Ventilation and IAQ performance of a typical split-system air-conditioning unit in a residential apartment in singapore

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ABSTRACT
Split system air-conditioning units are commonly employed in residential buildings in the tropics due to their convenience in terms of energy conservation, aesthetics, flexibility, acoustic performance and ease of operation. This paper presents our findings from a recent study of the IAQ and ventilation characteristics in a master bed-room of a condominium unit in Singapore, employed with a split system air-conditioning unit. The attached bathroom is equipped with an exhaust fan, whose operation and its impact on the resulting IAQ and ventilation characteristics was also studied. Four adults occupied the room throughout the course of the experiments. It was observed that the carbon dioxide level in the bed room can exceed 2000 ppm without the exhaust fan in about two hours. The operation of the exhaust fan quickly lowered the level of carbon dioxide to about 1000 ppm. The findings suggest the need to design for ventilation provision in split system air-conditioning units.

INDEX TERMS
Ventilation, Residential, Air change rate, Carbon dioxide, Tropics

INTRODUCTION
The last two decades in several countries in the tropical belt has necessitated the use of air-conditioning systems in tune with economic development, whose key benefits in enhancing thermal comfort acceptability and improved productivity in countries in the temperate climate is fairly well documented (Seppanen et al., 1999; Wargocki et.al., 2000). Rising affluence in several tropical countries has also extended the need for air-conditioned comfort in the living rooms and bed-rooms of a significant majority of the population.

Split system air-conditioning units are commonly employed for residential buildings due to their inherent advantages in terms of energy efficiency, aesthetics, acoustics and flexibility. However, typical split system units are seldom provided with any means of fresh air supply into the occupied rooms. The absence of a designed provision of ventilation can potentially lead to a build up of indoor pollutants in such buildings, as the only source of ventilation is through cracks and other openings between windows and door frames. This paper presents our findings from a recent study in which the impact of operating a split system air-conditioning unit on the resulting IAQ and ventilation characteristics are studied.

METHODS
The master bed-room of an apartment in a condominium in Singapore was used as a case study. As shown in Figure 1, the room was equipped with a split system air-

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conditioning unit and the attached bath-room had the provision of a wall-mounted exhaust fan. The master bed-room had one window facing north-west and there were two doors, one leading to the living room and the other to the attached bath room. Whilst the windows were quite airtight, both the doors are to be considered as reasonably leaky due to the presence of gaps between the edge of the door and the floor.

The measurements conducted at location P1 (Figure 1), include carbon dioxide, carbon monoxide, formaldehyde and total volatile organic compounds (TVOCs) concentration levels, total bacteria count, total yeast and mould count, particulate (PM10) level and thermal comfort parameters. Tracer gas studies were conducted using sulphur hexafluoride (SF_6) to obtain the air change rates. Whilst the chemical pollutants and the tracer gas measurements were obtained on a continuous monitoring mode, all other measurements were obtained as spot measurements.

The experiments were divided into two parts:

(a) CASE 1 - The enclosed room was under normal operating conditions with the window and the two doors closed and the exhaust fan not in operation. The air-conditioning unit was in operation and set to a temperature of 21° C. Four adult subjects occupied the room and natural metabolism led to the contribution of carbon dioxide to the environment. Spot measurements were conducted after steady state had been reached, which was also accompanied with the dosing of tracer gas and subsequent decay to determine the air change rate.

(b) CASE 2 - This was a repeat of CASE 1, except that the exhaust fan in the bathroom was in operation throughout this experiment

RESULTS AND DISCUSSION

The concentration decay profiles of CASE 1 and CASE 2, using SF_6 as the tracer gas is presented in Figure 2 and the air change rate (ACH) values are computed as follows:

	ACH	
Tracer Gas	**Case Study 1**	**Case Study 2**
SF_6	0.40	2.68

It is interesting to note that the ACH in CASE 2 is more than 5 times than in CASE 2. In CASE 1, the only means of outside air available for ventilation is through the gaps between the door and the floor and any possible leakages through the window. A continuous monitoring plot of CO_2 concentration levels is presented in Figure 3. It is observed that within a short period of just over half an hour and with four adult subjects occupying an enclosed room, the CO_2 level can reach to almost 2500 ppm. It is to be noted that most standards and guidelines typically recommend a threshold limit value of 1000 ppm for CO_2 (ASHRAE, 2001; ENV, 1996).

The use of the exhaust fan in the bath room significantly enhances the ventilation provided to the master bed-room, as is seen by a higher ACH value. It is to be noted that the door to the bath room was kept shut during this experiment and the high ventilation rate is caused primarily through the openings/gaps under the doors. It is observed from Figure 3 that during a period of 30 minutes, the CO_2 level reduces from 2200 ppm to 1500 ppm. It is pertinent to note that demand control ventilation is to be considered as an energy efficient strategy of operating the exhaust fan in order to mitigate the elevated cooling loads that will exist if the fans are over designed.

The measured values of other indoor pollutants during the two experiments are presented in Table 1 and it is seen that they are within the recommended threshold limit values of the respective pollutants (ENV, 1996). It is, thus, clearly evident that carbon dioxide is the primary indoor pollutant of interest in such residential buildings operated regularly with split system air-conditioning units.

CONCLUSIONS

The IAQ and ventilation characteristics of a space operated by a multi-split system air-conditioning unit in a residential building in the tropics is presented in this paper. A comparison of air change rates obtained by using two different tracer gases is presented. It is shown that CO_2 levels can reach fairly high levels in these situations within a relatively short period of time, about 2-3 times that of recommended thresholds. It is also demonstrated that the operation of such air-conditioning units in conjunction with an exhaust fan can result in significant reduction in the indoor CO_2 levels and contribute to better dilution and significantly enhanced indoor air quality.

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Table 1 : Summary of the measurements of indoor environmental conditions and the indoor pollutant levels

	Recommended Threshold Limit Values (TLV)	CASE 1		CASE 2	
		1	2	1	2
Temperature (^{0}C)	22.5 – 25.5	24.5	23.1	23.9	23.5
Relative Humidity (%)	<70%	59.0	51.6	63.4	55.5
Air Velocity (m/s)	<0.25	0.15	0.17	0.15	0.20
Carbon monoxide (ppm)	9	0.20 – 0.42		0.20 – 0.45	
TVOC (ppm)	3	1.40 – 1.80		1.40 – 1.80	
Formaldehyde (ppm)	0.1	0.10 – 0.20		0.05 – 0.15	
Particulate – PM10 ($\mu g/m^3$)	150	30	28	31	33
Bacteria (CFU/m^3)	500	370		361	
Yeast and Mold (CFU/m^3)	500	62		53	

Figure 1: Details of the experimental set-up (master bed-room of a condominium apartment)

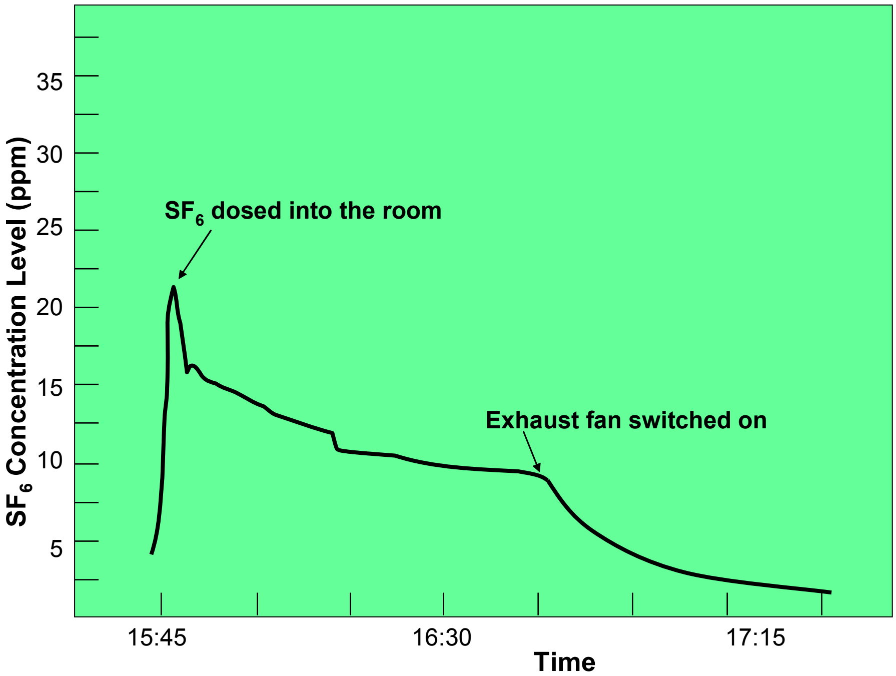

Figure 2 : SF_6 concentration decay curve on a linear scale

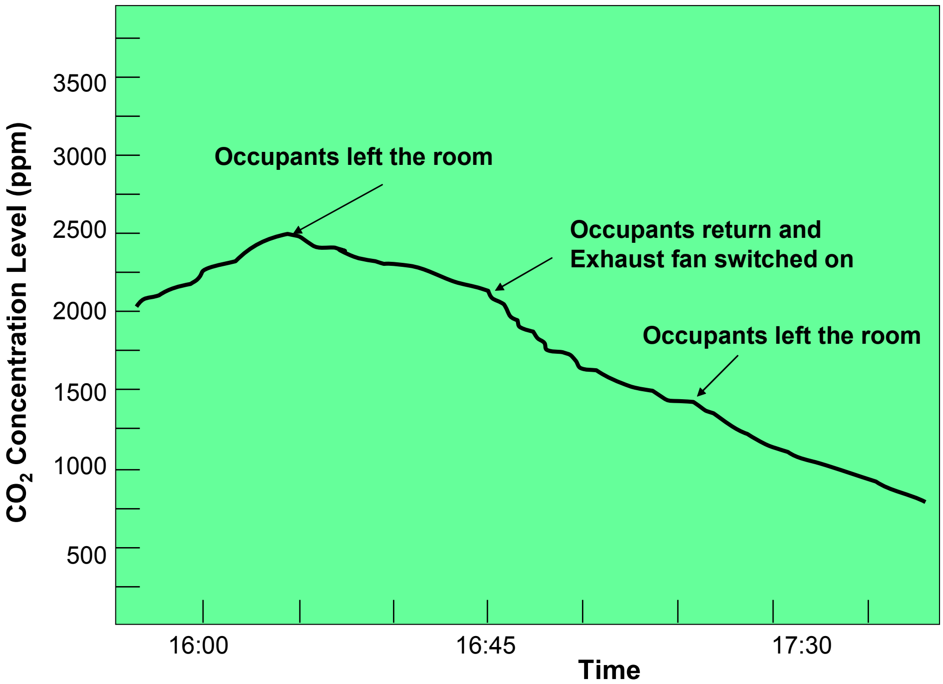

Figure 3 : Continuous monitoring plot of CO_2 concentration levels