INDOOR HUMIDITY CONTROL WITH DX A/C SYSTEMS IN SUBTROPICAL RESIDENCES

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ABSTRACT

Direct expansion (DX) air conditioning (A/C) systems are most commonly used in residential buildings in hot and humid subtropics. They are normally equipped with single-speed compressors and supply fans, relying on on-off cycling compressors to maintain indoor dry-bulb temperature only, leaving indoor humidity uncontrolled. The reason for this situation is the mismatching between an equipment sensible heat ratio (SHR) and an application SHR. This paper reports a study on this mismatching problem for DX A/C systems used in subtropical residences. With the aid of a building energy simulation program, EnergyPlus, the indoor humidity control problem with two SHRs' mismatching is discussed. An experimental station has been built, humidity control strategy with variable-speed compressor and supply fan is presented; and a complete simulation model representing DX systems, based on the design parameters and test data of the experimental station is developed.

KEYWORDS

DX A/C systems, humidity control, modeling, subtropical residences

1. INTRODUCTION

For residential buildings located in the subtropics, residential air conditioning is very often provided by the use of a discrete system, i.e., room air conditioners (RACs) which are generally of direct expansion (DX) type. In the hot and humid subtropics, it is more challenging and difficult to deal with space latent cooling load than space sensible load, using a RAC. This is partly due to the fact that the current trend in designing a RAC is to have a smaller moisture removal capacity, in an attempt to boost energy-efficiency ratings (EER) and coefficient of performance (COP) (Kittler 1996). This can potentially lead to a situation where a RAC will provide a desired temperature control but not a desired indoor humidity control, which will influence the occupants' thermal comfort, indoor air quality (IAQ) and energy efficiency (Murphy 2002, Westphalen 2004 and Shirey 1993). Sensible heat ratio (SHR), which is defined as a ratio of sensible cooling load to the total cooling load, is an important parameter in studying the ability of cooling and dehumidification for the cooling coil of a RAC. The SHR for an air conditioned space is normally called an application SHR and that for an air conditioner an equipment SHR. An equipment SHR is largely a function of the design of a cooling coil, an application SHR depends mainly on the characteristics of space sensible and latent cooling load (Amrane et al 2003).

A number of reported studies discussed this humidity control issue under part load conditions, and briefly mentioned that the mismatching between two SHRs can significantly influence indoor RH levels using RACs (Murphy 2002, Shirey 1993 and Amrane et al 2003). However, the quantitative analysis for the dismatching between equipment SHR and application SHR and its impacts on indoor humidity control were rarely addressed. For this purpose, With the aid of a building energy simulation program, EnergyPlus, the mismatching problem is analyzed, a multi-purpose experimental station and a complete simulation model representing DX systems, based on the design parameters and test data of the experimental staion is developed. Humidity control strategy with variable-speed compressor and supply fan is presented.

2. INDOOR HUMIDITY CONTROL PROBLEM

A hypothetic 30-story residential block, which was modeled after those widely used in Hong Kong was used as the platform for performing the EnergyPlus simulation study. The apartment facing west, one of a total of eight apartments in a floor, was used in this study. The floor plan of the selected west-facing apartment is shown in Figure 1.

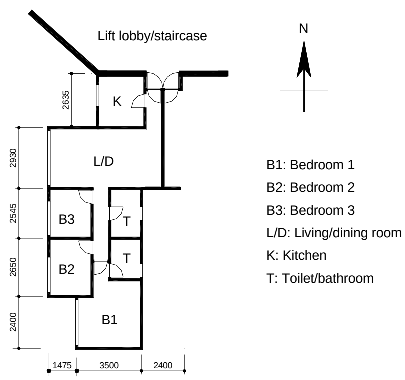

Figure 1: Floor plan of a west-facing apartment under study

The simulation conditions and assumptions, which were the required inputs to EnergyPlus, including construction details, activity levels of occupants, internal heat gain from lights, electric appliances, ventilation rate etc. were previously given (Lin 2004). Some essential details would be described here. It was assumed that this apartment was occupied by a four-person family and the living/dining room was occupied by all family members at daytime; and the master bedroom (i.e., bedroom 1) by the two adults and the other two bedrooms, each by one of the two children, respectively, at nighttime.The living/dining room and all bedrooms were equipped with window-type room air conditioners (WRACs), but no A/C was provided in the toilet/bathrooms and the kitchen. Simulations were performed under two operating modes. One was daytime operating mode (DOM), where the WRAC for the living/dining room operated daily from 7:00 to 21:00. The other was nighttime operating mode (NOM), where the WRAC in the master bedroom operated daily from 22:00 to 6:00. According to ASHRAE (ASHRAE 2004) and HK-BEAM (HK-BEAM 2001), 24°C and 50% RH were selected as the indoor setpoints. The outdoor cooling design conditions with summer design day for Hong Kong were used (Lam 1995).

Figure 2 shows the profiles of hourly space sensible and latent cooling loads for the living/dining room at DOM in the summer design day. It can be seen that the space latent cooling load stayed almost constant except for the first hour due to pull-down load at the beginning of DOM, the sensible load varied significantly and peaked at 17:00. Over all the operating hours, the hourly application SHRs ranged between 0.55 and 0.72, with an average being 0.63 which was smaller than 0.7-0.8, the equipment SHR for a standard DX WRAC (Kittler 1996, Amrane et al 2003). This implied that for subtropical residences, their application SHRs would be lower than the equipment SHRs if standard WRACs were used. Figure 3 shows the simulated indoor air RH levels at the three different equipment SHRs (0.65, 0.75 and 0.85) in the living/dining room in the summer design day. It is understood that air conditioners with different equipment SHRs would have the different ability to handle space sensible and latent loads. The smaller an equipment SHR of a RAC is, the larger its ability to deal with space's latent cooling load.

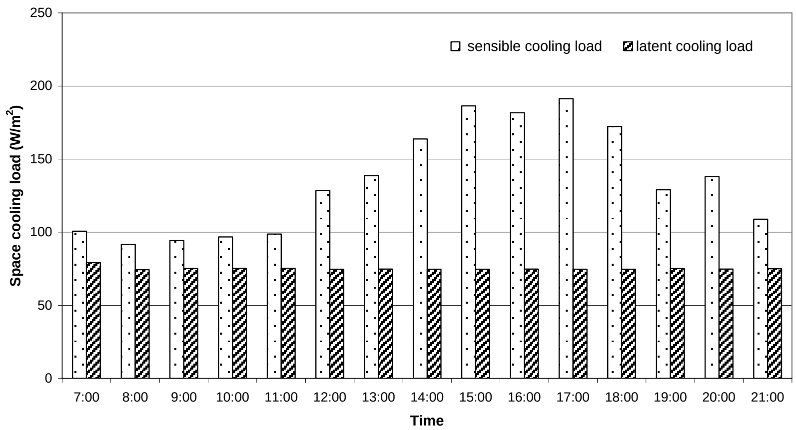

Figure 2: Profiles of hourly space sensible and latent cooling loads for the living/dining room at DOM in the summer design day

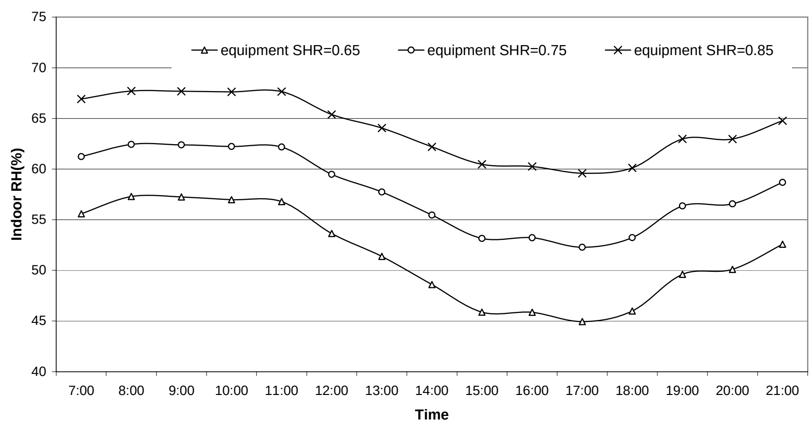

Figure 3: Indoor RH levels at different RAC's equipment SHRs in the living/dining room at DOM in the summer design day

Figure 4 shows the profile of both hourly space sensible and latent cooling loads for the master bedroom at NOM in the summer design day. It can be seen that while the sensible cooling load varied significantly with its peak occurring at the beginning, space latent load stayed relatively constant except for the first hour due to pull-down load at the beginning of NOM. Moreover, the hourly application SHRs for the bedroom ranged between 0.6 and 0.85, with an averaged value being 0.69. Figure 5 shows the indoor air RH levels at three different equipment SHRs (0.65, 0.75 and 0.85) in the master bedroom at NOM in the summer design day. It can be seen that there were also noticeable differences in the resulted indoor RH levels when RACs with different SHRs were used. Given that the averaged application SHR was 0.69, the use of a RAC with its equipment SHR being 0.85 would cause the indoor RH level to deviate more from the setting of 50% RH than the use of the RAC with their equipment SHRs being closer to 0.69.

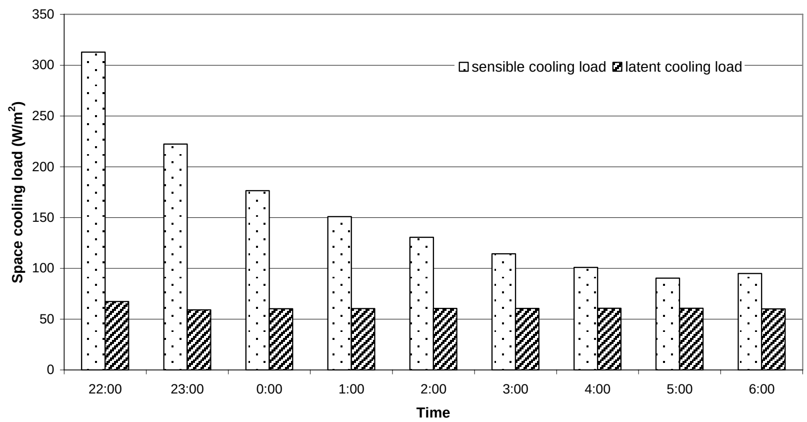

Figure 4: Profile of the hourly space sensible and latent cooling loads for the master bedroom at DOM in the summer design day

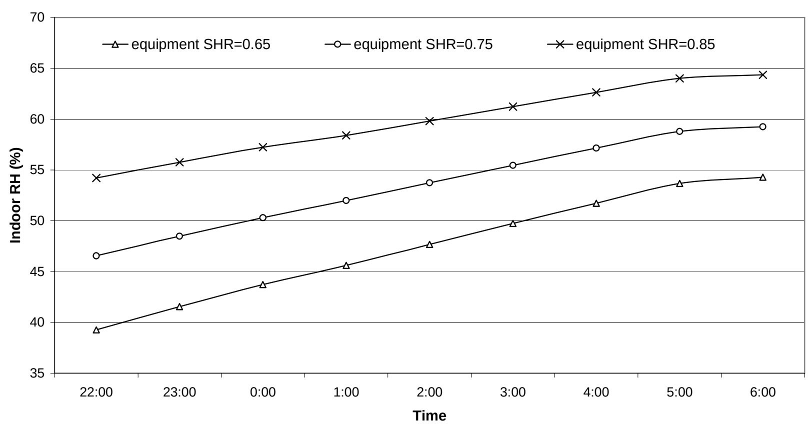

Figure 5: Indoor RH levels at different RACs' equipment SHRs in the master bedroom at NOM in the summer design day

3. DESCRIPTION OF EXPERIMENTAL STATION

A multi-purpose DX VAV A/C experimental station has been set up in the HVAC Laboratory of Building Services Engineering (BSE) Department of the Hong Kong Polytechnic University. The schematics of the air handling system and DX refrigerant plant of the experimental station are shown in Figure 6 and Figure 7, respectively. In the DX refrigerant plant, there is a condensing unit comprising of a rotor compressor driven by variable speed drive (VFD), an air cooled condenser with its axial fan driven by VFD. An electronic expansion valve (EEV) is used in the station. The refrigerant used is R22. The nominal cooling capacity is 10 kW and its modulation range is 30 to120% of the normal capacity. The air handling system includes an air handing unit (AHU) and an air conditioned room. Inside the AHU, the evaporator of the DX refrigerant plant is placed to be used as a DX air cooling coil. The supply fan in the AHU is of centrifugal type and VFD-driven. There are two sensible heat and moisture load generation units (LGU) inside room. Sensible heat and moisture load can be varied manually or automatically with the pre-set pattern by operator's programming.

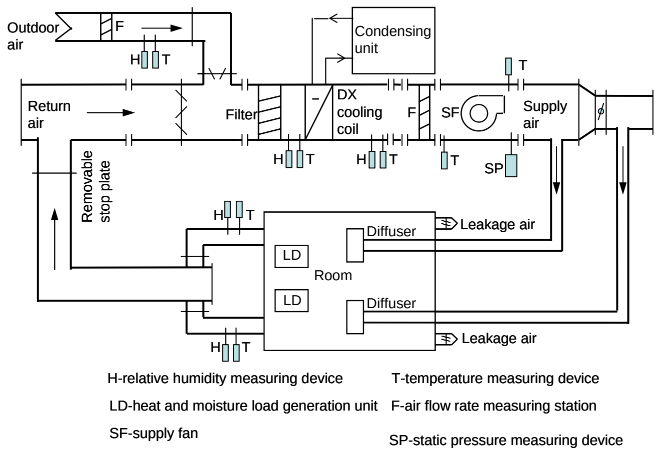

Figure 6: The schematic of the air handling system of the experimental station

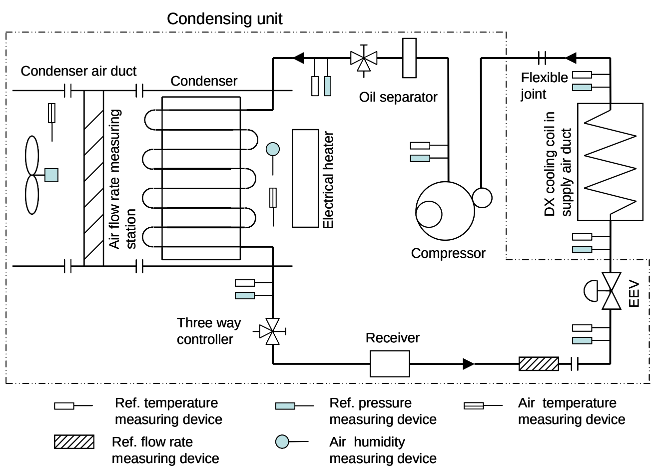

Figure 7: The schematic of the DX refrigerant plant of the experimental station

4. **DYNAMIC MODELING FOR DX SYSTEMS**

A complete dynamic simulation model representing a DX system, based on thermodynamic principle and test data of the experimental station, is developed. The complete system's simulation model is component-based, and takes the dynamic characteristics of a DX refrigeration plant into consideration. The complete conceptual model which depicts the zoning of the DX system is shown in Figure 8; each zone is treated as a stirred tank. The well-known A.C. Cleland Equations and air state equations recommended by ASHRAE are used to describe various thermodynamic and thermophysical properties of refrigerant and air, respectively. During the modeling of compressor, a polytropic compression process is assumed and a quasi-steady model is established by the traditional theoretical thermodynamic approach. EEV is represented by an orifice equation, and a varying valve opening that was modulated by refrigerant superheat at evaporator exit. The evaporator refrigerant side is basically divided into two regions: a two-phase region and a superheated region. The two-phase region is further divided into liquid and vapor zones. The counter-flow heat exchange between the refrigerant and the air is assumed for the air-cooled plate-fin-tube condenser. Discharged vapor from compressor is delivered into the vapor zone, the boundary layer and the liquid zone.

With this model and experimental station presented in Section 3, the investigation of humidity control with varied-speed compressor and supply fan could be carried out.

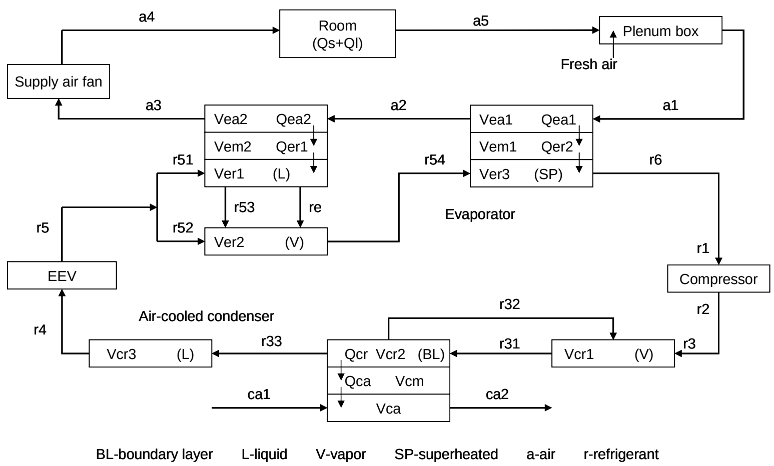

Figure 8: The conceptual model of the DX system

5. CONCLUSION

With the simulation results, for residential buildings located in hot and humid subtropics, the average application SHR was 0.63 and 0.69 for DOM and NOM, respectively, which were smaller than 0.7-0.8, the equipment SHR for a standard DX WRAC. This mismatching leaded to a situation that RH levels would be higher than the setpoint of 50%. The control strategy based on varied-speed compressor and fan would improve the humidity performance. The related experimental and simulation study will be reported in the future work.

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