DTU Library

Applicability of a desiccant dew-point cooling system independent of external water sources

Bellemo, Lorenzo; Elmegaard, Brian; Kærn, Martin Ryhl; Reinholdt, Lars; Markussen, Wiebke Brix

Published in:
Proceedings of the 6th International Conference on Solar Air-Conditioning

Publication date:
2015

Document Version
Peer reviewed version

Applicability of a desiccant dew-point cooling system independent of external water sources

Lorenzo Bellemo, Brian Elmegaard, Martin Kærn, Lars Reinholdt, Wiebke Markussen
Technical University of Denmark, Nils Koppels Allé, Bygning 403, 2800, Lyngby, DK
Phone: +45 45251978
lobel@mek.dtu.dk

ABSTRACT

The applicability of a technical solution for making desiccant cooling systems independent of external water sources is investigated. Water is produced by condensing the desorbed water vapour in a closed regeneration circuit. Desorbed water recovery is applied to a desiccant dew-point cooling system, which includes a desiccant wheel and a dew point cooler. The system is simulated during the summer period in the Mediterranean climate of Rome and it results completely independent of external water sources. The seasonal thermal COP drops 8% in comparison to the open regeneration circuit solution, and electricity consumption increases.

INTRODUCTION

Desiccant Cooling (DEC) systems are employed in air conditioning applications requiring both dehumidification and cooling. DEC systems handle latent loads efficiently, do not use harmful refrigerants, can use heat from renewable heat sources or waste heat and therefore have potential for reducing energy consumption and environmental impact in comparison to cooling-based dehumidification technologies [1]. Heat is used for regenerating desiccant dehumidifiers, water for evaporative coolers, and electricity for auxiliaries. Water is not readily available in all locations worldwide, and, when available, it has a cost and may require demineralization for ensuring a lasting operation of evaporative coolers, which increases operational costs, maintenance and waste of water. A patent pending technical solution is proposed for making DEC systems independent of external water sources. Its applicability is investigated by implementing it in a specific desiccant cooling system, termed Desiccant Dew-point Cooling (DDC) system [2]. The DDC system can decrease energy consumption and environmental impact in comparison to electric and absorption chillers, but a high amount of water is consumed [3]. Another study on a similar system concluded the electricity consumption is the critical economic and environmental factor for installing a desiccant cooling system [4].

Desiccant Dew-point Cooling system with Desorbed Water Recovery

The DDC system with Desorbed Water Recovery (DDC-DWR), is constituted by a Desiccant Wheel (DW), a Regeneration Heater (RH), an air-to-air Heat Exchanger (HEX), a Dew Point Cooler (DPC), an air-to-air Condensation Air Cooler (CAC), an Internal Heat Recovery Unit (IHRU), a water tank and auxiliaries.

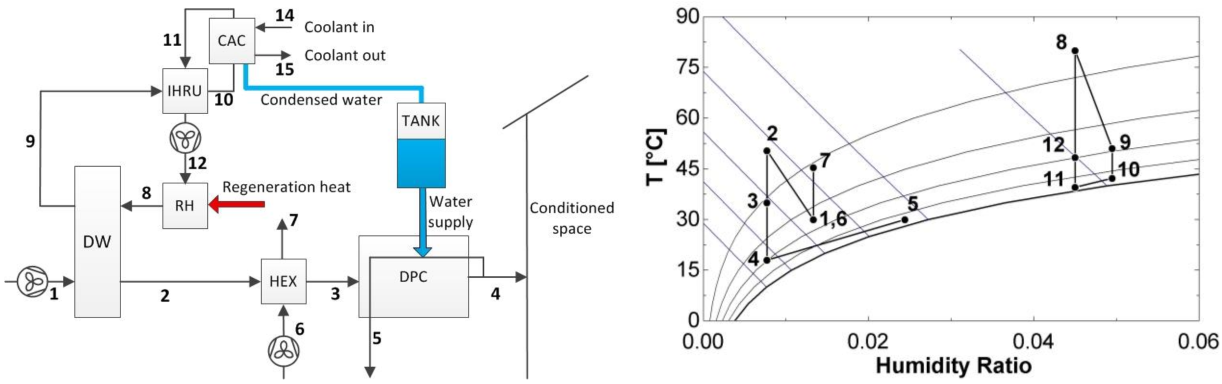

Figure 1. DDC-DWR system

Outdoor air (1) is dehumidified in the DW to (2), pre-cooled in the HEX to (3) with outdoor air (6) to (7) and balanced airflows, and cooled in the DPC to the supply temperature (4). The DPC is an indirect evaporative cooler that uses a fraction of the cooled primary airstream as secondary airstream; hence the theoretically lowest supply temperature is the primary air dew point. The secondary airstream, heated and humidified, is exhausted to the outdoor (5). Regeneration air flows in a closed circuit (8)-(12) where it is heated in the RH. Water is condensed in the CAC by means of outdoor air, and is collected into a tank for running the DPC. Condensed water is equivalent to distilled water, i.e. does not require demineralization. The Internal Heat Recovery Unit (IHRU) decreases both the cooling duty in the CAC and the regeneration heat consumption.

METHODS

Steady state component models based on the laws of thermodynamics and heat and mass transfer are derived and implemented in MATLAB.

Desiccant Wheel

A 2D model is used to compute the DW steady state operation [5]. The model is improved by adding a resistance to moisture diffusion in the desiccant pores assuming a parabolic moisture distribution within the plain desiccant wall, as described in [6] for a desiccant particle. The model is in good agreement with a validated 2D transient model implementing heat and mass transfer resistances at both air and solid sides [7]. The 2D steady state model is efficient and well suited for seasonal simulations.

Dew Point Cooler

A 1D steady state model [8] is used to compute the counter-flow DPC operation. A performance parameter, termed wet surface efficiency, is introduced to vary the secondary side mass transfer area, hence controlling cooling capacity, which is practically achieved by modulating the water spraying rate. The recirculated air fraction in the secondary channels maximizing the supply cooling capacity is 30% [8].

Heat Exchangers

The HEX and IHRU are modelled by the effectiveness-NTU method as counter-flow heat exchangers. The CAC is also modelled by means of the effectiveness-NTU method by considering an equivalent thermal capacity for the dehumidified airstream [9]. The exhaust temperature of outdoor air in the CAC, used as coolant, is controlled by regulating its airflow rate, defining the coolant fraction as ratio between outdoor and regeneration airflow rates. The RH is modelled as a simple heat source.

System Operational Modes

The system runs under different modes depending on the load:

1) DDC-DWR mode. If dehumidification is required, the DW, HEX and DPC are used with desorbed water recovery in a closed regeneration circuit.
2) DDC mode. The regeneration circuit is open with air pre-heating in the HEX if (1) the DDC-DWR mode does not dehumidify to the set point and enough water is stored in the tank, or (2) the coolant fraction in the CAC is too high.
3) DPC mode. If only cooling is needed, only the DPC runs.
4) Free cooling. Used if neither dehumidification nor cooling is needed.

RESULTS

The DDC-DWR system is simulated in the Mediterranean climate of Rome from June to September, every day from 8 am to 7 pm. The DDC system with no water recovery is also simulated for comparison. The systems are required to constantly supply 1500 m^3/h of fresh air. The set point supply conditions are T_{supply} 18°C and x_{supply} 7.8 g/kg. The supply dew point of 10°C is approximately the lowest limit for chiller-based A/C systems. Free cooling is used in case of outdoor conditions up to 22°C and 10.8 g/kg, while dehumidification is required for higher outdoor humidity ratios. A DW made of RD silica gel, with diameter of 0.85 m, depth of 0.2 m and 180° regeneration angle, is operated at constant rotational speed of 8 rph and a regeneration-to-process airflow ratio of 80%. The regeneration temperature is varied from max 90°C to min 50°C for the DDC system, and min 60°C for the DDC-DWR system. The DPC is 0.75 m high, 1.38 m long, 0.56 m wide, and is always operated with 30% air recirculation fraction. The HEX UA value is 2.8 kW/K, the IHRU UA value is 1.5 kW/K and the CAC UA value is 2 kW/K. The maximum allowed coolant fraction in the CAC is set to 5. According to Standard EN 15251-2007, considering commercial low polluting buildings, the supplied flow rate meets category I ventilation requirements for 210 m^2 single offices with 21 people, or 245 m^2 landscape office with 17 people, or 70 m^2 conference room or class room with 35 people.

Table 1. Comparison of seasonal results

	DDC-DWR system	**DDC system**
Water independence [%]	100	0
Water evaporated [litres]	11238	11192
Seasonal thermal COP	0.70	0.76
Seasonal heat consumption [kWh]	13811	13480
Maximum $\dot{Q}_{reg}$ [kW] at 90°C	20.1	20.7
Satisfied T_{supply} [%]	99.9	99.9
Satisfied/Accepted x_{supply} [%]	63.6 / 99.9	74.8 / 99.9
Op Mode distribution 1/2/3/4 [%]	69/10/11/10	0/79/11/10

Table 1 shows that the DDC-DWR system is independent of external water sources, and it provides satisfactory supply conditions: supply conditions are satisfied if set point values are reached, while accepted if within the limits of free cooling. The average seasonal coolant fraction in the CAC is 2.6. The stored water profile in the tank, Figure 2, shows a peak of 3364 litres at the end of the simulated period.

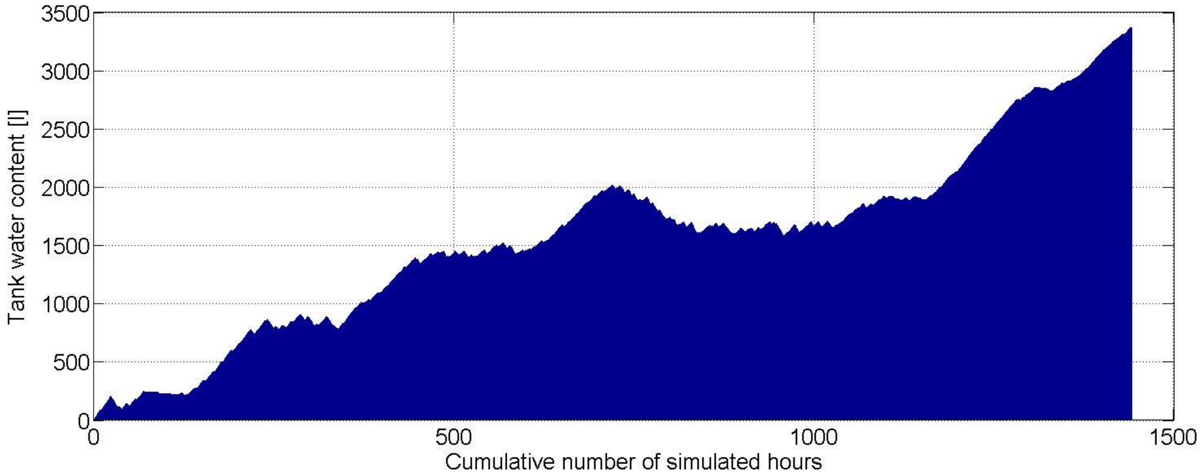

Figure 2. Seasonal profile of water stored in the tank

DISCUSSION

The results show an excess production of water, which can be used to optimize the system operation. Possible optimizations are adiabatic cooling of the coolant in the CAC, or in the HEX, or an increased use of the DDC mode. The latter leads to both heat and electricity savings, as the seasonal thermal COP increases and less electricity is needed without the IHRU and CAC. The required installed heat capacity is lower for the DDC-DWR system, due to the IHRU. Electricity consumption is not estimated as the HEX, IHRU, CAC and RH are not dimensioned. In particular the dimensioning of the CAC is critical to ensure sufficient water recovery while limiting electricity consumption. In terms of thermal COP, the system is found competitive with single stage H_2O-LiBr absorption chillers. The air cleaning potential of desiccants should also be taken into account for comparison with chiller-based systems, as ventilation requirements might be lowered [10]. More applications and climates should be considered in order to identify the most suitable working conditions for the recovery of desorbed water.

CONCLUSION

Seasonal simulations of a desiccant cooling system demonstrate that desorbed water recovery can ensure independence from external water sources. The energy consumption is higher than without water recovery, and thermal COP decreases 8%, while the increase in electricity consumption needs to be estimated in a future work by dimensioning all components. As excess water can be produced, the system operation can be optimized for minimizing both heat and electricity consumptions.

BIBLIOGRAPHY

[1] Daou K. et al (2006). Desiccant cooling air conditioning: a review. Renewable & Sustainable Energy Reviews, 10(2), 55-77.

[2] Bellemo L. (2011). New desiccant cooling system using the regenerative indirect evaporative process. MSc Thesis, DTU, Kongens Lyngby.

[3] Bellemo L. et al (2013). Modelling and analysis of a desiccant cooling system using the regenerative indirect evaporative cooling process. ECOS 2013, China.

[4] Goldsworthy M., White S. (2011). Optimisation of a desiccant cooling system design with indirect evaporative cooler. INT J REFRIG, 34(1), 148–158.

[5] Bellemo L. et al (2015). Formulation and validation of a two-dimensional steady-state model of desiccant wheels. Science and Technology for the Built Environment, 21(3), 300-311.

[6] Chant E., Jeter S.M. (1995). On the use of the parabolic concentration profile assumption for a rotary desiccant dehumidifier. J SOL ENERG, 117(1), 45-50.

[7] Goldsworthy M. (2015). Personal communication regarding development of desiccant wheel models. CSIRO Energy Centre, Newcastle, Australia.

[8] Bellemo L. et al (2013). Modeling of a regenerative indirect evaporative cooler for a desiccant cooling system. TPTPR 2013, the Netherlands.

[9] Jiang H. (2003). Development of a Simulation and Optimization Tool for Heat Exchanger Design, PhD Thesis, University of Maryland.

[10] Fang L. et al (2008). Desiccant wheels as gas-phase absorption (GPA) air cleaners: Evaluation by PTR-MS and sensory assessment. Indoor Air, 18(5), 375-385.