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Swimming pools as heat sinks for air conditioners: California feasibility analysis

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ABSTRACT

Earlier studies used field testing of swimming pool temperatures to validate a mathematical model for predicting the temperature of an unheated pool. Combining those results with manufacturers' data on the performance of vapor-compression air conditioners as a function of heat rejection temperature, the analyses in the paper suggest that rejecting air conditioning heat to a swimming pool can save approximately 25–30% of single-family residential cooling electricity use and reduce cooling electricity demand during peak conditions by 30–35%, as compared to using the same compressor to reject the heat to ambient air. The savings is expected to vary depending on the severity of the climate, as well as the pool temperature experienced during the summer. The original model was refined so as to accommodate air-conditioner heat rejection to predict pool temperatures based on weather data, pool size, shading of the pool, and air-conditioner heat rejection to the pool. The results of an experimental validation of the augmented pool thermal model are presented here. In addition, the model of a pool-coupled air conditioning system was used to develop a design tool for determining the pool size needed to absorb realistic heat rejection from air conditioners in various California climate zones.

1. Introduction

Rejecting waste heat from an air conditioner to a swimming pool rather than ambient air has the potential to decrease cooling electricity use and peak demand due to the significantly reduced temperatures seen by the refrigerant at the point of heat rejection. There are two key advantages of using swimming pools as heat sinks. The first arises from the fact that pools are much less susceptible to the large diurnal temperature swings seen by the ambient air, allowing air conditioner capacity and efficiency to stay relatively constant throughout even the hottest part of the day. In addition to reducing sink temperatures, the second advantage is that using water as the medium for heat rejection reduces the refrigerant temperature differential relative to the rejection-media temperature (i.e. the improved conductivity of water relative to air significantly reduces the heat transfer resistance seen by the refrigerant).

Applications for using swimming pools as heat sinks for space conditioning equipment have been demonstrated for solar cooling systems. One study performed an exergy analysis of an absorption chiller that utilized a residential swimming pool as the condensing medium for the refrigerant, crediting the heating of the swimming pool as useful work for the analysis [1]. The exergy analysis showed degradation in cooling efficiency with increasing pool water temperatures. The analysis provided in this paper offers insight into how the monitored systems in Ref. [1] impact pool temperatures and therefore the overall exergy efficiency ratio of the system.

Previous work by the authors presented a thermal model to predict the natural thermal behavior of unheated well-mixed pools, as well as an experimental verification of the model in one pool [2]. The swimming pool temperature predictions calculated by the pool air conditioner model evaluation tool (PACMET) were validated against observed values over a 56-day period, demonstrating that the model could make accurate predictions of the pool temperature. The RMS error of the temperature predictions compared to observed values was 0.4 °C with the largest discrepancy being 1.1 °C. A second experiment, the results of which are presented in this paper, was used to further validate the accuracy of PACMET by field measurements on a different residential pool used as the heat sink/source for a heat pump.

Significant research on modeling the thermal interaction between a swimming pool and its environment has been conducted, the primary focus of which has been to estimate pool heating needs for solar heating of pools [3–8]. To the authors' knowledge, the extensive monitoring period used to validate the PACMET model has not been repeated by any previous study. Additionally, the impact that rejecting waste heat from an air conditioner to a swimming pool has on air conditioner energy use, as well as pool temperature conditions has never before been investigated.

The objectives of this paper are: (a) to use PACMET to calculate energy use and associated cost for an air conditioning system

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Nomenclature

Variable description (SI)

AFUE	annual fuel utilization efficiency
CACZ	California climate zone
E_{sky}	emissivity of sky
E_w	emissivity of water
h	average convection coefficient (W/m^2 °C)
k_{air}	thermal conductivity of air (W/m °C)
L	length of panel (m)
$\overline{Nu_L}$	average Nusselt number
O_{sky}	opaque sky cover (tenths)
Pr	Prandtl number
q_{conv}	convection heat flux from panel (W/m^2)
q_{rad}	radiation heat flux from panel (W/m^2)
q_{panel}	total heat flux from panel (W/m^2)
Re_L	Reynolds number
T_a	ambient air temperature (°C)
SEER	seasonal energy efficiency ratio
T_w	swimming pool temperature (°C)
T_{sky}	effective sky temperature (°C)
V	wind speed (m/s)
μ	dynamic viscosity of air (N s/m^2)
ρ	density of air (kg/m^3)
σ	Stefan–Boltzmann constant 5.67 E^{-8} (W/m^2 K^4)

designed to reject waste heat to a swimming pool, (b) to present a tool to determine the needed pool capacity to absorb heat loads from a building, and (c) to demonstrate the use of the tool for houses in different California climates. PACMET was used to simulate the performance of an air-conditioner/pool system in multiple California climate zones (CACZ) to analyze energy use and pool temperatures over the cooling season. The results were then used to develop a methodology for determining the pool capacity needed to absorb heat loads from a particular building.

2. Active pool model validation

To validate the accuracy of PACMET for a pool that is being used as a heat sink/source, an experiment was conducted on a residential swimming pool that was coupled to a heat pump in Sacramento, CA (California climate zone 12). The thermal behavior of the pool was monitored over a 242-day period that included the summer of 2010. The experimental results are compared to PACMET predictions. The heat pump system was designed by a local pool contractor, who designed the system to have the capability to exchange heat with the pool, as well as with geothermal heat exchanger panels in the ground and/or radiant heat exchanger panels on the roof.

2.1. System design

The system evaluated in this study was a water-source heat pump designed for closed loop operation with a water-antifreeze solution. After the solution exits the heat pump it enters a heat exchanger where heat is exchanged between the solution and water from the pool. The water-antifreeze solution then travels to the geothermal panels for heat exchange with the ground before returning to the heat pump (Fig. 1).

The independent loops allow the heat pump and pool system to be isolated from one another, thereby preserving all warranties provided by the heat pump manufacturer. The pool pump is used to operate the pool loop under the control of a signal from the thermostat, and the integrated pumps in the heat pump are used to operate the closed loop. There are two shallow geothermal panels plumbed in parallel, which were included to assist the pool with the heat loads. Furthermore, solar thermal panels on the roof could be used at night to help reject additional heat from the pool to the night sky. It should be noted that this system design was not based upon any of the work presented in this paper.

2.2. Methodology for experimental validation

The ultimate goal of this experiment was to validate the pool temperature prediction of the PACMET model against observed temperatures for a pool that exchanges heat with a vapor-compression space conditioning system. Thus, the primary data points measured were local weather conditions and heat exchange between the heat pump and the pool. Additional monitoring included the radiant panel cooling capacity and the outdoor coil load of the heat pump.

2.2.1. Control scheme

The pool filter pump was scheduled to run continuously at a low flow rate to minimize temperature stratification and to improve the accuracy of the pool temperature sensors that were installed in the pool plumbing. In order to avoid impacting people who might use the pool, the well-mixed pool water temperature was taken inside the pool exhaust plumbing near the pool. This temperature was obtained at a suction line that pulled a combination of water from the bottom of the pool and from the pool skimmer at the surface. Normal pool operations required the filter pump to ramp up to higher speeds at times for pool-water filtering, and operating the pool sweep.

When a call for heating or cooling was requested by the indoor thermostat, the signal would be sent to both the outdoor unit of the heat pump as well as the pool pump used for sending pool water to the water-to-water heat exchanger.

The existing "solar-thermal pool heating" radiant panels on the roof were activated for part of the test period to measure their ability to be used to cool the pool if need be. The test occurred every night from 1:00 to 2:00 a.m. for 106 days starting on July 7th, 2010. This operation was programmed into the pool system's controller which operated a three-way valve that diverted the pool water to the panels on the roof.

2.2.2. Data acquisition and instrumentation

All data for the experiment was obtained using a DataTaker DT80 data acquisition computer that logged an instantaneous value for each measurement once a minute. These data were eventually aggregated into hourly input data for the model. Fig. 1 is a schematic of the experimental system and instrumentation locations. Details of the instrumentation employed may be found in Table 1.

PACMET requires several meteorological variables on an hourly bases including: global horizontal solar insolation, pool shading, cloud cover, ambient dry bulb temperature, ambient humidity, wind speed, and barometric pressure. All meteorological data were obtained on-site with a Vaisala WXT520 weather instrument, with the exception of the global horizontal solar insolation and cloud cover, which were obtained from the California Department of Resources' California Irrigation Management Information System (CIMIS) [9] and the National Oceanic and Atmospheric Association (NOAA) [10] respectively. Both the data from CIMIS and NOAA were taken from meteorological stations that were within 8 km of the test site and assumed to be representative of the local whether at the test site. These data were averaged for each hour and used as inputs to the model.

To quantify the heat transfer between the pool and the heat pump, another required input to PACMET, the water temperature entering and leaving the water-to-water heat exchanger, as well as the water flow rate, were measured on the pool side of the heat