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Development of a climate assessment tool for hybrid air conditioner

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ABSTRACT

Australian climate is highly suitable for using outdoor air for free building cooling. In order to evaluate the suitability of hybrid cooler for specific applications, a pre-design climate assessment tool is developed and presented in this paper. In addition to the consideration of the local climate, comfort zone proposed by ASHRAE handbook and specific design of building and operation of hybrid cooler, possible influence from environmental factors (e.g. air humidity and air velocity), as well as personal factors (e.g. activity level and clothing insulation) on occupant's thermal comfort are also considered in this tool. It is demonstrated that with the input of climatic data for a particular location and the associated design data for a specific application, the developed climate assessment tool is able to not only sort outdoor air conditions into the different process regions but also project them onto the psychrometric chart. It can also be used to estimate the hours for an individual operational mode under various climate conditions and summarize them in a table "Results".

1. Introduction

Australian climate is highly suitable for using outdoor air for free building cooling. It was found that except for Darwin, all Australian capital cities have more than 80% of hours when the outdoor temperature is lower than 25 °C [1]. Therefore, the adoption of economizers in air conditioning systems or the use of mixed mode or hybrid cooling systems could have great potential to save considerable cooling energy in Australia. A study by Rowe and Dinh [2] reported that by providing a capability to switch between conventional air conditioning and natural ventilation modes in Sydney, energy consumption can be reduced by up to 67%–75% in comparison with a conventional air conditioning system alone. A low energy hybrid cooling system developed by the Queensland Department of Public Works had also demonstrated that up to 80% of cooling energy can be saved through effectively using outdoor air for free cooling [3].

Based on the different circumstances of building type and comfort criteria, different operational regions may be defined on the psychrometric chart to represent various operational modes. Overall, four basic operational regions of "heating", "no heating and cooling", "evaporative cooling" and "refrigerate cooling" may be defined. Each region can be further divided to more detailed classifications to suit different circumstances. Three examples of such division are shown in Fig. 1.

Generally, the criteria used to classify process regions on the psychrometric chart are based on a set of requirements, including the set points of temperature, limit of air humidity and/or system characteristics. For example, the boundary line between heating region and natural ventilation region (e.g. no heating or cooling is required) is often based on a minimum temperature set point, which can be as low as 9 °C [6] or as high as 20 °C [4]. The boundary line between evaporative cooling and refrigerate cooling may be based on inlet air wet bulb temperature [7] or the system characteristics of evaporative cooling [8]. When the indoor air humidity limit is considered, the humidity ratio or dew point may also be used as a boundary line. It is further found that in addition to the different approaches adopted in the division of process regions, previous studies generally only focused specifically on the assessment of outdoor air temperature and humidity characteristics, without consideration of additional factors which may influence the perception of comfort by occupants and further enhance the applicability of hybrid cooling.

In order to estimate the hours for an individual operational mode under various climate conditions, a climate assessment tool for a hybrid cooler is developed and presented in this paper. For this purpose, a low energy hybrid air conditioner developed by the Queensland Department of Public Works is introduced first. This is followed by a discussion on the methodology, including criteria for assessing thermal comfort, the division of process regions for the

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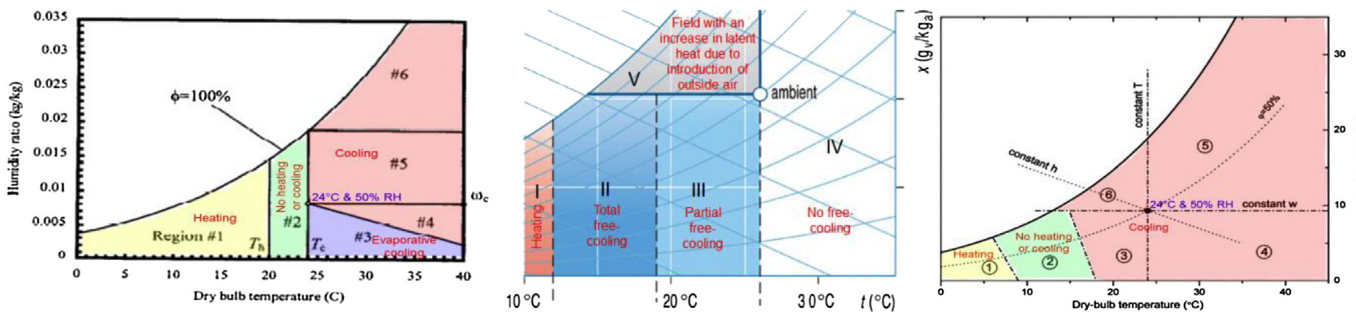

Fig. 1. Division of process regions on psychrometric chart [4–6].

hybrid cooler and the equations adopted for the tool development. Development of a climate assessment tool for the hybrid cooler will then be discussed in details. The application of the climate assessment tool will also be demonstrated and discussed.

2. A sample hybrid cooler

A low energy hybrid air cooler developed by the Queensland Department of Public Works has demonstrated significant potential in regard to energy savings [3]. This is achieved by both introducing free outdoor air cooling and by maximizing the use of conventional direct evaporative cooling. Unlike a conventional evaporative cooler, this low energy air conditioner is a cascade system, consisting of an open cycle, which is the primary system performing conventional evaporative cooling, and a closed cycle, which is the secondary system performing conventional refrigeration. The schematic diagram of this hybrid cooling system is shown in Fig. 2, which has included the following four major sub-systems [9]:

- An air delivery system that delivers (fresh) air from the outside of the space to the inside of the space. This system, therefore, does not rely on the recirculation of the conditioned space air in the cooling operational mode.
- An evaporative process which cools the air passing through the delivery system by the evaporation of water.
- A pre-cooler system which cools the water before evaporation in the primary system, so that during periods of unsuitable ambient wet bulb temperatures the supply air can still be delivered at the desired dry bulb temperature. This considerably extends the application range of the technology.
- A controller that provides multiple modes of operation by activating and deactivating the air delivery system, the primary system and the pre-cooler system, according to predetermined outside and inside temperature thresholds.

The overall design of the system features multiple modes of operation, including [10]:

- 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)
- Hybrid cooling (i.e., a succession of stages – evaporative cooling and refrigeration),
- Mixed heating modes.

3. Principles for climate assessment model development

3.1. Criteria for assessing thermal comfort

The criteria for assessing thermal comfort are based on the thermal comfort zones developed by ASHRAE [11]. As shown in Fig. 3, when the operative temperature is lower than 20 °C, heating may be required, and when the operative temperature is higher than 27 °C, cooling may be required. It is also noted that different criteria may be used to indicate the humidity requirement, either

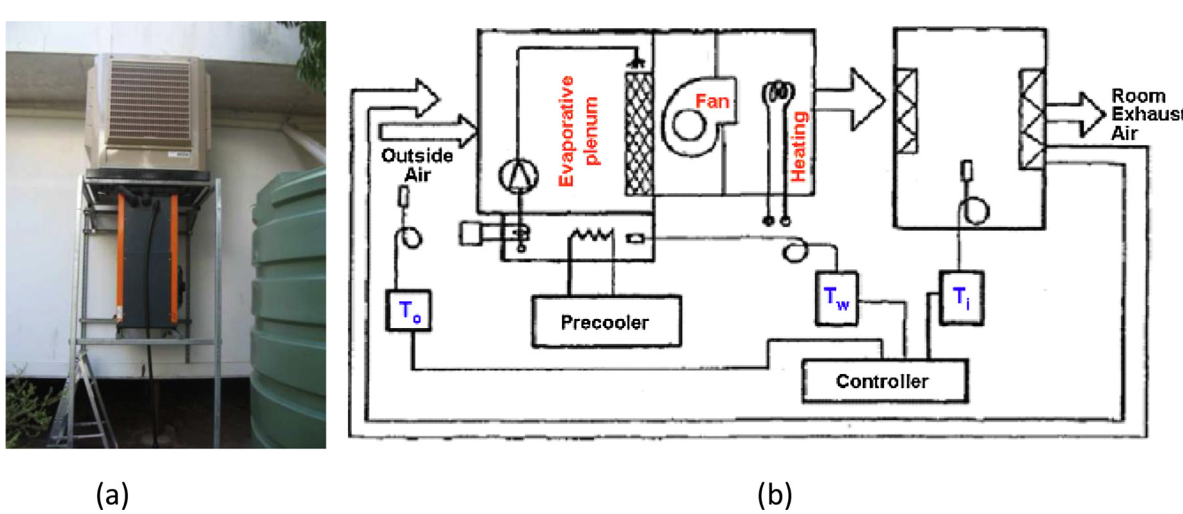

Fig. 2. An on-site photo (a) and schematic diagram (b) of the novel hybrid cooling system.