of iterative calculations, a converged solution for the pool temperature as a function of time is found and displayed in column B.

Results and discussions

Once the Excel model was developed, a variety of cases were examined. First, to test the model, a case without any mechanical heater input $(\dot{Q}_{heater} = 0)$ was analyzed and Figure 7 shows the results of the variation in temperature. The figure shows that the pool temperature remains relatively constant at 48°F – indicating that the model works accurately. The results of the other cases are presented below. In each case, it is required to operate the pool heater so that the temperature of the pool remains at (or slightly above or below) 80°F between the hours of noon and 8:00PM. A comparison of the results to find the case with

minimum energy consumption determines the optimum time of day to turn the pool heater on as well as the optimum mode of operation.

Variable Air Temperature, Forced Convection, Manually Controlled Heater

The variation in air temperature is represented by equation (1). By trial and error, it is determined that when the velocity of the wind is 10 mph, the heater must be kept on from 7:00AM to 2:00PM continuously (7 hours). Note that for this case, the forced convection correlation was used and a graphical representation of the variation in pool temperature is shown in Figure 7. It can be seen that the pool temperature starts to increase almost linearly when the heater is turned on and reaches a maximum temperature of 81.5^oF at 2:00PM. After the heater is turned off at 2:00PM, the pool temperature starts to decrease linearly and falls below the comfort level shortly after 8:00PM.

Variable Air Temperature, Free Convection, Manually Controlled Heater

In the next case, consideration is given to a case with no wind condition. In this case, the convective and evaporative heat losses from the pool are based on natural convection. In order to keep the pool temperature slightly above or equal to the desired set point of 80°F, it is determined by trial and error that the heater must be turned on at 7:30AM and turned off at 1:00PM. As a result, the heater is on for five and a half hours (1.5 hours less than the case with 10mph wind). The trend in the pool temperature profile is along with the air temperature are depicted in Figure 8. The results show that the pool temperature is above 80^oF for the desirable times.
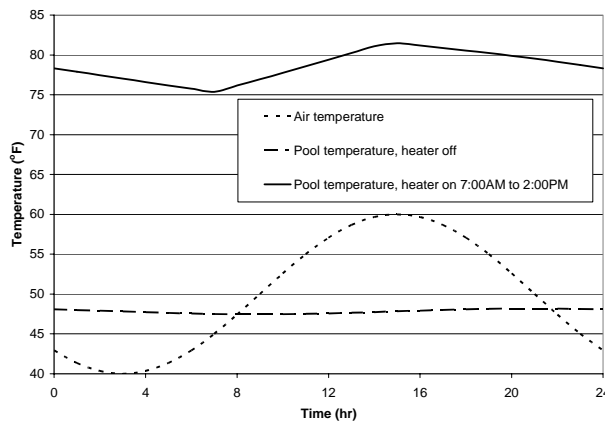
Figure 7: Modeling Results for Pool Temperature with Variable Air Temperature, Forced Convection (10mph Wind Conditions), No Sunshine, and Manual Operation of Pool Heater.
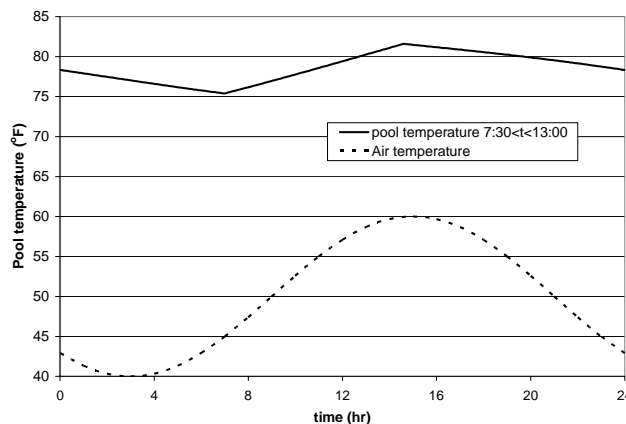
Figure 8: Modeling Results for Pool Temperature with Variable Air Temperature, Free Convection, No Sunshine, and Manual Operation of Pool.

Variable Air Temperature, Forced Convection, Thermostat Controlled Heater

If the heater is turned on continuously in the warm season, the pool temperature simply becomes too hot in a few days. Therefore, it becomes necessary to control the pool heater by a thermostat. A thermostat is used to turn the heater on when the pool temperature falls below a minimum setting (T_{min}) and turn the heater off when the pool temperature exceeds a maximum

setting (T_{max}). Therefore, in order to accurately examine the energy balance for the pool when using a thermostat to control the heater, it was necessary to develop a thermostat function using a VBA macro. This function is called "Thermostat" and has five argument variables. The listing of this function with its arguments is given below:

```
Function Thermostat(T, High, Low, Q, QP)
   'T     pool temperature
   'High   High temperature setting
   'Low    Low temperature setting
   'Q      Heater power
   'QP     Previous steps heating, Q or 0
   If T > High Then
      Thermostat = 0
   ElseIf T < Low Then
      Thermostat = Q
   ElseIf T > Low And T < High And QP = Q Then
      Thermostat = Q
   Else
      Thermostat = 0
   End If
End Function
```

The thermostat function is used with column X, $\dot{Q}_{heater}$, to keep the pool at the desired temperature $\pm$ ½ΔT^{o}F, where ΔT is a user supplied temperature variation tolerance. The high temperature setting in Thermostat, T_{max}, was calculated in the following manner:

$$T_{max} = Desired\ Pool\ Temperature + \frac{\Delta T}{2} \quad (21)$$

Similarly, the low temperature setting in Thermostat, T_{min}, was calculated as:

$$T_{min} = Desired\ Pool\ Temperature - \frac{\Delta T}{2} \quad (22)$$

However, it should be noted that the thermostat option can only be used if the temperature at 12:00PM (0 hr) is specified because the use of a circular reference (i.e., equating the pool temperature at 12:00PM and t = 0hr) results in no convergence when the thermostat option is employed.

A variety of cases were run when the thermostat function was turned on. In each instance, a temperature profile for the pool was developed. Two specific cases are compared below.

In the first case, the thermostat controlled heater was turned on at midnight (0 hr) and the resulting temperature profile is shown in Figure 9. In the second case, the thermostat controlled heater was not turned on until 8:00AM and the corresponding temperature profile is seen in Figure 10. In both cases, the initial temperature at midnight was 80°F, and the thermostat controls for ΔT =1°F were T_{max}=80.5°F and T_{min}=79.5°F . The results in Figure 9 indicate that the heater had to stay on for longer times from midnight to the early morning compared to that of the midday, i.e., the heater's on periods are longer and closer to each other after midnight while they are narrower and farther apart during midday. Contrary to this, when the thermostat controlled heater was not turned on until 8:06AM, Figure 10 shows that the heater remains on for five hours and turns off at 1:00PM when the pool temperature reaches T_{max} (80.5^{o}F). The heater then turns on again at 5:00PM when the pool temperature reaches T_{min} (79.5°F) and remains on for one hour until 6:00PM. The pool temperature remains at the desired level until 8:00PM. As shown in Figure 10, the pool's average temperature between midnight and 8:00AM is 78°F, 2°F less than when the heater was turned on at midnight. This results in lower heat loss (convective, evaporative and radiative) from the pool due to the smaller temperature difference between the pool and the air. The overall result is that less energy is consumed when the heater is not turned on until 8:06AM.
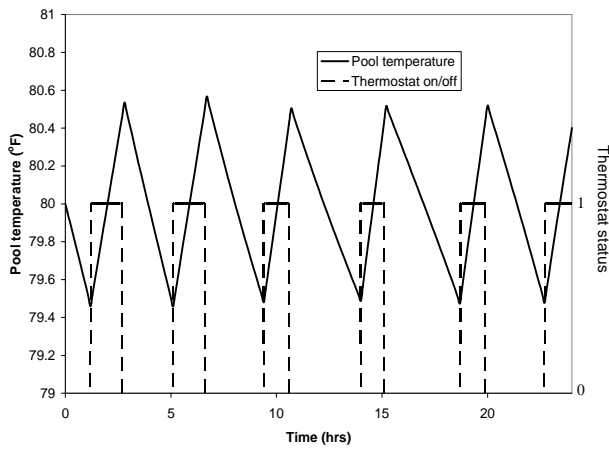
Figure 9: Variation of pool temperature when heater with thermostat running twenty four hours.
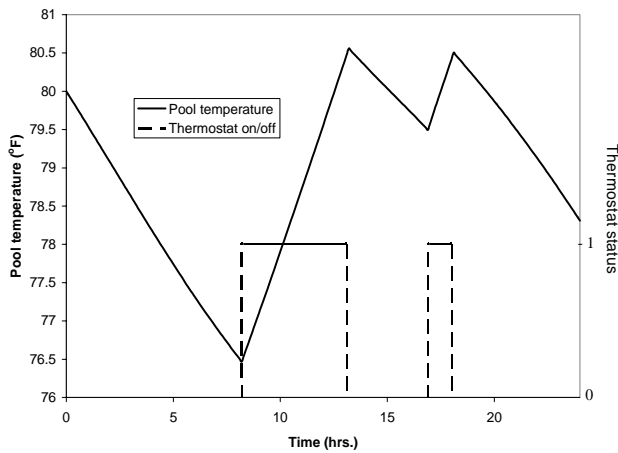

Figure 10: Variation of Pool temperature when heater with thermostat turned on at 8:06am and turned off at 8:00pm.

Table 1 compares the results of various runs when the thermostat option was turned on. For all cases, the desired pool temperature was 80°F. In the first three cases, the temperature at midnight varied from 79°F-81°F and ΔT was set equal to 2°F which resulted in a $T_{max} = 81°F$ and a $T_{min} = 79°F$. In the second three cases, the temperature at midnight varied from 79.5°F-80.5°F and ΔT was set equal to 1°F which resulted in a $T_{max} = 80.5°F$ and a $T_{min} = 79.5°F$. In all cases, the thermostat automatically turned the heater on when the pool temperature fell

below T_{min} and it turned the heater off when the temperature went above T_{max}. Column 3 in Table 1 shows the total energy output by the heater when it was turned on at midnight and column 4 shows the total energy output when the heater was turned on at approximately 8:00AM (the exact time is indicated in column 5). However, the most significant column in the table is the last column as it outlines the amount of energy saved (%) when the thermostat controlled heater is turned on at 8:00AM as opposed to midnight. The average energy savings for all 6 runs is approximately 23%. It should also be noted that the total energy consumption for the two cases presented earlier when the heater was manually controlled was 1,831,500 BTU for free convection and 2,331,000 BTU for forced convection. The average energy savings when the thermostat controlled runs (8:00AM start) are compared to the manually controlled run is 14.8% for forced convection. There is an average increase of 6.9% in energy usage when the thermostat controlled runs (8:00Am start) are compared to the manually controlled run for free convection. However, it should be noted that a case of free convection (no wind) in an open space is unlikely.

Concluding Remarks

In the absence of any green engineering principles, a heat transfer project of this scope would ordinarily require the students to simply determine a temperature profile for the swimming pool. The pool parameters and conditions, such as the time when the heater should be turned on, would be specified. However, when green engineering principles are incorporated into the project, a set of sequential calculations leading to a reasonable result is not sufficient. Instead, a "best" result is required. For example:

San Destin Green Engineering Principle #5 – minimize depletion of natural resources. The students are required (by either turning the heater on and off manually or by controlling the

heater with a thermostat) to find the best result that uses the least amount of energy. In all cases, the solution converged and a temperature profile was developed. In many instances, the amount of energy consumed varied very little. However, continued experimentation with the computer model showed the students that some runs did indeed perform more favorably than others with respect to depletion of resources, e.g., one run consumed 2.7×10^6 BTUs while another consumed only 1.6×10^6 BTUs, even though both maintained a constant pool temperature of 80°F between the hours of noon and 8PM.

San Destin Green Engineering Principle #6 – strive to prevent waste. Of the twelve cases outlined in Table 1, all simulations were able to meet the requirement of maintaining a constant, desired pool temperature between the hours of noon and 8:00PM. However, six of the twelve cases, 50%, kept the pool temperature at or near the desired temperature during the middle of the night – a time when it is highly unlikely that the pool would be used. Clearly, even if the results for these six runs were numerically acceptable, they would be unacceptable from a perspective of waste prevention. Hence, the student must no longer be concerned with the *correct* solution, but rather the "best" correct solution.

San Destin Green Engineering Principle #9 – Actively engage communities and stakeholders in development of engineering solutions. It has been widely accepted among pool owners that the best time of day to turn on a pool heater is at night. Clearly, an energy savings of 25% is enough incentive for any community, small or large, to change their practices and as a result, contribute to a substantial reduction in energy use. An Excel program such as this could be easily modified for the use of individual home owners to help them determine the best time of day, each day, to turn on their pool heater.

It has been shown that depending on the wind conditions, the air temperature, the initial pool temperature at t = 0hr, and the user specified tolerance, ΔT, that an entire family of solutions

exist as to when a pool heater should be turned on. However, the point is not that a solution exists, but rather that the student is made aware that a "best" solution exists - one that incorporates environmentally conscious attitudes, values and principles as well as the correct answer.

References

1. www.eng.vt.edu/eng/green/green

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Table 1: Total Daily Energy Consumption and Percent Difference for Thermostat Controlled Pool Heater Turned on at (a) Midnight and (b) Approximately 8:00AM.

Initial Pool Temperature (^{o}F) t = 0 hr	ΔT (^{o}F)	(a) Total Heater Energy Consumption (BTU) Midnight Start	(b) Total Heater Energy Consumption (BTU) $\approx$ 8:00AM Start	(b) Heater Start Time:	% Energy Savings
79	2	2730600	2164500	7:54AM	20.7
80	2	2530800	1898100	8:42AM	25
81	2	2464200	1631700	9:30AM	33.8
79.5	1	2730600	2197800	7:48AM	19.5
80	1	2597400	2064600	8:06AM	20.5
80.5	1	2364300	1964700	8:36AM	16.9