Energy Conversion and Management 121 (2016) 349–357

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Performance of a swimming pool heating system by utilizing waste energy rejected from an ice rink with an energy storage tank

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ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 9 May 2016
Accepted 18 May 2016
Available online 24 May 2016

Keywords:
Ice rink
Swimming pool
Chiller
Heat pump
Thermal energy storage tank

ABSTRACT

This study deals with determining the long period performance of a swimming pool heating system by utilizing waste heat energy that is rejected from a chiller unit of ice rink and subsequently stored in an underground thermal energy storage (TES) tank. The system consists of an ice rink, a swimming pool, a spherical underground TES tank, a chiller and a heat pump. The ice rink and the swimming pool are both enclosed and located in Gaziantep, Turkey. An analytical model was developed to obtain the performance of the system using Duhamel's superposition and similarity transformation techniques. A computational model written in MATLAB program based on the transient heat transfer is used to obtain the annual variation of the ice rink and the swimming pool energy requirements, the water temperature in the TES tank, COP, and optimum ice rink size depending on the different ground, TES tank, chiller, and heat pump characteristics. The results obtained from the analysis indicate that 6–7 years' operational time span is necessary to obtain the annual periodic operation condition. In addition, an ice rink with a size of 475 m^2 gives the optimum performance of the system with a semi-Olympic size swimming pool (625 m^2).

1. Introduction

One of the most important conditions for the development and industrialization of countries is energy and the ability to use it efficiently. A large part of energy such countries use is obtained from polluting sources, such as coal and fossil fuels, leading to the increase of CO_2, SO_x and NO_x emissions. Therefore, the national energy strategies of many countries should concentrate on the utilization of environmentalist, renewable and sustainable energy sources [1,2].

In addition, the number of sports facilities is increasing every day to promote public health, especially in developing countries. These facilities can contain several sections such as ice rinks, swimming pools, basketball courts, and volleyball courts. Widely, ice rinks and swimming pools are used for hockey, curling, figure skating, swimming races and water games. These swimming pools are commonly heated by conventional methods (e.g. coal or gas-fired boilers), and recently solar energy is also being used instead of these methods [3,4]. A swimming pool water temperature should be between 22 °C and 28 °C for comfortable conditions [5]. In an ice rink, in order to provide a necessary hardness of the ice surface for different types of ice sports, the ice temperature should be kept between −6 °C and −1 °C by circulating a brine solution in pipes or tubes under the ice layer [6]. Excess energy from the ice rink is rejected from the condenser of a chiller unit into the environment as waste energy by using conventional air source chillers [7–9]. Furthermore, the instantaneous change in air temperature can cause irregularity of the system performance (COP) and conventional air source chillers work at low COP values when the weather temperature is high in summer. However, a ground couple chiller, which uses the buried thermal energy storage (TES) tank in the ground as a heat exchanger, can operate at more stable COP values. This is because the ground temperature does not fluctuate greatly during the whole year. It can be easily seen that underground TES tank can be a viable solution for saving the waste energy from the chiller unit.

Analytical and experimental investigations have been studied in the literature related to the design, analysis and optimization of TES for heating and cooling applications. Caliskan et al. [10] investigated energetic, exergetic, environmental and sustainability analyses of various TES systems (Latent, Thermochemical, and Sensible) for building applications at varying environment temperatures. They reported that the most sustainable system is the aquifer TES while the worst sustainable system is the latent TES. Rismanchi et al. [11] developed a computer model to determine

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http://dx.doi.org/10.1016/j.enconman.2016.05.049
0196-8904/

Nomenclature

A	area (m^2)
AF	activity factor
C	specific heat (kJ/kg K)
COP	coefficient of performance
f	gray body configuration factor
F	view factor
h	convection heat transfer coefficient (W/m^2 K)
H	ceiling height (m)
k	conduction heat transfer coefficient (W/m K)
ln	length (m)
L	thickness (m)
LH	latent heat (kJ/kg)
M	rate of mass transfer (kg/s)
N	number of daily repetition
p	pressure (kPa)
q	dimensionless heat energy
Q	heat energy (kW)
r	radial distance from the tank center (m)
R	tank radius (m)
t	time (s)
T	temperature (°C)
v	air velocity (m/s)
U	overall heat transfer coefficient (W/m^2 K)
V	volume (m^3)
w	dimensionless work
wd	width (m)
W	work (kW)
x	dimensionless radial distance
α	thermal diffusivity of the ground (cm^2/s)
γ	dimensionless parameter
ε	emissivity
η	Carnot Efficiency (CE)
ρ	density of ground (kg/m^3)
σ	Stefan-Boltzmann constant (5.67×10^{-8} W/m^2 K^4)
τ	dimensionless time
ϕ	dimensionless temperature
Φ	relative humidity
ψ	dimensionless temperature

Indices

b	building
c	ceiling
C	cooling
$comp$	compressor
$cond$	conduction
$condns$	condensation
$conv$	convection
eva	evaporation
flw	flood water
$frzw$	freezing water
fw	supplementary feed water
g	ground
H	heating
i	indoor
ia	indoor air
ice	ice
IR	ice rink
is	ice surface
j	component number
$light$	lighting
lum	luminaries
o	outdoor
oa	outdoor air
ps	pool water surface
pw	pool wall
rad	radiation
ren	renovated feed water
$rsurf$	ice resurfacing
SP	swimming pool
TES	thermal energy storage
w	water
∞	infinity

the potential energy savings of implementing cold TES systems in Malaysia. They found that the overall energy usage of the cold TES storage strategy is almost 4% lower than the non-storage conventional system. Kizilkan and Dincer [12] presented a comprehensive thermodynamic assessment of a borehole TES system for a heating case at the University of Ontario Institute of Technology (UOIT). They performed energy and exergy analyses based on balance equations for the heating application. COP_{HP} and overall exergy efficiency of the studied system are calculated as 2.65% and 41.35%, respectively. Zhang et al. [13] analyzed a model of a space heating and cooling system of a surface water pond that has an insulating cover, which serves as the heat source in the winter and heat sink in the summer. They considered three running modes to analyze the interaction of the seasonal heat charge and discharge for heating and refrigeration individually. Yumrutaş and Ünsal [14] analyzed an annual periodic performance of a solar assisted ground coupled heat pump space heating system, which had a hemispherical surface tank as a ground heat source based on a hybrid analytical–numerical procedure, using analytical and computational models. Yumrutaş et al. [15] presented an analytical and a computational model for a solar assisted heat pump with an underground cylindrical storage tank. Yumrutaş et al. [16] developed a computational model for determining the annual periodic performance of a cooling system utilizing a ground coupled chiller and a spherical underground TES tank.

In this study, an analytical model and a computational program written in MATLAB were developed to obtain the annual variation of ice rink and swimming pool energy requirements, a periodic solution of the transient heat transfer of the underground TES tank, system performance (COP), and the optimum size of the ice rink. The program was executed to investigate the effects of the size of the ice rink and parameters such as ground type, Carnot efficiency, and TES tank volume. Results obtained from the computational program are given as figures and discussed in the study.

2. Description of the system

The simplified system shown in Fig. 1 is located in the city of Gaziantep in Turkey, which lies between 37°4′ latitude N and 37°29′ longitude E and has a Mediterranean climate. The system under investigation consists of five main sections: an ice rink, a swimming pool, an underground TES tank, a cooling unit (Chiller) and a heating unit (Heat pump). In the system, the ice rink and the swimming pool are coupled by the chiller and the heat pump to the underground TES tank, respectively. The swimming pool is semi-Olympic sized (625 m^2) [17]. Different ice rink sizes (375–625 m^2) are considered in order to obtain optimum performance of the system. Both of the systems are covered with 10 m high ceilings as well.