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Supporting district heating and cooling networks with a bifunctional solar assisted absorption chiller

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ABSTRACT

Supplying the heating demand of the absorption chillers connected to district heating systems is challenging during summertime when there is not enough demand to take advantage of the high temperature discharge water of the chillers. In this work, a new configuration of a bifunctional solar assisted absorption chiller is proposed by which the heating demand of the chiller is efficiently supplied. This innovative system takes advantage of an evacuated tube solar thermal system and has no cooling tower. The proposed system is designed and simulated for a case study in Denmark, i.e. the Aarhus University Hospital. The effect of applying the proposed system to the performance of the hospital cooling systems and the local district heating network is assessed over an entire year. The results show that the proposed system could make a 30% contribution to the heat preparation process of the absorption chiller during the summer and a 17% contribution seen over the entire year. Aside from this, the system can contribute a large amount of heat production for district heating purposes during the cold months. As such, the effect of replacing the conventional system with the proposed configuration on the CO_2 emission of the case study is evaluated. Finally, the two economic criteria of net present value and internal rate of return are used to assess the effectiveness of the project economically, finding it very feasible and economical with a payback period of less than two years.

1. Introduction

The reports released by energy organizations in different countries show a sharp increase in cooling demand of buildings in Europe (and probably other parts of the world) [1]. In addition, the studies show that the phenomenon global warming has affected the potential of passive cooling and, as a result, the potential of climatic cooling has decreased and is predicted to fall considerably in the future [2].

An absorption chiller is a device that not only mitigates the dependence on electricity and reduces environmental impact caused by greenhouse gases, but it is also capable of easily taking advantage of waste energies and renewable resources [3]. LiBr-water and ammonia-water pairs are the most common absorption chiller types. The ammonia-water pair is not suitable for being coupled with solar heat as it needs a high driving temperature (125–170 °C) and this level of temperature can only be obtained with medium concentration ratio parabolic collectors [4]. Regardless of the operating fluid and refrigerant, absorption chillers could be found in single, double and triple effect configurations. Generally, the configurations with higher number of effects present higher coefficient of performance (COP) values, though their driving temperature levels are higher. In single effect absorption technology, a peak COP of around 0.7 is obtainable and the heat input temperature is in the range 90–120 °C. Double and triple effect chillers require driving temperatures of around 180–240 °C and can reach COPs of up to 1.4 and 1.8, respectively [5]. Hence, a single effect LiBr-water absorption chiller is the most appropriate solar assisted systems.

A massive amount of numerical and experimental studies on solar absorption chillers can be found in the literature. For example, Shirazi et al. [6] presented a comprehensive, multi-objective optimization of solar-powered absorption chiller systems for air-conditioning applications. Bellos et al. [7] presented a thorough dynamic energetic, exergetic and financial evaluation of a solar driven absorption chiller. Marc et al. [8] developed a dynamic modelling of a 30 kW LiBr-water single effect solar absorption chiller for solar application and compared their numerical results with experimental validation elements. An experimental investigation of the performance of a dual source (gas engine waste heat and solar heat) powered absorption chiller was carried out in [9]. Xu et al. [10] accomplished an experimental study to evaluate the performance of a variable effect LiBr–water absorption chiller

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Nomenclature

A	area (m^2)
B	benefit (DKK)
C	cost (DKK)
C_b	bond conductance (W/m^2)
c_p and c	specific thermal capacity (kJ/kg °C)
COP	Coefficient of Performance
D	diameter (m)
E	emission (tCO_2)
F_R	collector removal factor
F'	collector efficiency
$\bar{h}$	convective heat transfer coefficient (W/m^2 K)
h	specific enthalpy (kJ/kg)
IRR	internal rate of return
k	thermal conductivity (W/m K)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
n	year counter
NPV	net present value
P	pressure (kPa)
$\dot{Q}$	heat transfer rate (kW)
r	discount/interest rate
R	heat resistance (m^2 K/W)
t	time (step) (s)
T	temperature (°C or K)
U_l	collector overall heat loss coefficient (W/m^2 K)
v	specific volume (m^3/kg)
$\dot{W}$	work rate (kW/kg)
X	concentration (%)

Greek Symbols

μ	Emission concentration of a given gas (%)
ζ	Exhaust gas volume (m^3)
Γ	Absorber plate width (m)

Subscriptions

abs	absorber
c	collector
cond	condenser
cv	convective
dc	district cooling
dh	district heating
e	external
eV	evaporator
f	working fluid
fu	fuel
g	generator
g-a	glass to ambient
i	internal
p	pump
p-g	plate to glass
r	radiative
s	solution
st	storage tank
shx	solar heat exchanger
w	water

designed for high-efficient solar cooling systems. Shirazi et al. [11] did a systematic parametric study and feasibility assessment of solar-assisted single-effect, double-effect and triple-effect absorption chillers for heating and cooling applications. Weber et al. [12] offered a linear concentrating Fresnel collector to drive two absorption chillers, achieving a solar system efficiency of 50–60% and observing a sound operating behavior and promising results for industrial process integration. Porumb et al. [13] investigated the operating conditions and performance of the LiBr-water solar absorption chiller. Their results proved that their numerical model was capable of describing the behavior of the equipment and of evaluating the safe operating conditions from the crystallization point of view and from the degassing point of view. Albers [14] developed a new configuration of solar driven absorption chiller with a constant water temperature, increasing the efficiency and decreasing the water consumption.

Just like district heating (DH), district cooling (DC) also has significant benefits as it provides better comfort in areas with large cooling demands, and it can increase the integration of the electricity, heating and cooling sectors. In Denmark, DC covers only 4% of the cooling consumers. In Sweden, which has experienced an expansion over the last 20 years, 40% of the cooling consumers are connected to DC networks today [15]. Therefore, expanding the areas covered by DC in Denmark is one of the policies that energy planners are following, though there are many challenges. One of these challenges is the method for providing the required thermal energy for the absorption chillers which are usually one of the main suppliers of the DC networks. For those chillers connected to the DH network, the DH supporting hot water produced by heat production systems, such as waste incinerations plants, boilers, etc., is used to drive the chillers. The problem with this configuration is the mismatch between the DC demand and the operation load of the supporting heat production plants during summer. In high ambient temperature when the cooling demand is high and, as a result, the heating demand of the absorption chiller is high, the heat production stations work on very low operation loads because the DH network demand is very low. However, just to provide the required heat for the chillers, the heat production systems have to increase their production. The DH-connected absorption chillers usually need a heat supply temperature of 90–95 °C while the discharge temperature is still at the high level of 80–85 °C. This discharge temperature is neither appropriate for coming back to the heat production stations for recovery as it will decrease the production efficiency nor can it be used for DH purposes as the demand is very low.

In this work, a new configuration of a bifunctional solar powered absorption chiller is proposed by which not only the heating demand of the chiller decreases considerably in the summer, but the heat extracted from the absorber and condenser of the chiller could also be used for further support of the DH system over the rest of the year. Aarhus University Hospital (AUH), as the largest hospital in Northern Europe [16], is the case study of this work. The effect of employing this DH-connected bifunctional solar powered chiller to provide the cooling demand for the hospital is assessed techno-economically. The net present value (NPV) and the internal rate of return (IRR) are the economic criteria of this study. In addition, the potential of the systems to decrease the amount of CO_2 emission is evaluated.

2. Method

2.1. The configuration of the bifunctional solar powered absorption chiller

In this section, the operation details of the proposed bifunctional absorption chiller are presented. The schematic diagram of