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Low cost humidity controlled air-conditioning system for building energy savings in tropical climate

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ABSTRACT

The viable solution to the high latent load that naturally occurs in tropical regions requires an alternative system that runs at relatively low energy consumption yet be able to provide indoor thermal comfort by effective handling of the excessive humidity. Although the existing outdoor air treatment system is a proven approach, it is unpopular in developing countries due to its high initial cost. In this paper, a new system termed Dual Air Handling Unit system is proposed to be the answer. The function of Humidity-control Air Handling Unit is to remove the moisture from the conditioned room up to the desired humidity level and in the process the room temperature is also fractionally reduced. The Temperature-control Air Handling Unit completes the task by removing the remaining sensible heat so that the room temperature is maintained at the required set-point. By reducing the relative humidity to 50%, a much lower value than that of the normal air-conditioning could offer, room temperature of the new system is shifted higher to 26 °C in order to reduce the energy consumption. The simulation result shows that the proposed system offers energy savings up to 13.2% compared to the conventional air-conditioning system, without compromising the thermal comfort of the occupants.

1. Introduction

Buildings located in the surroundings of tropical climate are exposed to the considerable amount of solar heat and high humidity. They require a system that could successfully remove both heat and humidity to provide indoor thermal comfort to the occupants. The typical environment of hot and humid weather throughout the year necessitates the continuous operation of air-conditioning without any season break. Since the air-conditioning equipment is the main energy consumer in buildings, more attempts are focused on the improvement related to its usage and operation. There are growing concerns about energy consumption in developing countries such as Malaysia and its implications for the environment [1–4]. High economic and population growth has led to an increase in energy usage in recent years. The contribution from buildings towards energy consumption has steadily increased. Hence, it is crucial to consider new measures for energy conservation from the air-conditioning system point of view.

The yearly temperature of Kuala Lumpur averages at about 31 °C and the relative humidity reading is consistently high, norms at 70% or above. Getting rid of the sensible heat using conventional air-conditioning can be done successfully, but due to design limitations, the same could not be said for latent heat removal. It is the humidity that brings the challenge to the air-conditioning system in the tropical environment. Excessive moisture is the actual cause of thermal discomfort, as also happening in other tropical countries. The incapability of the existing system to reduce the humidity to the presumed level hinders the attainment of the indoor thermal comfort of the occupants. A renowned solution the problem is by having a low-temperature set-point of around 23 °C and by doing so the humidity level is brought down inherently. Unfortunately, the infamous practice is neither comfort cautious nor energy friendly. There is also another way to achieve satisfactory room condition by utilizing the technique of overcooling and heating to the supply air. However, the consequence of having extreme energy consumption makes the option less favorable to the extent that the method is legally prohibited in many countries. As a result, the humidity conundrum remains unsolved, and building energy consumption remains as high.

The effort to overcome humidity problem leads to the innovative method of separate latent cooling. The most popular method is the outdoor air treatment system through desiccant cooling that overcomes the humidity by curing the ventilation air separately before it enters the conditioned room [5,6]. Niu et al. [7] researched the possibility of

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combining the desiccant cooling with chilled ceiling system. With such combination, temperature and humidity control were decoupled by using desiccant wheel for moisture removal and ceiling panels for temperature control. Zhang and Niu [8] researched the system combining chilled ceiling with air dehumidification strategies. It was observed that one hour in advance dehumidification in the summer could eliminate the condensation problems. Ghali [9] designed a hybrid model where the regenerative heat needed by the desiccant wheel was partly supplied by the condenser dissipated heat while an auxiliary gas heater supplied the rest. Compared to a conventional system, the hybrid can reduce annual running cost substantially with a payback period of less than five years. Mumma [10] took the initiatives to study outdoor air pre-conditioning equipment that utilizes passive desiccant wheels, sensible heat exchangers and deep cooling coils. The advantages of the proposed system are lower energy consumption, smaller chiller size and proper zoning ventilation. Kinsara et al. [11] proposed the moist leaving the dehumidification packed bed was dried or re-concentrated in another packed bed and then recirculate back to the dehumidification packed bed. The system proved to be successful as it consumed only about one-thirds of energy compared to the normal air-conditioning system. Yau [12] took the initiative to study dehumidification enhancement through thermosyphon-based heat pipe heat exchanger application. It was observed that the setup could reduce the sensible heat ratio substantially.

While the improved desiccant system certainly effective in doing its job in reducing humidity and energy, the problem that remains unsolved is the equipment cost. The multi-mechanism that exists in the desiccant system renders high initial expense from the procurement point of view. As a result, the installation requires a relatively higher budget than that of normal air-conditioning. Extra financial provision for the initial cost is a major concern thus causing the outdoor air treatment system unfavorable. Therefore, the objective of this paper is to propose a suitable solution by introducing an air-conditioning system that is capable of reducing energy consumption, provides humidity control and thermal comfort yet affordable in terms of equipment cost for new and existing buildings. The research looks into justifying its performance in tropical climate through simulation exercises.

2. Thermal comfort conditions

The perception of comfort varies from one individual to another since there are many factors affecting the thermal sense of human. The key parameters involved are air temperature, humidity, air velocity, physical activity, clothing and duration of occupancy. A widely renowned thermal comfort design basis for air-conditioning is ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) Standard 55 [13] which is established based on 80% acceptability. The comfort boundaries of ASHRAE Standard 55 for occupants with clothing insulation of 0.5 clo and 0.1 m/s air speed is shown in Fig. 1. It is derived from the predicted mean vote (PMV) and predicted percent dissatisfied indices, consistent with the method used in ISO Standard 7730 [14]. As for local design conditions, the outline of thermal comfort design in Malaysia has been initially defined by Malaysian Standard MS1525 in the latest revision published in 2007 [15]. In the standard, the recommended dry bulb temperature is in the range of 23–26 °C while the recommended relative humidity is stated to be between 55 and 70%. These conditions are suggested in provision to the air movement of 0.15–0.50 m/s.

The actual indoor condition of office buildings in Malaysia reveals an interesting scenario. More often than not, the measured indoor temperature presents a much lower value than the standard's recommendation based on various observation reports [16–19]. The findings revealed that the general temperature set-point is around 22–23.5 °C, which in turn gives a measured relative humidity of around 45–65%. It is observed that the presence of high humidity level instigates the

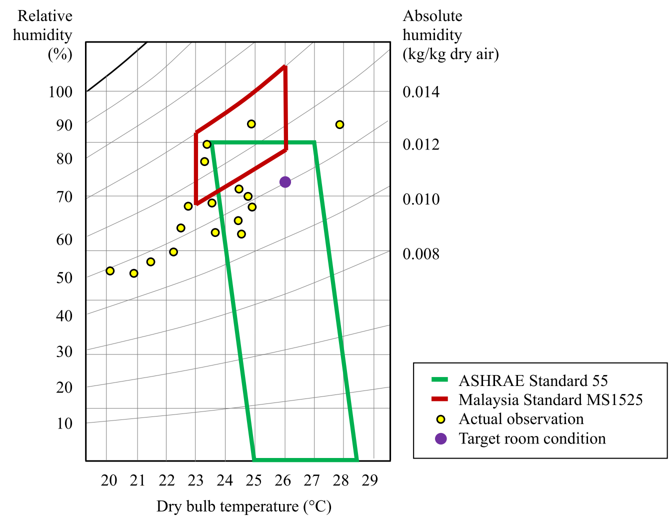

Fig. 1. Thermal comfort zone and room condition.

technique of overcooling to lower the humidity of the room. Normal design of air handling unit being used in most premises does not dehumidify enough unless the temperature is brought down to a low set-point. The situation causes worsening state of thermal comfort for the occupants of the buildings in a tropical climate. They would feel uncomfortable due to the excessive coolness to the extent that additional clothing is required for thermal protection.

The existing comfort zone based on MS1525 is meant for existing air-conditioning system without humidity control. However, the actual room condition does not match the existing comfort zone due to the hindrance of excessive moisture. In the proposed air-conditioning system, humidity control is made available. Therefore, a new room condition is proposed with the caveat of energy consumption and thermal comfort. According to the past research in Table 1, the proposed room condition should be in the region of 25–26.5 °C. For the sake of argument, this paper suggests 26 °C of temperature and 50% of relative humidity as its target room condition. The chosen condition is deemed suitable in terms of energy saving and indoor comfort in a tropical climate. Sekhar has studied the possibility of employing higher temperature set-point of 26 °C in a room of tropical building and its effect on thermal comfort [20]. As shown in Fig. 1, the recommended room condition is well inside the ASHRAE standard zone and should be thermally acceptable. A more thorough inspection through PMV calculation between the actual and proposed room condition is shown in Table 2. As the existing air-conditioning system does not offer any humidity control, the resultant humidity of 63% in the actual room condition is not objective and may differ according to cooling coil performance and room heat gain. The calculated PMV of the real room condition demonstrates that the occupants are exposed to excessive coolness compared to the neutral situation achieved in the proposed room condition.

3. Design concept of humidity controlled air-conditioning system

The new system to be proposed is introduced as Dual AHU and its

Table 1
Past studies of thermal comfort.

Researcher	Neutral value	Comfort range
R. Daghigh et.al [21]	26.1 °C	25.8–26.3 °C
Y.H Yau et.al [22]	26.4 °C	25.3–28.2 °C
Y.H Yau et.al [13]	25.3 °C	23.8–26.6 °C
F. Azizpour et.al [23]	26.6 °C	24.6–27.6 °C