A STUDY OF THE IAQ OF RESIDENTIAL BUILDINGS IN SINGAPORE

NH Wong*, BRJ Huang, KW Tham, C Sekhar and DKW Cheong

Dept. Of Building, School of Design and Environment, National University of Singapore, Singapore

ABSTRACT
IAQ measurements were carried out in 3 residential dwellings in Singapore to find out the indoor air quality of the bedrooms. It was found that when the subjects utilized air-conditioners while sleeping, there was a considerable build-up of carbon dioxide (>1000ppm) for all types of air-conditioners. These CO_2 levels were substantial higher as compared to naturally ventilated bedrooms. A survey was also conducted to investigate whether occupants exhibited Sick Building Syndrome (SBS) symptoms while sleeping in air-conditioned as well as naturally ventilated bedrooms. A comparison showed that almost all occupants who used air-conditioners while sleeping exhibited one or more SBS symptoms and these occupants usually displayed more SBS symptoms after using air-conditioning than when they utilised natural ventilation. The survey also revealed that the frequency and duration of usage of air conditioning has important impact on the exhibition of the SBS symptoms.

INDEX TERMS
IAQ, residential buildings, Sick Building Syndrome (SBS), subjective evaluations

INTRODUCTION
Singaporeans are becoming more affluent as the nation transcends from a developing to a developed country status. In 1998, a study showed that 57.7% of Singaporeans possess air-conditioners in their homes as compared to 19.4% in 1988 (Department of Statistics of Singapore 2000). Increasingly, Singaporeans staying in public housing (about 86%) are also utilizing air-conditioners and there seems to be a trend towards the use of air-conditioners to alter the thermal conditions within the home, especially while sleeping. The air-conditioners that are used in domestic homes are different from the ones used in office buildings. They are mainly the multi-split or window units. Most of these domestic air-conditioners have no fresh air intake and this could affect the IAQ of the bedrooms significantly. Thus, there is a need to measure the IAQ of residential flats in Singapore to determine the impact of the use of air-conditioners while the occupants are sleeping and compare to that in naturally ventilated conditions.

The main objectives of this study are:

1. To determine the IAQ status of the residential bedrooms in both air-conditioned(AC) and naturally ventilated(NV) bedrooms.
2. To find out whether SBS is more prevalent in NV or AC environments in residential homes (WHO 1993).
3. To identify the common SBS symptoms that the occupants exhibit in both naturally ventilated and air-conditioned environment.

* Contact author email: bdgwnh@nus.edu.sg

4. To determine the relationship between the frequency and duration of usage of air-conditioner and the types or prevalence of SBS symptoms.

METHODS

In order to ascertain the IAQ of the residential flats, 3 similar public residential units were selected for the study. Table 1 shows the information about the 3 residential units under investigation. For each residential unit, the following equipments were deployed to measure the various IAQ parameters (Hill et al 1992). These include:

- Q-Trak IAQ Monitor Model 8550/8551 - to measure the carbon dioxide, relative humidity, carbon monoxide and room temperature. Sampling of the parameters were done using automatic logging every minute over at least 8 hours overnight.
- Dust Trak Model 8520 - to measure the aerosol content within the room. Sampling was done using automatic logging every minute over at least 8 hours.
- Anemomaster Model 8061 - to measure the wind velocity within the bedroom. Sampling was taken hourly.
- Single stage Anderson sampler – to collect the sample for bacteria and fungi. Sampling was done at 3 intervals: when the air-conditioner was switched on, 3 hours after the air conditioning was switched on and at 8am in the morning.

Table 1. Data on the residential units under investigation

Flat Type	*Location*	*Types of air conditioning system*	*Photos of air conditioning system*	*Floor height*	*Measuring Period and Time*
5 room	Telok Blangah Rise	Vertical casement (no fresh air intake)		8th	June 22nd,23rd, 24th & 25th 10pm-8am
5 room	Bukit Merah Central	Window unit • Air vent opened • Air vent closed		18th	July 2nd & 3rd 10pm-8am
5 room	Bukit Merah Central	Portable air conditioner (with fresh air intake)		18th	July 2nd & 3rd 10pm-8am
5 room	Yishun Avenue 7	Multi-split air conditioner (no fresh air intake)		16th	July 5th & 6th 10pm-8am

All the equipments were positioned in the middle of the room at a height of 1.2m according to the measuring parameters set out by the guidelines for indoor air quality in offices for small areas (Ministry of Environment 2001). For each residential unit, the measurement was conducted simultaneously in two bedrooms, one with the air conditioning on and the other naturally ventilated.

For the subjective measurement, a questionnaire survey was formulated to find out the IAQ perception of the occupants and whether they exhibited any SBS symptoms in NV and AC dwellings. A total of 300 questionnaires were sent out to the residents staying in the similar residential units and 105 responded.

RESULTS

Objective Measurements

Carbon Dioxide (CO_2) Profiles and Concentration Levels

Figures 1a-d show the CO_2 profiles and concentration levels of the bedrooms utilizing the different air conditioning systems. Each of the figures also shows the corresponding CO_2 profiles and concentration levels of the bedroom utilizing only NV. From the figures, it can be seen that the CO_2 levels of those bedrooms utilizing AC are consistently higher than those utilizing NV. For those air-conditioners with no fresh air intake, the CO_2 level can reach about 1600 ppm. The figures also show that for the window unit, when the air vent was opened, the CO_2 level reduced from about 1200 ppm to about 1000 ppm. In the case of Portable air-conditioner, the CO_2 levels hover around 750 to 800 ppm. For NV bedrooms, the CO_2 levels for all bedrooms were about 550 to 600 ppm.

Figure 1a: Vertical Casement Air conditioner

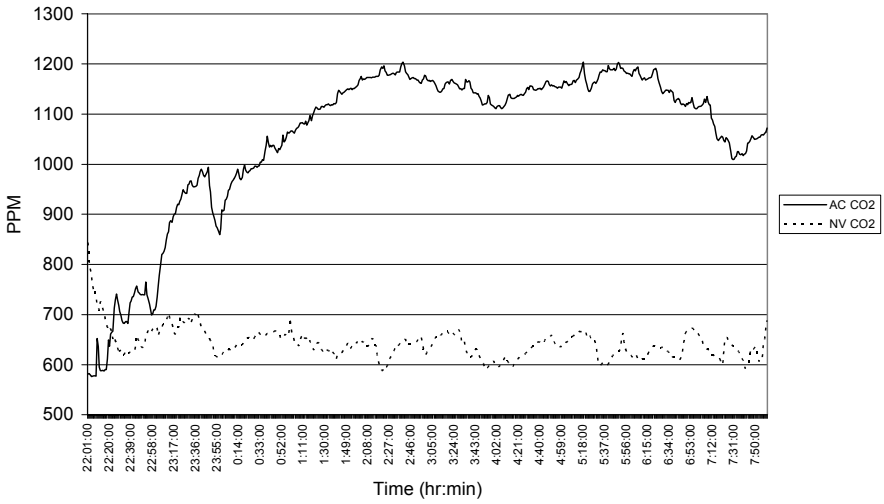


Figure 1b: Window Unit(vent opened and closed)

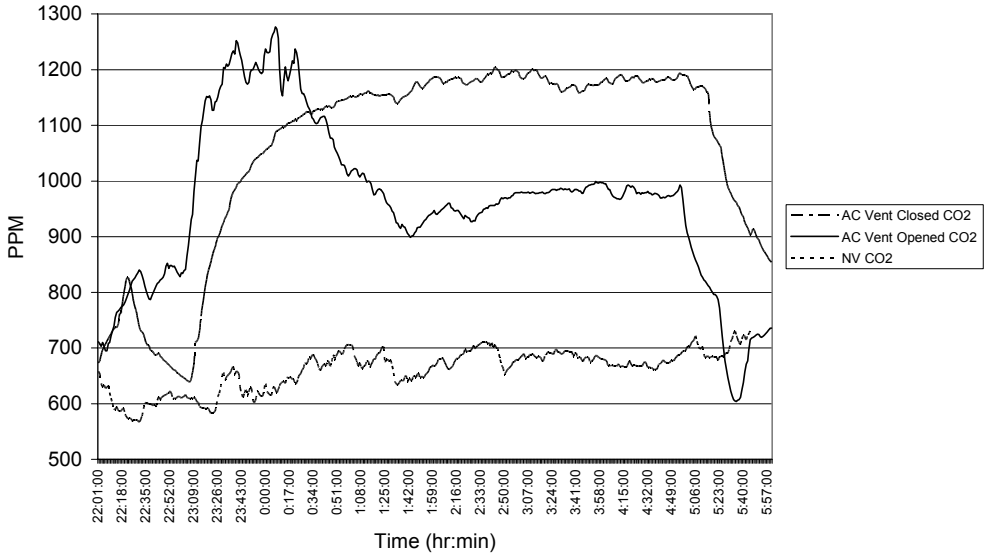


Figure 1c: Portable Air Conditioner

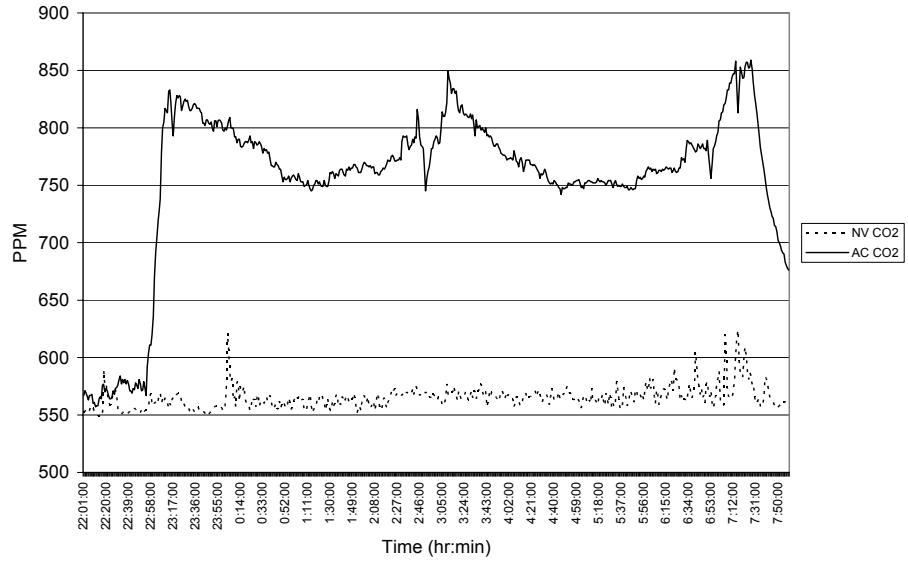
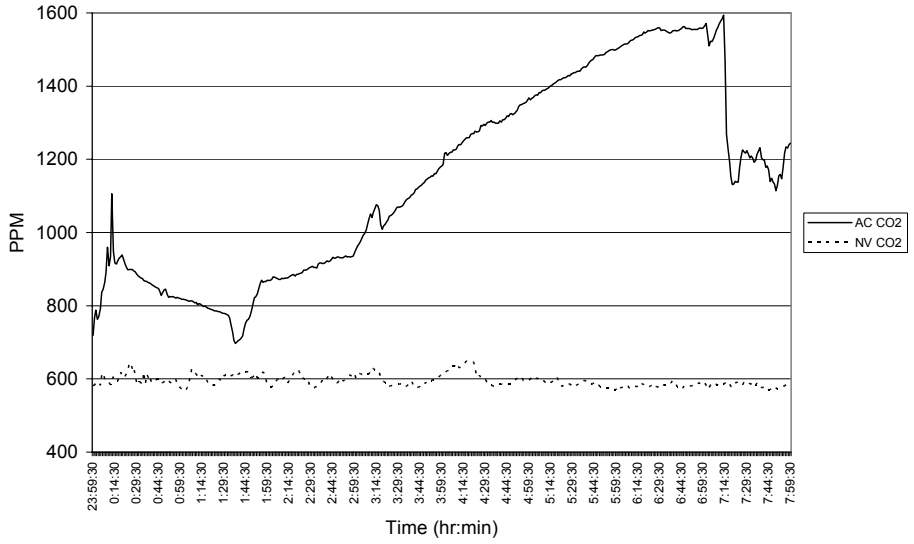


Figure 1d: Multi-split air conditioner



Figures 1a-d: Comparison of CO_2 profiles of bedrooms using different air-conditioning systems and natural ventilation

Temperature and Relative Humidity (RH) Profiles

For NV bedrooms, the temperatures recorded ranged from 29 to 30^{o}C and the RH 70 to 75%. For AC bedrooms, the temperatures vary from 23 to 28 ^{o}C even though all the air-conditioners were set at 22 ^{o}C. The results showed that when the air vent was opened, the initial temperature was higher than when the air vent was closed. However, after few hours, the temperature became similar. For the portable air-conditioner, the temperature was only marginally lower than the NV bedrooms. For RH, the fluctuation was very high for most air-conditioners showing the constant dehumidification by the air-conditioners to remove the moisture produced by the occupants.

Particulate Profiles

The results showed that the particulate levels were higher for NV bedrooms than AC bedrooms. For NV bedrooms, the levels varied from 40 to about 80 μg/m^3. For AC bedrooms, the levels varied from 40 to about 70 μg/m^3. The results also showed that the particulate level for NV bedrooms is only marginally higher for AC bedrooms with fresh air intake.

Subjective Evaluations

Comparison of SBS Symptoms between NV and AC

Figure 2 shows that NV homes had lesser occurrences of SBS symptoms than AC homes. For those homes utilizing natural ventilation, about 48% of the occupants did not exhibit any SBS symptoms whereas for those using air-conditioners, only 17% did not exhibit the symptoms. The most common symptoms exhibited by the occupants using AC include dry eyes, blocked nose, running nose, dry throat, flu like symptom and dry skin. Figure 3 shows the relationship between frequency of usage of AC and the occurrence of SBS. It was intriguing to discover that for those who switched on their air-conditioners daily, they actually had lesser occurrences of SBS than for those who switched on their air-conditioners irregularly (other than "daily"). For those who switched it on daily, they had the highest percentage of people who displayed "no symptoms" (27.78%). One possible explanation for such a phenomenon could be that the occupants had acclimatised themselves to the air-conditioned environment after a period of time.

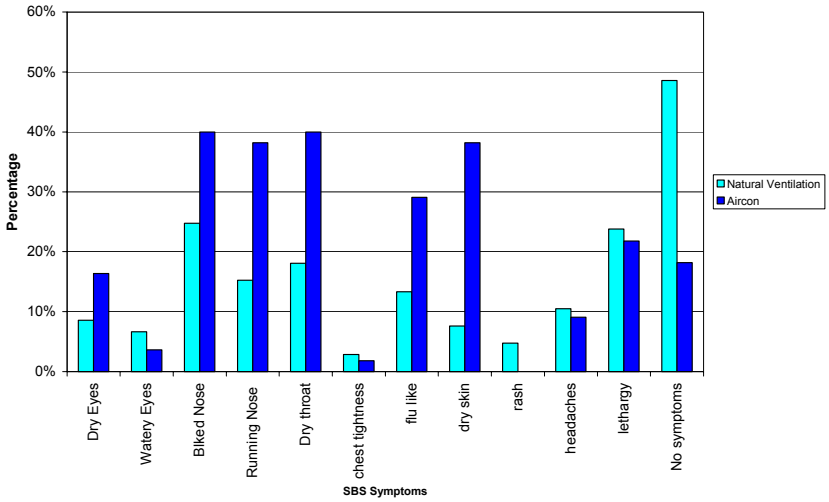


Figure 2: Comparison of the SBS symptoms between NV and A/C residential units

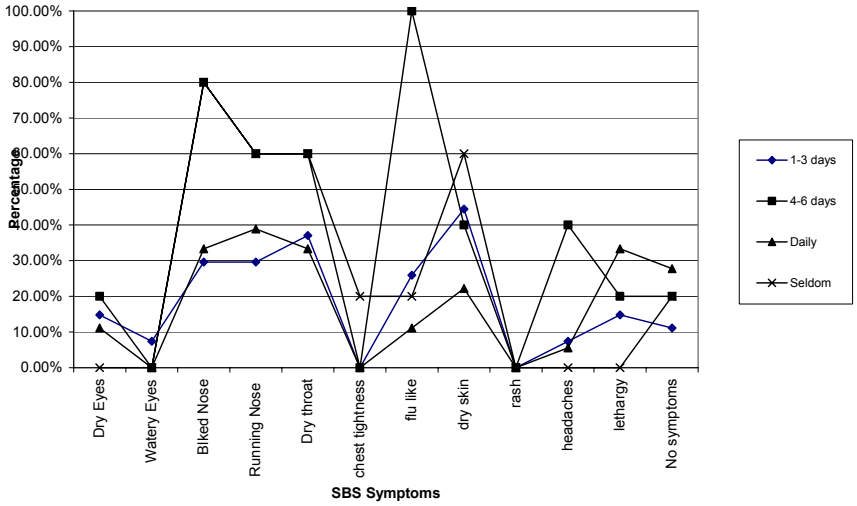


Figure 3: Effect of the frequency of usage of A/C on SBS symptoms

DISCUSSION AND CONCLUSION

Table 2 summarizes the status of the various IAQ parameters measured for bedrooms using different air-conditioners and those which were naturally ventilated.

From the objective measurement of the 3 residential bedroom units utilizing both NV and different types of air-conditioning systems, it can be observed that:

Table 2: Comparison of the IAQ status between NV and AC environments

Types of AC/NV	*CO2 (ppm)*	*Temp (^oC)*	*RH (%)*	*Wind Speed (m/s)*	*Aerosol ($\mu g/m3$)*	*Bacteria (CFU/m3)*	*Fungi (CFU/m3)*
Natural Ventilation	618	28.9	73.7	0.050	65	7	28
Vertical casement	1100	24.8	57.6	0.020	39	N.A	N.A
Window unit • Air vent closed	1146	20.5	53.2	0.020	35	N.A	N.A
Window unit • Air vent opened	1003	21.5	52.7	0.020	42	N.A	N.A
Portable air conditioner	778	26.5	60.2	0.020	72	36	39
Multi-split air conditioner	1164	25.1	44.5	0.020	42	44	43

- CO_2 levels of bedrooms using AC are consistently higher than those utilizing NV. For those AC with fresh air provision, the CO_2 levels are lower.
- RH and air temperature of NV bedrooms are higher than those of AC bedrooms. Mechanical fans are usually utilized to improve the thermal conditions.
- For particulate levels, those in NV bedrooms are shown to be higher than in AC bedrooms. However, for those AC with fresh air provision, the particulate levels were similar or marginally higher than NV bedrooms. This indicates that the main source of particulates is from out-door and that the filtration systems of the air-conditioners may not be effective.
- The occupants utilizing AC tends to exhibit more SBS symptoms than those utilizing NV.
- The frequency of usage of AC has important impact on the occurrence of SBS symptoms. Those who utilize AC daily tend to exhibit less symptoms indicating some form of acclimatization have taken place.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the research funding from National University of Singapore - R-292-000-033-112 that make this study possible.

REFERENCES

Hill, B.A., Craft, B.F. and Burkat, J.A. 1992 "Carbon dioxide, particulates, and subjective human responses in office buildings without histories of indoor air quality problems", *Applied Occupational Environmental Hygiene*, 72, pp 101-111.

WHO. 1983. Indoor Air Pollutants: Exposure and health effects. *EURO reports and Studies 78*. Copenhagen, WHO Regional Office for Europe.

Department of Statistics of Singapore 2001. Ownership of household consumer durables S'pore: Department of Statistics.

Ministry of Environment 2001 Indoor Air Quality Guidelines for Offices in Singapore, Ministry of Environment.