A NUMERICAL STUDY ON VARIOUS HEATING OPTIONS APPLIED TO SWIMMING POOL FOR ENERGY SAVING

MATTHYS JORDAAN, RAMADAS NARAYANAN

Bibliographic citation

Jordaan, M., & Narayanan, R. (2019). A numerical study on various heating options applied to swimming pool for energy saving. *Energy Procedia, 160*, 131–138. https://doi.org/10.1016/j.egypro.2019.02.128

Link to Published Version: https://doi.org/10.1016/j.egypro.2019.02.128

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 160 (2019) 131–138

Energy Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Energy and Power, ICEP2018, 13–15 December 2018, Sydney, Australia

A numerical study on various heating options applied to swimming pool for energy saving

Matthys Jordaan, Ramadas Narayanan *

Central Queensland University, 6, University Drive, Bundaberg, QLD 4670, Australia

Abstract

With the advent of human-induced climate change, an effort towards reducing greenhouse gas emissions has been a priority for many communities and households. Pool heating is highly energy intensive and it accounts for major part of energy bills and a large carbon footprint. It is important to investigate the possible ways of reducing the energy consumption of the heated pools. The pool selected for this study is a 25 × 18-metre swimming pool located at Central Queensland University Community Sports Centre, Rockhampton, Queensland, Australia. The pool maintained at a temperature of 28 °C during the winter months by burning natural gas which causes excessive energy bill and ramps up the emissions of the university's operations. A mathematical model of the swimming pool incorporating the weather data files and various heating options is developed using the software TRNSYS, adopting relevant Australian Standards. The model is to be used to study the various heating options such as flat plate solar collectors, evacuated tube collectors, photovoltaic systems, electricity-driven heat pumps, natural gas heat pumps. With the use of this model, this paper investigates the amount of natural gas cost that is reduced when applying alternative heating concepts that exploit renewable energy or higher coefficients of performances.

Keywords: Pool Heating, Renewable Energy, TRNSYS modelling

* Corresponding author. Tel.: +61 74150 7107 ; fax: +61 74150 7090.
E-mail address: r.narayanan@cqu.edu.au OR ramadas.n@gmail.com

1876-6102 © 2019 The Authors. Published by Elsevier Ltd.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)
Selection and peer-review under responsibility of the scientific committee of the 2nd International Conference on Energy and Power, ICEP2018.
10.1016/j.egypro.2019.02.128

1. Introduction

Pool heating allows to extend swimming season and ensures that the pool can be used anytime. But, heating a pool requires a large amount of energy. There are many ways to heat a pool, but incorrect method can cost you a lot of money and provide unsustainable solutions, so it's important to investigate the various options thoroughly to select the right option.

Central Queensland University (CQU) Community Sports Centre located at the city of Rockhampton in Queensland, Australia, features a 25 m by 18 m pool, with an average depth of 1.8m and volume of 810,000 litres of water. Natural gas provides the pool heating during the winter months. The heater is programmed to maintain the water at a constant temperature of 28 ^{O}C when the gas system is turned on.

Nomenclature

A_p = Pool Water Surface Area (m^2)
q_e = Rate of heat loss by evaporation (MJ/m^2.d)
q_r = Rate of heat loss by long wave radiation (MJ/m^2.d)
q_c = Rate of heat loss by conduction (MJ/m^2.d)
q_s = Rate of heat gain from solar radiation (MJ/m^2.d)
q_e = Rate of heat loss by evaporation (MJ/m^2.d)
q_r = Rate of heat loss by radiation (MJ/m^2.d)
q_{solar} = rate of incidence of solar radiation (MJ/m^2.d)
P_w = Saturation water vapour pressure at water temperature (t_w) (kPa)
P_a = Partial water vapour pressure in the air (kPa)
V = Wind velocity at height of 0.3 m over the pool (m/s)
P_s = Saturated water vapour pressure at air temperature (t_a) (kPa)
P_s is defined from the same equation as P_w however in terms of air temperature.
RH = Relative Humidity
h_r = Radiation-heat transfer coefficient (W/m^2.K)
V = wind velocity at a height of 0.3m above the pool
t_w = water temperature
t_a = air temperature
α = absorption factor (0.85 for light-coloured pools, 0.9 for dark coloured pools)
Q_eva = Evaporative Heat Loss
Q_rad = Radiation Heat Loss
Q_conv = Convection Heat Loss
Q_solar = Solar Heat Gain
Q_col = Solar Collector Heat Gain

Abbreviations
AUD = Australian Dollars
CQU = Central Queensland University
COP = Coefficient of Performance
TRNSYS = Transient System Simulation Software
PV = photovoltaic

Every year roughly $34,000 is spent towards heating this pool with an average daily cost of $380. So its important investigate various methods that can achieve the heating for a lower cost. A reduction in the financial impact on CQ University allows for more funding to be allocated towards other student facilities. The act of burning fossil fuels amplifies the greenhouse effect that is caused by the by-product gasses that are released into the atmosphere. Reducing gas usage improve the carbon foot print of the university campus which one of the priority for the facilities management.

This study investigates several heating options that can potentially reduce the consumption of non-renewable energy. The flat plate collector, evacuated tube collector and photovoltaic solar panel are considered options that utilises solar energy. The heat pumps utilise the refrigeration cycle to "pump" heat into the pool from the atmosphere whilst exploiting a high coefficient of performance. The performance of each system depends on many climate related factors, the characteristic and types of pool and various heat exchange mechanisms used. So, a transient simulation study is required assess the each heating option.The simulation model that is developed for this study can be extended to many other pools. This study also incorporates different Australian Standards for pool heating. The investigation attempts to identify the capacity of various heating applications to save energy whilst maintaining the heating demands of the pool. This is done by developing a simulation model of the pool with various heating configurations. The study aims at comparing the alternative heating applications with the existing pool heater demand. The comparison allowed each heating configuration to be evaluated in terms of energy saving and heating potential.

The alternative methods to pool heating that is researched in this study are solar collectors, solar panels and heat pumps. In flat plate collectors the heat is transferred with a heat exchange fluid. The system is designed such that a plate with a dark surface absorbs the radiation emitted by the Sun. An absorber sheet (often aluminium, steel or copper) with fluid coils, transports the gathered energy to a desired application. Evacuated tube collectors also heat a fluid, however it is stored within a copper tube inside a vacuum tube. The heat is transported into a water stream through a heat exchanger as the fluid is heated.

Photovoltaic solar panels generate energy by converting solar radiation into a current. Unlike solar collectors, the captured energy is electric, rather than thermal. To heat the pool water, this energy can be used to heat a heating element or to power a heat pump. Heat pumps are heat transfer applications that use the refrigeration cycle to draw heat from the atmosphere and transport it to a desired application. The compressor of a heat pump can be driven by electricity or natural gas. Studies done by Scarpa, explores to optimise the heat pump concept by integrating a solar PV system along with a natural gas power source for the compressor. With this method, heating is possible in periods when the solar PV unit does not perform sufficiently [1].

One of the recent research in this area presents a dynamic model of a "passive" solar heating system composed by horizontal solar flat collectors coupled to an outdoor swimming pool [2]. The results demonstrate that unglazed collectors are appropriate for this kind of use and evacuated collectors can be useful just in case of very big swimming pools in order to reduce the absorbing area of the solar panels. The research carried out by Starke et.al includes a multi-objective optimization of indirect solar assisted heat pump systems for outdoor swimming pool heating. This optimization results demonstrate that solar-assisted configurations present significant improvements in performance for almost all locations [3].

2. Methodology

2.1. Model Development

The study utilises TRNSYS software and components. TRNSYS is a graphically based software environment used to simulate the behaviour of transient systems and for assessing the performance of thermal and electrical energy systems [4-6]. The pool body component is created from TRNSYS equation modules, which allow formulae to be inserted and dynamically calculated during the simulation. The equations for the pool component are acquired for Australian Standards 3634–1989. The validity of these equations have been crossed checked with ASHRAE standards [7]. The outcome of this is nearly identical energy loss coefficients. The whole model is shown in Figure1.

The weather input file does not include some necessary variables, such as water vapour pressure, which are required for certain energy loss equations. An equation component is incorporated which determines these variables based on the available variables from the weather file then applied to the model equations. In order to ensure that the energy gain is applicable to expected results in Australia, the weather file inputs variable values that is taken from weather data located in Brisbane. This allows the simulation to incorporate weather properties that is representative of the weather expected in the region of Rockhampton.

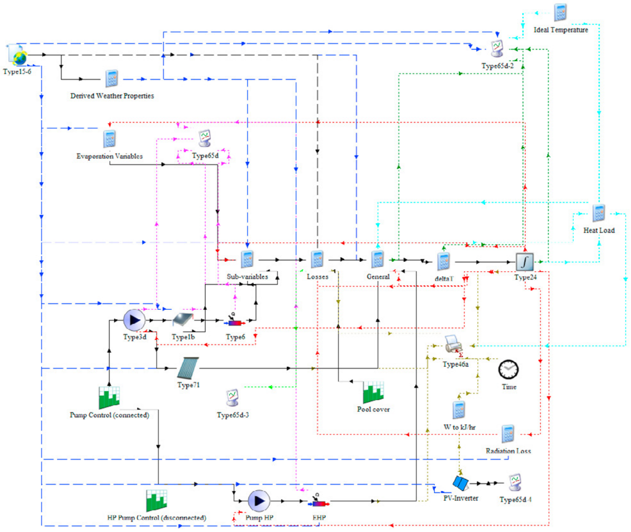

Fig 1.Trnsys Model

2.2. TRNSYS components

TRNSYS is a transient simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design. The TRNSYS includes the fundamental components, such as the pump, solar collector, heat pumps and auxiliary heating components. All these components are validated with experimental results are referred with a Type number. Each component incorporates input parameters and variables that are present in their real components. For example, the solar collector can be adjusted in size, efficiency and angle of incidence to the solar radiation. The auxiliary heating in this model represents the currently installed natural gas burner. The amount of energy required by the auxiliary heater is used to determine the amount of gas burned in the simulation.

2.3. Flat-Plate Solar Collector

The flat-plate collector utilizes solar irradiance and supplies heated water to the pool body. The component, Type-1b, simulated the characteristics of a valid flat-plate collector, with efficiency curves that are applied from ASHRAE standards [8].

2.4. Evacuated Tube Solar Collector

Like the flat-plate collector, TRNSYS library has a component which simulates the characteristics of an evacuated tube solar collector. The Type-71 evacuated tube collector component, utilised the same equations as the flat-plate collector for design purposes. The efficiency curves for evacuated tube collectors are defined by the Solar Ratings and Certification Corporation. The efficiency of an evacuated tube solar collector is higher than that of a flat-plate collector per unit of area, which is a property that is simulated within the TRNSYS model.

2.5. Electric Heat Pump

The electric heat pump exploits the refrigeration cycle to draw heat energy from the air into the pool body. This component was simulated utilising TRNSYS component Type-6. This heat pump featured a coefficient of performance of 5 with a 28.3 kW output.

2.6. PV Assisted Electric Heat Pump

PV assisted heat pump is a configuration of the heat pump, with a Type 194 component applied as a power supply. The PV-Inverter component has its parameters extracted from an existing reference model. The reference model was the default TRNSYS PV component scaled up to 450 m2. An alternative model was produced in a case study by O. Ositelu presents the performance of a PV system for Pennsylvania State University using TRNSYS software, however this model is deemed to be inefficient [9]. The PV system used in the current study has its parameters set to identical values to that of the default TRNSYS model. It was decided to use the default PV model, as experimentally validating PV performance is beyond the scope of this study.

2.7. Gas Heat Pump

A gas heat pump is a heat pump which the compressor is run with mechanical power output of a heat engine which works on natural gas. The gas heat pump was modelled with the same parameters as the electric heat pump. Gas heat pumps consumes natural gas to power the compressor of the refrigeration cycle. The difference between this component and the electric heat pump is that the calculated power consumption is translated into natural gas usage. H.Mao claims based on a TRNSYS modelling study that the expected coefficient of performance (COP) of a heat pump is more than 4 [10].

2.8. Equations

The pool heating load is defined by AS 3634 – 1989 giving the relationship:

$$Q_{load} = A_p(q_e + q_r + q_c - q_s) \tag{1}$$

Evaporation Heat Loss

$$q_e = 1.41(3.1 + 4.1V)(P_w - P_a) \tag{2}$$

Where:

$$P_w = 0.0044t_w^2 - 0.01t_w + 0.7 \tag{3}$$

Radiation Heat Loss

$$q_r = 0.082h_r(t_w - t_s) \tag{4}$$

Where:

$$h_r = 2.268 \times 10^{-7}\left(\frac{t_w+t_s}{2} + 273.15\right)^3 \tag{5}$$

Convection Heat Loss

$$q_c = 0.086(3.1 + 4.1V)(t_w - t_a) \tag{6}$$

Solar Heat Gain

$$q_s = \alpha q_{solar} \tag{7}$$

3. Results

3.1. Model Validation by Cross-Checking Results

A study conducted by Ruiz & Martinez, explores the energy benefits of applying a flat plate collector to a private open-air swimming pool. The study has been done with a similar model using TRNSYS software [11]. This study is referenced to validate the accuracy in the results of this study's model. By identifying areas where energy losses and gains are varied significantly in terms of relative proportion to one another, a conclusion can be made as to whether or not the model is making realistic outcomes.

A noticeable difference between the model and the results of Ruiz & Martinez was observed by the convective heat loss in the models. The negative value on the study model where no solar collector is applied, suggests that the ambient air has overall provided heat to the water [9]. The instantaneous convective heat loss rate is always negative when the air temperature is higher than the water temperature.

The results are consistent to predictions by Ruiz & Martinez, with regards to an increase in heat loss values as the solar collector area is increased. This is a result of higher pool temperatures due to the increased energy input from the solar collector. An increase in pool temperature will result in greater difference between the pool and environmental conditions, which increases the energy loss rate of the heat losses. The convection gain present in the results can be observed to revert back to a loss as the average water temperature is increased to a higher value than ambient air temperature.

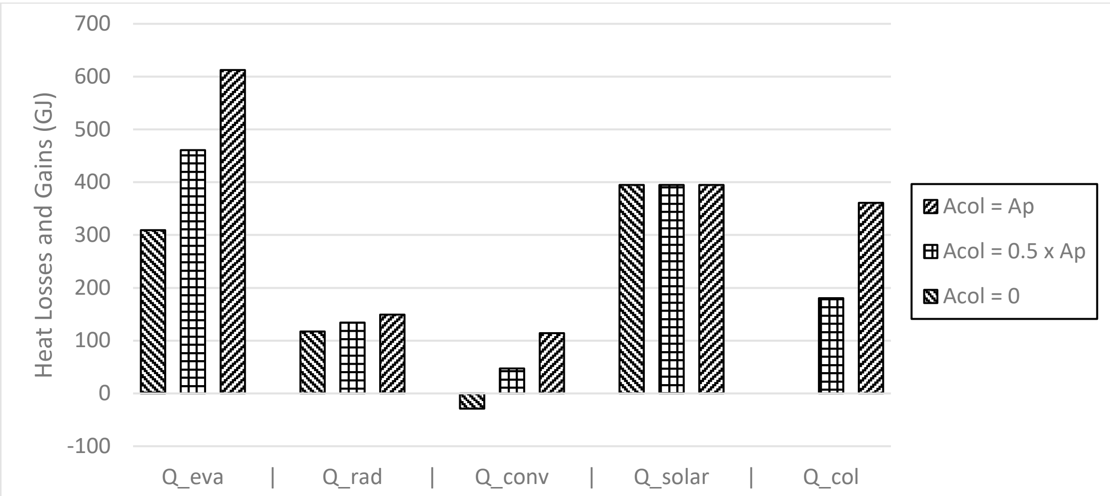

Fig 2, Flat plate collector area comparison

In order to determine the energy saving potential of the flat plate collector, the TRNSYS results are used to compare the flat plate and auxiliary heater outputs for three different size flat plate collectors as shown in Figure 2. The sizes are equal to the pool surface area (represented by Acol = Ap), half of the pool surface area (Acol = 0.5 x Ap) and no surface area, or no output (Acol = 0) to compared against the current system. It can be observed that as the solar collector area is increased, the required auxiliary heater input is decreased, which represents energy saving potential.

The results indicate that a flat plate collector with equal surface area to that of the pool surface would benefit from a 360,930 mega joule heat gain for the season. This is equivalent to 16.2% of the initial auxiliary heater input. The flat plate collector with half of the pool surface area resulted in a linear decrease in solar energy input, with 180,465 mega joules for the season. This is equivalent to 8.1% of the existing natural gas heating configuration input.

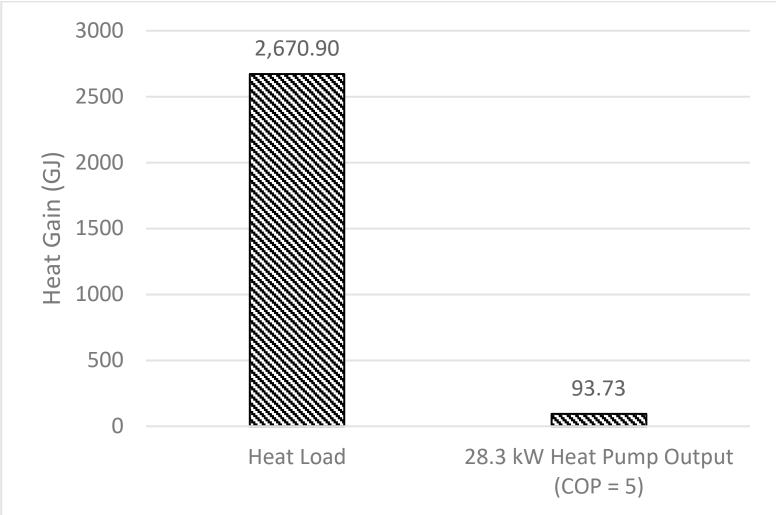

Fig 3: Electric Heat Pump Results

The comparison of heat load and the output of a standard 28.3 kW heat pump is given in Figure 3. The results indicate that 93.73 GJ of energy would be applied by the heat pump throughout the simulation period. Under optimal conditions, the heat pump output should supply 3.5% of the required load to maintain ideal pool temperature throughout the season. Therefore, it is concluded that either a larger capacity heat pump, or multiple heat pumps are required to maintain the optimal pool conditions.

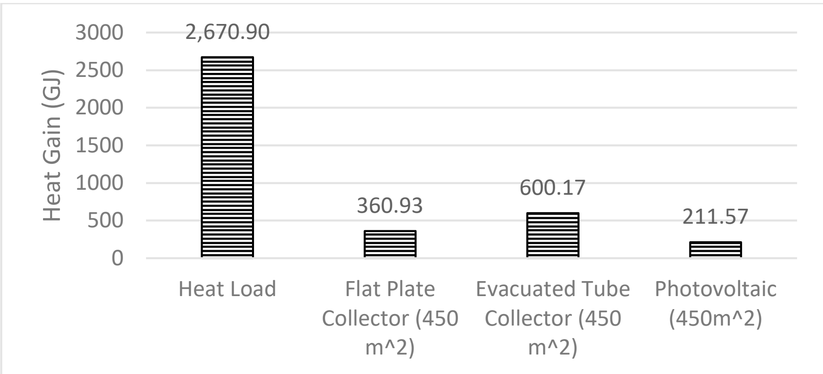

Fig 4: Solar Collector Results

The output of the PV-inverter component which is based upon the default PV model provided by TRNSYS, which has been scaled up to 450 m^2. This provided more energy than the model defined by Ositelu, however that model is deemed inefficient by the study itself. The heat load represents the amount of external energy input required to maintain the pool temperature at 28ºC throughout the winter season. From Figure 4, the PV-inverter module supplied a total 211.57 GJ, with the same collector area as pool surface area (450 m^2), over the three month simulation period. This amount is 7.9% of the required energy to maintain ideal water temperature throughout the season. By multiplying the PV output with the heat pump COP, an electric heat pump with a COP of 5 could theoretically supply 1057.85 GJ, or 39.6% of the required heat load when driven by the PV system.

The results indicate that a flat plate collector with equal surface area to that of the pool surface would benefit from a 360.93 GJ heat gain for the season. This is equivalent to 13.5% of the initial auxiliary heater (gas heater) requirement. The flat plate collector with half of the pool surface area resulted in a linear decrease in solar energy input, with 180,465 MJ for the season. At half collector area, an equivalent of 8.1% of the existing natural gas heating configuration input is eliminated. The evacuated tube collector out-performed the flat plate collector in the simulation with an average of 66% increased efficiency. For the same surface area, it is observed that the evacuated tube is a more efficient solar collector than the flat plate collector. The evacuated tube collector with equal surface area to the pool surface produced 600.17 GJ for the simulation period at 22.5% of the total heating energy requirement.

4. Conclusion

By applying Australian Standards equations and using validated components and cross-referencing, a model of the CQ University Community Sports Centre was created. The model displayed data which is indicative of functional pool characteristics. This model also provided results for various heating configurations for the pool. These results supported the evaluation of the energy requirement analysis. The results from the analysis indicate that among solar thermal collectors, the evacuated tube collector presents the most feasible option. This is due to the increased efficiency of the module compared to flat plate collectors. In order to maintain the ideal temperature, the solar collectors of all types needed to be at least twice the area of the pool surface. The least effective solar collector option was the photovoltaic direct heating. This required a photovoltaic collector surface area that was significantly large, however this method can be used to reduce the load of electric heat pumps significantly. A much larger heat pump output than the investigated 28.3 kW example would be required for this pool. With the heat pump's high COP, it is likely to allow for energy saving opportunities in real-world applications.

5. References

[1] Scarpa, F., Tagliafico, L.A. and Bianco, V. "A novel steady-state approach for the analysis of gas-burner supplemented direct expansion solar assisted heat pumps." *Solar Energy* 96 (2013):227–238.

[2] Matteo Dongellini, Stefania Falcioni, Andrea Martelli, and Gian Luca Morini. "Dynamic Simulation of Outdoor Swimming Pool Solar Heating," *Energy Procedia* 81(2015) :1-10, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2015.12.053.

[3] Allan R. Starke, José M. Cardemil, Sergio Colle, Multi-objective optimization of a solar-assisted heat pump for swimming pool heating using genetic algorithm, *Applied Thermal Engineering* 142 (2018):118-126.

[4] TRNSYS, A *Transient System Simulation Program*, Version 17(2004).

[5] Narayanan, R. "Heat-Driven Cooling Technologies." in *Clean Energy for Sustainable Development: Comparisons and Contrasts of New Approaches* (2017):191-212. London, UK. Elsevier.

[6] Narayanan, R., Halawa, E. and Jain, S. "Performance Characteristics of Solid-Desiccant Evaporative Cooling Systems." *Energies 11*(10) (2018): 2574.

[7] "Solar Heating Systems for Swimming Pools." *Australian Standard AS3634-1989,* Standards Australia

[8] ASHRAE *Applications Handbook (2003) American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE*

[9] Ositelu, O., Cetiner,R. , Bayrakci, M., Tammineedi, C. and Jagarlamudi. V. "Design and Simulation of a Distributed PV System for Pennsylvania State University, (2010), Pennsylvania State University.

[10] Mao, H., Feng, W. "Study on Simulation Performance of Solar Energy and Gas Heat Pump for Heating Supply." *Procedia Engineering*, 121(2015):1482-1489.

[11] Ruiz, E. and Martinez. P.J. "Analysis of an open-air swimming pool solar heating system by using an experimentally validated TRNSYS model." *Solar Energy* 84 (2010):116-123.