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Performance analysis & energy benefits of a desiccant based solar assisted trigeneration system in a building

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A B S T R A C T

In this paper, performance details and operational benefits of a large scale solar trigeneration system that provides for solar assisted desiccant cooling, heating and hot water generation installed in a teaching institute building have been reported. A two-rotor desiccant system designed for handling 12 000 m3/hr of air was integrated into existing plant to provide a net reduction in energy consumption over the pre-existing heating ventilation and air-conditioning and domestic hot water systems. The system is controlled and monitored by a building management system which has been used to investigate and analyse the typical system behaviour. Heat from solar energy contributed consistently to reduce gas usage for water heating and on an annual basis showed a reduction of 21% of consumed energy. The solar energy contribution for space heating varied over winter months and during some months it was observed to contribute more than 50% of the total energy requirements for space heating. Under suitable ambient conditions, approximately 35% of total building cooling load was met by the solar driven desiccant cooling system. Continuous monitoring has also helped understand some of the operational issues of the system.

1. Introduction

According to International Energy Agency (IEA) estimates, space heating, cooling as well as hot water account for roughly half of global energy consumption in buildings [1]. Using solar energy to meet this demand is a promising approach towards net zero energy buildings. Solar thermal systems that provide heat for domestic hot water and space heating requirements of the building are well known and have been practised across the world for over 20 years [2,3]. Solar trigeneration systems that include building cooling demand as well (in addition to heating and hot water) extend the use of solar heat throughout the year. Studies carried out in European countries indicate such trigeneration systems can achieve 10–60% of solar fraction [4].

Desiccant Evaporative Cooling (DEC) systems are an attractive option for meeting the cooling demand due to their high electrical coefficient of performance, lower system cost and ease of construction. These systems, driven by solar heat, have been shown to have high potential for primary energy savings in buildings (e.g. Refs. [5–8]).

As a result, there have been studies of operational performance of solar desiccant system installations and their impact in reducing building energy consumption. La et al. [9], have reported on solar desiccant system installation examples from various countries in Europe and China. Baniyounes et al. [10], monitored the performance of a solar desiccant system at a University building in Queensland, Australia. The desiccant system was designed to handle 1450 m^3/hr of air flow. They reported an 18% annual energy saving due to the desiccant system installation. Enteria et al. [11], reported a first and second law analysis of a solar desiccant system installed in a laboratory building at Tohoku University, Japan. This system treated 300 m^3/hr of outside air through the desiccant wheels. Through their studies, they were able to identify energy loss contributions from components such as the water pipes and storage tank. Performance studies of a solar desiccant system installed at University of Palermo, Italy have been reported [12]. This system was designed for handling 2500 m^3/hr of air through the desiccant unit. This system was monitored throughout a year for cooling and space heating performance. In summer, this system provided nearly 50% primary energy savings compared to a conventional air handling unit. The performance of a solar trigeneration system with desiccant cooling in a building has also been reported by Bader et al., [13]. Operational and monitoring issues

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Nomenclature.

A	Area (m^2)
C_p	Specific heat (kJ/kg K)
h	Specific Enthalpy (kJ/kg))
I	Global Solar Irradiance (kW/m^2)
m	Mass (kg)
$\dot{m}$	Dry mass flow rate (kg/s)
P	Power (kW)
Q	Heat transfer (kJ)
r	Ratio
T	Temperature (°C)
Vol	Volume (m^3)
η	Efficiency

Subscript

a	Air
ambient	Air stream at TAC unit inlet
b	Boiler
CHW	Chilled water
coil,gas	Mechanical gas heating coil
coil,sh	Solar hot water coil
DEC	Desiccant component of TAC unit
DHW	Domestic hot water
DHW,gas	Gas component of DHW
DHW,sh	Solar pre-heat component of DHW
EvapOff	Air stream after evaporative cooler
gas	Natural gas
I	Inlet
O	Outlet
panels	Solar collector panels
regen	Desiccant wheel regenerative coil
Sav	Savings
sc	Solar Collectors
supply	Air stream at TAC unit output
Tank	Solar hot water tank
TAC	Tempered air conditioner unit
w	Water

related to desiccant system operation have been highlighted by these authors. La et al. [14], and Ge et al. [15], have reported on the operation and performance of two rotor desiccant system installations. Studies with these two stage systems have shown increased efficiency of solar energy use over a single stage system due to lower regeneration temperatures.

In this paper, one year performance details and operational benefits of a large scale solar trigeneration system fitted with a solar desiccant cooling system are reported. The system is the first of its kind in the world, combining a novel two desiccant-rotor intercooled cycle with low cost flat plate solar collectors. The two desiccant rotor intercooled cycle, enables greater dehumidification from what would otherwise be a very low temperature heat source from the flat plate solar collectors. Specifically, conventional desiccant cooling cycles require temperatures of around 80 °C for adequate dehumidification, whereas this system runs at temperatures as low as 60 °C which enables much higher solar collector efficiency than otherwise achieved [16,17]. Furthermore the system has been designed and implemented as an integrated whole-of-building solution which simultaneously provides both heating, ventilation and air-conditioning (HVAC) and domestic hot water (DHW).

While there have been a number of solar airconditioning installations around the world, only limited information on long term performance of these systems are available. There is still a need to share design learnings and performance figures, including details of the often reported below design performance of operating systems due to high pressure losses and thermal losses (e.g Refs. [12,19]). Insitu performance analysis of a large scale trigeneration system such as this, which utilises solar heat throughout the entire year, will assist industry to progressively identify common issues, improve installations and designs, as well as assess the commercial viability of such systems.

Operational since mid 2012, these two rotor, intercooled solar desiccant evaporative trigeneration system for space heating, cooling and DHW was installed at the Hamilton campus of the New South Wales Technical and Further Education (TAFE) commission in Newcastle, Australia. Newcastle is located on the east coast of Australia approximately 160 km north of Sydney with coordinates of 31°55′S, 151°45′E. Winters are typically mild and summers warm. Mean monthly temperatures range between 16.7 °C–25.6 °C. Peak summer temperature can reach over 40 °C. The coastal location leads to a mean annual relative humidity at 3 pm of 66% and mean temperature of 20.1 °C [18].

The installed system consists of two Solar Desiccant Evaporative Cooler (SDEC) Tempered Air Conditioner units, labelled TAC 3 and TAC 7. TAC 7 supplies the kitchens, preparation room and store, TAC 3 either serves the offices or, if cooling/heating is requested, the dining room by means of a request button installed in the room (Fig. 1). TAC 3 can only serve one area at a time, therefore the conventional compression chiller based air conditioner maintains the comfort conditions in the offices if cooling by TAC 3 is requested in the dining room. TAC 3 and TAC 7 are identical in design with the only differences being higher air and water flow rates for TAC7. The floor area serviced by both combined units is 500 m^2 when serving the office space. Under dining room request, the serviced floor area is 470 m^2. The desiccant system is designed for handling 12 000 m^3/hr of air.

The primary consideration for the cooling system design was to accommodate the high fresh airflow requirements of the kitchens. While the offices and sporadically occupied function area required tighter comfort ranges, they were not as frequently occupied or used as intensively for the long hours of the kitchen. The operating environment of the kitchens meant that air could not be recirculated as combustible gases, grease, aromatics or other contaminates may be present. Therefore, air conditioning the kitchens was energy intensive with higher energy consumption required in comparison to conventional scenarios which allow recirculation.

The less ‘tempered’ air stream constraint and fresh air requirements for the kitchen application were well suited to solar desiccant systems where the amount of available cooling is more variable. The fresh air and a reduction in humidity may be sufficient to satisfy the comfort requirements for the occupants. The removal of latent heat by solar desiccant systems enables them to integrate well with conventional HVAC systems that provide sensible cooling and humidity management.

The site also has a high demand for potable hot water for both cleaning and food preparation. The temperatures required for this combined with desiccant cooling and space heating are achieved by use of flat plate solar panels in combination with the water storage tanks. These collectors are widespread in Australia and relatively inexpensive and the addition of the domestic hot water pre-heating