EFFECT OF THE ACTIVITIES INSIDE A HOSPITAL THEATRE ON ITS IAQ

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Abstract:
A close relationship can be observed between the building performance and the activities associated with the building. Since those activities have a great impact on Indoor Air Quality (IAQ) of the building, it is necessary to consider the activities that would take place inside a building, at its design stage.

In this research study, the effect of the activities associated with a hospital theatre, on its IAQ has been studied since the theatre staff of a leading hospital in Sri Lanka, experience some discomfort while being inside the theatre. In order to evaluate this, variation of Carbon Dioxide (CO_2), Carbon Monoxide (CO), Total Volatile Organic Compounds (TVOC) and Particulate Matter less than 2.5 microns ($PM_{2.5}$) concentrations inside the theatre were measured and analysed.

Significant variations were observed in the concentrations of CO_2, TVOC and CO inside the operation theatre. CO_2 concentration inside the room increased at the beginning and end of the surgeries due to high occupant density and also during *Laparoscopic surgeries.* TVOC concentration was affected by the usage of different chemicals during the surgery. Major effect to the CO concentration was by *Diathermy.*

Key words: *Indoor Air Quality (IAQ), Hospital theatre, Sick Building Syndrome (SBS)*

1. Introduction

Activities associated with a building, along with the design features have a great impact on the Indoor Air Quality of a building. The activities which will take place inside the buildings should be taken into account at the design stage. Apart from that it is essential to maintain proper building operational practices as well. Thus the adverse effects the indoor activities pose on IAQ will be minimized, resulting a 'Healthy Building'.

Recently the scientific community has become increasingly interested in the air quality of indoor areas of hospitals and healthcare facilities. Operation theatres, laboratories, hospital wards and private practices have been examined, as the locations where there is a higher possibility for both patients and hospital staff to get exposed to infectious agents, which can be harmful to their health. [1]

In a hospital theatre, the stagnation of the emissions from the chemicals used inside is expected to be high, since it is an enclosed space. This creates a larger health impact on the staff associated with surgeries, as they are exposed to these polluted environments for long hours.

The staff members associated with the theatre of the one of the leading hospitals in Sri Lanka have been complaining about discomforts they are experiencing during the surgeries and afterwards. Since this is an indication of Sick Building Syndrome (SBS), the IAQ of the hospital theatre under the existing ventilation condition was measured.

In order to understand the indoor air pollution, it is essential to identify causative agents and the sources of them. Sulphur Dioxide (SO_2),Nitrogen Dioxide (NO_2),Carbon Monoxide (CO) ,Volatile Organic Compounds (VOC),Carbon Dioxide (CO_2),Particulate Matter (PM) can be identified as common types of causative agents. Since the chemical reactions are active at higher temperatures, thermal measurements are also useful in the study. Different types of surgical equipment and chemical solutions used during surgeries, release various causative gases. Depending on the chemicals present, the impact on indoor comfort and occupant health can vary.

2. Objectives

The main objective of this research study was to determine the concentrations of IAQ parameters due to the various chemicals used during surgeries and the effects on the occupants due to the long term exposure. The adequacy of the existing ventilation system was also assessed for its suitability for dilutional dispersion of pollutants.

3. Methodology

3.1. Test Chamber

The study took place at an operation theatre of one of the leading hospitals in Sri Lanka. This theatre consisted of two compartments, surgery area and doctor's changing room, attached to each other by a door (size 2.0m x 0.9m) which was kept open throughout. The dimensions of the openings of the test chamber are shown in Figure 1.

The room mainly consisted of steel furniture which included the theatre bed, two cupboards, trolleys and stools. In addition, equipment such as theatre lighting, anaesthetic machine, sucker machine and laparoscopy machine (occasionally) were available. Since almost all the furniture and equipment were made out of steel or plastic the effect of absorbing the contaminants and releasing with time, has not become a major issue in this study.

Both compartments of this room were ventilated by a central air conditioning system, of which the corresponding outlet was located directly above the theatre bed as indicated in Figure 1. Both the compartments were under sterilization throughout. The state of the art equipment and technology is used in this hospital with old infrastructure which in turn results poor air quality.

The occupant density of the room was not constant during the course of the experiment. At the initial stage of a surgery the occupant density of the room reached to the maximum value. But gradually it decreased during the surgery and came to an average value of 10. At the end of the surgery also the occupant density increased to about 15. This was the major factor for higher CO_2 concentration inside the room.

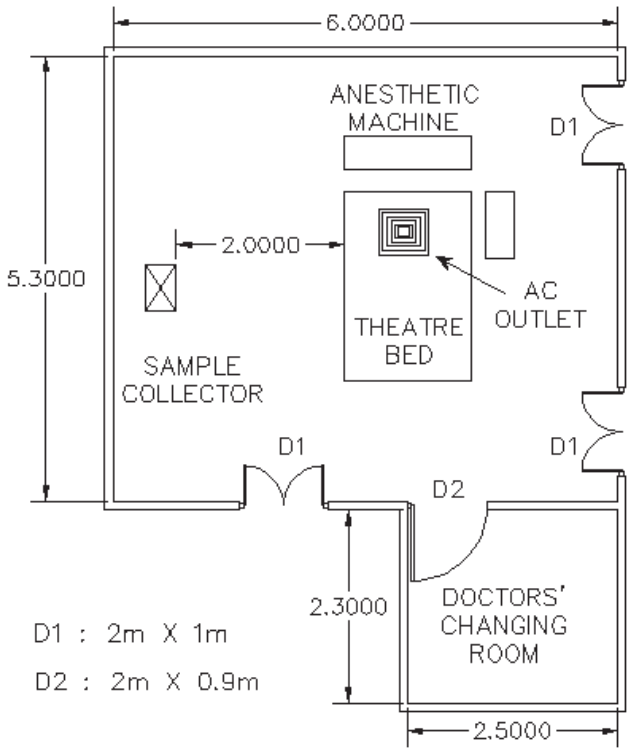

Figure 1: Plan view of the theatre (Dimensions are in meters)

3.2. Measured Parameters and the Equipment Used

The variations of the concentrations of indoor air pollutants under the influence of the chemicals used during various types of surgeries were measured. Measurements of Carbon Monoxide (CO), Volatile Organic Compounds (VOC), Carbon Dioxide (CO_2), Particulate Matter ($PM_{2.5}$) concentrations, variation of room temperature and Relative Humidity were recorded.

The pieces of equipment used in this study were Indoor Air Quality Monitor (IQM60 Environmental Monitor V5.0) and Haz-Dust Particulate Air Monitoring Equipment.

Indoor Air Quality Monitor (IQM60 Environmental Monitor V5.0) was used to measure the concentrations of CO, Total VOC, CO_2, room temperature and relative humidity. Haz-Dust Particulate Air Monitoring Equipment was used to measure the concentrations of $PM_{2.5}$ throughout the study.

3.3. Experimental Programme

Instruments were placed at a height of 0.9m from the ground and at 2m distance from the theatre bed. Both the instruments were plugged in for warming up for one hour before the surgeries were started. Test was conducted in an air conditioned and sterilized environment. Measurements were taken for several days, during different surgeries in order to obtain the effect of different types of surgeries taking place inside the theatre. The theatre was allowed to function under its normal condition, thus the doors were opened and closed time to time.

In order to gather information on experiences and complains of staff members on the effect of IAQ inside the theatre, a questionnaire survey was conducted.

4. Results

Results obtained are illustrated below in two categories;

i. Data obtained from the questionnaire survey
ii. Concentrations of the causative agents measured inside the theatre.

4.1. Questionnaire Survey

A questionnaire was prepared in order to gather information on occupant comfort levels with respect to indoor air quality of the theatre. There were 50 copies of the questionnaire distributed among the staff members. In the selected sample there were 6 out of 50 were invalid and this sample of 42 included 5 Surgeons, 20 Medical Officers, 16 Nursing Officers and 1 Attendant. The response rate for the questionnaire survey was 100% and rate of validity was 88%.

The questionnaire was focused on the discomforts experienced, duration of exposure, suspected causes and suggestions for improvements.

4.1.1. Symptoms

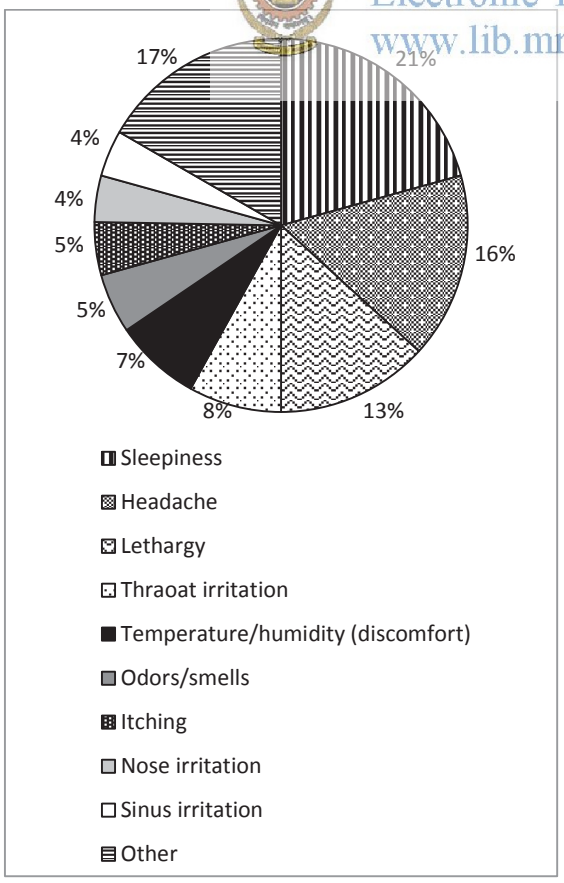

Figure 2: Symptoms/ Complain

According to the analysed results of the questionnaire survey (*Figure* 2), it is apparent that majority of the occupants are suffering from headache (21%), lethargy (16%) and sleepiness (13%). A significant number of occupants has complained about throat irritation, discomfort due to variation of temperature/humidity, odors/smells, itching, nose irritation and sinus irritation. The number of occupants suffering from cough, dizziness, eye irritation, fatigue fever, shortness of breath, chills, chest tightness, nausea, swelling and congestion was observed to be smaller. These are the symptoms of Sick Building Syndrome (SBS) due to the adverse effects of the poor IAQ.

4.1.2. Suspected Causes and Causative Agents

Main cause for the poor IAQ inside the theatre was the leakage of air from the anaesthetic machine as suspected by the majority of the occupants (41%). According to them, the causative agents are *Perasafe* and *Halothane* gases generated by the anaesthetic machine. Poor ventilation inside the theatre is another major factor that causes discomfort to the occupants. Although the theatre has a central air conditioning system, air circulation inside the theatre is not in a satisfactory level. Thus the released air stagnates around the theatre bed, where the occupant density is high. Longer the exposure during surgeries to the stagnated air, higher the discomfort for the occupants.

Diathermy induced gases also cause higher level of discomfort for the occupants. But, it seemed that the occupants are accustomed to the odor because of the frequent exposure. In occupants' point of view it is apparent that the long working hours and the exposure into different chemicals such as N_2O, CO_2 and Ether may cause the symptoms mentioned in Figure 2. Therefore, it is important to have a proper ventilation system that provides a better indoor environment. (*Figure 3 and 4*)

4.1.3. Discomforts felt at different time periods of the day

According to Figure 5 the discomfort is more severe (54%) after coming out of the theatre. There is the substantial effect while inside the theatre and also during a surgery.

When the Figure 6 is considered, it is apparent that the higher numbers of complaints are from the occupants who are exposed to the poor indoor air for a comparatively lower time period (i.e. less than 24 hours per week). The main reason for this could be the occupants who are working long hours have been adapted to this indoor environment so that they feel less discomfort and thus the actual effect is not felt by them (acclimatization). People who are exposed to this environment for lower time periods have complained more on the uneasiness compared to the ones who are exposed for long hours, which in turn shows the effect of acclimatization. When the Figure 7 is considered it is noticeable that the effect lasts for about 3 hours for the majority of occupants. A fewer number of people suffer from discomfort for more than 12 hours. Sleepiness, Lethargy and headache are the symptoms which last for a longer period. Therefore it is apparent that the majority of the occupants suffer from SBS.

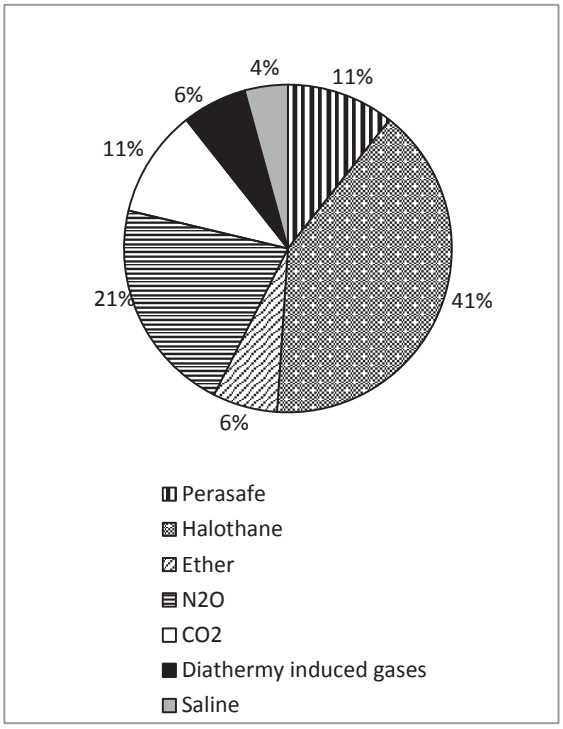

Figure 4: Suspected Causative Agents

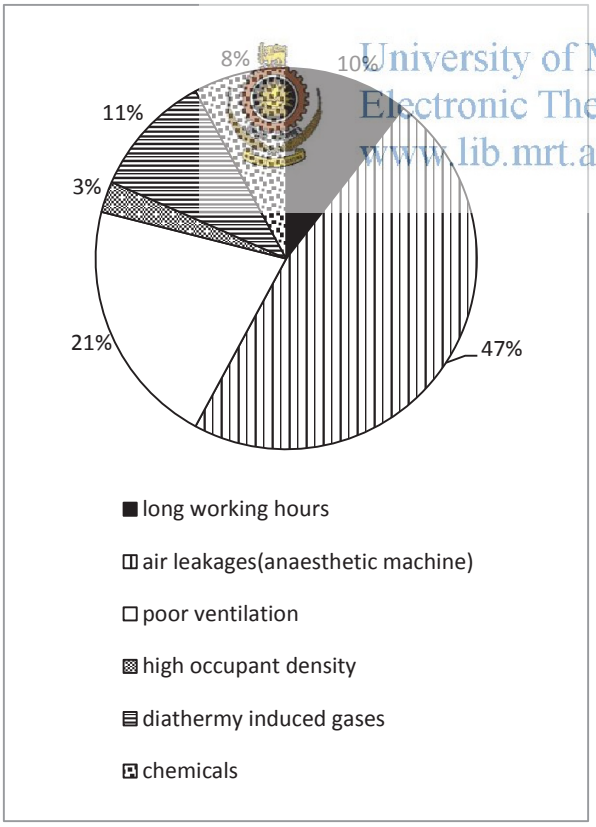

Figure 3: Suspected Causes

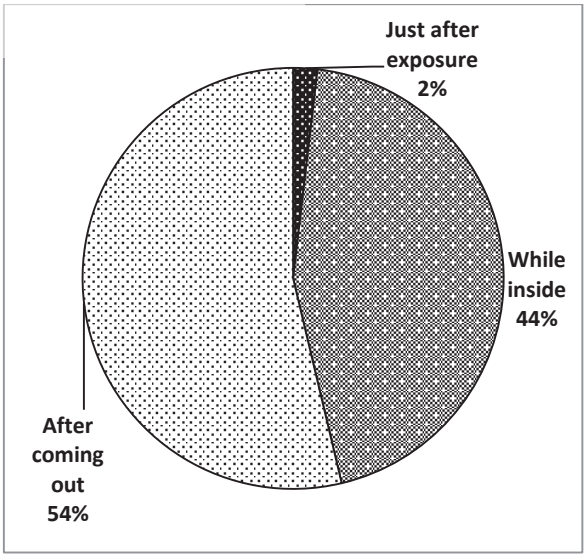

Figure 5: Discomforts felt at different times of the day

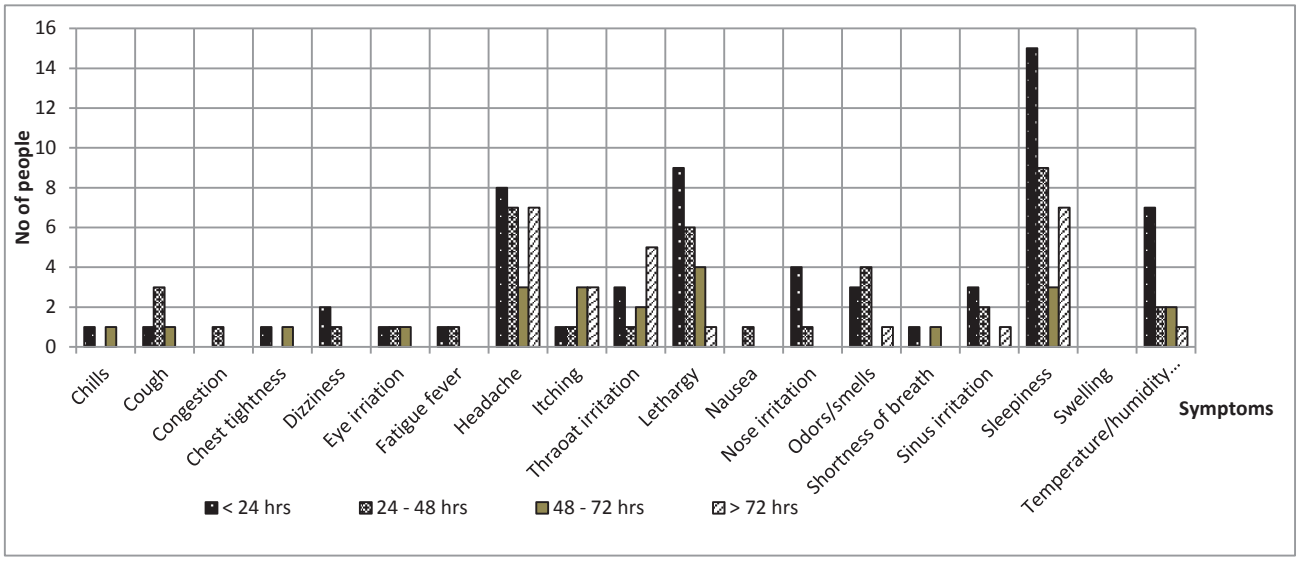

Figure 6: Exposure Levels and Discomforts

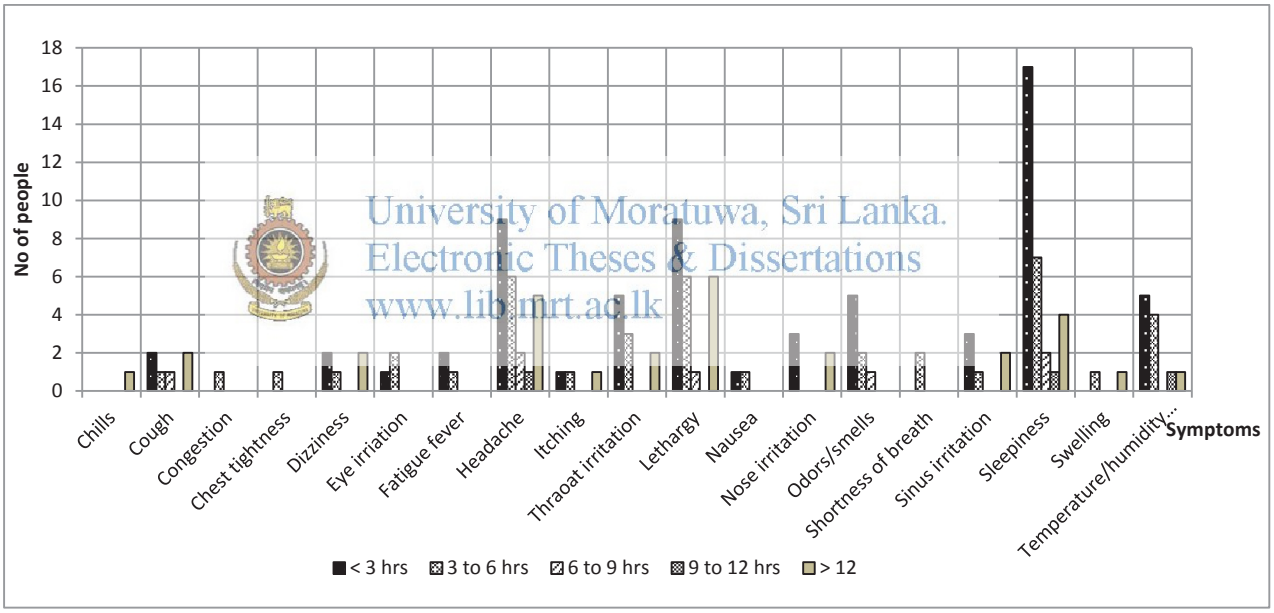

Figure 7: Time Periods Symptoms Persist

4.2. Concentrations of the IAQ Parameters

Due to the usage of different chemicals and also the differences in the number of occupants inside the theatre, significant variation in the concentrations of measured parameters was witnessed. The concentrations of causative agents in three days showed different variation patterns depending on the type of surgery.

4.2.1. Carbon Dioxide (CO_2)

Occupant density is a major concern with respect to the CO_2 concentration inside a room. Therefore, the number of occupants inside the operation theatre was counted in order to assess the variation of CO_2 concentration. Since the occupant density inside the theatre is generally high at the commencement of a surgery and also at the end of the surgery, CO_2 levels have shown high concentrations during those instances. (*Figure 8a, 8b and 8c*) The concentration of

CO_2 is a function of the number of occupants as well as the time they spent in the room. This factor is indicated in Figure 8.

Further to that, '*laparoscopic surgeries'* also have shown an increase in the indoor CO_2 concentration. (*Figure 8b*) That is because CO_2 was blown into the body of the patient during these surgeries to get a much clear image of the area under the surgery on the screen.

Although CO_2 level has exceeded the ASHRAE (American Society of Heating Refrigerating and Air conditioning Engineers)[2] recommended value only once, the concentration of CO_2 was observed to be relatively higher than the usual indoor CO_2 concentration.

4.2.2. Total Volatile Organic Compounds (TVOCs)

The TVOC concentration inside the theatre has shown a variation with high peaks at the start and at the end of surgeries. This is mainly due to disinfectants such as '*Ether*' and '*Surgical spirit*' applied on the patient prior to and after the surgery. (*Figure 9a, 9b and 9c*) During these periods researchers experienced a breathing difficulty, which was not bothering the surgical staff. The long term exposure to these chemicals has acclimatized them not to feel the discomfort TVOC s create on their respiratory systems.

It can be observed in the graph that the TVOC concentrations increase well above the permissible level, mostly in the range of 10 to 25 times the permissible level. Maximum value TVOC concentration has reached more than 55 times the permissible. It is noticeable that the time taken for dispersion lies above 30 minutes for each peak TVOC level reached. Therefore, the increased concentrations can harm occupants, especially those who get exposed to these conditions daily.

4.2.3. Carbon Monoxide (CO)

Variation of CO concentration was examined to be within a range of 2 ppm from its initial value of 0 ppm. From the graphs, it is indicated that *Diathermy* can be the main cause of emitting CO to the indoor air. Since incomplete combustion takes place during *Diathermy*, the mechanism of burning veins in order to seal them and prevent bleeding during a surgery, CO is emitted. Although a sucker machine is used at the point where *Diathermy* is carried out, some amount of CO gets escaped to the indoor environment.

Apart from that, an increase in indoor CO concentration was observed during Laparoscopic surgeries as well.

Nevertheless, concentrations of CO inside the theatre did not reach the permissible value and was in the range of 0-22% of the permissible value (*Figure 10a, 10b and 10c*).

4.2.4. Particulate Matter ($PM_{2.5}$)

Particulate matter concentration for the particles of size less than 2.5µm was measured inside the theatre. Even in the normal condition, the concentration was lying half way closer to the permissible value. It was observed that the $PM_{2.5}$ goes beyond the permissible value of 0.025mg/m^3 during the period of surgery, especially when *Ether* was used. (*Figure 11*)

4.2.5. Temperature and Humidity

Temperature inside the room did not show any significant variation, which was varying between few degrees. Relative humidity was also varying between 65-75% without showing abrupt changes.

It should be noted the fact that these measurements were taken from a distance of 2m from the theatre bed, at a distance which will not disturb the on-going surgeries. The concentrations of pollutants such as TVOCs and CO closer to the theatre bed can be higher than the recorded values. Thus, the effect can be more severe for the surgical staff, as they work around the theatre bed.

Permissible concentrations considered in this study for each causative agent is listed in *Table 1*.

Table 1: Permissible Concentrations of Parameters

Parameters measured	Permissible value
CO	9 ppm [a] (24 hr)
TVOC	0.75 ppm [b] (24 hr)
CO_2	1000 ppm [a] (24 hr)
$PM_{2.5}$	0.025 mg/m^3 [c] (24 hr)

[a] - ASHRAE Standards [2]
[b] - OSHA Standards [3]
[c] - WHO Guidelines [4]

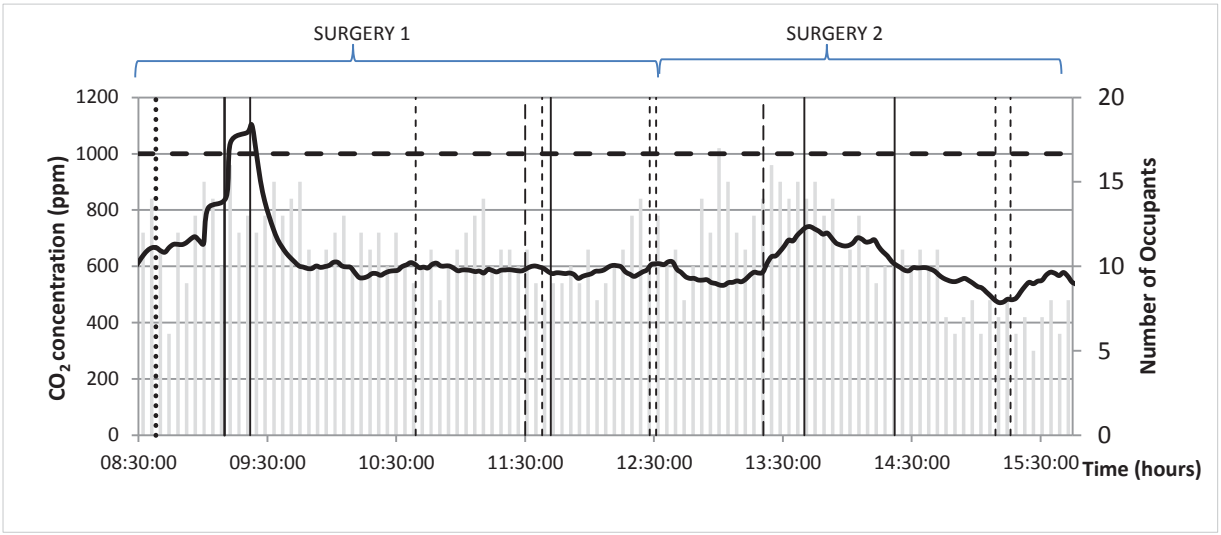

Figure 8a: CO_2 Concentration inside the Theatre (Day 1)

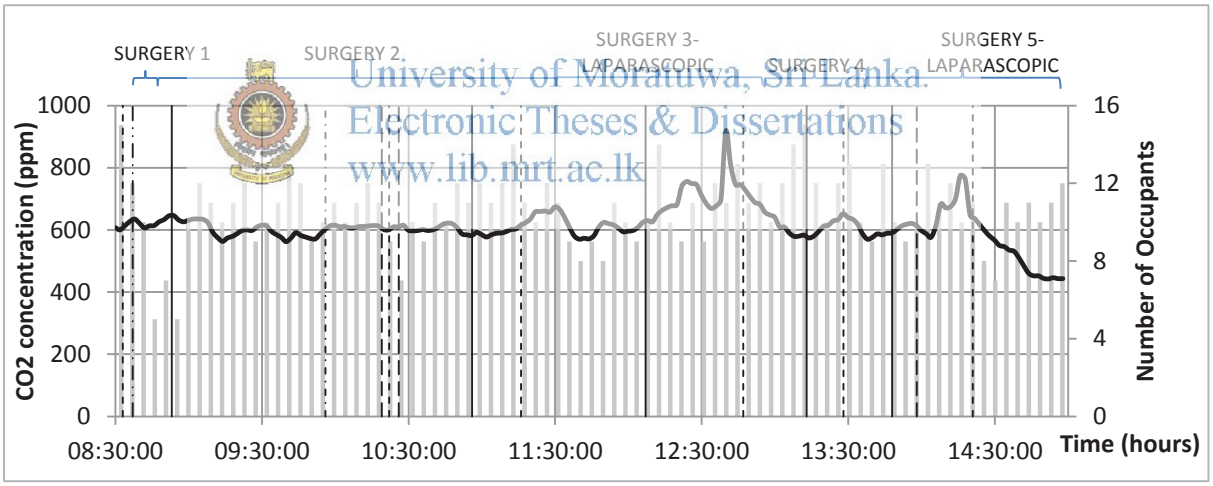

Figure 8b: CO_2 Concentration inside the Theatre (Day 2)

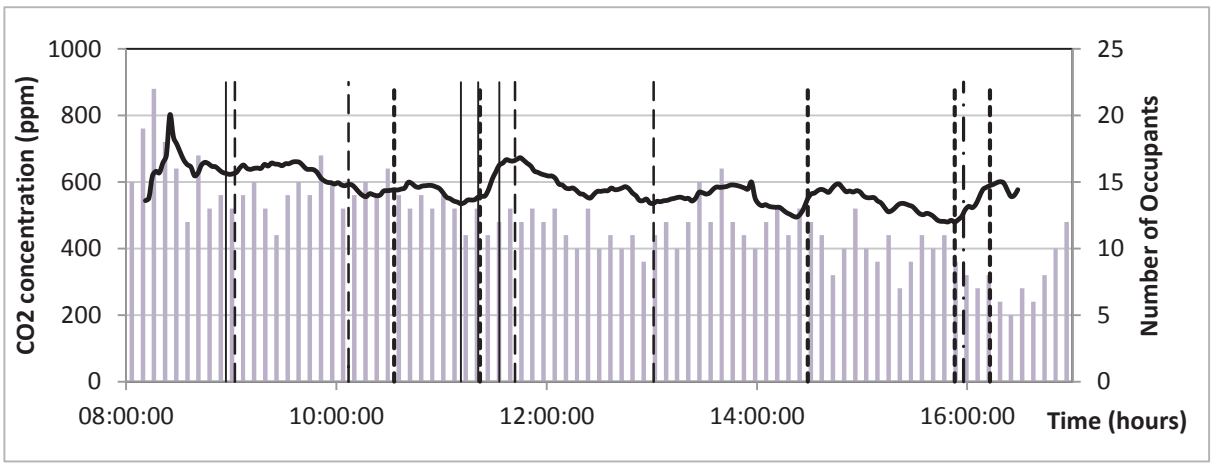

Figure 8c: CO_2 Concentration inside the Theatre (Day 3- One surgery throughout)

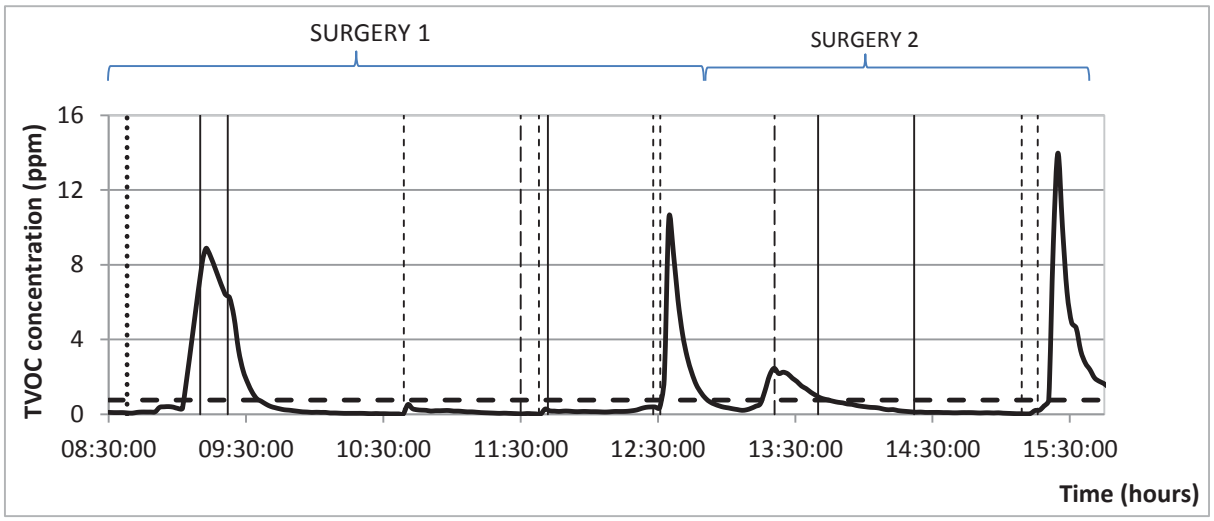

Figure 9a: TVOC Concentration inside the Theatre (Day1)

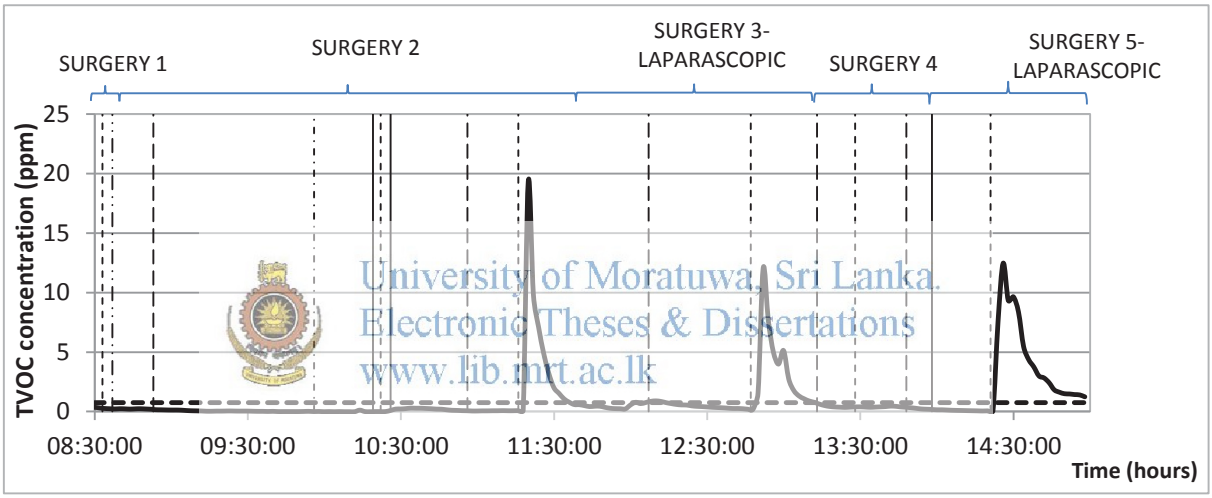

Figure 9b: TVOC Concentration inside the Theatre (Day2)

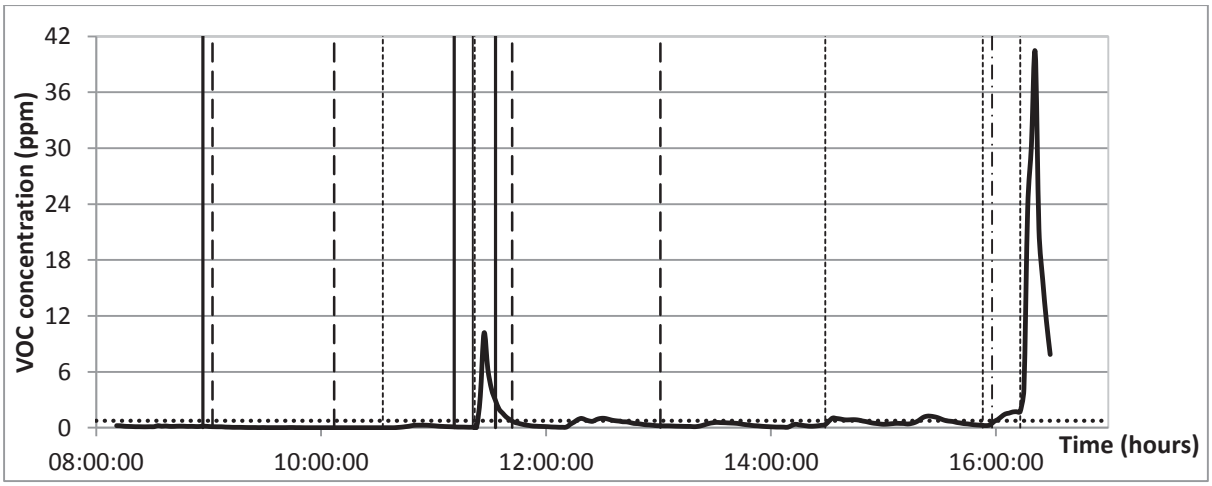

Figure 9c: TVOC Concentration inside the Theatre (Day 3- One surgery throughout)

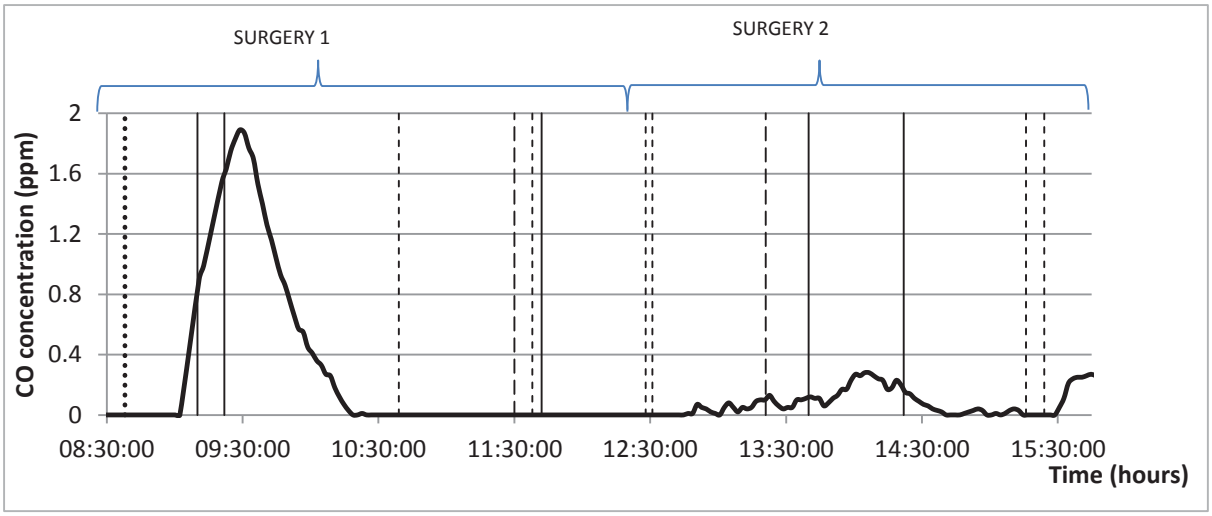

Figure 10a: CO Concentration inside the Theatre (Day 1)

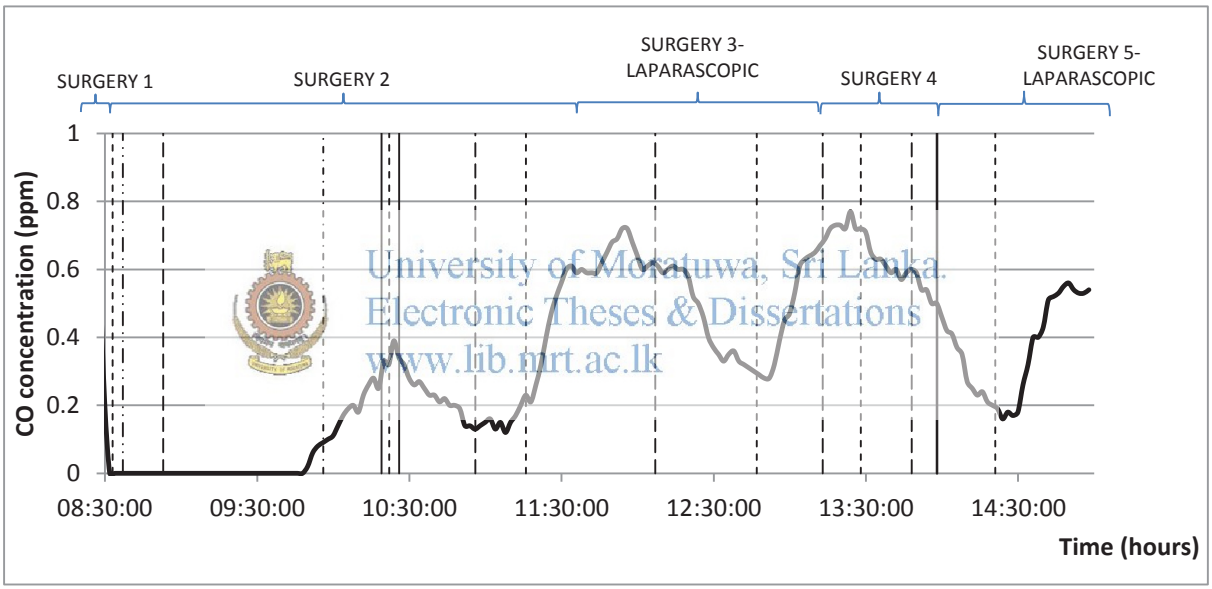

Figure 10b: CO Concentration inside the Theatre (Day 2)

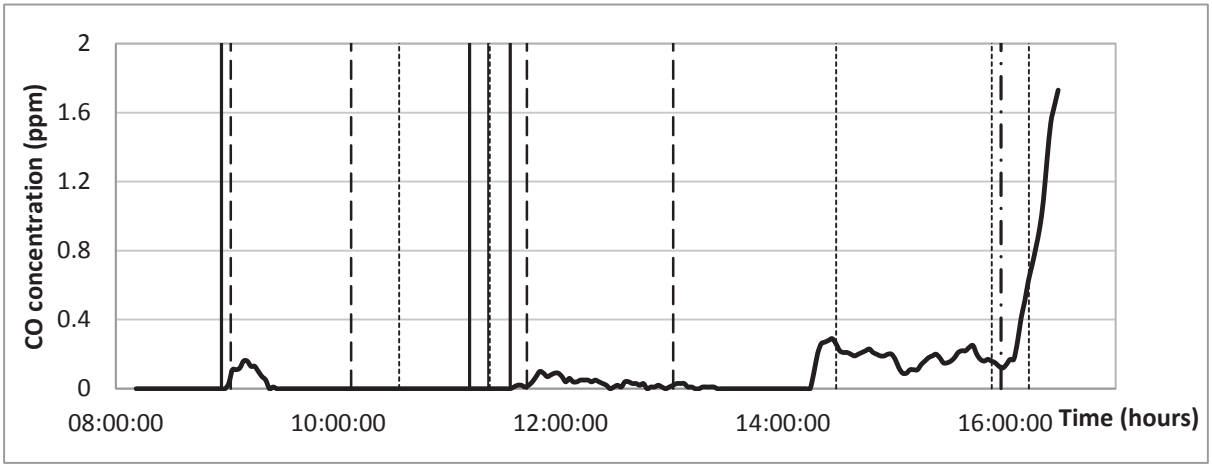

Figure 10c: CO Concentration inside the Theatre (Day 3- One surgery throughout)

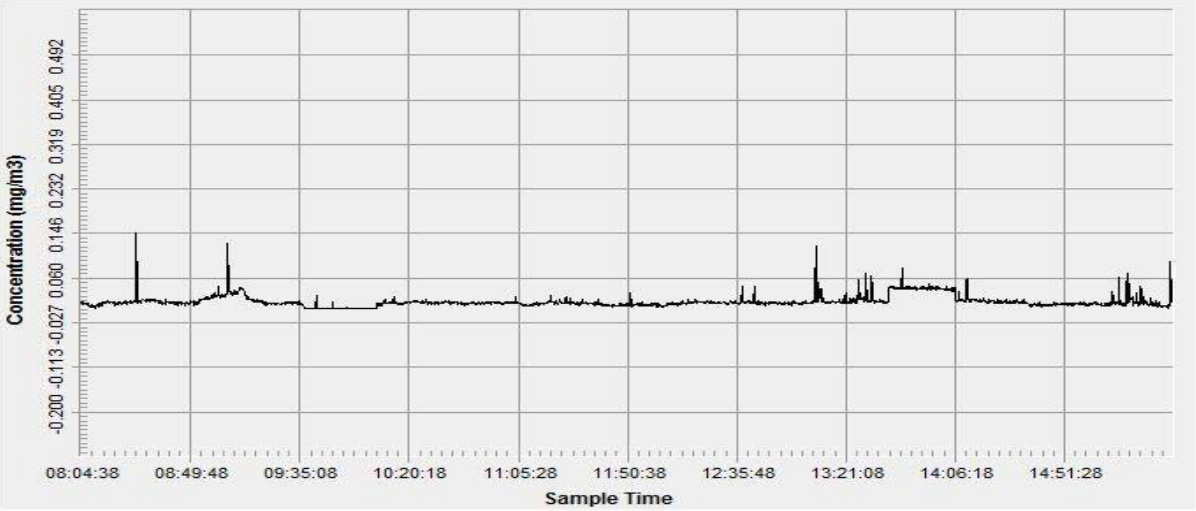

Figure 11: $PM_{2.5}$ Concentration inside the Theatre

Currently, a proper air circulation system is not available for this theatre, which results in higher stagnation of released gases. An air circulation system as shown in Figure 12[5] will enhance the IAQ of the theatre by flushing out indoor air pollutants generate around the theatre bed.

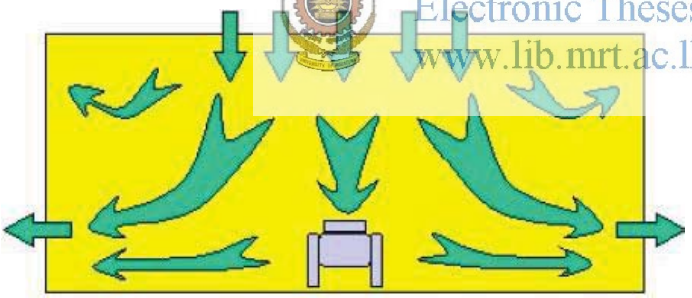

Figure 12: Recommended air circulation system for the Operation Theatre.

5. Conclusion and Recommendation

The IAQ status of an operation theatre in a leading hospital in Sri Lanka was studied while surgeries were taking place, to study the effects of different chemicals and methods used, on the concentrations of CO, TVOC, CO_2 and $PM_{2.5}$.

- Since the sample collection was carried out at a distance from the theatre bed, the recorded variations of the concentrations of CO, TVOC, CO_2 and $PM_{2.5}$ are lower than the actual variations of concentrations near the surgical area. Therefore the surgical staff around the theatre bed is exposed to the more severe conditions than the measured values. Since they are exposed to these conditions for long hours it is important to plan the design of the building and equipment to minimize the release of causative agents.

- Proper air circulation methods should be adopted to have better IAQ inside the theatre. It should be designed such that it flushes out the indoor air pollutants generate around the theatre bed as indicated in Figure 12.

- Exhaust fans should be installed on each side of the theatre room, so that the polluted air could be removed from the room. This should be a major consideration at the design stage. It also could be adapted to existing systems to improve the IAQ.

- It would be important, if an air suction system could be installed, so that anesthetic gas or evaporated medication emanating from surgical area could be collected.

- Indoor air of the clinic should be renewed either by natural or mechanical ventilation during non-working hours. Sterilization of the area can be done afterwards. [6]

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