Energy and Buildings 108 (2015) 185–194

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Evaluating the potential use of direct evaporative cooling in Australia

Lisa Guan*, Michael Bennett, John Bell

Queensland University of Technology (QUT), 2 George Street, GPO Box 2434, Brisbane, QLD 4001, Australia

ARTICLE INFO

Article history:
Received 6 May 2015
Received in revised form 12 August 2015
Accepted 12 September 2015
Available online 14 September 2015

Keywords:
Climate assessment tool
Direct evaporative cooling
Sensitivity study
Design parameters

ABSTRACT

Greenhouse gas emissions and associated global climate change are a significant and growing concern for the world community. In order to improve building energy efficiency, the use of evaporative cooling systems is attracting growing attention. Using a climate assessment tool, the potential use of direct evaporative coolers over different Australian climates is evaluated. It is found that overall, the potential use of direct evaporative cooling is very significant in Australian climates. Among all the eight capital cities across Australia, except for Darwin, the need of hybrid cooling for other cities is found to be insignificant, and is less than 5% if appropriate air circulation is provided on hot/warm days. It is also found that the potential use of evaporative cooling can be significantly influenced by a change in the applications or design parameters. In Brisbane, it is estimated that with an increase of sensible cooling load from 30 W/m^2 to 40 W/m^2 in the conditioned space, the requirement in hours of hybrid cooling can increase significantly, from 4.06% to 14.89%.

1. Introduction

Evaporative cooling is a process which can be used to cool either air and/or water through employing large enthalpy of water vaporization. The underlying principle is to converse the sensible heat to latent heat during the evaporation of water, causing a decrease in the temperature and an increase in humidity of the surrounding air. Compared to the conventional air conditioning system, it is estimated that evaporative cooling systems may only require around one quarter of the electric power that mechanical vapour compression uses for air conditioning [1]. In addition, evaporative cooling can also offer other significant advantages, including simplicity of operation, low initial and maintenance costs, good indoor air quality (e.g. 100% fresh air ventilation), low pollution and low high-grade energy requirement [2,3].

Broadly, evaporative cooling can be divided into two groups of direct and indirect evaporative cooling (DEC and IEC) [4], which can be used either individually or as part of a more complex setup (i.e. hybrid air cooling systems) as shown in Fig. 1. Although evaporative cooling techniques have evolved over many years, their applications have decreased in recent years due to a number of reasons, including their capacity to respond to external warming conditions and increasing comfort requirements from occupants. To promote the use of evaporative cooling systems and overcome their limitations, in addition to the use of combined direct and indirect evaporative cooling technologies [5], various hybrid air cooling systems have also been designed and used [3,6–16].

A hybrid air cooling system is essentially a combination of evaporative cooling with other passive cooling system (e.g. solar chimney, nocturnal radiative cooling) [3,6–8], active cooling systems (e.g. mechanical refrigeration cooling system, conventional air conditioning system) [9–12] or dehumidifiers (e.g. desiccant wheel, membrane air drying) [13–16]. Previous research has shown that in comparison with a sole conventional air conditioning system, the adoption of hybrid system (e.g. an indirect evaporative cooling combined with a cooling/reheating treatment) may achieve reductions of the energy consumption of the order of 40–60% [9]. Because hybrid air cooling systems inherit the merits of two or more systems, they can potentially extent the suitability of cooling range and achieve higher overall energy efficiency.

For this study, a novel hybrid air conditioner was chosen to demonstrate the benefits of multi-operating modes of low energy direct evaporating cooler [11]. This sample hybrid air conditioner represents a new-generation of evaporative cooling technology with advanced control systems. It not only extends the feasibility of direct evaporative cooling to almost any climate, but also has significantly increased the capacity to use passive cooling. Moreover, the newly developed climate assessment tool [17] was also employed in this paper to assess the performance of this hybrid air conditioner. This tool is not only able to project outdoor air conditions

* Corresponding author.
E-mail address: l.guan@qut.edu.au (L. Guan).

http://dx.doi.org/10.1016/j.enbuild.2015.09.020
0378-7788/

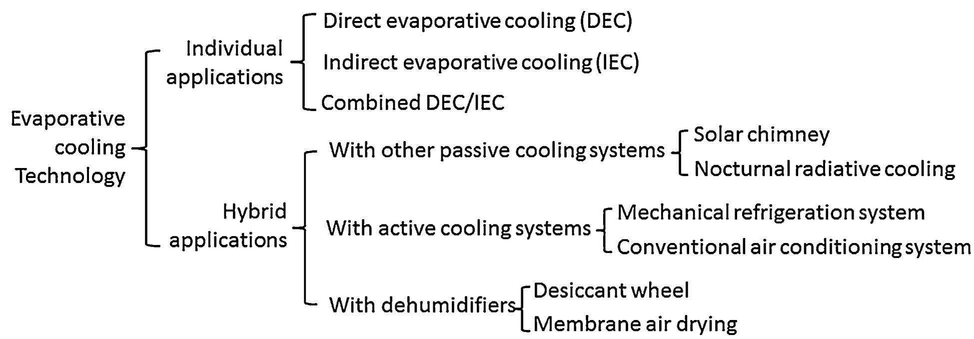

Fig. 1. Classification of evaporative cooling technology.

to different process regions on the psychrometric chart, but also quantifies and estimates the operating hours for each individual operating mode under various climate conditions and thermal comfort requirements. Such a combination of image-data presentation of research results will be able to provide significant new insights and knowledge for the design and operation of evaporative cooling technology. Specifically, with good sensitivity studies and in-depth discussions, this study will also further be able to provide quantified practical advice for the industry and policy makers.

In this paper, the potential use of direct evaporative cooling for Australian climate is investigated. After this introduction, the methodology used in this study is presented, which includes an overview of the performance of a chosen sample hybrid air conditioner, features of the climate assessment tool, the sample base case application, and the scenarios adopted for sensitivity study. Examination of potential use of direct evaporative cooling in all Australian capital cities is also carried out. Sensitivity of design parameters on hybrid air conditioner is further investigated and the opportunities and limitations for hybrid air conditioners in Australia are discussed.

2. Methodology

In this section, the study approach to evaluate the potential use of direct evaporative cooling in Australia is outlined. This includes a description of the sample hybrid air conditioner, the developed climate assessment tool, the base case scenario and the study locations.

2.1. The sample hybrid air conditioner

A sample hybrid air conditioner, developed by the Queensland Department of Public Works, is chosen and shown in Fig. 2. This low energy air conditioner is basically a modified direct evaporating cooler (or air washer), consisting of an open cycle (primary system) – closed cycle (secondary system) cascade system, featuring multiple modes of operation [17,18], including:

- Natural ventilation cooling (i.e. through open windows).
- Forced mechanical ventilation cooling (i.e. supply air fan only – 100% outside air).
- Conventional evaporative cooling (i.e. no refrigeration, so the precooler is at off mode).
- Hybrid cooling (i.e. a succession of stages – evaporative cooling and refrigeration so the precooler is at on mode).
- Mixed heating modes (i.e. supply air fan only with minimum fresh air requirement).

The volume control of supply air is through a damper, which will vary from minimum fresh air requirement to maximum fresh air intake for mechanical ventilation. The conventional direct evaporative cooling is first used for cooling and the precooler is normally at off mode. The precooler is only turned on to cool circulating water for evaporative cooling when extra cooling is needed. The cooling source for the precooler is provided by the conventional mechanical vapour compression refrigeration.

For example, through adopting a set of logic control strategies, the operational mode may be set to natural ventilation mode in very mild climatic conditions. As the climatic conditions change and the indoor environment begins to move away from the pre-determined condition, the operational mode may then be changed to either mechanical ventilation or evaporative cooling or, finally, evaporative with fluid tempering. The recommended control strategies for the hybrid air conditioner are shown in Table 1 [17], where t_{min} is the set point for heating temperature and t_{max} is the set point for cooling temperature. When humidity constraints are applied, e.g. the humidity limit can be either humidity ratio (W_{max}), relative humidity (φ_{max}) or wet bulb temperature (t^*_{max}).

By using such a cascade design arrangement, the system has overcome the major limitations of previous evaporative cooling technology. Particularly, it has provided the necessary control flexibility to enable the changing of operational modes to suit the prevailing climatic conditions, the functional requirements of the building, and the severity of the space thermal load. This allows the energy efficiency of the system to be maximized.

It was found that to achieve the same thermal conditions, the energy use by this low energy cooling system was only equivalent to that of a 7.5 kWr conventional system [11]. This is in comparison with the required capacity of 40.5 kWr of a conventional air conditioning system. This clearly demonstrates the potential benefits of this technology. With large scale applications, it is predicted that the cooling energy requirements of commercial buildings could be reduced by up to 80% by this technology. It is also envisaged that this low energy cooling technology, particularly when used in large building applications, will result in installations that do not require cooling towers, leading to significant energy and water savings. Compared to a typical chilled water or direct-expansion (DX) cooling coil, experimental results showed that direct-contact dehumidification can significantly reduce fan power requirements, static pressure losses, and energy consumption [12].

2.2. The developed climate assessment tool

Based on the consideration of various aspects, including local climate conditions, occupant's thermal comfort, characteristics of specific building and the performance of its evaporative cooling system, a climate assessment tool was previously developed to estimate the performance of the hybrid air conditioner under various operational modes [17]. Although the determination of occupant's thermal comfort was based on the ASHRAE comfort zone, the possible influence of environmental factors (e.g. air humidity and air velocity) and personal factors (e.g. activity level and clothing