Analysis of a solid desiccant cooling system with indirect evaporative cooling

The demand for air conditioning has been consistently increasing worldwide in recent years, concomitantly to the introduction of ambitious energy and environmental targets. As a result, high efficiency air conditioners running on low polluting energy sources need to be developed. This thesis investigates the performance of a solid desiccant cooling system implementing in-direct evaporative cooling processes. The aim is to quantify the system thermal and electrical performance for varying component dimensions and operating conditions, and to identify its range of applicability. This information serves to support the industrial development of the system. Ultimately, the aim is to understand if and to which extent the system is more efficient than electrically and thermally driven chiller-based systems.

The core system components are a silica gel desiccant wheel and a counter-flow indirect evaporative cooler. Detailed steady state numerical models are developed and implemented in MATLAB. The models need to be accurate and require low computational effort, for analysing the internal heat and mass transfer processes, as well as carrying out repetitive design and optimization simulations and seasonal simulations.

The desiccant wheel model is based on the parabolic moisture concentration profile assumption, which enables to consider the resistance to moisture diffusion in the desiccant pores while keeping a low computational effort. The comparison with a validated transient model indicates the parabolic profile assumption is very accurate for wheel rotational speeds up to 20 rph, considering silica gel properties and typical desiccant layer thickness.

The indirect evaporative cooler model is tuned to predict the performance of coolers manufactured by StatiqCooling, according to the manufacturer selection software. Different compositions of the secondary air stream are considered, including partial recirculation of the cooled primary air stream, i.e. dew point cooling, and use of air from a separate ambient. The desiccant cooling system combines the two components, including a compact air-to-air heat exchanger for enhancing cooling capacity and thermal performance. The system performance is investigated considering regeneration temperatures between 50 ºC and 90 ºC, which enable low temperature heat sources, such as solar energy or waste heat, to be used. The effects of several geometrical and operational parameters on the system thermal and electrical performance, supply conditions, and water consumption are investigated. The use of exhaust air from the conditioned space for indirect evaporative cooling provides the most promising results, with thermal COP above 1 and electrical COP above 20. These results indicate the system has a great potential for saving energy in respect to electrically and thermally driven chiller-based system.

An exergy analysis is carried out to identify the most important sources of irreversibility in the system, including the conversion of primary energy sources into heat and electricity. Results indicate that solar energy is utilized more efficiently than fossil fuels for supplying low regeneration temperatures.

In the end, a novel technical solution aiming to make desiccant cooling systems independent of external water sources is introduced. Water desorbed from the desiccant dehumidifier is condensed in a closed regeneration circuit and used to run evaporative coolers. This solution enables the system to run regardless of water availability, and avoids the use of water demineralization equipment, which consumes additional water and increases operational costs and maintenance. These benefits are achieved at the expense of higher electricity consumption, regeneration temperatures, space requirements and investment costs. The solution is analysed for the desiccant cooling system operating with dew point cooling. Mediterranean climatic conditions are considered for seasonal system simulations, with the possibility to store water recovered in excess for operating the system with open regeneration circuit in case of high loads. The system is found independent of external water sources.