Indoor Air Quality and Thermal Comfort Assessment of a Split Air Conditioner with Ventilation System

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Abstract: Now days, split air conditioners are popularly used in India for residential as well as commercial purpose. The main drawback of split air conditioner (SAC) is lack of fresh air supply in the conditioned space for which the CO_2 level goes on increasing and relative humidity (RH) goes on decreasing for the long run of AC because of the circulation of same air inside the conditioned room which leads to sick building syndrome (SBS). This paper presents the experimental investigation of the indoor air quality (IAQ) and thermal comfort (TC) inside a split air conditioned room by using Fanger's model to determine the thermal comfort condition and CO_2 level is measured throughout the experimentation under different ambient condition. Fresh air mixed with the circulated air was introduced to the evaporator coil. The values of IAQ and TC were analyzed for the duration of 6 hrs. It was observed that TC increases based on the fan speed of evaporator at 3m and 6m from evaporator outlet and CO_2 level reduces from 2132ppm to 1187ppm. in 2 hrs of time inside the room.

Keywords — SAC, IAQ, TC, RH, SBS, CIRCULATED AIR

I. INTRODUCTION

SAC is accounted for 76% of the total market in India due to its popularity of easy handling, installation and lower maintenance. Almost 30-40% of energy is consumed by buildings all over the world. One of the most important areas of study in air conditioning system is to analyze the effect of Indoor air quality (IAQ) and comfort on occupant well-being.[1,2] Some well known comfort variables are air temperature (Ta), radiant temperature , air velocity ,air relative humidity (RH), along with the actual people clothing and metabolic rate. There are numbers of thermal comfort model which are used for the measurement of TC. The most popular and common model is Fanger's comfort indices which associated with PMV and PPD [3]. Sanjeev Gupta et.al found out a direct relation between the average SBS score and CO_2 concentration [4]. They found that the average SBS score increased with CO_2 concentration. Daisey et al. reviewed the literature on IAQ, ventilation and health symptoms in schools and showed that ventilation was inadequate in many classrooms, possibly leading to health problems[5]. The associations between indoor CO_2 concentrations and sick building syndromes (SBS) from the analysis of the 1994–1996 BASE study data and showed the regression results between maximum indoor 1 h average CO_2 minus outdoor co_2 concentrations and SBS were very similar[6,7]. Higher ventilation rates in air conditioned space, up to about 25 L/s per person, were found to be associated with reduced prevalence of sick building syndrome (SBS) symptoms. Inflammation, respiratory infections, asthma symptoms, and short-term sick leave increase with lower ventilation rates. In a study involving the ventilation performance of a split air-conditioning unit in a residential building, Sekhar observed that that CO_2 levels can reach fairly high levels in the rooms within a relatively short period of time, about 2-3 times that of recommended thresholds[8]. It was seen that the amount of outdoor air provided to the room was significantly low in the range of 0.69-0.86 lps per person. From the perspective of IAQ and comfort the main drawback of split air to conditioner is the recirculation of air inside the conditioned space without sufficient amount of fresh air.[9] S.C. Sekhar[10] has done study on ventilation performance of air-conditioning systems in residential buildings. 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. Such units are also popular among small offices, shopping complex and even as supplementary air-conditioning units beyond normal office-hours in large commercial and office buildings. This paper presents findings from a recent study of the ventilation performance and indoor air quality (IAQ) 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 ventilation characteristics was also studied. Four adults occupied the

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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 2 hr. 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. Z.T. Ai [11] et.al have investigated the overnight evolution of CO_2 concentration in air-conditioned residential buildings and then focuses mainly on the evaluation of three ventilation strategies, including overnight natural ventilation, short-term mechanical ventilation and short-term natural ventilation. On-site measurements were conducted in a typical residential bedroom in Hong Kong in September. The indoor and outdoor CO_2 concentration, air temperature and relative humidity as well as the outdoor wind speed during the measurements were analyzed. Ventilation rates were calculated based on the time series of CO_2 concentration. This study confirms that additional ventilation is usually needed in air-conditioned residential buildings. Overnight natural ventilation with even a small opening is associated with excessive energy consumption and deteriorated indoor thermal environment. Short-term natural ventilation strategies are inefficient and uncontrollable. Compared to the best short-term natural ventilation strategy, a reasonably designed short-term mechanical ventilation strategy requires only a 41% of ventilation period to complete one full replacement of indoor air and to reach a lower indoor CO_2 concentration. Nighttime case studies and a theoretical analysis suggest that a few several-minute mechanical ventilation periods could potentially maintain an acceptable indoor air quality for a normal sleeping period of 8 hours.

Split air conditioners are mostly used for residential and small offices of India. From above discussion it is clear that in case of split air conditioner the same air circulates inside the conditioned space as there is no specific provision of fresh air ventilation system. As a result the CO_2 (ppm) goes on increasing as the time passes and the humidity percentage decreases then the prescribed ASHRAE level which may lead to SBS. According to ASHRAE the concentration of CO_2 inside a room should not exceed 700ppm above the outdoor air CO_2 levels. ASHRAE recommends that the relative humidity for human comfort should be maintained between 40% and 65%.In this paper one attempt is made to do some experimental study by introducing fresh air through the evaporator coil and to study the Indoor air quality and the thermal comfort of a split air conditioned room. For this purpose to study thermal comfort inside the room Fangers thermal comfort model is considered. For IAQ only CO_2 parameter is chosen and in the same way it is measured inside the room at different location. As the experimentation was done in Guwahati city, Assam, India and Guwahati being a humid city when we introduce fresh air and mixed it with recirculated air and pass it through the evaporator coil it is found that the humidity remains high inside the air conditioned room than the prescribed value of ASHRAE.

II. METHODOLOGY

IAQ and TC assessment are done for a 1.5 ton split air conditioner in a room with 5 nos. of occupancy. It is found that CO_2 levels goes on increasing and RH level goes on decreasing as the time passes. This effects the IAQ and TC. In this paper attempt is taken to supply adequate amount of fresh air with proper calculation through the coil of evaporator and to do the experimental analysis for IAQ and thermal comfort inside a room. For this purpose one duct is designed and fabricated with proper calculation and experimental analysis were done to analyze the flow inside the duct after mixing of supply fresh and circulated air to the evaporator coil of split air conditioner. Here it is observed that on introduction of fresh air a drastic reduction of CO_2 levels were observed. Using equal friction method the following duct dimension with pressure loss are obtained. Table:1 The duct dimensions and total pressure drops

Duct	Length (m)	Type	Dimension (mm)	Total Press. drop
Main	0.65	▭	L=556 B=140	0.4375 mm of water
Branch	0.1	○	D=157	-1.755 mm of water

The duct is used for the mixing of fresh and recirculated air and passing through the evaporator coil as shown in the figure.

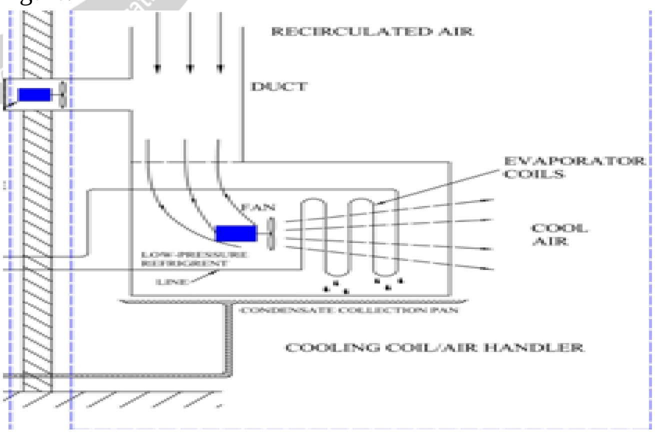

Fig.1. Schematic diagram of experimental set up.

The temperature and velocity profile of the duct for 34^0C ambient temperature and 78%RH , where the velocity of recirculated air is 3.469 m/s, velocity of fresh air is 3.168 m/s and the maximum blower velocity is 4.25m/s as shown in the figure below(Figure 2,3).

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Figure2. Temperature Profile of air in the duct

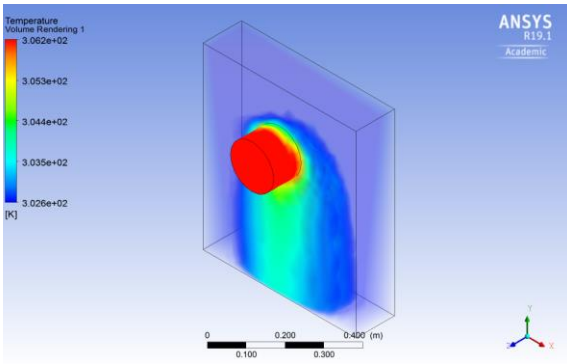
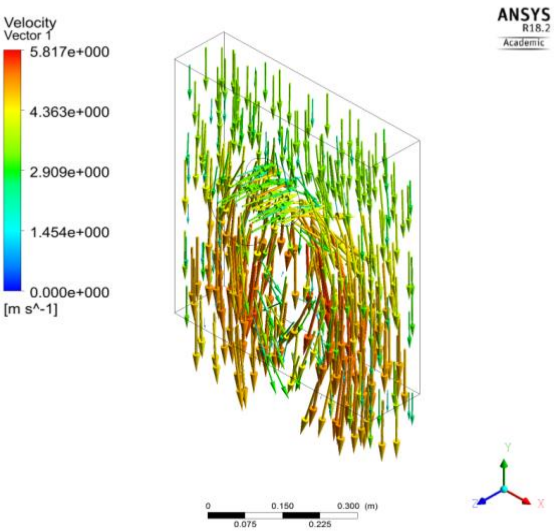


Figure3. Velocity Profile of air in the duct



III. RESULT AND DISCUSSION

The experimentation was done in the month of April and May and the readings were taken at different evaporator coil setting condition like at 17°C,22°C and 25°C with high, medium and low fan speed. The indoor measuring parameters are room air temperature, velocity of air, relative humidity. at a distance of 0m, 3m, 6m from the inlet of evaporator. From these readings PMV and PPD are calculated using Fangers Model for two different modes as follows:

i) With circulation of same air
ii) With supply of fresh air through the evaporator coil after every 2 hours

Table1: The instruments used for the experiment

Sl .no	Measuring Instruments	Measuring Parameters
1.	Hygrometer (Testo 625)	DBT,WBT,DPT,RH
2.	Datalogger (Testo174H)	DBT,RH
3.	Animometer (Testo 416)	Air velocity ,Volume flow rate
4.	IAQ monitor (Testo 480)	CO_2 ppm, RH,DBT,MRT,Air flow velocity
5.	Air Capture Hood (Testo 420)	Volume flow rate, RH, DBT

Table2: IAQ and TC inside the experimentation room at 22°C evaporator setting temperature with medium evaporator fan speed (Q = 0.2457 m^3/s, v=3.5m/s) without fresh air.

Outdoor Conditions:

Average Ambient temperature, T= 34°C
Dew point temperature ,T_{dp} = 29°C
Wet bulb temperature, T_{wb} = 30.1°C
Relative humidity, RH= 78%
Outdoor CO_2 in ppm = 453ppm

Indoor Conditions:

Time (minutes)	T_a (°C)	T_r (°C)	V (m/s)	RH (%)	CO_2 (ppm)	PMV	PPD (%)
0	28.1	28.7	0.44	62.2	491	0.32	7
15	27.5	28.3	0.41	60	677	0.17	6
30	26.9	27.6	0.45	58.4	953	-0.10	5
45	26.7	27.4	0.4	55.5	1165	-0.12	5
60	26.5	27.1	0.42	54.1	1395	-0.24	6
75	26	26.8	0.37	52.5	1660	-0.30	7
90	25.7	26.3	0.37	52	1901	-0.42	9
105	25.8	26.4	0.38	51.5	2123	-0.41	9

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120	26.2	26.9	0.42	51.2	2330	-0.34	7

From the above table it is clear that the RH goes on decreasing and CO_2 concentrations goes on increasing with time whatever maybe the setting temperature of the evaporative coil. This is because of absence of fresh air as same air passes through evaporator coil again and again the air goes dry with time. Now experiment is done with supply of fresh air after each 2 hours of running of air conditioner and the following readings are taken for each setting temperature of evaporator coil. One of those reading is shown in the following table.

Table 3**:** IAQ and TC inside a room at the following given conditions.

Outdoor Conditions:

Average ambient temperature T = 34°C

Dew point temperature T_{dp} = 29.3°C

Wet bulb Temperature T_{wb} = 30°C

Relative Humidity RH = 86%

Outdoor CO_2 in ppm = 450ppm

Indoor Conditions:

Time (minutes)	T_a (°C)	T_r (°C)	V (m/s)	R H	CO_2 (ppm)	PMV	PPD (%)
Evaporator setting temperature = 22 °C with medium evaporator fan speed(Q = 0.2457 m³/s, v=3.5m/s) without fresh air supply							
0	28.2	29.3	0.43	68	475	0.48	10
15	27.4	28.1	0.41	61.9	625	0.14	5
30	26.7	27.5	0.37	59.5	930	-0.03	5
45	25.8	26.5	0.39	53.9	1177	-0.40	8
60	25.5	26.3	0.36	52.9	1415	-0.45	9
75	25.5	26.2	0.38	51.5	1677	-0.49	10
90	26.1	26.7	0.41	51	1909	-0.37	8
120	26.3	26.9	0.39	51.8	2132	-0.27	7
Evaporator setting temperature = 17 °C with medium evaporator fan speed(Q = 0.2457 m³/s, v=3.5m/s) with fresh air supply							
135	27.1	27.7	0.39	55	2002	0.00	5
150	27.5	28.1	0.43	55.6	1884	0.08	5
165	26.9	27.6	0.40	56.1	1543	-0.06	5
180	26.5	27.1	0.37	54.7	1257	-0.16	5
195	26.7	27.3	0.36	54.7	1192	-0.08	5
210	26.4	27.0	0.37	54.5	1187	-0.19	6
225	26.4	27.1	0.42	54.8	1185	-0.25	6
240	26.2	26.9	0.43	55	1187	-0.32	7
Evaporator temperature = 22 °C with medium evaporator fan speed (Q = 0.2457 m³/s, v=3.5m/s) without fresh air supply							
255	26	26.6	0.39	50.9	1204	-0.37	8
270	26.1	26.8	0.41	51.6	1345	-0.35	8
285	25.9	26.5	0.44	48.9	1604	-0.48	10
300	26.5	27.2	0.36	49.4	1954	-0.18	6
315	26.4	27.0	0.38	46.7	2145	-0.27	6

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330	25.8	26.4	0.37	50.9	2155	-0.40	8
345	26.2	26.8	0.43	51.6	2145	-0.36	8
360	26.1	26.8	0.41	52.6	2147	-0.34	7

Similarly, readings were taken for evaporator fan speed: low (Q = 0.1722 m^3/s and v = 2.4 m/s), medium (Q = 0.2457 m^3/s, v = 3.5 m/s) and high (Q = 0.3314 m^3/s, v = 4.7 m/s) for each thermostat temperature setting i.e. 17°C, 22°C and 25°C.

IV. CONCLUSION

The IAQ and TC of an air-conditioned space is discussed in this paper. The comparison between same air circulation and fresh air introduced to evaporator coil is presented. On introducing fresh air the CO_2 level comes below 1200 ppm from 2132ppm within two hours of time. This fall within the upper limit set by ASHRAE and which leads to better dilution and thus IAQ is significantly improved. In winter and spring season, best thermal comfort was achieved when the temperature in the thermostat was set at 25°C. It was achieved for both the conditions, i.e., with fresh air supply and without fresh air supply. Since the need for actually running the air conditioner in winter is very low, the system can be used as an air ventilation system. There is no need to switch on the air conditioner, only switching on the blower fan will be enough to maintain good IAQ inside the room. In summer, the thermal comfort reduces when hot and humid outdoor air was supplied. A balance between IAQ and thermal comfort was achieved when outdoor air was introduced at two hour intervals. During summer, increasing the evaporator fan speed improves thermal comfort at 6 m distance but reduces at 3 m, even when fresh air was supplied. Therefore we can get the best result by keeping medium evaporator fan speed (Q = 0.2457 m^3/s, v = 3.5 m/s).PPD was found 100% when the thermal comfort was checked immediately in front of the air conditioner. So from the experimental study it can be concluded that in an split air conditioned room for better circulation of fresh air to enhance the air quality inside the room by maintaining a well balanced thermal comfort this modified air conditioning system can be adopted with the control of blower fan velocity.

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