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High potential of full year operation with solar driven desiccant evaporative cooling systems

Anita Preisler\textsuperscript{a}\textsuperscript{*}, Markus Brychta\textsuperscript{a}

\textsuperscript{a}AIT Austrian Institute of Technology, Giefinggasse 2, A-1210 Vienna, Austria

Abstract

The energy saving potential of solar driven desiccant evaporative cooling (DEC) systems are mainly evaluated for the summer period, but not for the winter time. Here, the sorption rotor has high energetically advantages for humidity recovery purposes. The solar driven DEC systems installed in the ENERYbase office building have been monitored within the last two years to analyze also this effect. The primary energy saving potential during the winter time is unexpectedly high due to the humidity recovery mode. Further simulations with different climates using the same system configuration will show the general potential of this effect.

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1. Introduction

Solar driven desiccant evaporative cooling (DEC) systems are mainly installed to achieve certain inlet air conditions (temperature and humidity) during the summer period under ecological conditions. Therefore, this technology offers an interesting alternative to air handling units using cooling coils driven by compression chillers with quite low supply temperatures (6°C) for cooling and dehumidification purposes.

Currently, sorption rotors in DEC systems use silica gel or lithium-chloride for the dehumidification of the air in summer time. These materials have also the ability for humidity recovery in winter time which is in most cases not analyzed in detail.

* Corresponding author. Tel.: +43-50550-6634; fax: +43-50550-6613
E-mail address: anita.preisler@ait.ac.at.
The humidification of air is a big issue in Austria as the outside air with minimum values of 1 to 2 g/kg is much too dry during the winter time. In the ENERGYbase office building in Austria two solar driven DEC systems are installed which have been monitored by the Austrian Institute of Technology (AIT) since 2010 to evaluate also the advantages of DEC systems in winter. Fig. 1 shows the configuration of the two identical solar driven DEC system in the ENERGYbase office building.

2. Methodology

For the evaluation of a full year operation of a solar driven DEC system the monitoring data of 2010 from the ENERGYbase DEC systems were evaluated according to the IEA SHC Task 38 procedure (Napolitano, Sparber, Thür, Finocchiaro, & Nocke, 2011) level 3. Following equations are used to elaborate the primary energy saving (\( f_{\text{sav,shc}} \)) and the electrical coefficient of performance (\( \text{COP}_{\text{el}} \)) for solar heating and cooling systems.

\[
f_{\text{sav,shc}} = 1 - \frac{Q_{\text{boiler}}}{\epsilon_{\text{boiler}} \cdot \eta_{\text{boiler}}} + \frac{Q_{\text{RES}}}{\epsilon_{\text{RES}} \cdot \eta_{\text{RES}}} + \frac{E_{\text{el,ref}}}{\epsilon_{\text{elec}} + \epsilon_{\text{cooling,ref}}} + \frac{Q_{\text{cooling,missed}}}{\epsilon_{\text{elec}}} \cdot \frac{SPF_{\text{ref}}}{SPF_{\text{elec}}} \tag{1}
\]

\( Q \) … Thermal energy demand [kWh]
\( E \) … Electrical energy demand [kWh]
\( \epsilon \) … Primary energy factor [-]
\( \eta \) … Mean annual/ monthly efficiency [-]
\( SPF \) … Seasonal performance factor [-]
\( RES \) … renewable energy sources
\( boiler \) … gas boiler
\( elec \) … electricity
\( ref \) … reference system
\[
COP_{el} = \frac{Q_{cooling}}{E_{el}}
\]

\[Q_{cooling} \ldots \text{useful cooling energy [kWh]}\]
\[E_{el} \ldots \text{electricity consumption [kWh]}\]

3. Results

Fig. 2 shows that the COP\textsubscript{el} of the DEC system is much better during the winter period than in the summer period. Here the humidity recovery by the sorption rotor (lithium-chloride) has high energetically advantages compared to a reference system. The reference system is defined as a conventional air handling unit for temperature and humidity control of fresh air for a whole year. The heat is delivered by a gas boiler and the cold by a compression chiller system. Table 1 shows the chosen parameters for the primary energy assessments. The evaluation of \(f_{av,shc}\) shows that in summer time the primary energy savings are quite good compared to conventional air handling units, but really high primary energy savings can be achieved in winter time. The average \(COP_{el}\) of the solar driven DEC system is 7.0 in 2010.

![COP and f_av,shc results](image)

**Fig. 2. Results of \(COP_{el}\) and \(f_{av,shc}\) for the solar driven DEC systems in ENERGYbase, year 2010 (Preisler, Thür, Neyer, & Hilbert, 2012)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\varepsilon_{elec})</td>
<td>2.5</td>
</tr>
<tr>
<td>(\varepsilon_{fossil \ (gas)})</td>
<td>1.11</td>
</tr>
<tr>
<td>SPF\textsubscript{ref} (compression chiller)</td>
<td>2.8</td>
</tr>
<tr>
<td>(\eta_{boiler})</td>
<td>0.95</td>
</tr>
<tr>
<td>SPF (\text{heat pump (monitored)})</td>
<td>3.2</td>
</tr>
</tbody>
</table>

**Table 1. Parameters for primary energy assessment**

Fig. 3 gives the primary energy demand per month of the solar driven DEC system according to monitoring data 2010 compared to a simulated reference system in the simulation environment TRNSYS.
17. The highest potential for primary energy savings occurs in winter time from January until March and October until December with 73.9%. During the summer months (June, July and August) 18.2% of the primary energy savings can be achieved. The transition time (April, May and September) only adds 7.9% to the primary energy savings.

![Diagram](image_url)

**Fig. 3.** Comparison of primary energy demand, 2010, Austria (Source: AIT, 2012)

Fig. 4 and Fig. 5 show the individual parts of the primary energy demand for the reference system and the solar driven DEC system. The composition of the reference system makes clear that the main part of the primary energy demand is needed in winter for the heating coils; the electricity demand of the air handling unit plays a minor role. To achieve not only the desired supply temperature but also a relative humidity of 42%, the supply air is humidified which causes also a temperature drop of the supply air and has to be reheated up afterwards again. Here, the DEC system has the advantage of the sorption rotor which operates in winter time as an enthalpy wheel. Therefore, the primary energy demand for reheating up the air after the humidifier is much lower. The evaluation of the summer of the solar driven DEC system shows that only the electricity demand of the DEC system (fans, humidifier, water treatment system, rotors) is important, as the primary energy demand of the solar thermal system is very low.

![Diagram](image_url)

**Fig. 4.** Primary energy demand of reference system, 2010, simulated (Source: AIT, 2012)
Besides the monitoring evaluation according to the IEA SHC Task 38 procedure the operation and energy performance of the components of the DEC system LA01 were analyzed in detail. Fig. 6 shows the operating hours of the DEC system (office time) in 2010 and for how many hours following components have been active:

- Sorption rotor as enthalpy wheel
- Sorption rotor in dehumidification mode
- Heat recovery rotor in heating mode
- Heat recovery rotor in cooling mode
- Humidifier return air (adiabatic cooling)
- Humidifier supply air (adiabatic cooling)
Fig. 7 shows the achieved humidification of the supply air by humidity recovery of the sorption rotor in winter. Over the operating hours the humidity recovery behaves nearly linear between 0 and 6.6 g/kg, in 20 hours a humidity recovery > 6 g/kg was achieved.

![Graph of humidity recovery](image1)

Fig. 7. Sorted values of humidity recovery by sorption rotor (LiCl), LA01, 2010 (Source: AIT, 2012)

The dehumidification performance of the sorption rotor is to 62.1% of the time nearly constant at 2.8 g/kg; in 37.9% of the operating hours the dehumidification is between 3.0 and 4.4 g/kg.

![Graph of dehumidification](image2)

Fig. 8. Sorted values of dehumidification by sorption rotor (LiCl), LA01, 2010 (Source: AIT, 2012)

In the next step these promising results related to primary energy savings of solar driven DEC systems in Austria were evaluated by using different climate conditions. Following locations were chosen to represent different climate zones:
- Moderate climate: Frankfurt
- South Europe: Athens, Rom, Madrid
- Other hot climates: Abu Dhabi, Sydney, Los Angeles
Tropical and subtropical climates were excluded in these analyses as a DEC system with this kind of configuration isn’t able to dehumidify to the desired supply air humidity conditions. The calculated primary energy savings were in the same range for all locations in south Europe and other hot climates with approx. 50%. Fig. 9 shows as an example the results of Los Angeles. The set point for the supply air in summer was limited with 24°C and 60% relative humidity, which were also in all here evaluated locations possible to achieve with this kind of configuration. For Frankfurt a primary energy saving of 66% could be achieved.

![Graph showing primary energy demand comparison](image)

**Fig. 9.** Comparison of primary energy demand, Los Angeles (Source: AIT, 2012)

### 4. Conclusions

The evaluation of the Austrian DEC systems in the ENERGYbase office building made clear that solar driven DEC systems have high primary energy saving potentials compared to a reference system with an air handling unit using compression chillers for air-conditioning. In winter time the highest primary energy savings can be achieved for heating and humidity recovery purposes of fresh air as well as moderate savings during summer time for cooling and humidity control. When the outside temperature and humidity are close to the set points of the supply air, the primary energy savings compared to a reference system are quite low, which occurs in locations with moderate climate such as in Vienna during transition time. In 2010 the solar driven DEC system achieved 60.5% primary energy savings compared to a reference system.

The evaluation of the operation modes showed that the sorption rotor was used most of the time for heating and humidity recovery (87.5% of the operating hours) and only for less operating hours as desiccant rotor for dehumidification purposes (12.0% of the operating hours). The dehumidification performance of the sorption rotor was for most of the operating hours quite low.

When the set point limits of the supply air are chosen in a moderate range in summer (here 24°C and 60% relative humidity) this kind of solar driven DEC configuration can be used in south Europe and other hot climates achieving primary energy savings of about 50% compared to a reference system.
References
