Environment Protection Engineering

Vol. 38 2012 No. 1

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AN ASSESSMENT OF INDOOR PM2.5 CONCENTRATIONS AT A MEDICAL FACULTY IN ISTANBUL, TURKEY

Indoor PM2.5 levels have been measured in the Cerrahpasa Medical Faculty during the autumn of 2007 between September and December. PM2.5 was measured for a period of 8 h during the workday (8.30 a.m.–4.30 p.m.). The maximum PM2.5 level equal to 388.5 μg/m^3 was found at the administrative building. The highest average PM2.5 was 160.1 μg/m^3 measured at the waiting room of central laboratory.

1. INTRODUCTION

Indoor air quality (IAQ) has gained great attention in recent years, mainly due to the large amount of time which people spend indoors in modern times. Although we tend to believe that buildings in which we live will shelter us from harmful substances in the ambient environment, it is actually not justified [1]. The air could be polluted with harmful substances including particulate matter (PM). The health burden due to particulate matter is one of the biggest environmental health concerns around the world [2, 3]. PM is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Respirable particulates (RP) with aerodynamic diameters smaller than 10 μm (PM10) are easily inhaled and deposited within the respiratory system. RP is divided into a coarse fraction (>2.5 μm in diameter), most of which will be retained in the upper airways, and a fine fraction (< 2.5 μm in diameter), which is also often referred to PM2.5 and pose the greatest health risks [4]. The sources of PM2.5 include fuel combustion from automobiles, power plants, wood burning, industrial processes, and diesel powered vehicles such as buses and trucks. These fine particles are also formed in the atmosphere when gases such as sulfur dioxide, nitrogen

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oxides, and volatile organic compounds are transformed in the air by chemical reactions. PM2.5 is associated with a range of serious health effects, including increased morbidity and mortality from cardiovascular and respiratory conditions. Scientific studies suggested links between fine particulate matter and numerous health problems including asthma, bronchitis, acute and chronic respiratory symptoms such as shortness of breath and painful breathing, and premature deaths. Most of these premature deaths are the elderly whose immune systems are weaker due to age or other health problems such as cardiopulmonary diseases [2, 4, 5].

Children are more susceptible to the health risks of PM2.5 because their immune and respiratory systems are still developing. Indoor air quality, especially in workplaces, caught attention of scientists and the public in recent years [6]. WHO's air quality guidelines use the mass concentration of PM2.5 or PM10 as the indicators of health risk. WHO air quality guidelines define the PM2.5 standards by adding new and annual 24 h PM2.5 standards at 10 $\mu g/m^3$ and 25 g/m^3, respectively [7]. USEPA revised the primary (health-based) particulate matter standards by adding new annual and 24 h PM2.5 standards at 15 and 35 g/m^3, respectively, to more effectively control the aerosol problem [8]. Studies have been unable to identify a threshold concentration below which ambient PM has no effect on health: a no-effect level. After a thorough review of recent scientific evidence, a WHO working group concluded therefore that, if there is a threshold for PM, it lies in the lower band of currently observed PM concentrations in the European Region [9].

The hospital was selected to be investigated and their indoor PM2.5 was focused on. This is based on the following considerations. Hospitals are regarded a special and important type of public place. Every day, the number of people is much higher in hospitals than in other public places. Therefore, effect of hospital IAQ to people is more significant than other public places (i). Epidemiological studies showed that hospital-acquired respiratory system infection is well affined with hospital indoor aerosol which is the carrier for virus diffusion by adhering to aerosol particles [5, 4, 10]. Thus, assessment of PM2.5 levels assumes significance from epidemiology (ii). Faculties are considered leading instituties in science and taken as models by public (iii). Finally, few studies only focused on the IAQ of hospitals in the world (iv). Our study aimed to measure the indoor PM2.5 concentrations, since knowing the concentrations of particles from various sources in the hospital would facilitate targeted abatement policies and more effective control measures to reduce the burden of disease due to air pollution [6, 10, 11]. The aim of this study is to present the PM2.5 levels in a faculty hospital in Turkey and make the public aware of the risk posed by fine particles.

2. MATERIAL AND METHODS

This study is a descriptive one presenting only PM2.5 levels in Cerrahpasa Medical Faculty and does not include an analytical component about where does the PM2.5

levels emanate from. It was conducted during the autumn of 2007 between September and December. Indoor concentration levels of PM2.5 were measured for a period of 8 h during the workday (8.30 a.m.–4.30 p.m.). This sampling time covers whole day activities inside the faculty including the hospital which is occupied by patients all day. The faculty campus is located in the ancient city centre on the slope of 7th hill with a view to the Marmara sea far from the traffic jam [12]. The main road on the shore is minimum 750 m away from the buildings where the measurements were done. The surveyed faculty buildings are ventilated naturally or by air conditioners. They forbid smoking indoors and house-cleanings are done in the very morning before operations start.

The faculty campus consists of several buildings which are 32 years old. They are divided into three categories according to their functions: a) administrative buildings, b) educational facilities, c) hospital. In the administrational buildings, the work is carried out in offices. We grouped the offices according to the numbers of officeworkers working in: "offices with one person", "offices with two" and "offices with more than two". From each cathegory of offices we selected only one randomly. Theoretical education is given in amphitheatre halls located in the centre of the basic health sciences building. We randomly selected three amphitheatre halls out of 9. In the hospital, the central laboratory, polyclinics and the clinics are located. The central laboratory comprises one common waiting room and laboratory rooms. The laboratory rooms were grouped according to the stuff working in similarly as for offices: "rooms with one person", "rooms with two" and "rooms with more than two". We selected one from each cathegory and also the waiting room. The outpatient clinics (polyclinics) were divided into three cathegories according to the numbers of patients treated in a day: a) <50, b) from 51 to 500, c) >500. Each cathegory is represented with one polyclinic room in our sample of spaces and also the one common waiting room. The clinics of the branches whose polyclinics were selected for the study were taken into the sample. The clinics enclose one big common space and rooms around it with one, two or more than two patients staying in. This common space and one room from each cathegory in the clinics were selected into our sampling. As a whole, 3 offices, 3 amphitheatre halls, 1 waiting room, 3 rooms of central laboratory, 1 waiting room and 3 rooms of polyclinics, 1 common space and 3 patient rooms of 3 different clinics have been taken consideration (Table 1). The measurements have lasted 26 days in total as each place needed one whole day to be measured.

PM2.5 measurements were accomplished using a MIE DataRAM model portable aerosol monitor (Thermo Inc., USA). The DataRAM (Model DR–2000) continuously monitors the real-time concentration of particulate matter with PM2.5 size separator. It has the widest measurement range of any real-time aerosol monitors – from 0.0001 mg/m^3 (0,1μg/m^3) to 400 mg/m^3. The measurement error of PM instrument is within 2%. It is a high-sensitivity nephelometric monitor whose light scattering sensing configuration has been optimized for the measurement of the respirable fraction (PM10 and PM2.5) of airborne dust in indoor environments.

Table 1

Conditions in the offices, lecture halls, central laboratory, polyclinics and clinics during sampling

Nature		Building age [years]	Area [m^2]	Elevation	Floor material	Ventilation type
Administrative buildings	room with 1 person	14	23	3rd floor	carpet	air conditioner
	room with 2 persons	14	18	3rd floor	vinyl floor covering	natural
	room with 3 persons	14	28	1st floor		
Lecture halls	capacity of 300	30	410	1st floor		air conditioner
	capacity of 150	30	320	1st floor		
	capacity of 100	30	285	Basement		
Central laboratory	waiting room	32	235	Basement	stone	natural
	room with 1 person	32	18	Basement	vinyl floor covering	
	room with 2 persons	32	25	Basement		
	room with more than 2 person	32	28	Basement		
Polyclinics	common waiting room	32	318	1st floor	stone	
	Geriatrics (<50 Patients)	32	60	1st floor		
	Nephrology (51–500 patients)	32	60	1st floor		
	Cardiology (>500 patients)	32	60	1st floor		
Geriatric clinic (<50 patients)	waiting room	32	165	2nd floor		
	room with 1 person	32	15	2nd floor		air conditioner
	room with 2 persons	32	24	2nd floor		natural
	room with more than 2 persons	32	28	2nd floor		
Nephrology clinic (51–500 patients)	waiting room	32	165	2nd floor		
	room with 1 person	32	15	2nd floor		air conditioner
	room with 2 persons	32	24	2nd floor		natural
	room with more than 2 person	32	28	2nd floor		
Cardiology clinic (>500 patients)	waiting room	32	165	4th floor		
	room with 1 person	32	15	4th floor		air conditioner
	room with 2 persons	32	24	4th floor		natural
	room with more than 2 person	32	28	4th floor		

The MIE Model 2000 DataRAM has averaging/updating intervals of 15 s. The DataRAM samples the air at a constant, regulated flow rate by means of a built-in diaphragm pump. The instrument is calibrated by zeroing procedure, accomplished by an inlet filter cartridge (with Teflon filter). In addition, the instrument automatically checks agreement with its original factory calibration by checking its optical background during the zeroing sequence. The calibration procedure of the Partisol FRM Air Sampler was performed by the EPA 17:2000 method. The correlation (r) between two methods is 0.98. For the measurement of this pollutant for indoor, the instrument was positioned in the centre of the measuring place at the height of 1.5 m from the ground.

3. RESULTS

The maximum PM2.5 levels in various rooms ranged from 122.5 to 388.5 μg/m^3, showing increase according to the number of persons working in the room. The average PM2.5 level measured in the room with 1 person working was lowest as expected, but the level in the room with two persons was higher than that of the room with 3 persons.

Table 2

Levels of PM2.5 [μg/m^3] in the administrative buildings

Measurement place	Mean±SD	Min	Max	Median
Room with 1 person working	50.2±16.1	23.9	122.5	46.8
Room with 2 persons working	154.8±83.7	34	388.5	146.6
Room with 3 persons working	100.8±64.1	23.2	297.4	97.8

PM2.5 levels during the day are shown in Fig. 1. The maxima and minima of PM2.5 levels in the room with two persons were due to coffee breaks during which the doors and windows were kept open and people were coming in and out. The PM2.5 level in a room with one person is almost constant after opening the window. Those in a room with three persons are constantly increasing with some peaks due to people coming in.

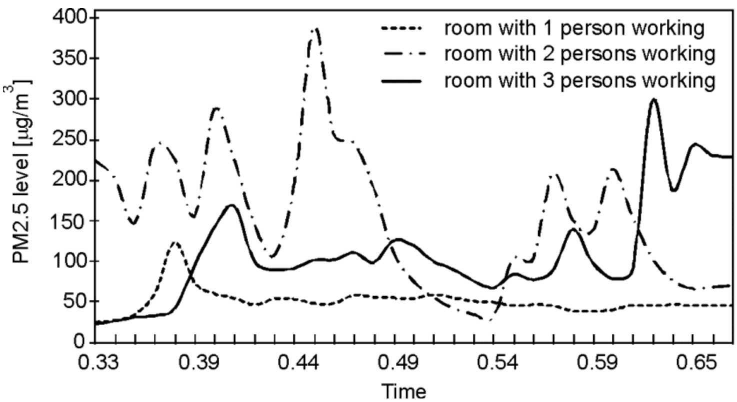

Fig. 1. Average PM2.5 levels at the administrative offices during work time

The three lecture halls in which measurements were done are located in another building. While the maximum levels of PM2.5 increased as the capacity of the lecture halls increased, the average levels did not show the same feature. As the average level of the lecture hall with the lowest audience capacity reached the lowest one, the lecture halls both with the audience capacity of 150 and 300 had almost the same average levels

Table 3

Levels of PM2.5 [µg/m^3] in the lecture halls

Measurement place	Mean±SD	Minimum	Maximum	Median
Lecture hall (with the audience capacity of 100)	30.6±12.9	12.2	61.3	18.4
Lecture hall (with the audience capacity of 150)	53.4±14.6	40.6	85.3	77.3
Lecture hall (with the audience capacity of 300)	53±32.5	17	118.4	66.6

The largest lecture hall was hosting the first year class students when the measurements were done. These students filled the lecture hall and stayed until the end of the lecture, while the students of upper classes in other lecture halls were leaving the room as time went by (Fig. 2).

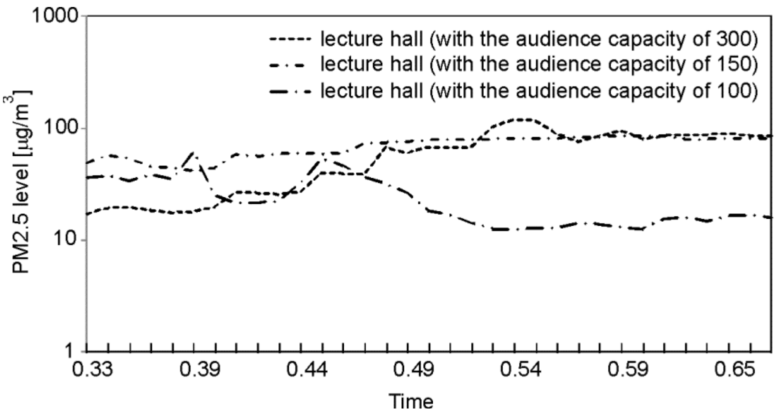

Fig. 2. Average PM2.5 levels at the lecture halls during work time

The central laboratory, polyclinics and clinics where measurements were done are located in the same building. While the central laboratory and polyclinics are on the ground floor, the clinics are on the upper floors. The waiting room of the laboratory has a seating capacity of 150. The average and maximum levels of the waiting room were higher than the operating rooms by far. The operating rooms with different numbers of persons working there had a small range of PM2.5 average and maximum levels if compared with those in waiting room (Table 4).

Table 4

Levels of PM2.5 [µg/m^3] in the Central Laboratory and Polyclinics

Measurement place	Mean±SD	Minimum	Maximum	Median
Waiting room of central laboratory	160.1±46.1	77	268.5	167.5
Room with 1 person working	23.8±3.9	16.6	31.7	23.4
Room with 2 persons working	30.9±8.9	21.4	65.2	26.7
Room with 4 persons working	15.9±4.2	9	24.8	12.5
Common waiting room	164.9±37.6	92.9	207.1	181.2
Geriatrics (<50 Patients)	18.1±4.5	8.9	23.1	10.5
Nephrology (51-500 Patients)	23.4±3.3	16.4	31.4	18.9
Cardiology >500 Patients	37.9±13.3	18.3	58.5	26.9

While PM2.5 levels in the operating rooms were constant, that in the waiting room increased until the lunch time after which it dramatically decreased corresponding with the people leaving the hall due to break (Fig. 3).

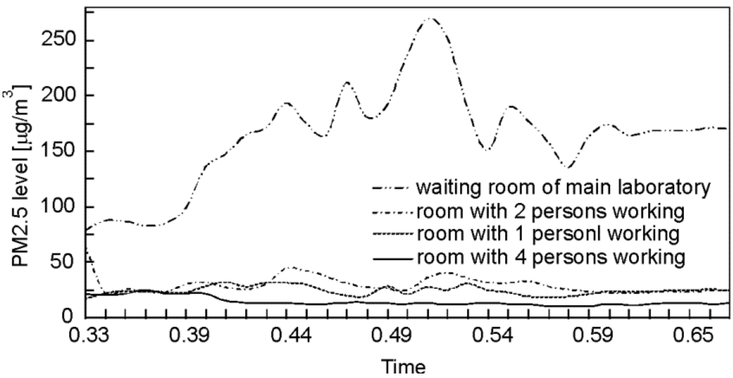

Fig. 3. Average PM2.5 levels at the central laboratory during work time

Table 5

Levels of PM2.5 [µg/m^3] in the Clinics

Measurement place	Mean±SD	Minimum	Maximum
Common waiting room of geriatrics	27.8±6.8	9.1	167.5
Room with 1 patient	25.2±7.4	12.4	45.6
Room with 2 patients	21.2±8.6	3.1	42.1
Room with 3 patients	17.9±2.7	12.6	59.7
Common waiting room of nephrology	76.5±4.6	31.9	326.7
Room with 1 patient	20.9±3.8	9.2	85.17
Room with 2 patients	24.7±6.6	18.9	104.9
Room with 3 patients	29.5 ±21.3	6.0	85.7
Common waiting room of cardiology	137. ±14.5	70.3	386
Room with 1 patient	33.6±9.4	12.2	100.3
Room with 2 patients	39.9±2.8	31.9	251.7
Room with 3 patients	26.4±4.5	11.5	68.1

Similarly, the three polyclinics of different specialties with different numbers of patients treated had a small range of average and maximum levels of PM2.5, the average and maximum levels of PM2.5 in common waiting room were much higher (Table 5). During the measurements in polyclinics, the same trend was observed with the one in central laboratory just with a slower decrease in waiting room after lunch break (Fig. 4).

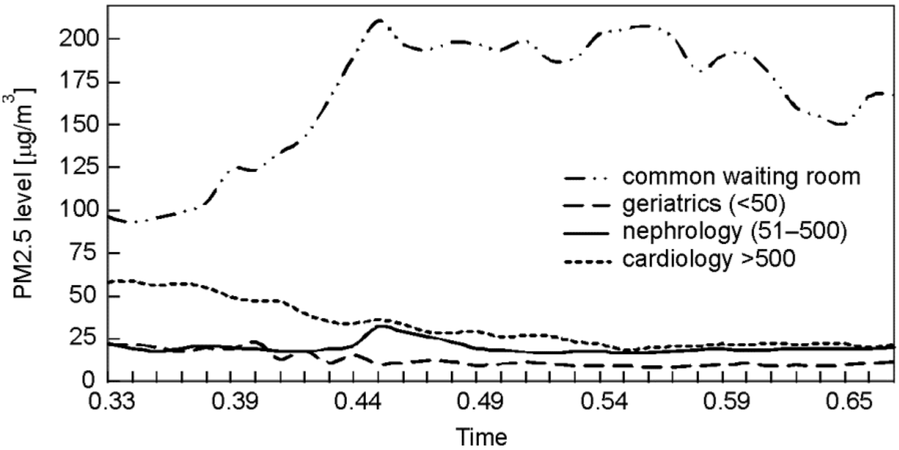

Fig. 4. Average PM2.5 levels at the polyclinics during work time

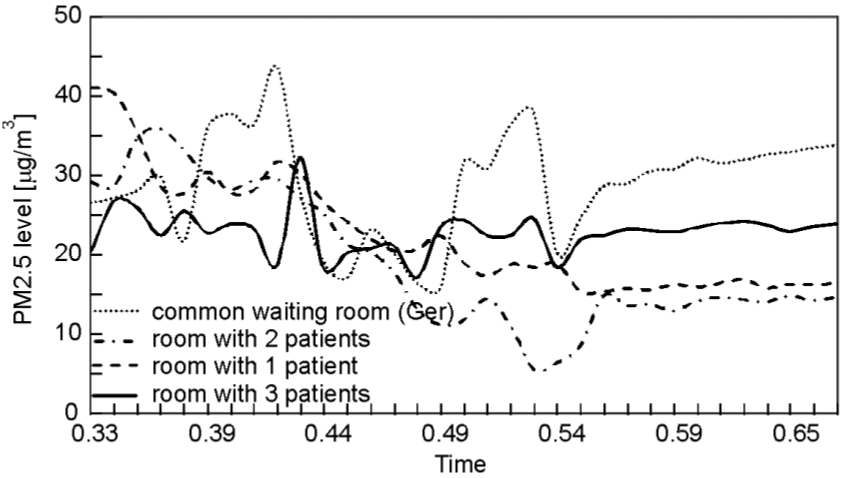

Fig. 5. Average PM2.5 levels at the geriatrics clinics during work time

The clinics of different branches have the various sizes. The waiting rooms do not have a direct access to open air. The common waiting rooms of each services had the highest PM2.5 levels, with one exception of the patient room with more than two beds in the nephrology clinic. The cardiology clinic has the highest PM2.5 levels of each category whereas geriatric clinic has the lowest ones (Table 5). The most complicated trends of PM2.5 levels were observed in geriatric clinic. As the windows in the rooms with 2 patients were open when the measurements started, the windows of the room with one patient was closed. After the windows were opened, the trends were in accord with those of others. The waiting hall had two peaks of PM2.5 levels one before noon and one in the afternoon because of relatives of patients waiting there at that time (Fig. 5).

When the measurements in the nephrology clinics were started, the windows of the rooms with 1 and 3 patients were closed. Short afterwards, the windows of those rooms and the door of the room with two patients were opened. There were no people waiting in the waiting hall during the measurements as it was the case in the geriatrics clinic (Fig. 6).

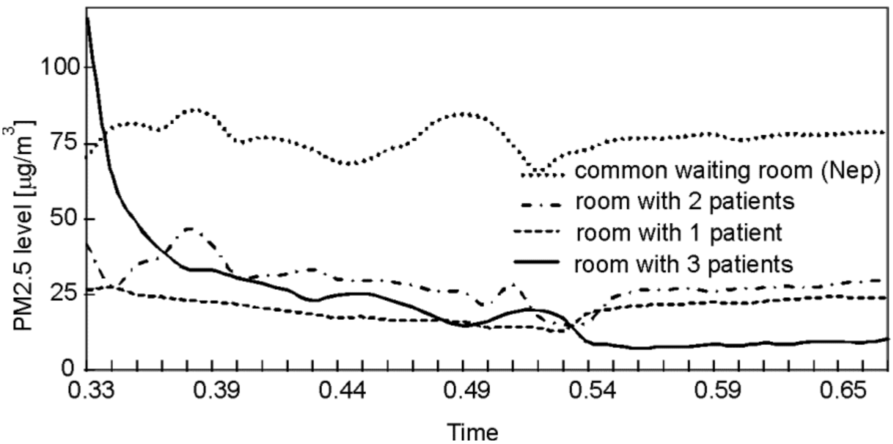

Fig. 6. Aerage PM2.5 levels at the nephrology clinics during work time

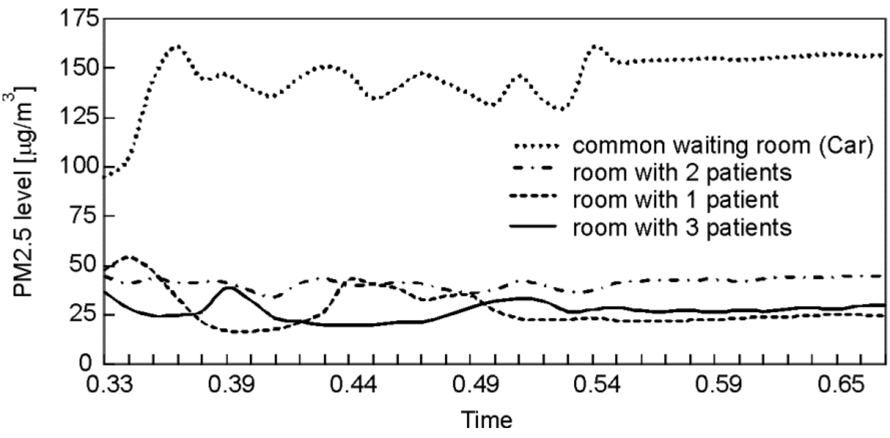

Fig. 7. Aerage PM2.5 levels at the cardiology clinics during work time

The cardiology clinic was the most crowded of the three clinics where the measurements were carried out. As the rooms of patients had their own accesses to the open air, PM2.5 levels there were different from that observed in the waiting hall (Fig. 7).

4. DISCUSSION

Fine particulate matter PM2.5 is also known as respirable particles because it penetrates the respiratory system further than larger particles. As the size of particles is directly linked to their potential for causing health problems, particles smaller than 2.5 μm down to 0.1 in diameter pose the greatest problems, because they can get deep into lungs, deposit there or may even get into bloodstream. People with asthma, cardiovascular or lung disease, as well as children and elderly people, are considered to be the most sensitive to the effects of fine particulate matter. With these regards hospitals are the places where fine particles should be monitorized and measures should be taken to make the spaces particle free as possible as it could be.

As Cerrahpasa Medical Faculty is composed of different buildings rather than being a monobloc, it seems to be relatively easier to control the indoor air pollution in the buildings where patients are hospitalized. According to the results of our study the administrative building of the faculty was imposing the highest levels of air pollution also in the rooms which were separate from the common corridors and halls. Interestingly, of the rooms included in our study the room with 2 people working had higher levels of PM2.5 than the room with 3 persons. This is mostly because of the job done by 3 persons caused more people go in and out which possibly needed windows kept open longer. However in the 3 rooms where measurements were done, the limits of both WHO and USEPA were exceeded. Figure 1 shows that the PM2.5 levels in the three rooms had never been under the limit during the measurement day. The exposition to the higher levels of pollution lasted practically all day. In the study of Liu et al. [11], offices of different sizes and occupants were evaluated. Only one office out of them was found to be exceeding the limits of USEPA. The room had the surface area of 10 m^2 and two occupants smoking during the work. Additionally to these pollutant factors, the office was close to the heavy traffic conditions outdoors [8, 13]. As in the offices of Cerrahpasa smoking is not allowed and the buildings are far from heavy traffic, it is hard to explain why this big difference with the other 10 offices evaluated by Liu et al. occurred. The pollution could emanate from the surrounding roads with a light traffic.

Although the lecture halls presented lower levels of PM2.5 than the administrative rooms did, they were also in general over the limits of WHO and USEPA. The lecture hall with the audience capacity of 150 never had acceptable levels of PM2.5 according to the limits of WHO and USEPA. Probably the lecture hall could not be ventilated sufficiently at all, even during the breaks between the lectures. The lecture hall with the audience capacity of 100 exceeded two times the limits of WHO and USEPA during two lessons when air conditioners were off. After air conditioner was turned on, the levels of PM2.5 decreased to the normal level and stayed there constantly during the lessons also. For that size of audience capacity, the ventilation through the air conditioner seemed to be sufficient to keep the spaces within the normal range of PM2.5 levels. The lecture hall with the audience capacity of 300 posed a real air pollution problem. Although air conditioner was on, the room got more polluted as time went by. The pollution peaked during the afternoon lessons. During those lessons, students were exposed very high levels of PM2.5. In the study of Liu et al., 1 out of 7 classrooms exceeded the PM2.5 limits recommended by WHO and USEPA with approximately 170 $\mu g/m^3$. Liu et al. pointed out that this classroom was a street level classroom with open front door. Liao et al., cited in Liu's study, found that the particulate concentration was seriously influenced by emissions from vehicles [13]. In Cerrahpasa, the mean levels were not such high, though slightly higher than limits of WHO and USEPA, most probably because doors and windows were closed and air conditioner was on during the measurements.

According to the study carried out by Fromme et al., the PM2.5 levels measured in the primary and secondary schools in Munich were found to be 38.9 $\mu g/m^3$ in winter and 22.1 $\mu g/m^3$ in summer, which were actually lower than the levels measured in Cerrahpasa [14]. The schools in Germany do not have air conditioning systems. Fromme claims that inadequate ventilation plays a major role in the establishment of poor indoor air quality. They also suggest that the physical activity of pupils contributes to a constant process of resuspension of sedimented particles [14]. Similarly, Ho et al. measured the PM2.5 level as 39.67 $\mu g/m^3$ in a classroom with 40–60 occupants and mechanical ventilation [10]. Gemenetzis et al. found the indoor concentrations of PM2.5 measured in the 40 University rooms to be 91 $\mu g/m^3$. They suggested that in terms of PM2.5 levels indoor air at high level floors is probably less impacted by near ground level sources like traffic emissions [15]. According to their study, air purification devices were proved highly efficient in decreasing indoor PM2.5 levels.

The central laboratory, the polyclinics and the inpatient clinics are in the same building. This building is the most often visited part of the medical faculty, where the patients and accompanying persons spend most of their time in the faculty. Central laboratory and polyclinics are located on the ground floor. They started to work at 8 o'clock, but the doors of the waiting rooms were opened earlier. Until lunch time the level showed the same values as people came in and out. The seating capacity in the waiting hall of polyclinics is 30 and 100 in that of central laboratory which were always occupied despite the circulation of people. This is because the laboratories and polyclinics are usually working beyond their capacity and thus behind their schedule. As the waiting hall of central laboratory has no windows and air conditioner to provide air ventilation, that of polyclinics have windows on one edge. There was no person in charge of controlling the air quality of the hall and opening the windows. It was done very random. The PM2.5 levels rose up to 250 μg/m^3 in both waiting halls and never went down to the acceptable limits of WHO and USEPA even after the lunch break when the work was no more intensive as it was before noon.

High levels of PM2.5 in waiting halls pose great risk on the people spending some time there, especially when considered that already sick people stay there mostly. As hospital indoor aerosols can be the carrier for virus diffusion by their adhering to aerosol particles, hospital acquired respiratory system infection is the closest risk to the people using those places.

The clinics in the upper floors have the same design of construction: relatively small common areas surrounded with the patient rooms of various sizes. The desk of the nurses is located in this common area which facilitates them to control the clinic. The common areas have no window and air conditioner and the access to those areas from the corridors between the clinics is only possible through a narrow gate. As a consequence, the common areas convey a potential of pollution according to the number of people standing there. The clinics which are most visited and need more people to work are most polluted as it was the case in our study. The common area of cardiology clinic was the most visited place of the clinics where we carried out our study. The cardiac patients need more support than other patients and this causes more people stay in the common areas. As the PM2.5 levels of the cardiology clinic increased to 160 μg/m^3, those of geriatric and nephrology clinics stayed under 85 and 45 μg/m^3, respectively. The nephrology clinic was most crowded than geriatrics clinic and less than cardiology clinic. All patient rooms have access to open air through windows. Except for geriatrics clinic, also the patient rooms have exceeded the limit values of WHO and USEPA.

When we compared our results with a similar study done in China by Wang et al. we saw that in terms of PM2.5 levels the situation in Cerrahpasa was quite better than in hospitals in Guangzhou [4]. As in Cerrahpasa the treatment rooms and patient rooms had PM2.5 levels generally under the limits of WHO and USEPA, in the hospitals of Guangzhou the limits were exceeded in all rooms measured. The problem of the hospital of Cerrahpasa was the waiting rooms where the limits were much exceeded because of the big numbers of people waiting.

5. CONCLUSIONS

The indoor PM2.5 levels were evaluated in three buildings of Cerrahpasa Medical Faculty, at 26 different places. It was observed that indoor PM2.5 levels were significantly higher than PM2.5 standards of 25 μg/m^3 and 35 μg/m^3 recommended by WHO and USEPA, respectively. These high levels point to the need of an urgent preventive action as they were measured in a faculty hospital which claims to be a model one. They also let us consider the importance of monitoring the indoor pollution levels in hospitals. Air conditioning systems should be switched on according to the needs of indoor air quality. Further investigations are necessary to increase knowledge on predictors of PM concentration, to assess the toxic potential of indoor particles and to develop and test strategies how to ensure improved indoor air quality in hospitals and affiliated buildings.

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