Performance Analysis of the HVAC System in a Hospital Building in Hyderabad

Mohammed Ishaq, Raza Ahmed Khan, Mohammed Abdul Majeed

Abstract— Indoor air quality (IAQ) is a term which refers to the air quality within a building, especially as it relates to the health and comfort of building occupants. The hospital is a high risk indoor place which has airborne infection from patients. The complex hospital environment requires special attention to ensure healthy IAQ to protect patients and healthcare workers against hospital-acquired infections and occupational diseases. The aim of this study is to recommend effective guidelines for the control and management of hospital IAQ. A one week survey was carried out in the Continental Hospital and Research Centre situated at Gachi Bowli, Hyderabad. It is a massive eighteen storied structure, competently managed by senior professionals. In the experimental analysis for indoor air quality, measurements were recorded on four floors for Temperature, Relative Humidity and Carbon Dioxide. In the observation analysis the operation and maintenance of the HVAC system and the well-being of the occupants were observed.

Index Terms— CO_2, HVAC Systems, Indoor Air Quality, Occupant Comfort, Pollutants, Relative Humidity, Temperature

1 Introduction

Hospital buildings and health care facilities are among the most complex indoor spaces. In particular, the most demanding indoor zones are hospital operating theatres (suites) that comprise operating rooms (ORs) or surgical theatres, their interconnecting hallways and ancillary work areas. The indoor environmental quality (IEQ) in ORs, including thermal, visual and acoustical comfort and indoor air quality, affects the working conditions, well-being, safety and health of patient and the medical personnel who work in these environments. About 50% of the total number of doctors works in the ORs, as surgeons or with other responsibilities (e.g. anesthesiologist), while about 10% of the total medical staff also work in the OR. Heating, Ventilating and Air-Conditioning (HVAC) installations control indoor air quality and aseptic conditions, and secure health, safety and suitable indoor thermal (i.e. temperature, humidity, air quality and airflow) conditions for surgeons and medical staff, and of course, the patients. The air in an OR must be aseptic, at a reasonably constant temperature and humidity and have relatively low air velocity in order to avoid drafts and swirls that promote the recirculation of microbes and may disrupt the procedures during an operation. The ventilation rate is expressed as the volumetric air flow through the space divided by the volume of the space, e.g. number of air changes per hour (ACH). The desirable conditions can be met by proper design, installation, operation and maintenance of the electromechanical equipment, such as the HVAC equipment and lighting systems of the space. Due to their demanding indoor conditions, operating theatres constitute the most expensive sector of the healthcare establishment mandating an efficient management. Indoor air quality (IAQ) can be affected by gases (including carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria), or any mass or energy stressor that can induce adverse health conditions. Source control, filteration are the primary methods for improving indoor air quality in most health care facilities.

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2. HVAC System Investigation

The preliminary HVAC investigation involved the discussions with property owners and building management, walk through investigation of building and surrounding areas, interviewing HVAC operation & maintenance personnel, study of as-built drawings, review of maintenance schedule and preventative maintenance program.

Preliminary observation/review of the HVAC system was carried out. Direct instrument measurements of carbon dioxide, relative humidity, and temperature were recorded to know the status of IAQ and comfort of building occupants.

3. Hospital Occupant Survey

A hospital occupant's questionnaire was developed to get the demographic background and socio-economic status of the respondents such as personal information, health status, symptoms of sickness, and level of comfort inside the hospital. The questionnaire include the occupant's health status and symptoms of Sick building syndrome (SBS) such as chronic cough, cough with phlegm, chest tightness, and shortness of breath. Questionnaires also contain questions on the previous workplace, working history, and location of current workstation (near the entrance door, near to photocopied area, etc), and also working background such as overtime, shift work

schedule, duration of work per day, duration of work per week and the employment years at the office. Zoning of each worker's workstation then categorized accordingly with the reference of floor plan. Reported sick building syndrome (SBS) symptoms were recorded from the respective respondents on each day of IAQ assessment conducted and the score given in the analysis of data as shown in Fig. 1.

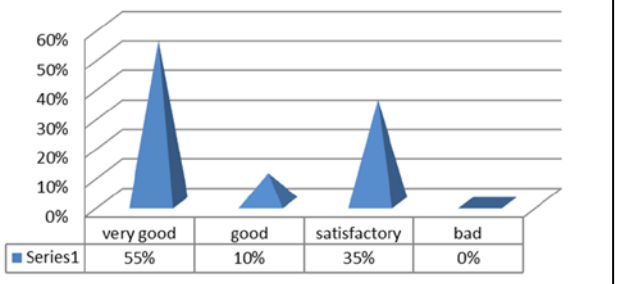


Fig. 1. Hospital occupant's perception of Indoor Air Quality

4. Hospital Building Infrastructure

The questionnaire was done in the Hospital Building in Hyderabad which is fully Air Conditioned controlled by Building Management Sysytem. A continuous data log of carbon dioxide, temperature, and relative humidity for approximately one week. Indoor air quality analysis was carried of the Hospital having buildup area of 1,20,000 sq mtrs with 18 floors of capcity 750 beds controlled and maintained by HVAC system of capacity 4000 Ton.The hospital requires close coordination among Medical staff, Support staff and patients along with the maintenance of diagnostic equipment along with disinfection and sterlization techniques in order to improve health of patients, avoid infections among patients and hazards for hospital occupants.

5. Parametric Measurement

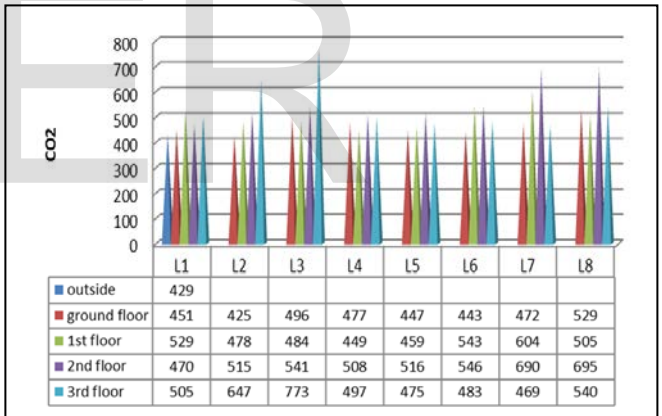
The parametric measurement of carbondioxide, Relative humidity and Temperature are major factors in health care facilities indoor air quality (IAQ). The interiors are deemed to be the most important indicators that the quality of the indoor air is good enough, when people themselves are the main source of emissions. Poor indoor air quality leads to tiredness, lack of concentration and can even bring about illnesses.

5.1 Carbon dioxide

Carbon dioxide (CO_2) level is considered to be an indicator for purpose of evaluation of indoor air quality (IAQ). Hospital occupants asre the main sourse of Carbon dioxise levels variation and air borne infections along with the concentration of body odour. Carbon dioxide is relatively varies with respect to seasons and even within a day, human traffic, occupants living habits. The useful approach is to measure surrogate for indoor pollutants emitted by humans, and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to grow drowsy, to get headaches, breathing and pulse rate increase, nausea, unconscious, further exposure 100,000 ppm leads to death. Humans are the main indoor source of carbon dioxide in most buildings. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity.

To eliminate most complaints, total indoor carbon dioxide should be reduced to a difference of less than 600 ppm above outdoor levels. NIOSH considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation.These higher limits are concerned with avoiding loss of consciousness (fainting), and do not address impaired cognitive performance and energy, which begin to occur at lower concentrations of carbon dioxide.

Carbon dioxide concentrations increase as a result of human occupancy, but lag in time behind cumulative occupancy and intake of fresh air. The lower the air exchange rate, the slower the buildup of carbon dioxide to quasi "steady state" concentrations on which the NIOSH are based. Therefore, measurements of carbon dioxide for purposes of assessing the adequacy of ventilation need to be made after an extended period of steady occupancy as recorded in figure no 2. Portable instruments used to measure carbon dioxide should be calibrated frequently and outdoor measurements used for calculations should be made close in time to indoor measurements.



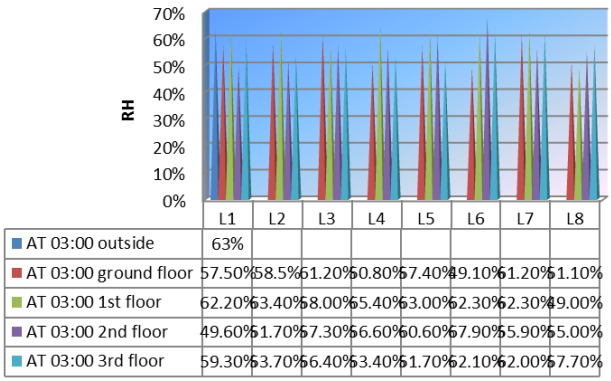
	L1	L2	L3	L4	L5	L6	L7	L8
outside	429							
ground floor	451	425	496	477	447	443	472	529
1st floor	529	478	484	449	459	543	604	505
2nd floor	470	515	541	508	516	546	690	695
3rd floor	505	647	773	497	475	483	469	540

Fig. 2. Carbon Dioxide values recorded at different floors

5. .2 Relative Humidity

Hospital buildings having high humidity levels can cause damage to sensitive hospital equipment and products used during surgery apart from discomfort to occupants. Sources of biological contaminants are major source of risk to patients health. Relative humidity also affects the shelf life and product integrity results unexpected malfunction. Air humidity must be maintained at acceptable levels because it is closely related to the space hygiene and thermal comfort conditions. Humidity control is most often accomplished by treating the ventilated air for lowering (dehumidification) or increasing (humidification) its water content, using proper equipment and controls. HVAC system configurations can achieve humidity targets for delivering the required supply air conditions, without energy wastage. High humidity levels favor the growth and transfer of bacteria that can be easily become airborne on wa-

ter molecules high humidity levels cause thermal discomfort. During low humidity level electro-medical equipment is effected by electrostatic discharge. The ventilation requirements influence humidity control. Depending on climatic conditions, additional ventilation may increase the dehumidification load more than the sensible cooling, imposing a disproportionate demand on the HVAC equipment. Low humidity levels (dry air) favor blood coagulation, which is undesirable during a surgery. In addition, moisture can be absorbed into the duct lining and building materials where it may support microbial growth. With the heavy use of electric equipment, low humidity levels may cause problems associated with static electricity on medical equipment and surfaces. In addition, this may even pose a fire hazard, as there may be flammable gases present in the environment. The recommended levels of indoor relative humidity are 30–60%, according to international regulations and standards. Most regulations establish where the use of in-flammable anaesthetic gases is possible, volatile liquids are used frequently, and in order to prevent the accumulation of static electricity should maintain a humidity of about 60%. Humidification may be necessary to increase low humidity levels, commonly encountered during winter. Special care must be exercised with humidification to assure that there is no potential for transferring bacteria through the ventilation system, since humidifiers may provide favorable environment for bacteria growth. Proper maintenance and cleaning practices will minimize this kind of risks. Humidification is best accomplished by supplying dry steam. Cold-water humidifiers in HVAC systems must be connected to a domestic water source and provided with a drain line to remove the water. Stand-alone, console-type humidifiers that re-circulate water for humidification should not be used because the water in these systems becomes contaminated with microorganisms rapidly and have been linked to outbreaks of Legionnaires' disease. Study recorded as shown in Figure no. 3.

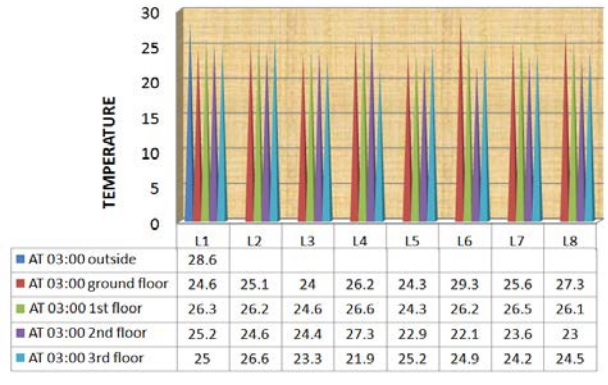


	L1	L2	L3	L4	L5	L6	L7	L8
AT 03:00 outside	63%							
AT 03:00 ground floor	57.50%	58.5%	61.20%	60.80%	67.40%	69.10%	61.20%	61.10%
AT 03:00 1st floor	62.20%	63.40%	68.00%	65.40%	63.00%	62.30%	62.30%	69.00%
AT 03:00 2nd floor	49.60%	51.70%	57.30%	56.60%	60.60%	57.90%	55.90%	55.00%
AT 03:00 3rd floor	59.30%	53.70%	56.40%	53.40%	51.70%	52.10%	62.00%	57.70%

Fig. 3. Relative Humidity values recorded at different floors

5.3 Temperature

The indoor air temperature must be maintained within the recommended ranges to ensure acceptable conditions. The Indoor air temperature must be uniform within the space. Special care must be taken to operation theater account for the different internal loads (e.g. surgical lamp) by proper design of the air conditioned supply and exhaust vents and temperature of the air supply stream. The desirable indoor air temperature is usually 20–24°C, according to international regulations and standards. Use of lower or higher temperature is acceptable when patients' comfort and/or medical conditions require those conditions. For example, for specialized procedures, such as cardiac surgery, the indoor air temperature may be set as low as 17°C, on the other hand paediatric surgeries usually demand a higher indoor air temperature because children are more sensitive to lower temperatures. In any event, a high indoor air temperature may cause discomfort and offers more favorable growing conditions for bacteria or their mitigation from and to the patient. Practically, it is not possible to provide all occupants with 100% acceptable indoor thermal conditions. Similarly, the medical staff working in an Operation Room may have a different perception of prevailing indoor conditions due to different levels of activity and even working positions within the OR. In general, surgeons tend to feel from ''slightly warm'' to ''warm''. Regulatory sweating is also present very often. Anaesthetists and nurses, by Contrast, experience from ''slightly cool to cold'' thermal sensation. This is especially true for temperatures below 21°C. These are in agreement with other studies where preferable thermal comfort conditions were reported for aesthetics (23–24°C), for nurses (22–24.5°C) and for surgeons (18–19°C). For patient's, the recommended air temperature ranges between 24 and 26°C. Medical clothing will have a direct impact on personnel's thermal comfort conditions. Surgical scrub garments are typically worn by OR personnel to control airborne contamination, although there is no scientific data to support this practice as a means for preventing transmission of infection. Heavier gown requirements used by the surgical team for protective reasons during an operation (i.e. because of AIDS) may require an indoor temperature down to 18°C or even lower. The field measurement was conducted at various floors present in figure-4 at various locations.



	L1	L2	L3	L4	L5	L6	L7	L8
AT 03:00 outside	28.6							
AT 03:00 ground floor	24.6	25.1	24	26.2	24.3	29.3	25.6	27.3
AT 03:00 1st floor	26.3	26.2	24.6	26.6	24.3	26.2	26.5	26.1
AT 03:00 2nd floor	25.2	24.6	24.4	27.3	22.9	22.1	23.6	23
AT 03:00 3rd floor	25	26.6	23.3	21.9	25.2	24.9	24.2	24.5

Fig. 4. Temperature values recorded at different floors

Finally, asymmetric thermal radiation from surgical lights on the surgical staff is a potential source of thermal discomfort. Thermal radiation emitted from surgical lights regardless of the indoor air temperature.

6. Building HVAC System

The procedures used to calibrate indoor air quality of health

care facilities are as follows:

- Determine the effective volume of the hospital.
- Record the temperature and humidity conditions, the method of distribution of air (ceiling outlets, side wall, floor outlets, etc.) and the operation hours of the system.
- Collect the specifications of the airside system (type, capacity of supply air, fresh air and return air flow rate, control method, etc.) and the accessories such as fresh air damper, type of diffuser, etc.

To calculate the air change rate when the air-conditioning system was operating, the hospital was pressurized and infiltration is reduced.

The Outdoor air requirement is significant important for IAQ. The outdoor air requirement is related with the number of occupants and net available occupancy.

HVAC system should provide sufficient fresh air to avoid concentration of contaminated indoor air pollution. Supply air velocity for each supply air grill was measured by using anemometer. Airflow rate was designed and measured of supply air flow rate for fan coil units and Air Handling Unit.

7. Conclusion

The measurements were carried out to check the values Carbon dioxide (CO_2), Relative Humidity (R.H %) & Temperature (T). It was observed that throughout the week the values of CO_2, relative humidity and temperature were in acceptable range. It indicates that the overall performance of HVAC systems is good in this hospital building.

Since the feedback gathered from the occupants of the building also indicate that a majority of them feel comfortable inside the building and do not report of any severe complaints, it can be concluded that the HVAC systems is providing sufficient amount of fresh air along with maintaining the temperature and relative humidity.

The above measurements were recorded for a period of one week only. However, a long term field measurements have to be recorded to analyze the performance of HVAC systems and IAQ issues on a minute scale.

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8. References

[1] R.W. Marans. Evaluation Research in Architecture. In: J. Snyder, ed. Architectural Research. New York, 1984. Van Nostrand Reinhold.

[2] Akimenko VV, Anderson I, Lebowitz MD, Lindvall T. 1984. The "Sick" Building Syndrome

[3] Proceedings of the Third International Conference on Indoor Air Quality and Climate. Swedish Council for Building Research. Stockholm. 6:87-97

[4] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1990

[5] ANSI/ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality. Atlanta, USA.

[6] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1992.

[7] ANSI/ASHRAE Standard 55-1992. Thermal Environmental Conditions for Human Occupancy.Atlanta, USA.

[8] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1993.

[9] ANSI/ASHRAE Guideline 4-1993: Preparation of Operating and Maintenance Documentation forBuilding Systems. Atlanta, USA.

[10] Armstrong CW, Sherertz PC, Llewellyn GC. 1989. Sick Building Syndrome Traced to ExcessiveTotal Suspended Particulates. Proceedings of IAQ 89. 3-7

[11] E. Marcon, S. Kharraja, G. Simonnet, The operating theatre planning by

[12] the follow-up of the risk of no realization, International Journal of Production Economics 85 (1) (2003) 83–90.

[13] Macario, T.S. Vitez, B. Dunn, T. McDonald, Where are the costs in perioperative care? Analysis of hospital costs and charges for inpatient surgical care, Anesthesiology 83 (1995) 1138–1144.