AIR CONDITIONING AND REFRIGERATION
Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : April-June 2005

CO_2 Levels in Auditoriums

Varying the quantity of fresh air intake into an auditorium's air conditioning system has a marked effect on CO_2 levels in the space, as this study reveals.

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Comfort is a major concern of the HVAC industry. In the early days of the industry, comfort at reasonable cost was the single most important concern of the average customer. A comfortable environment was generally taken to be a healthy one. In the 1970s, the threat of energy shortage and economic factors led to tighter buildings and reduced indoor ventilation air. Activities within buildings changed and the HVAC systems that were in place were often poorly maintained.

All of these factors contributed to a variety of incidents involving the health of building occupants. Quality of air in indoor air conditioned spaces is no less important a factor, than temperature control and one that greatly influences the health and comfort of occupants. Studies in recent years have identified that air inside a building can be substantially more polluted than fresh air and hence the need for improved indoor air quality (IAQ). It is strange but a fact that the air we breathe working or living in an air conditioned space may be more injurious to health than fresh air.

The Importance of Fresh Air and CO_2 Concentration on IAQ

ASHRAE Standard 62 defines "acceptable indoor air quality as air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction".

Indoor spaces occupied for any length of time require the intake of some fresh air to maintain air quality. Some fresh air may enter a space by infiltration through cracks in ceilings, doors, and walls of spaces or buildings but generally in air conditioned buildings most fresh air is brought into a space by supply air, to meet the air quality requirements.

For both comfort and process air conditioning systems, fresh air is required to carry out the following functions:

- To meet metabolic requirements of the occupants.
- To dilute the indoor air contaminants, odors and pollutants in order to maintain an acceptable indoor air quality.
- To support any combustion process or replace the amount of exhaust air required in laboratories, manufacturing processes, kitchens or toilets.
- To provide makeup for the amount of exfiltration. ASHRAE Standard 62 specifies that *where only dilution ventilation is used to control indoor air quality, a carbon*

dioxide indoor-to-outdoor differential concentration (C_s–C_o) not greater than about 700 ppm indicates comfort (odor) criteria related to human bio-effluents are likely to be satisfied. Carbon dioxide is a byproduct of respiration. The rate at which we produce it varies with diet and health, as well as with the duration and intensity of physical activity. The more exertion an activity entails, as measured in metabolic equivalent task (MET) units, the more carbon dioxide we produce. Appendix C of Standard 62 provides a steady-state mass balance equation to predict the difference between indoor and outdoor concentrations of carbon dioxide, given constant rates of ventilation and CO2 generation (occupant activity).

$$C_s - C_o = N/Vo$$

Where, C_s = CO_2 concentration in the space, ppm

C_o = CO_2 concentration in the outdoor air, ppm

N = CO_2 generation rate, cfm/person

Vo = outdoor airflow rate, cfm/person

If the rate of CO_2 generation is 0.0105 cfm (0.3 L/ min) per person and the ventilation rate is 15 cfm per person, the resulting difference at steady state is 700 ppm.

$$C_s - C_o = 0.0105/15 = 0.007 \text{ (or 700 ppm)}$$

High concentration of CO_2 causes effects like drowsiness, discomfort and increases absenteeism. In short, the productivity in offices, factories, restaurants, conference halls, theatres, auditoriums and laboratories goes down.

Field Investigations

To determine how some of our high occupancy air conditioned buildings measure up to ASHRAE Standard 62, we decided to study two auditoriums and two cinema halls in Baroda city. During the study we measured, the total air quality in circulation, fresh air quality, dry bulb and wet bulb temperatures and levels of CO_2, SO_2, NO_2 and SPM (suspended particulate matter) in the air conditioned space.

All the buildings in the case studies introduced fresh air at a constant rate and therefore CO_2 levels could be considered as an important parameter for evaluating IAQ. The indoor CO_2 levels were measured at different locations with respect to time. ASHRAE Standard 62 stipulates that indoor CO_2 levels should not exceed 1,000 ppm.

The aim of these investigations is to create awareness among all HVAC consultants, engineers, designers, architects, builders and other concerned persons, about the relationship between the quantity of fresh air introduced into the building's air conditioning system and the quality of indoor air that the occupants breathe. A typical person eats 1-2 kgs of food per day, drinks 2-5 kgs of water per day, breathes 20-25 kgs of air per day and while that person is generally careful about the quality of food and water consumed, the quality of air that is taken into the lungs seems to be of little concern even though its affects his/her health in the long run. It is therefore the duty of AC system designers to educate their clients about the importance of IAQ and the need for the right quantity of fresh air introduction into an air conditioned space for the benefit of the millions of persons spending more and more of their time in AC buildings.

Instrumentation Used for Measurements

For measuring CO_2 levels we used a "Telair" make digital infrared sensing instruments, with a range of 0- 10,000 ppm and an accuracy of 1 ppm. This instrument was provided courtesy of Artic India, Mumbai.

For air quantity measurement we used a conventional twisted vane arm type portable digital anemometer of "Lutron" make, model AM 4201, with a range of 80- 5910 fpm.

Instruments used for measurements.

Case Study 1 (Auditorium-A : Prof. C.C.Mehta)

The Prof. C. C. Mehta Auditorium is located within the M.S. University campus at Sayajigunj, Baroda city with a 600-seat capacity. It was built in 1957. The central AC plant comprising 2 × 63 ton vapour absorption chillers, generates chilled water, which is circulated to cooling coils inside AHUs. There are two AHUs, one serving the stage (central AHU) and the other serving the auditorium area. The auditorium AHU return air duct is connected to a grille at the bottom of the stage. The stage AHU draws air from one side of the stage. In both AHUs fresh air addition takes place at the suction side of the AHU in the return air duct after which the air is filtered (wire mesh type), cooled and dehumidified while passing through the cooling coil and then distributed through galvanized ducting network. CO_2 level readings were measured at different locations of return air grilles like L.H. side of stage, R.H. side of stage and central AHU (stage) return air grills. See **Figure 1**.

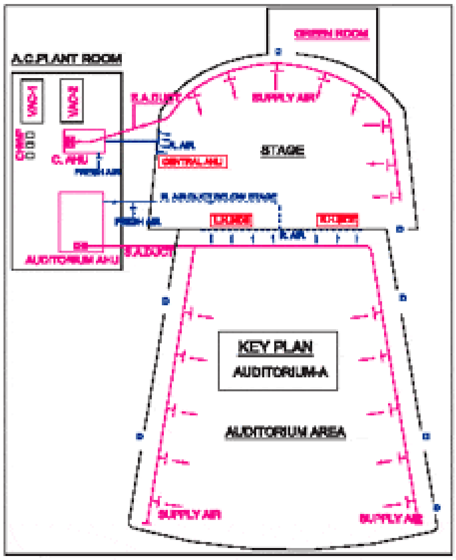

Figure 1: Auditorium-A Key plan.

Basic data as measured

Total air changes/hour =20

Fresh air changes/hour =2

Fresh air quantity =4170 cfm (i.e 7.6 cfm/person)

Occupancy (during study)=550

Ambient CO_2 level (C_o) =1135 ppm

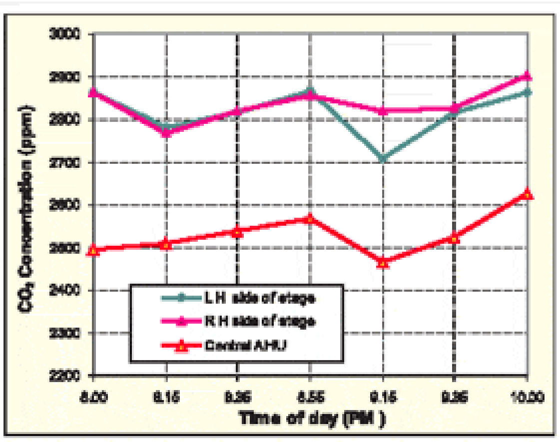

Figure 2: Variation in CO_2 level with constant fresh air.

Fresh air supplied was constant over the entire time period. Readings were taken at fixed, regular intervals of time to observe the effect of time due to high occupancy as shown in **Figure 2**.

It can be observed that during a two hour period in the auditorium area, CO_2 level varied between 2700 to 2900 ppm. The maximum (C_s-C_o) was 1765 ppm and the minimum (C_s-C_o) was 1565 ppm. Both are higher than the acceptable 700 ppm as per ASHRAE Standard.

Case Study 2 (Auditorium-B)

The air conditioning plant in this auditorium is located in the basement behind the stage and the AHU was placed below the stage in an AHU Room. The plant consists of reciprocating, open type compressors 4 × 30 ton, water-cooled and DX cooling coils in the AHU. Air is distributed through galvanized ducting network with supply air grilles in the sidewalls. Return air is drawn back by the AHU through grilles under the stage. Fresh air addition takes place in the AHU Room. CO2 level readings were measured at different locations such as L.H. side of return grilles near the stage, R.H. side of return grilles near the stage, central location of hall at C_1/ C_2 and end of hall. See **Figure 3**.

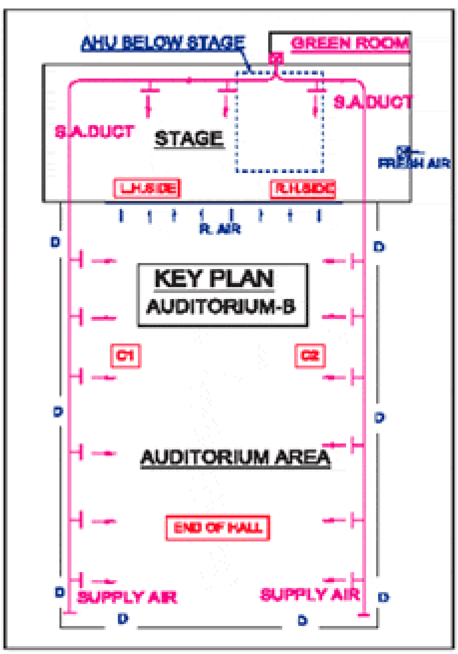

Figure 3:Auditorium-B Key plan.

Basic data as measured

Total air changes/hour = 6.5

Fresh air changes/hour = 0.9

Fresh air quantity = 3550 cfm (i.e 2.5 cfm/person)

Occupancy (during study)= 1400

Ambient CO_2 level (C_o) = 1350 ppm

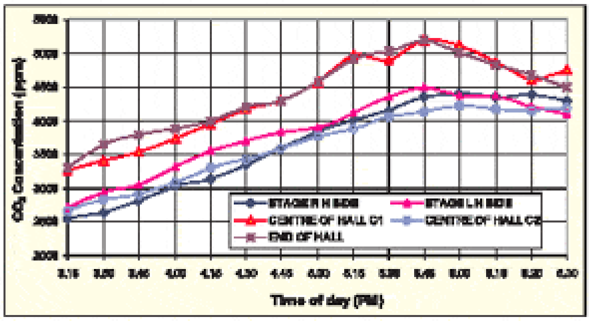

Figure 4: Variation in CO_2 level at constant fresh air.

Fresh air supply was constant over the entire period, as there was no damper on the fresh air intake. Readings of CO_2 were taken at the return air grille, center and backside of the hall. To observe the effect of time on CO2 level, readings were continuously taken as shown in **Figure 4** at regular intervals of time. After 5.30 pm the occupancy level reduced due to the end of the program, which was indicated by a small reduction in CO level.

It will be observed that the initial CO_2 level increased from 2500-3300 ppm to 4200-5300 ppm and the maximum (C_s-C_o) was 2850 to 3950 ppm while the minimum (C_s-C_o) was 1150 to 1950 ppm, during a period of two and half hours, which may be due to reduced fresh air supply. These levels are also higher than the acceptable 700 ppm as per ASHRAE Standard.

Case Study 3 (Theatre - A)

The air conditioning plant comprising of a combination of screw and reciprocating chillers generates chilled water, which is circulated through cooling coils placed inside the AHU located in an airtight room. Supply air is distributed to the hall by a network of galvanized ductwork and ceiling diffusers. Return air is drawn by the return grille located at the topside of the walls of the hall and sent back to the AHU room through R.A. duct 1 and 2. The fresh air intake is located in the AHU room drawing air from the atmosphere along with a regulating damper. CO_2 level readings were measured at opening of R.A. duct 1 and 2 inside the AHU room. See **Figure 5**.

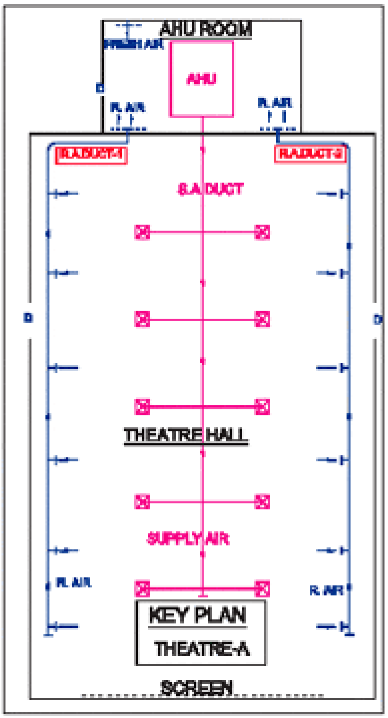

Figure 5: Theatre-A Key plan.

Basic data as measured

Total air changes/hour =10.5

Fresh air changes/hour =1.86

Fresh air quantity =1950 cfm (i.e 3.86 cfm/person)

Occupancy (during study)=505

Ambient CO_2 level (C_o) =1350 ppm

The fresh air intake damper was initially closed for three hours. Readings of CO_2 level were taken and after taking the first set of readings, the fresh air damper was kept open allowing entry of fresh air (1950 cfm) in order to observe the pattern of dilution effect of the fresh air with respect to time and observe when a steady state was reached. Later we took readings at regular intervals for all periods. See **Figure 6**.

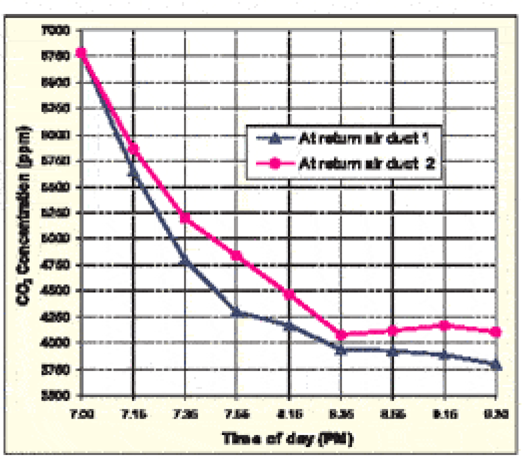

Figure 6: Variation in CO_2 level after constant fresh air addition.

We can observe that after 2.35 hours (8.35pm) the CO_2 level reached a steady state of around 3750 ppm, which indicates (C_s– C_o) equals 2400 ppm. This is also higher than the acceptable 700 ppm as per ASHRAE Standard.

Case Study 4 (Theatre - B)

An air conditioning system comprising of floor mounted package ACs (4nos total 52.5 TR) with supply air distributed to the theatre hall through insulated ductwork and return air sucked back through a return duct which is connected to the package ACs. Fresh air is introduced at the main return air duct. The regulation of fresh air is controlled by a fresh air damper. CO_2 level readings were measured at the openings of R.A. duct 1,2,3 & 4. See **Figure 7**.

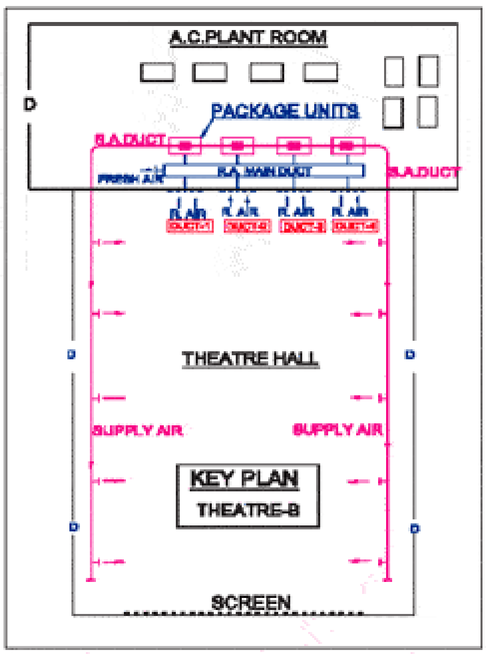

Figure 7: Theatre-B Key Plan.

Basic data as measured

Total air changes/hour =8.5

Fresh air changes/hour =0.7

Fresh air quantity =2180 cfm (i.e 3.96 cfm/person)

Occupancy (during study)=550

Ambient CO_2 level (C_o) =699 ppm

The fresh air intake damper was initially kept closed. Readings of CO_2 level were taken and after taking the first set of readings, the fresh air damper was opened allowing entry of fresh air (2180 cfm) in order to observe the pattern of dilution effect with respect to time and observe when a steady state was reached. Later we took readings at regular intervals for 50 minutes. After 4.50 pm, the fresh air damper was closed again to observe the variation of CO_2, after constant fresh air addition and closing of fresh air to observe the CO_2 level at regular intervals. See **Figure 8**.

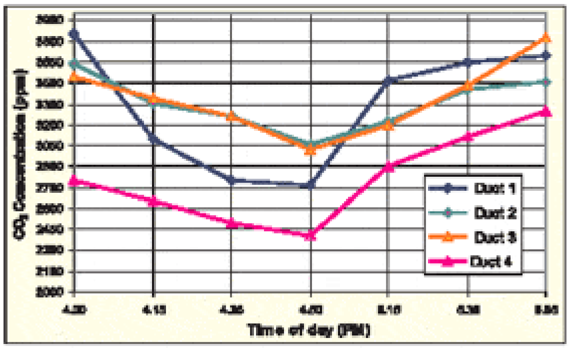

Figure 8: Variation in CO_2 level after constant fresh air addition and closing fresh air.

One can observe that, initially, due to addition of fresh air after 2.50 hours, the CO_2 level reduced and again when fresh air was closed, it start rising. In this case also we observed the minimum (C_s– C_o) was 1703 ppm. This is also higher than the acceptable 700 ppm as per ASHRAE Standard.

Conclusion

Based on the above case studies it is evident that, in almost all the locations the concept of IAQ has been completely over looked, while more stress is given to thermal comfort only.

The case studies clearly show the importance of fresh air to maintain the desired indoor CO2 level with respect to time. ASHRAE Standard 62 stipulates that indoor CO_2 level should not exceed 1,000 ppm and indoor-tooutdoor differential concentration (C_s– C_o) should not be greater than about 700 ppm, which was not observed in any of the case studies. Average maximum CO_2 level and the differential concentration (C_s– C_o) found in all cases were too high due to insufficient fresh air, 2.5 to 7.6 cfm/person, as compared to the quantity recommended by ASHRAE ventilation standard 62 as 15 cfm/person.

Recommendations

Laying down guidelines for minimum outdoor air requirements for ventilation in commercial facilities such as offices, shopping malls, hotels and auditoriums / theatres in our National Building Code is the first step to be taken.

Educating owners of such facilities about the importance of following such standards and the effect that inadequate fresh air has on CO_2 levels and the health of the public that occupies such spaces is the next step. Consultants will play a very important part in such education and monitoring of final installation. The temptation to reduce outside air quantity, plant capacity and therefore price is very great and unscrupulous elements can take advantage to maintain comfortable temperatures with inadequate outside air for ventilation, without the knowledge of the owner.

Acknowledgement

The authors are grateful to Mr. Mehta and Mr. Hindol Bhattacharya of Arctic India, Mumbai and Arctic India Engineering, Gurgaon, for lending their Telair CO_2 measuring instrument and Mr. Sanjay Shah, Mr. Amarjeet, Mr. Mitesh Shah of Fairair, Baroda (Dealer of ERV-Arctic India). The authors are also thankful to Mr. G.D. Karhadkar – Convenor of Prof. C.C. Mehta Auditorium and also the owners/in-charge of other premises for giving permission and access to buildings and sparing their valuable time in bringing this work to its present shape.

References

1. Faye C. McQuiston, Jerald D. Parker, Jeffrey D. Spitler. *"Heating, Ventilation and Air-conditioning Analysis & Design."*
2. Shan K. Wang, *"Handbook of Air-conditioning and Refrigeration, Second edition."*
3. Bholanda. J.V, M.E Dissertation report on *"IAQ for high occupancy air-conditioned building"*.
4. M. Schell, S. Turner, and R. O. Shim, *"Application of CO_2-based demand-controlled ventilation." (www.trane.com).*