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Configuration based modeling and performance analysis of single effect solar absorption cooling system in TRNSYS

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ABSTRACT

Solar based cooling systems may assume various configurations depending upon the manner in which the individual system components are inter-connected and the adopted control scheme. In this study, simulation based performance analysis of a solar assisted single effect absorption cooling system is done for two system configurations in TRNSYS. The analysis is carried out to meet a peak cooling demand of 298 kW for an educational building located in Islamabad (33.71°N, 73.06°E). In configuration-1 (C-1), the working fluid returning from the generator of the absorption chiller always flows towards the hot storage tank which acts as a common element between the solar collector and the absorption chiller. In configuration-2 (C-2), the working fluid returning from the absorption chiller may become isolated from the collector-storage tank loop if the fluid temperature in the storage tank is less than the required temperature (i.e. 110 °C) and is directly fed to the auxiliary boiler. Both system configurations are fully modelled in TRNSYS and dynamic simulations are run for the entire summer season. Various performance factors such as solar fraction, collector efficiency and primary energy savings are evaluated to optimize the key system design variables which include collector tilt, storage volume, type and size of the solar collector. Simulation results demonstrate that for the whole summer season, C-2 with flat plate or evacuated tube solar collectors always results in higher primary energy savings than C-1. However, on the basis of solar fraction and monthly collector efficiency, difference between C-1 and C-2 is estimated to be marginal. Overall, C-2 in conjunction with evacuated tube collectors (ETC) results in minimum collector area per kilowatt of cooling demand and higher monthly collector efficiency than C-1.

1. Introduction

Air conditioning demand is significantly increasing due to population growth and higher comfort standards in buildings [1]. Fossil fuel consumption and harmful emissions can be significantly reduced using solar energy for air conditioning in buildings. Absorption cooling systems are reliable and can be driven by low-grade thermal energy [2]. The main advantage of absorption chillers is their higher coefficient of performance than other thermally operated refrigeration cycles, i.e., adsorption or desiccant cooling systems. One of the major challenges in solar based cooling systems is to reduce the unnecessary consumption of auxiliary energy and other parasitic energy losses from electrical devices [3]. Various possible system configurations and control schemes are still being studied to optimize the system's performance with regards to increase in energy savings. With the development of equation solver based simulation tools (e.g. TRNSYS, Modelica, etc.), performance predictions of such systems can be accessed over long periods of time. A reasonable approximation of the expected results can then be obtained and the need of building expensive testing rigs is therefore minimized. The simulation based analysis may not fully replicate the varying operating conditions encountered in actual systems and generally over predicts the system performance. It is, therefore, necessary to simulate the system components near to reality and to at least predict the trend of expected results. TRNSYS is quite a mature simulation tool which is based on established analytical and differential correlations to predict and simulate the transient performance of a wide range of energy systems. Over the years, TRNSYS is being used by many researchers for modelling and simulating the long-term operation and dynamic performance of the solar based cooling systems which is otherwise very difficult to estimate in the planning phase.

Assilzadeh et al. [4] presented a solar cooling model for the climate of Malaysia and similar tropical regions. Evacuated tube collector (ETC)

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Nomenclature

A_c	solar collector area (m^2)
a_o	optical efficiency (–)
a_1	efficiency slope ($kJ\,h^{-1}\,m^{-2}\,K^{-1}$)
a_2	efficiency curvature ($kJ\,h^{-2}\,m^{-2}\,K^{-2}$)
COP	coefficient of Performance (–)
Cp_f	specific heat of liquid ($J\,kg^{-1}\,K^{-1}$)
Cp_{chw}	specific heat of chilled water ($J\,kg^{-1}\,K^{-1}$)
Cp_{cw}	specific heat of cooling water ($J\,kg^{-1}\,K^{-1}$)
FPC	flat plate solar collector
$f_{DesignEnergyInput}$	fraction of rated capacity (–)
$f_{sav,shc}$	fractional primary energy saving for a solar heating and/or cooling system (–)
G	incident global solar radiation on the collector plane (W/m^2)
M	mass flow rate through the solar collector ($kg\,h^{-1}\,m^{-2}$)
$\dot{m}_{chw}$	mass flow rate of the chilled water ($kg\,s^{-1}$)
$\dot{m}_{cw}$	mass flow rate of the cooling water ($kg\,s^{-1}$)
$\dot{m}_f$	mass flow rate of the fluid from storage tank to chiller ($kg\,s^{-1}$)
$\dot{Q}_{aux}$	energy of solution pump, fluid pumps, controls etc. in the absorption chiller (kW)
$\dot{Q}_{boiler}$	heat energy of the auxiliary boiler (kW)
$\dot{Q}_{chilled}$	heat energy absorbed from chilled water (kW)
$\dot{Q}_{cw}$	heat energy of absorption and condensation rejected by the absorption chiller (kW)
$\dot{Q}_{hw}$	heat energy of the generator in the absorption chiller (kW)
$\dot{Q}_{solar}$	heat energy gain from solar collector (kW)
$\dot{Q}_{cooling,ref}$	energy for cold provided by a conventional vapor compression refrigeration system (W)
SF	solar Fraction (–)
$T_{col,i}$	temperature of fluid at the inlet of solar collector (K)
$T_{col,o}$	temperature of fluid at the outlet of solar collector (K)
T_i	temperature of fluid at the inlet of auxiliary boiler (K)
T_o	temperature of fluid at the outlet of auxiliary boiler (K)
$T_{g,i}$	temperature of fluid at the inlet of generator in the absorption chiller (K)
$T_{g,o}$	temperature of fluid at the outlet of generator in the absorption chiller (K)
$T_{st,i}$	temperature of fluid at the inlet of storage Tank (K)
$T_{st,o}$	temperature of fluid at the outlet of storage Tank (K)
$T_{chw,in}$	chilled water inlet temperature (K)
$T_{chw,set}$	chilled water set-point temperature (K)
$T_{cw,i}$	cooling water inlet temperature (K)
$T_{cw,o}$	cooling water outlet temperature (K)

Greek symbols

η_c	thermal efficiency of solar collector (–)
ε_{heat}	efficiency of boiler (–)
ε_{elec}	efficiency of thermal power plant (–)
θ	angle of incidence (degree)
ΔT	temperature difference between fluid and ambient temperature (K)

Abbreviations

C-1	configuration-1
C-2	configuration-2
ETC	evacuated tube collector
FPC	flat plate collector

and absorption chiller were used for the simulation in TRNSYS. ETCs were tilted at 20° and 35 m^2 area of solar collectors fulfilled the requirement of 3.5 kW along with a hot storage volume of 0.8 m^3. Tsoutsos et al. [5] simulated a cooling and heating system of a hospital in Crete using TRNSYS, where the criteria to optimize the system was solar fraction. Different parameters like collector area, size of storage tank, collector slope, back up heater, cooling tower and nominal capacity of absorption chiller were optimized. Mateus et al. [6] assessed the yearly performance of a solar absorption heating and cooling system with reference to a residential, an office and a hotel building in TRNSYS for three different locations, i.e., Rome (Italy), Berlin (Germany) and Lisbon (Portugal). The results showed better cost and CO_2 emission savings for south European regions and annual solar fraction of 60% resulted in the cost alleviation of about 35–45%. Molero et al. [7] compared different configurations for solar absorption cooling system with a nominal COP of 0.695 for a residential building in Spain and effects of hot and cold storages were analyzed. Collector area, efficiency curve of solar collector, COP of absorption chiller, size of thermal storage, and temperature set points of chiller were optimized. The results showed a better performance of the system configuration when cold storage was employed in the system, especially when the storage size was large and collector area was small. Florides et al. [8] presented a model for solar absorption cooling for the weather of Nicosia, Cyprus using TRNSYS. Optimization of type, area and tilt angle of solar collector, volume of thermal storage, thermostat setting of the auxiliary boiler was carried out. The optimum slope of the parabolic trough collectors was estimated to be 30° from horizontal and optimum size of hot water thermal storage was 600 Ls. Mazloumi et al. [9] simulated a solar single effect lithium bromide absorption cooling system in Ahwaz (Iran). Parabolic trough collectors were used to feed hot water to the chiller. The system met the cooling demand of a typical house having peak cooling load of 17.5 kW. The required collector area was 57.6 m^2. One of the major conclusions of this work is that collector mass flow rate has a significant effect on the optimal efficiency of thermal storage. Hang and Qu [10] investigated the impact of hot and cold storages on the solar absorption cooling system performance for an office building. The system is located in Los Angeles, California. 200 m^2 area of ETC was used and the system capacity was 120 kW. It was concluded that the cold storage did not have significant effect on the system's energy performance as compared with hot storage. The sensitivity analysis revealed that on the basis of solar fraction the system is most sensitive to solar collector area, followed by chiller's capacity, hot storage and cold storage. Tao He et al. [11] validated a solar absorption cooling system in Beijing, China by TRNSYS simulations. Cooling load of the building was 175 kW and total aperture area of evacuated tube collectors was 358 m^2. Solar collectors were tilted at 10° facing south and rated COP of the absorption chiller was 0.7. A biomass boiler was used as a backup auxiliary device. The size of thermal storage tank and cooling storage tank was optimized and the optimum sizes were 15 m^3 and 8 m^3, respectively. Average annual efficiency of solar collectors was found to be 37.6% and solar fractions for summer and winter were 0.76 and 0.38. Tashtoush et al. [12] did an optimization study of a solar based ejector cooling system in TRNSYS for a cooling capacity of 7 kW. Key design variables such as collector type and area, storage volume, and mass flow rates are optimized. Shirazi et al. [13] conducted a comprehensive TRNSYS based simulation study of single, double and triple effect absorption chiller for both heating and cooling systems. Their results suggest that for fraction of normal incidence solar radiation less than 50%, single and double effect chillers with ETCs require less collector area than parabolic and linear Fresnel collectors. Double effect chillers with evacuated tube collectors resulted in better thermal and economic performance for various climatic conditions. Abed et al. [14] did an experimental study of ammonia-water based single stage solar absorption cooling system with three configurations in the cooling