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COMPARATIVE AMBIENT AND INDOOR PARTICULATE MATTER ANALYSIS OF OPERATION THEATRES OF GOVERNMENT AND PRIVATE (TRUST) HOSPITALS OF LAHORE, PAKISTAN

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ABSTRACT

The link between infection and indoor air quality (IAQ) in operating theatres is well established. The level of airborne particulate matter (PM) in operating theatres in Pakistan has not yet been studied comprehensively. Monitoring of both indoor (operating theatre) and outdoor concentrations of PM in both activity and non-activity time periods was done using a DUSTTRAK Aerosol Monitor (TSI Model 8520) and DRX Aerosol Monitor (TSI Model 8533) for 24 hours. Two hospitals in Lahore were selected: Services Hospital (government – site 1) and Shalamar Hospital (private – site 2). The highest concentration of PM was observed in the orthopaedic operating theatre at site 1 during working hours with an average concentration of 757(±540), 809(±58), 824(±585), 875(±586) and 970(±581) µg/m³ of PM_1 ,$PM_{2.5}$, PM_4, PM_{10} and PM_{Total} respectively while the average $PM_{2.5}$ outdoor concentration was 294 µg/m^3. The minimum average PM concentration was found in the orthopaedic operating theatre at site 2 during working hours: 18(±8), 19(±8), 20(±9), 26(±9) and 39(±9) µg/m³ for PM_1, $PM_{2.5}$, PM_4, PM_{10} and PM_{Total} respectively. The use of vertical laminar air flow ventilation strategy was found to be an effective measure in reducing PM levels and it might be possible to predict the air quality of operating theatres by determining PM dust load. Factors such as ventilation system, door opening /closing rates, building age, possible sources of infiltration, number of people present in the operating area all play a role in influencing PM concentrations in operating theatres.

Key words: Particulate matter, Operation theatre environment, IAQ in hospitals, Pakistan.

INTRODUCTION

The primarily role play by the hospitals is to offer patients with treatment and nursing care. It is necessary to maintain air quality in the health care facilities to prevent infections in hospitals especially in case of immune compromised and immunosuppressed patients along working staff and visitors. Among the various departments of hospitals, such as out patients departments, intensive care units, radiology departments, laboratories and pharmacies, the operating theatres are of greatest concern. It is important to optimize the environment of the operating theatre to reduce surgical site infection. The ventilation frame work plays an uncertain role in surgical site infection prevention (Salassa and Swiontkowski, 2014).

The air quality in hospitals is related with the inappropriate building health, ventilation rate and air conditioning systems. The overcrowding of humans in the reserved spaces of operating theatres seems to increase airborne hazards. Urban settings typically have greater air quality problems as compared to the rural settings due to population growth, industrialization and change use of urban land (Cho and Choi, 2014). In low income countries outdoor air pollution results in around 3.7 million premature deaths due to exposure to PM10. This induces respiratory, cardiovascular diseases and cancer (WHO, 2014). As urban settings have high concentrations of air pollutants, the hospitals locating there have relatively more elevated levels of PM as compared to the ones in rural areas. The assessment of risk factors for particulate and microbial contamination of air in operating theatres suggests that the dust load and the airborne microbial contamination can be interrelated (Scaltritia, 2007). So it is acceptable to use dust load (PM levels) to predict the air quality of the operating rooms other areas in hospitals. Airborne contaminants inside the operating theatres are actively contributed and mobilized by working staff and patients and their activities. The suspended PM fraction sized between 5–7µm appears to be associated with the airborne microbial concentration. Hence it can be inferred that PM levels can be used as a surrogate in assessing the air quality of operating rooms (Tang and Wan, 2013).

The purpose of this study was to determine the possible sources of PM in operating theatres and to examine the role of vertical laminar flow as effective strategy towards improving air quality in the operating rooms.

MATERIALS AND METHODS

Sampling site: Two tertiary care hospitals were selected in Lahore. Lahore city, the second largest city of Pakistan, is the capital of Punjab with a total population of 11,000,000 and a total area of 1772 km^2. One was a government hospital (Services Hospital) Site 1, while the other was run by a Trust (Shalamar Hospital) Site 2 (Fig. 1) .Table 1 represents the profile of the selected sites.

Table- 1. Profile of the selected sites

Parameters	Services hospital (Site 1)	Shalimar Hospital (Site 2)
Number of operation theatres	8 minor operation theatres and 27 major operation theatres	9 major operation theatre and 1minor operation theatre
Number patients visit hospital per day	2000 patients approx.	1300 patients approx.
Locality	Urban, Busy road	Urban ,Busy road
Type of surgeries	Spine surgeries, Neurosurgeries, Thoracic, Lung surgery, Laparoscopic operations. Breast surgery, Cancer surgery, Intestinal surgery, Thyroid and Neck surgery, Liver, Gall Bladder and Pancreatic surgery, Vascular surgery, Ano-Rectal surgery	Laparoscopic operations. Breast surgery, Cancer surgery, Intestinal surgery, Thyroid and Neck surgery, Liver, Gall Bladder and Pancreatic surgery, Vascular surgery, Ano-Rectal surgery, Orthopaedic surgery
Building age	Establish in 1958	Establish in 1978
Building structure	Infirm	Compact
Selected theatre for sampling	GOT_1, OOT_1, EOT_1	GOT_2, OOT_2, EOT_2
Ventilation system	Natural	Natural except OOT_2

GOT_1= General operation theatre site 1, OOT_1=Orthopaedic operation theatre site 1, EOT_1=Emergency operation theater site 1, GOT_2= General operation theatre site 2, OOT_2=Orthopedic operation theatre site 2, EOT_2=Emergency operation theater site 2.

Fig.1: Location of hospitals where monitoring was carried out

Selection of Operation theatres: In both hospitals three operating theatres were selected for PM monitoring. The selection was based on the type of surgeries configured (Table 2).

Table- 2: Summary details of Operation theatres at Site 1 and site 2

Site	Floor area	Surgeries practicing hour	Door during surgery Hours	Door during nonworking hours	People present during surgeries	Ventilation system	Surgeries done during working hours
GOT_1	29.42m^2	8:00 am - 12:30am	Open	Close	5-7	Natural	3
GOT_2	29.09m^2	9:00 am - 9:30 pm	Close	Open	5-6	Natural	8
OOT_1	30.73m^2	8:00 am -2:00 pm	Open	Close	7 -16	Natural	5
OOT_2	30.56m^2	9:00 am- 12pm	Close	Close	8-9	Laminar flow	6
EOT_1	39.03m^2	24hour	Varied	Open	6-9	Natural	15minor
EOT_2	25.46 m^2	9:00 am -10:00am	Close	Close	3-4	Natural	2minor

Sampling Design and Instrumentation: Parallel monitoring was carried out in both the operating theatres and ambient air. The outdoor air was sampled only for $PM_{2.5}$ while the indoor air was assessed for PM_1, $PM_{2.5}$, PM_4, PM_{10} and PM_{Total} fractions. Apart from PM monitoring, CO_2, CO, temperature and relative humidity levels were also monitored for a period of 24 hours within and outside of each operating theatre. $PM_{2.5}$ monitoring was carried out in the outdoor air by using a real time aerosol monitor (DustTrak, Model 8520, TSI Inc.). The other parameters were measured with the IAQ Gas Probe (BW technologies). In the operating theatres a DustTrak DRX Aerosol Monitor (Model 8533, TSI Inc.) was used for sampling.

Data analysis: Activity and non-activity time in each operating theatre was noted and the difference in levels of PM during the two periods was compared for each operating theatre. Parameters such as number of people present in theatre, size of the theatre, number of surgeries, humidity, CO_2 concentration and temperature were also taken in an account.

The data were further analysed hourly to investigate the particulate matter levels for each sampling space. Statistical analysis was carried out with SPSS (version 17). The correlation of the indoor air quality (operating theatre) and ambient air was define by the correlation bivariate analysis with $\alpha = 0.01$ .The role of vertical laminar flow in OOT_2 against naturally ventilated OOT_1 was determined by applying an independent t test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Table 3 presents the PM hourly mean and standard deviation for the theatre and ambient air for working and non-working hours. The comparative monitoring of theatres and respective ambient sites reveals higher $PM_{2.5}$ concentrations in the ambient environment as compared to the indoor except the OOT_1. This may be due to the congested, less compact structure of the theatre along with poor ventilation where there was least air circulation and all the vents and windows were closed.

The indoor particulate matter levels are intimately related to the outdoor concentrations which show the indoor particulates are mainly contributed by those outdoors (Morawska *et al*, 2004). A positive correlation was found between all studied operating theatres and ambient air for $PM_{2.5}$ except OOT_1. The p values for EOT_1, GOT_1, OOT_1 and their respective outdoor concentrations were 0.002, 0.004 and 0.718 respectively while for EOT_2, GOT_2 and OOT_2 the obtained p values were 0.000, 0.001 and 0.003 respectively.

Figure 2(a) and 2(b) represents PM levels in the general operating theatres at sites 1 and 2 during 24 hours. The concentration of particulate matter was considerably higher in GOT_1 as compared to GOT_2. This increased indoor particulate matter fraction in GOT_1 is probably due to building structure, increased human traffic and activities inside the theatre i.e. congested, old and infirm providing more source of infiltration and long term suspension of the particulate matter while, the building structure of GOT_2 is comparatively firm and more spacious. During monitoring at GOT_1 there was a dust storm which along with the less compact building structure may have caused the infiltration of particulate matter.

Increased levels of particulate matter were found at EOT_1 as compared to EOT_2 (Fig 3a and 3b). According to Scaltriti *et al*. (2007) the monitoring of the air quality in the operating theatres shows the dust load in the operating environment, which is most likely due to the suspension of the particles before settlement along the different size fractions of the particulate matter, are positively correlated with the operation duration. Our results are in accordance with this. In EOT_1 surgeries were carried out throughout the night incorporating maximum working hours and surgeries as compared to EOT_2. Additionally a comparative reduction in PM was observed during surgeries hours with the door closed, as compared an open door as shown in figure 3(a).

Table -3: Particulate matter hourly mean and standard deviation at the two studied Sites 1and Site 2

Site	PM_1		$PM_{2.5}$		PM_4		PM_{10}		PM_{Total}	
	Hourly Mean	**SD**	**Hourly Mean**	**SD**	**Hourly Mean**	**SD**	**Hourly Mean**	**SD**	**Hourly Mean**	**SD**
GOT_1	200	±87.30	208	±90.24	214.95	±93.78	245	±116.28	284	±148.59
GOT_1^W	262	±50.18	272	±50.46	282	±51.29	332	±58.15	418	±77.01
GOT_1^N	178	±87.74	185	±90.83	191	±94.48	215	±117.05	238	±140.01
GOT_1^*	-	-	368	±152.76	-	-	-	-	-	-
GOT_2	186	±84.62	195	±87.42	199.62	±86.94	216	±83.76	241	±78.15
GOT_2^W	135	±48.78	143	±50.65	149	±51.01	172	±50.84	21	±53.11
GOT_2^N	244	±80.52	255	±83.83	258	±84.62	267	±87.47	274	±91.59
GOT_2^*	-	-	314	±100.55	-	-	-	-	-	-
OOT_1	355	±376.77	373	±407.23	377.97	±411.07	396	±425.38	426	±450.88
OOT_1^W	757	±539.66	810	±584.28	824	±585.05	875	±585.87	967	±581.1
OOT_1^N	220	±114.09	226	±117.96	229	±119.65	235	±124.29	243	±127.99
OOT_1^*	-	-	294	±73.57		-	-	-	-	-
OOT_2	140	±117.20	145	±121.84	146.24	±122.11	150	±121.30	155	±118.38
OOT_2^W	18	±7.56	19	±8.12	20	±8.53	26	±8.85	39	±9.35
OOT_2^N	163	±113.46	170	±118.05	171	±118.32	174	±117.94	177	±116.61
OOT_2^*	-	-	357	±144.58		-	-	-	-	-
EOT_1	340	±155.33	350	±161.38	360.82	±165.98	406	±184.62	451	±199.31
EOT_1^W	338	±166.49	349	±172.99	360	±177.93	406	±197.90	450	±213.59
EOT_1^N	342	±15.16	351	±15.30	361	±15.26	400	±17.36	444	±23.64
EOT_1^*	-	-	591	±214.12		-	-	-	-	-
EOT_2	232	±125.06	244	±129.74	252.13	±131.25	275	±134.30	295	±135.79
EOT_2^W	499	80.75	523	84.63	534	85.77	565	92.03	594	99.54
EOT_2^N	207	96.68	217	99.85	226	101.03	247	102.64	267	101.79
EOT_2^*	-	-	341	±185.68		-	-	-	-	-

^{W}= working hours, ^{N}= non-working hours,
*=Ambient air sampled parallel to respective operation theatre

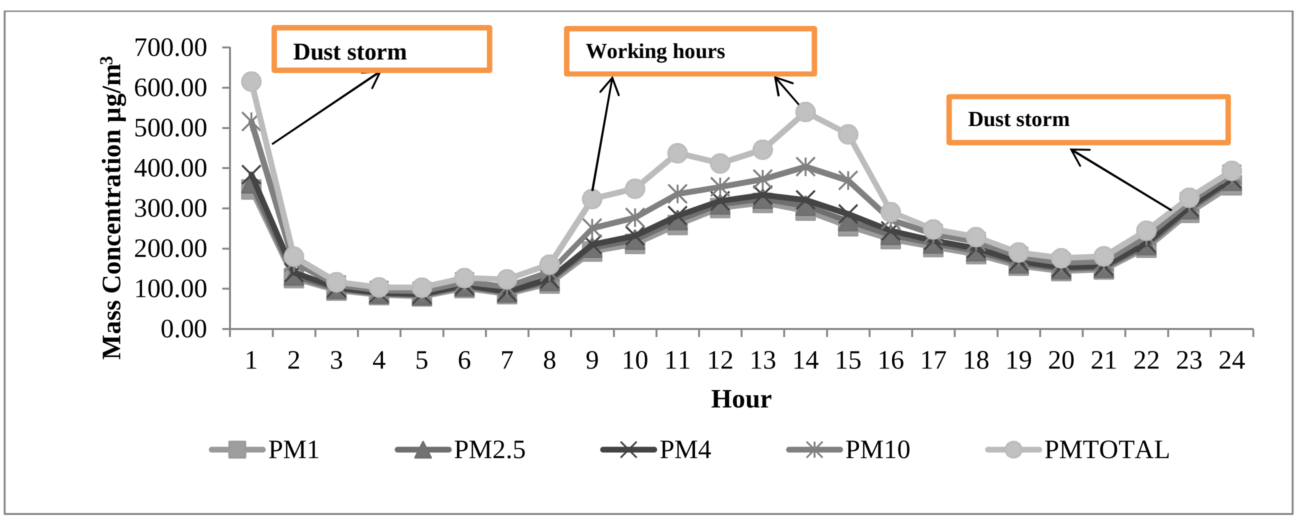

Fig.2 (a): Hourly mean PM levels in General Operation theatre (GOT_1), at Site 1

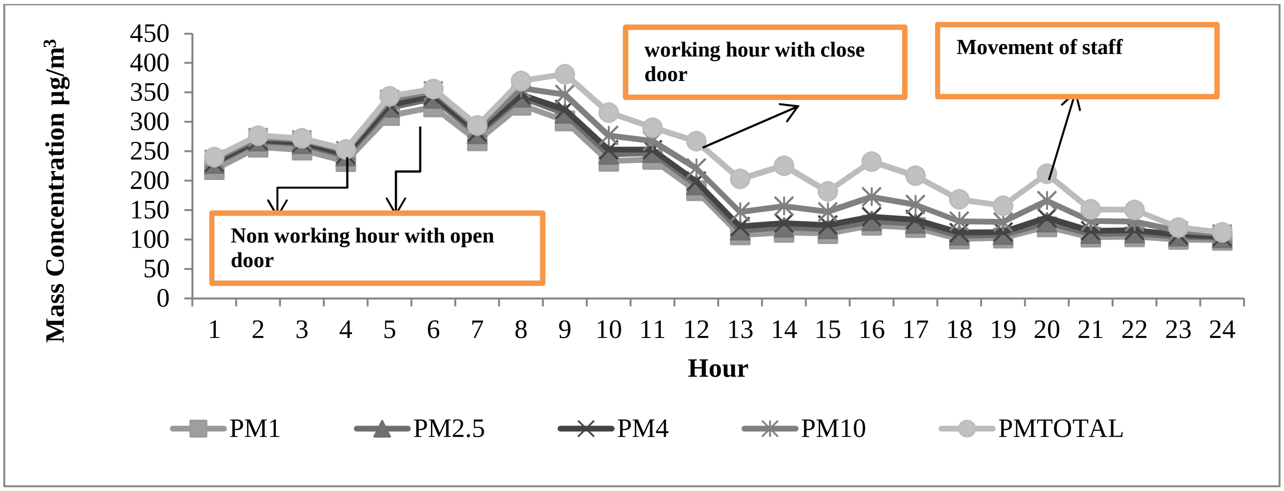

Fig.2 (b): Hourly mean PM levels at General Operation theatre, (GOT_2) at Site 2

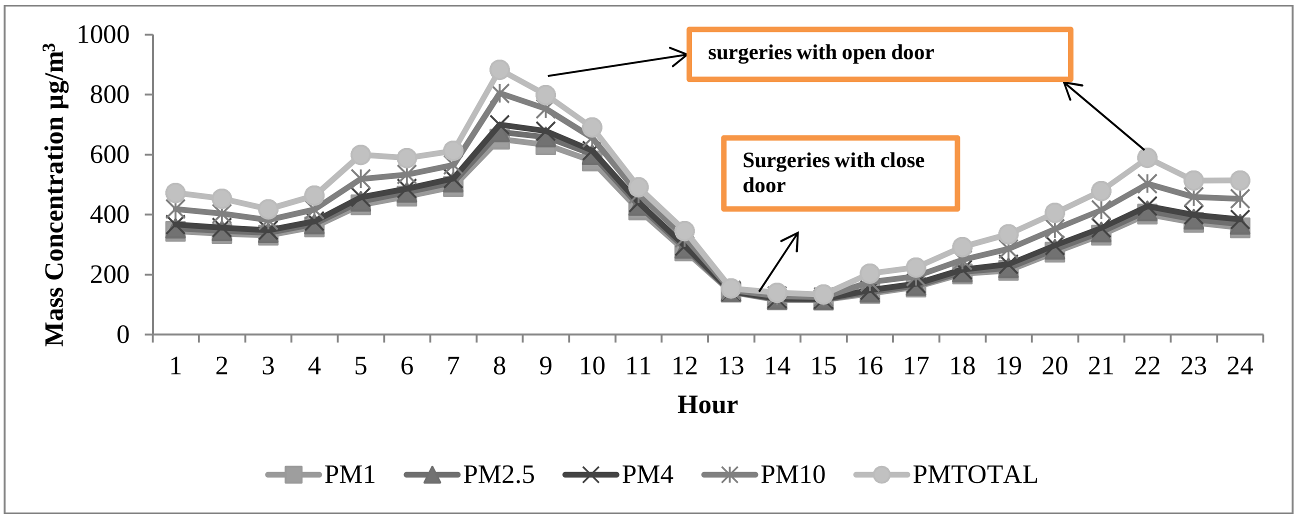

Fig. 3(a): Hourly variation in PM levels during the monitoring in Emergency Operation theatre (EOT_1), at site 1 during 24 hour

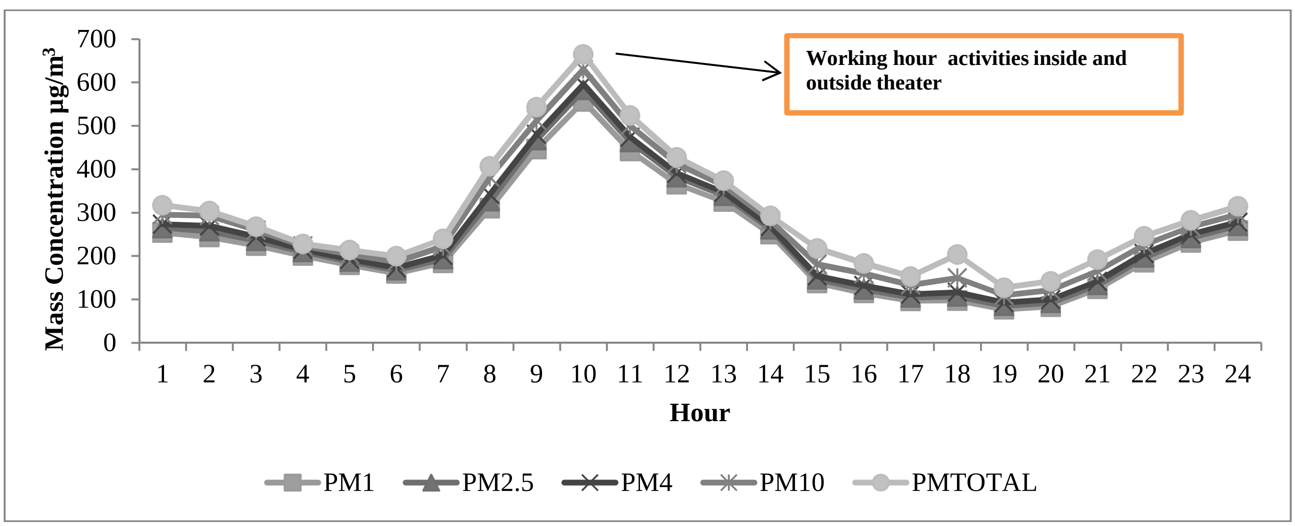

Fig. 3(b): Hourly variation in PM levels during the monitoring in Emergency Operation theatre (EOT_2), at site 2 during 24 hour

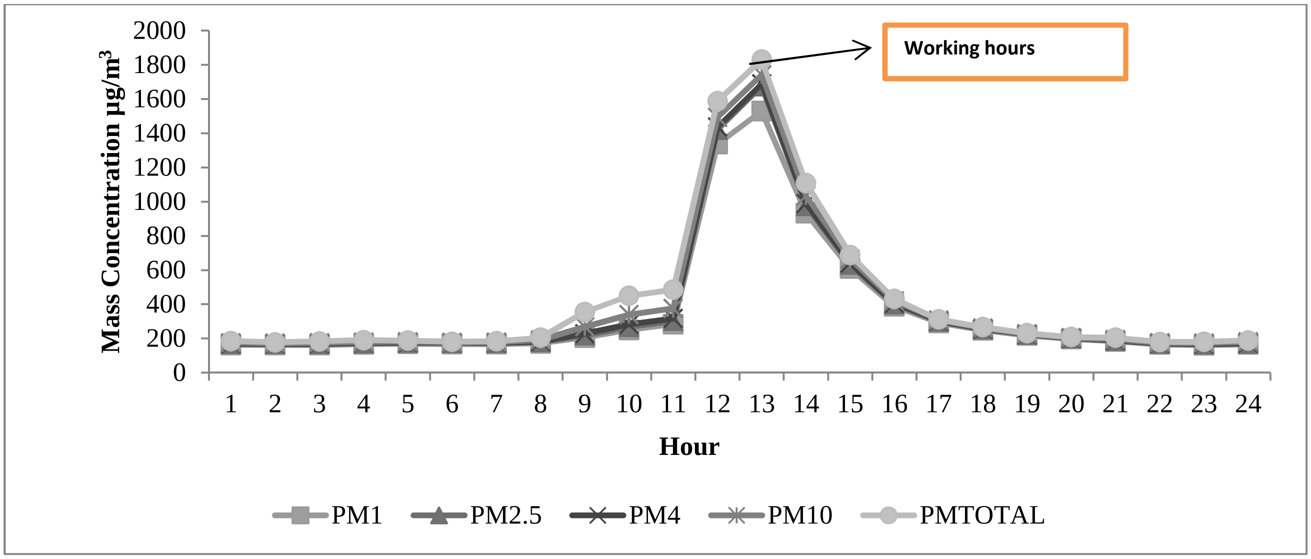

Fig. 4(a): Hourly variation in PM levels during the monitoring in Orthopaedic Operation theatre (OOT_1), at site 1 during 24 hour

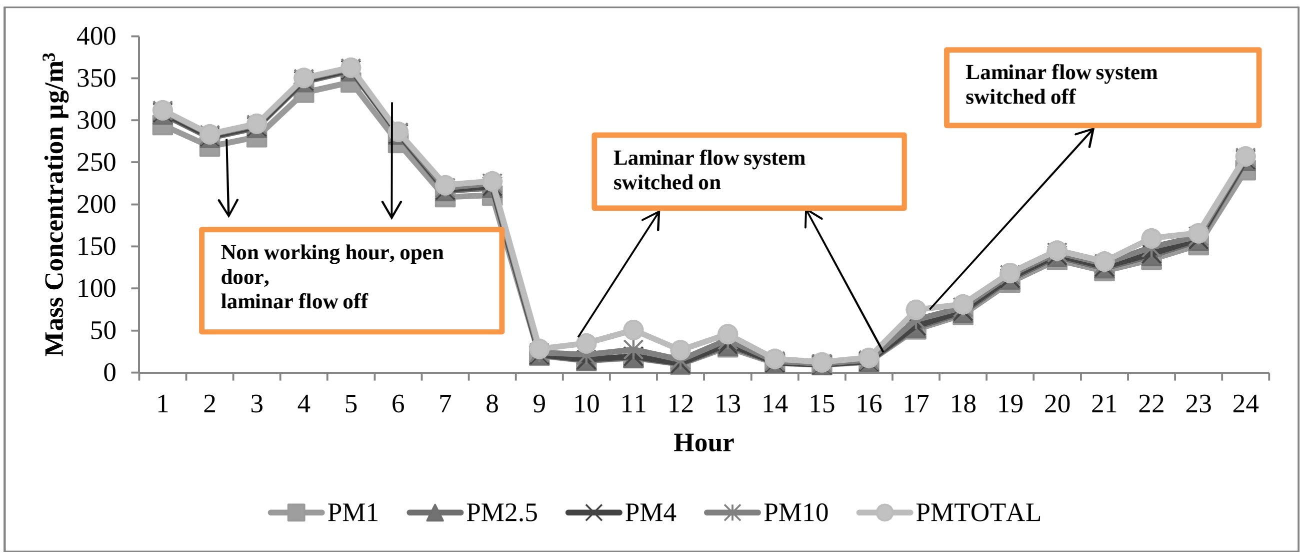

Fig. 4(b): Hourly variation in PM levels during the monitoring in Orthopaedic Operation theatre (OOT_2), at site 2 during 24 hour

The highest level of particulate matter was recorded in the OOT_1 while the lowest levels were monitored in the OOT_2 (Fig. 4a). OOT_2 was the only theatre equipped with the laminar air flow system among the studied theatres of the selected hospitals. Figure 4(b) represents the impact of laminar air flow system installed in the orthopaedic operating theatre and the mass concentration of PM during the working and non - working hours. The laminar air flow system only runs during the working hours. As a result of 24 hours sampling, average hourly concentrations of PM_1, $PM_{2.5}$, PM_4, PM_{10} and PM_{Total} inside the theatre during working hours were 18, 19, 20, 26 and 39 µg/m³ respectively. An independent sample T-test applied to check whether there was any significant difference in PM levels during working hours in the two orthopaedic operating theatres. A statistically significant difference was found between the laminar flow supported OOT_2 at site 2 and naturally ventilated OOT_1 at site 1. The p values for the comparative ratios PM_1, $PM_{2.5}$, PM_4, PM_{10} and PM_{Total} were 0.013, 0.014, 0.013, 0.011 and 0.009 respectively. As a result it may be concluded that ventilation design has a significant impact IAQ in operating theatres. An orthopaedic operating theatre is termed to have maximum infection probabilities and needs ultra clean air quality (Melhado *et al*, 2006). The orthopaedic operating theatre at site 1 was found to be the most contaminated. Ventilation is one of the most important parameters in decreasing the general particulate matter concentration levels in operating rooms where the medical procedure and surgical techniques can result in the production of aerosols that are hazardous (Morawska *et al*, 2004).

Laminar air flow operating rooms have been considered to be one of the best to control the air quality of the operating suite, however controversial opinions over the impact of laminar air flow in reducing surgical site infection are present (Brandt *et al*, 2008; Haslam and Kenneth, 1974). The undesired turbulence in the uni-directional flow by the laminar flow system avoids nosocomial infections. The contaminants dispersed by the pollutants are removed by vertical laminar flow, supplying air vertically from ceiling to the surgical site (Leung and Chan, 2006). According to our findings laminar air flow systems prove to be an effective strategy in reducing PM levels and maintaining a better indoor environment.

The air quality of the operating theatre is effectively stimulated by the various factors such as the number of persons in the operating theatre. The human traffic inside the theatre seems to have significant effect on the indoor air quality (Wan *et al*, 2011). The number of people present in the orthopaedic operating theatre during working hours at site 1 resulted in elevated levels of PM. Furthermore, the anaesthetic gases used in surgeries and the particles generated during various indoor activities and particles from outdoor may remain suspended inside the theatre for long time. Additionally a higher concentration of PM was also observed during non-activity periods with open door scenarios. Figures 2(b) and 4(b) represents the increased concentration of the particulate matter during non-working hours especially at night time when no activity was conducted in GOT_2 and OOT_2. This is probably because the door of the operating rooms at site 2 usually remains closed in the operating hours and open during the night during non-working hours.

Table 4 summarizes additional environmental parameters from theatres that can be used to assess the indoor environmental quality and effectiveness of ventilation strategies being employed.

Table -4: Various environmental parameters measured in Operation theatres at site 1 and site 2 hospitals.

Site	CO_2(ppm)		Temperature		Relative humidity%	
	Hourly Mean	Standard deviation	Hourly Mean	Standard deviation	Hourly Mean	Standard deviation
GOT_1	834	±324.78	23.50	±1.32	62.09	±7.97
GOT_2	1046	±541.58	23.75	±1.14	61.20	±5.64
OOT_1	2208	±1474.93	24.92	±0.76	86.93	±7.33
OOT_2	618	±112.65	22.54	±0.76	61.29	±4.42
EOT_1	1493	±240.48	25.99	±1.55	44.82	±5.62
EOT_2	1377	±394.21	24.65	±0.94	63.28	±4.48

The parameters that were measured during the sampling were CO_2, relative humidity and temperature. Significant levels of carbon monoxide were monitored in the general and emergency operating theatre at site 1 as shown in Table 4. The most probable cause of presence of the CO_2 is the attached sterilization room to the emergency operating theatre and boiler room to the general operating theatre. Laparotomy, endoscopic endocrine neck surgeries, and surgical lasers and soft tissue interaction are the surgeries that requires carbon dioxide which eventually is dispersed inside the theatre. The number of the health care personnel and the surgical staff are also causal agents of carbon dioxide. The highest amount of CO_2 was observed in the orthopaedic operating theatre of site 1 that is probably because of the poor ventilation along with congested space. CO_2 levels of 2208 ppm in OOT_1 suggest inadequate ventilation may lead to higher risk of surgical site infections due to high concentrations and long residence time of airborne contaminants in the operating suite. In a number of studies it is concluded that decreasing levels of CO_2 causes a reduction in the sick building syndrome risk (Seppanen, 1999). The lowest concentration of CO_2 was monitored in the site 2 orthopaedic operating room with the laminar air flow system. The recommended standards for relative humidity by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and American Institute of Architects (AIA) are 30% to 60%, while according to United States Department of Veterans Affairs (VA) is 45% -55 % (Murphy, 2006). The maximum humidity level that was observed in the orthopaedic operating theatre at site 1 was 90%. It should be considered that the increased humidity levels also supports propagation of bio aerosols. The recommended standard for temperature by the ASHRAE is 20-24°C. (Murphy, 2006).The maximum average temperatures among the studied theatres were found in the emergency operating theatre at site 1.

This observed level of PM both indoors and outdoors has implications in terms of environmental health. Both of the hospitals are located near a busy road, thus motor vehicle exhaust, especially by poorly maintained and ageing automobiles might be a major cause of the elevated levels of $PM_{2.5}$. Other sources such as industrial units without adequate by-products release control, natural sources, dispersion of particulate matter and other pollutants and various climatic conditions e.g. wind, temperature, rain etc might have resulted in the increase in $PM_{2.5}$ in the outdoor sampling sites.

The indoor/outdoor (I/O) ratios were less than 1 except OOT_1. : GOT_1 (0.56), GOT_2 (0.62), EOT_1 (0.59), OOT_1(1.26) and OOT_2 (0.40). The OOT_1 probably has its own PM generation sources. Some of the factors as infiltration from outdoor sources, door opening practices, ageing building, lack of proper ventilation system, and attached boiler rooms to the operating theatres may serve as a source of elevated levels of PM.

Conclusion: Levels of particulate matter along with temperature, relative humidity and CO_2 were monitored in different operation theatres at two hospital in Lahore. The results suggest poor environmental health in the operating theatres. Different activities of the surgical team (including shifting of the patients and surgical equipment and movement) and inadequate ventilation resulted in an increase concentration of particulate matter. Open doors cause maximum infiltration from outside resulting in increased vulnerability of immuno-comprised patients and health care workers to air borne pollutants. The vertical laminar flow was found to be effective strategy while refining the air quality of the operating room. Monitoring of particulate matter and CO_2 can be used as a tool to gauge the air quality of the operating room and effectiveness of the ventilation strategy. A critical consideration regarding ventilation strategies and building design is required in these urban-based health care environments.

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