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CHALLENGES AND DEVELOPMENTS OF SUBTROPICAL RESIDENTIAL AIR CONDITIONING

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ABSTRACT

In the subtropical regions such as Hong Kong, residential air conditioning is usually by using unitary air conditioners of direct expansion nature, to beat both heat and moisture, not only at daytime but also at nighttime for providing occupants with a thermally suitable living and sleeping environment. This paper firstly presents the major challenges faced by subtropical residential air conditioning such as indoor humidity control and issues related to nighttime residential air conditioning. This is followed by reporting recent developments in subtropical residential air conditioning including nighttime air conditioning ventilation and novel control algorithms for simultaneous indoor air temperature and humidity control using direct expansion (DX) systems in residences in the subtropics.

1. INTRODUCTION

With the increased level of living standard, people's expectations for thermal comfort are also increased. Consequently, the demand for residential air conditioning has significantly arisen for the last few decades. In the Hong Kong Special Administrative Region (HKSAR), China, due to its sub-tropical climates, air conditioning in residences is usually required for up to eight months and the use of residential air conditioning has become very popular. This results in both an increased annual total residential energy use and an increased share of its weighting in the total annual energy consumption, in Hong Kong, as shown in Figures 1 and 2, respectively.

It is well known that residential air conditioning is in general simple in its configuration; normally being direct expansion (DX) packaged units, i.e., window types or split type air conditioners. Because of their simple configuration, lower initial costs and suitability for energy consumption apportionment by individual end-users, they are widely used in residences in the sub-tropical Hong Kong. (Figure 3 and 4)

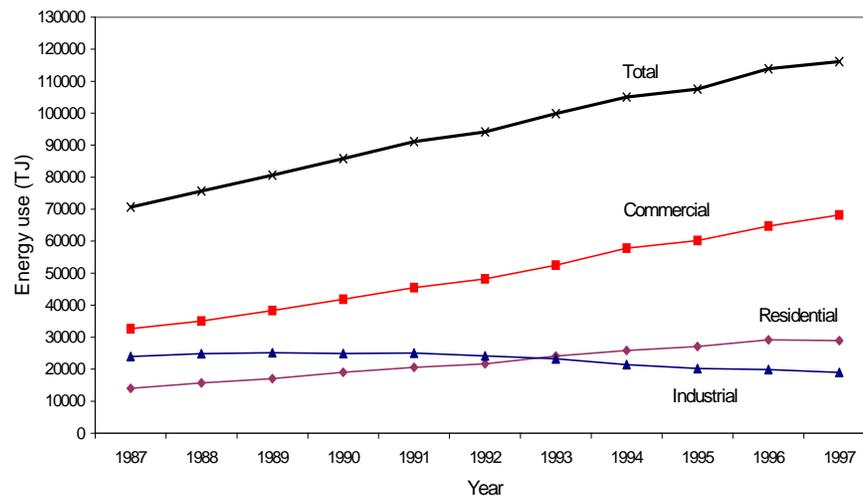


Figure 1. Energy consumption in Hong Kong by different sectors (1987-1997)

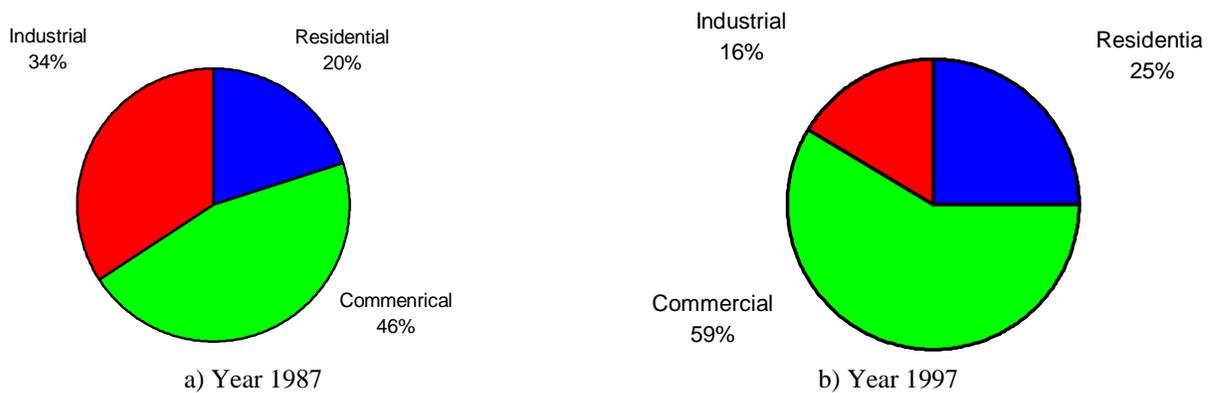


Figure 2. Breakdown of energy consumption in Hong Kong by different sectors (87 and 97)

Nonetheless, when compared to large scaled air conditioning installations in commercial buildings or other types of large buildings, packaged residential DX systems are under developed. Although millions of residential air conditioners are manufactured annually, their fundamental structures and controls remain very much similar to the technology decades ago. Certain manufacturers may have well made important improvements to their products, these are not easily identifiable in open literatures. This actually restricts their further developments.



Figure 3 Installed window type air conditioners



Figure 4 Installed outdoor units of split type air conditioners

2. CHALLENGES

Currently in the subtropics, there are a number of challenges for DX-based residential air conditioning. These include:

- Indoor fresh air supply;
- Indoor humidity control using on-off cycling compressor based only on indoor dry-bulb temperature;
- Air conditioning for sleeping environments for residential buildings served by DX air conditioning: thermal comfort criteria and cooling load characteristics at night;

- Without affecting indoor thermal comfort, developing new control strategies to minimize the energy use for residential air conditioning.

2.1 Indoor Fresh Air Supply

In Hong Kong SAR, under its sub-tropical climates, there is no organized fresh air supply for DX based residential air conditioning, which is particularly true for the residences using split-type air conditioners. The sources of fresh air include infiltration of outdoor air through gaps or leaks in building envelopes and/or random opening of doors or windows. This is probably acceptable for daytime air conditioning (i.e., non-sleeping hours) in residences, however this is less acceptable during sleeping hours. Furthermore, as the most important single indoor moisture source in residences is outdoor air, un-organized fresh air supply would certainly cause problem to indoor humidity control and impact on energy use by air conditioning.

2.2 Indoor Humidity Control Using on-off Cycling Compressor Based on Indoor Dry-bulb Temperature

As shown in Figure 5, in the residences in sub-tropic Hong Kong, a simulation study has suggested that indoor moisture load is mainly from outdoor air, accounting for over 80% of the total moisture load. On the other hand, indoor moisture load would significantly vary with the changes of season. As illustrated in Figure 6, space Sensible Heat Ratio (SHR) is changeable with season. SHR can be lower than 0.5 in the wettest April and higher than 0.7 in the relatively dry month of October.

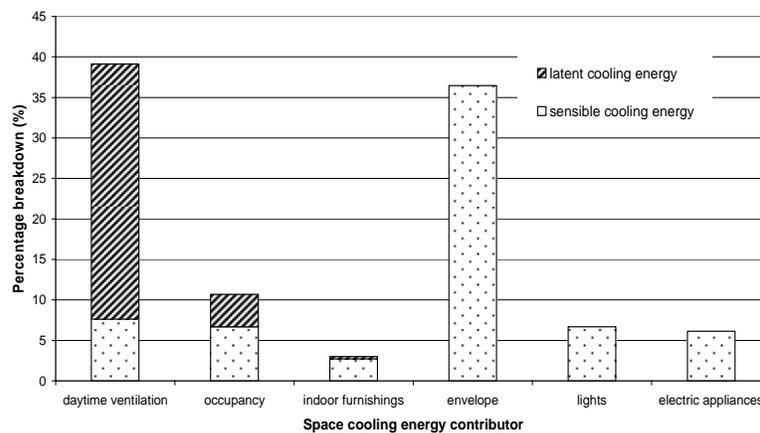


Figure 5 Simulated percentage breakdown of the daytime air conditioning load / energy use in a living room

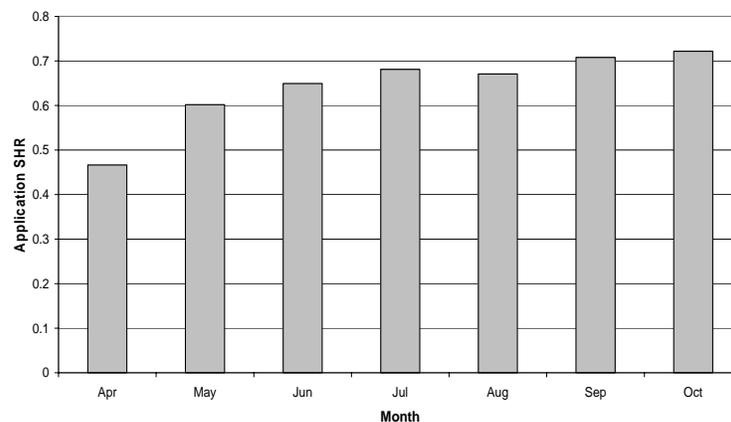


Figure 6 Simulated nighttime space SHR from April to October in a bedroom

Since the indoor moisture load is mainly from fresh air which is in turn dependent on the number of occupants, it is not realistic to significantly reduce the indoor moisture load. On the other hand, building energy saving measures mainly focus on reducing indoor sensible loads including such measures as improving the thermal performance of building envelope and employing energy efficient luminaries to reduce heat gain from lighting system. Ironically, for DX based packaged air conditioners, the increasingly stringent requirements on their energy efficiency significantly lower their ability to dehumidify, leading to mismatches of both sensible and latent load between space and equipment.

Furthermore, under on-off control, condensate retained on the surface of a cooling coil during on-period may re-evaporate during its off-period when the cooling coil stops dehumidifying and the supply fan is normally still in operation, flowing back to a conditioned space and increasing its humidity level.

2.3 Air Conditioning for Sleeping Environments in Residences Served by DX Air Conditioners

In the sub-tropical Hong Kong SAR, during its long summer, outdoor air relative humidity remains high and the diurnal variations of ambient temperatures are comparatively small, the use of air conditioning to maintain a thermally acceptable sleeping environment has become widely spread. On the other hand, the so called “air conditioning quilts” are available in the local market and recommended for use in an air conditioned sleeping environment. Why so? The outcomes from a number of questionnaires surveys suggested that in Hong Kong, actual averaged indoor air temperature in air conditioned sleeping environments was at about 22 °C. Therefore it appeared reasonable to use “air conditioning quilts”. However the question that remains to be asked is why indoor air temperature is set at 22 °C, but not at 25 °C or above. This may be explained by the fact that for an on-off controlled DX air conditioner, if the setting of its thermostat is high, the conditioner would probably be at its off-period for a prolong period of time, so that the effect of indoor dehumidification is impaired. Therefore setting indoor air temperature at 22 °C or even lower for better passive dehumidification becomes common and the use of “air conditioning quilts” becomes normal.

2.4 Energy Consumption by Residential Air Conditioning

As mentioned earlier, residential energy use is increased on an annual basis in Hong Kong. The main reason for this is the significant increase of the energy use by residential air conditioning. Amongst a number of factors affecting the residential air conditioning energy use, indoor humidity control plays an important role. When active humidity control can be hardly achieved, passive humidity control by lowering indoor air temperature becomes common so as to increase the run time of an air conditioner. In doing so, indoor sensible load is unnecessarily increased, leading to more energy use. On the other hand, when fresh air supply is not properly organized, over supply of fresh air would also lead to excessive energy use. This also applies to a sleeping environment. When a person is asleep, both his activity level and metabolism level are lowered. Then, does the person when sleeping still need the 7.5 L/s fresh air supply as recommended by ASHRAE?

3. DEVELOPMENTS

Research related to the challenges described above has been undertaken and is briefly introduced as follows.

3.1 Air conditioning for sleeping environments

Studies showed that the space cooling load characteristics for nighttime air conditioning are significantly different from those for daytime air conditioning. Based on the weather conditions of, and the typical layouts of high-rise residential blocks in Hong Kong, a simulation study using EnergyPlus building energy simulation package resulted in the space load characteristics for four bedrooms facing four different orientations during nighttime air conditioning, as shown in Figure 7. It may be seen from the figure that all peak loads occurred at the start of a nighttime air conditioning process, irrespective orientation. This is clearly different from the timing of peak load occurrence for daytime air conditioning, which is believed to be related to the heat gained due to temperature difference and solar radiation and stored in building envelope and furniture, leading to a large starting load.

Furthermore, with proper modifications to Fanger’s daytime thermal comfort equation, a thermal comfort equation applicable to sleeping environment has been established and comfort lines for sleeping environments in Hong Kong developed, as illustrated in Figure 8. I_t in the diagram represents the equivalent thermal resistance of a “bedding system” including a bed itself, sleepwear and quilts /blankets. As can be seen from the figure, at a lower I_t , indoor air dry bulb temperature may be set at a higher value, which shows the inappropriateness of using the so called air conditioning quilts.

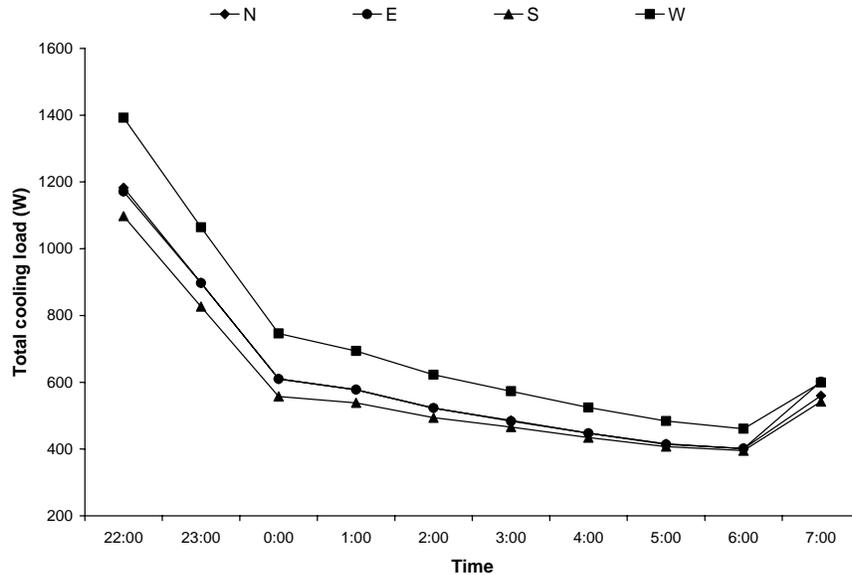


Figure 7 Hourly profiles of the total cooling load for the bedrooms facing four different orientations in the summer design day at nighttime air conditioning

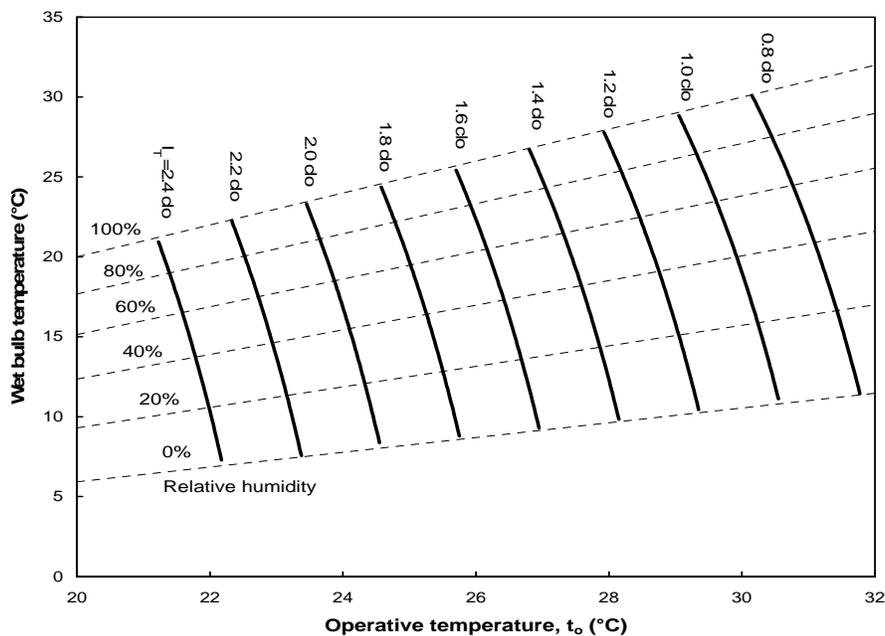


Figure 8 Comfort lines with an air velocity not greater than 0.15 m/s for sleeping environments in Hong Kong

With regards to fresh air supply during nighttime air conditioning, after considering an occupant's adaptation to his sleeping environment and lower metabolism level, fresh air supply may be theoretically lowered to 1.5 L/s/person. However, a design value of 3 L/s/person has been recommended.

3.2 A novel controller using SHR as a controlled variable for simultaneous indoor temperature and humidity control

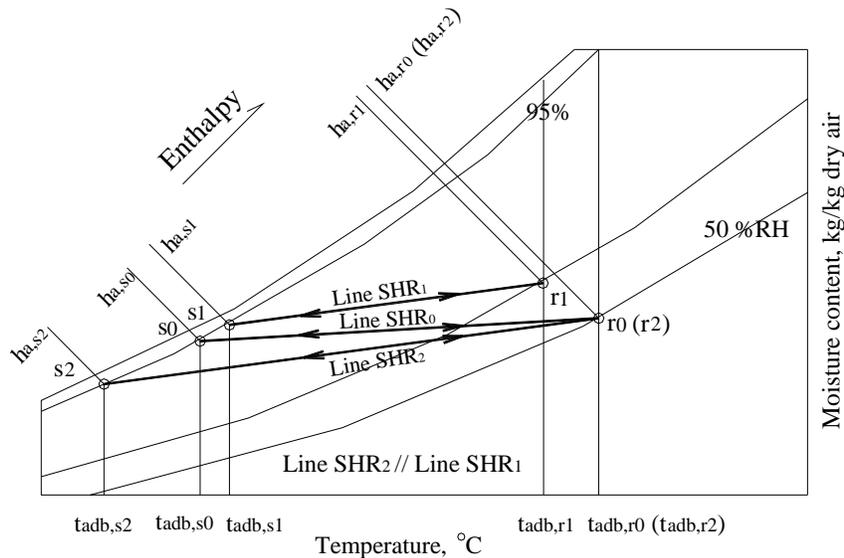


Fig. 9 Control algorithms shown on a psychrometric chart

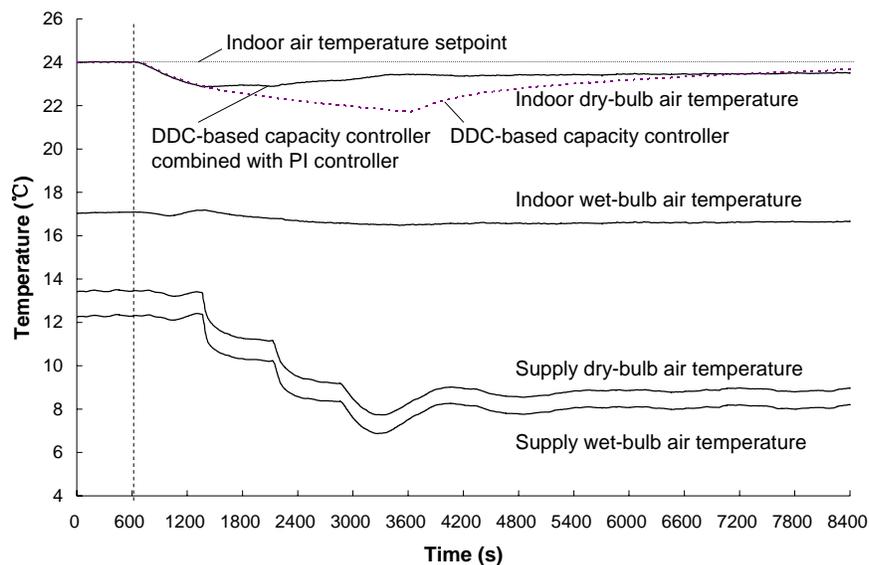


Fig. 10 Air temperature variation profiles

Studies have shown that for a DX air conditioner having a variable speed compressor and a variable speed supply fan, simultaneous varying both speeds can alter the total cooling output and its equipment SHR. Therefore a novel DDC-based controller using SHR as a controlled variable for simultaneous indoor temperature and humidity control

has been developed. Its control algorithm is shown in Figure 9. The controller is developed based on the energy balance between the air side and refrigerant side, using a number of real-time measured system operating parameters to calculate the required fan and compressor speeds. Preliminary controllability tests showed that such a control is operational with acceptable control accuracy but relatively poor control sensitivity. Therefore, the controller was improved by incorporating a traditional PI control loop. Further tests showed that such an improved controller can achieve both control accuracy and sensitivity, as shown in Figure 10 and 11, respectively.

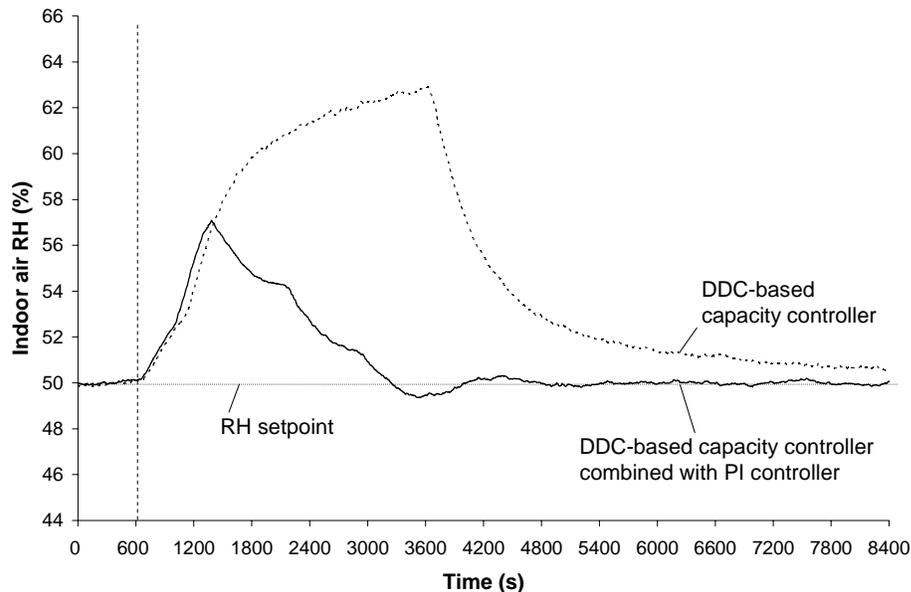


Fig. 11 Indoor air RH variation profiles

4. CONCLUDING REMARKS

This paper has briefly introduced the challenges faced by and recent developments in residential air conditioning in the subtropics such as Hong Kong SAR. It may be said that related research work on DX based residential air conditioning in the subtropics is far from adequate and further work is surely required.

ACKNOWLEDGEMENT

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