TOTAL VOLATILE ORGANIC COMPOUNDS (TVOC), CARBON MONOXIDE (CO), CARBON DIOXIDE (CO_2) CONCENTRATIONS IN THE HOSPITAL BUILDING OF A MEDICAL FACULTY IN ISTANBUL, TURKEY

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ABSTRACT

• ***Objective:*** *This study was conducted to determine the levels of TVOCs, CO, CO_2 concentrations of Cerrahpasa Medical Faculty, Istanbul University .*

• ***Material and Method:*** *In this study the VOCs, CO and CO_2 levels in the largest hospital building of the Cerrahpasa Medical Faculty were measured.*

The sample comprised three rooms from the central laboratory and the common waiting area; three rooms from the polyclinics and the common waiting room; three patient rooms from three different inpatient clinics.

• ***Results:*** *The concentrations of TVOCs were above 1 ppm in the common waiting rooms and below 1 ppm in the operating rooms of the central laboratory and polyclinics except for the cardiology polyclinic.*

• ***Conclusion:*** *No regulatory standard for indoor TVOCs, CO and CO_2 levels have been established in Turkey and few studies have been done in this field. Results from this study will assist in helping the indoor air quality regulations in Turkey to be revised by the relative authorities.*

• ***Key Words:*** *Indoor air, volatile organic compounds, carbon monoxide, carbon dioxide, hospitals* ***Nobel Med 2010; 6(3): 66-72***

TÜRKİYE'DE İSTANBUL'DA BIR TIP FAKÜLTESİNDE TOTAL UÇUCU ORGANİK BİLEŞİKLER (TVOCS), KARBON MONOKSİT (CO), KARBON DİOKSİT (CO_2) KONSANTRASYONLARI

ÖZET

• **Amaç:** Bu çalışmanın amacı Cerrahpaşa Tıp Fakültesi'nin Monoblok binasındaki Uçucu organik bileşikler (TVOCs), CO ve CO_2 düzeylerini saptamaktır.

• **Materyal ve Metod:** Cerrahpaşa Tıp Fakültesi Monoblok binasında TVOCs, CO ve CO_2 düzeyleri ölçülmüştür. Çalışmanın örneklemi merkez laboratuvarı bekleme odası ve üç operasyon odasını, üç poliklinik muayene odası ile ortak bekleme salonunu ve üç farklı servisin üç hasta odası ile ortak bekleme alanını kapsamaktadır.

• **Bulgular:** Kardiyoloji polikliniği dışında TVOCs düzeyleri tüm polikliniklerde ve merkez laboratuvarının operasyon odalarında 1 ppm'in altında bulunmuştur. Merkez laboratuvarının ve polikliniklerin bekleme salonlarında ise 1 ppm'in üzerindedir. CO düzeyleri genel olarak kabul edilebilir olan 3 ppm'in altında iken, CO_2 düzeyleri WHO ve EPA tarafından önerilen 1000 ppm limitini aşmıştır.

• **Sonuç:** Türkiye'de kapalı ortamlar için TVOCs, CO ve CO_2 düzeyleri için bir yasal standart oluşturulmamıştır ve bu alanda yapılan çalışıma sayısı çok azdır. Bu çalışmanın sonuçları Türkiye için iç ortam hava kalitesi standartlarının geliştirilmesine yardımcı olabilecektir.

• **Anahtar Kelimeler:** İç ortam havası/ uçucu organik bileşikler, karbonmonoksit, karbondioksit, hastaneler **Nobel Med 2010; 6(3): 66-72**

INTRODUCTION

Volatile organic compounds (VOCs) include a variety of chemicals, some of which may have short- and long-term adverse health effects. They vaporize at room temperature and are released from many housekeeping and maintenance products, building materials, furnishings and equipment, and from human metabolism.[1] The concentration of many VOCs are consistently higher indoors than outdoors especially during and for several hours immediately after certain activities, such as house cleaning or paint stripping.[2] The acceptable limit of TVOCs set by the Environmental Protection Agency (EPA) and the World Health Organization (WHO) is 3 ppm respectively.[3-5]

Carbon monoxide is colorless and odorless and is a normal constituent of exhaust gases from incomplete combustion. It is generated by combustion of fossil fuels in general. In urban areas, automobiles are the main sources of these gases. Elevated outdoor concentrations primarily influence the higher indoor concentrations of the homes near higher-traffic areas.[6] Average levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm). No standards for CO have been agreed upon for indoor air. The U.S. National Ambient Air Quality Standards for outdoor air are 9 ppm (40,000 micrograms per meter cubed) for 8 hours, and 35 ppm for 1 hour. Concentrations greater than 5 ppm may indicate the presence of exhaust gases in the indoor environment and should be investigated.[4]

Carbon dioxide (CO_2) is a surrogate for indoor pollutants emitted by humans and correlates well with human metabolic activity. Humans are the main indoor source of carbon dioxide. CO_2 is a normal constituent of exhaled breath and is an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. The level of CO_2 is therefore often used to assess the efficiency of ventilation. CO_2 concentrations in office buildings typically range from 350 to 2,500 ppm.[7] The national institute for occupational safety and health (NIOSH) considers that indoor air concentrations of CO_2 that exceed 1,000 ppm are a marker suggesting inadequate ventilation.[8] According to the WHO and EPA standards indoor CO_2 levels should not exceed 1000 ppm to ensure satisfactory comfort.[8,9] The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) recommends a minimum office building ventilation rate for offices of 10 L/s per person, corresponding to an approximate steady state indoor concentration of CO_2 of 870 ppm.[10] A high level of CO_2 may indicate that other contaminants in the building may be present at elevated levels. The CO_2 level is usually greater inside a building than outside. Occupational safety and health administration (OSHA) limits CO_2 concentration in the workplace is 5,000 ppm for prolonged periods, and 35,000 ppm for 15 minutes.[4,11] This study was conducted to determine the levels of these three important air pollutants: 1) The indoor air concentration of TVOCs was elevated following the use of chemicals in the construction and refurbishment of the buildings.[12] 2) CO is another indoor air pollutant in an urban area like Istanbul and the greatest source of vehicle emissions.[6] 3) CO_2 is a surrogate for indoor air pollutants emitted by humans and correlates well with human metabolic activity.[4] →

Table 1: The areas sampled, their location, type of flooring and type of ventilation in the central laboratory, polyclinics and clinics

Sampling sites		Area (m^2)	Sampling site is located on	Floor materials	Type of ventilation
Central laboratory	Waiting room	235	Basement	Stone	Natural
	Room with 1 personnel	18	Basement	Vinyl	Natural
	Room with 2 personnel	25	Basement	Vinyl	Natural
	Room with 4 personnel	28	Basement	Vinyl	Natural
Polyclinics	Common waiting room	318	1 st floor	Stone	Natural
	Geriatrics (<50 Patients)	60	1 st floor	Stone	Natural
	Nephrology (51-500 Patients)	60	1 st floor	Stone	Natural
	Cardiology >500 Patients	60	1 st floor	Stone	Natural
Geriatrics clinic (<50 patients)	Waiting room	165	2 nd floor	Stone	Natural
	Room with 1 personnel	15	2 nd floor	Stone	Air conditioner
	Room with 2 personnel	24	2 nd floor	Stone	Natural
	Room with 3 personnel	28	2 nd floor	Stone	Natural
Nephrology clinic (51-500 patients)	Waiting room	165	2 nd floor	Stone	Natural
	Room with 1 personnel	15	2 nd floor	Stone	Air conditioner
	Room with 2 personnel	24	2 nd floor	Stone	Natural
	Room with 3 personnel	28	2 nd floor	Stone	Natural
Cardiology clinic>500 patients	Waiting room	165	4 th floor	Stone	Natural
	Room with 1 personnel	15	4 th flor	Stone	Air conditioner
	Room with 2 personnel	24	4 th flor	Stone	Natural
	Room with 3 personnel	28	4 th flor	Stone	Natural

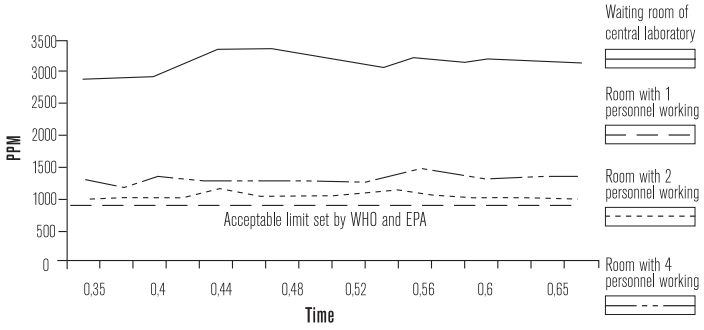

Figure 1. Measurements of CO_2 concentrations in the central laboratory

Cerrahpasa Medical Faculty of Istanbul University is a 42 year old institution consisting of several buildings reserved for administrative, educational and medical services located on one campus area. Hospitals are public places where a large number of people seek medical attention and they may be vulnerable and the possible effects of indoor air pollutants could be detrimental to them. We aimed to determine the selected indoor air pollutant levels in the hospital and so, make the people aware of them and contribute to the efforts of taking more effective control measures.

MATERIAL and METHOD

Study site: The setting for this study was the Monobloc of the Cerrahpasa Medical Faculty of Istanbul University, which is the largest of the hospital buildings of the faculty. The Monobloc building is a 32 year old 6 storey building containing of in patient and outpatient clinics of the surgical department and the internal medicine department. The central laboratory is located on the ground floor. The inpatient clinics are located on the upper floors and each of these has a common space surrounded by the patient rooms of different sizes and are connected to the wide halls of the building through a gate which is usually kept closed. The outpatient clinics of the departments are on the first floor and lined against one side of the common waiting area (Table 1). The clinics all have windows looking onto the small inner court of the building. The opposite side of the waiting area has an outdoor connection through windows. The central laboratory on the ground floor comprises one common waiting room and smaller laboratory rooms located beyond the gate which opens to the waiting room. The building leans against a steep hill and the central laboratory is underground and consequently this laboratory and its waiting room have not direct connection to the outside.

The faculty campus is located in the ancient city center on the slope of 7th hill of the city with a view to the Marmara Sea which is far removed from traffic.[13] The campus area is 300 000 m^2 and two thirds of this area is covered by buildings. On average 3 000 vehicles daily pass through the campus according to the records of the hospital management. One of the main traffic roads of the city crossing along the shore is a minimum of 750 meters down the hill where the study site was located. The spaces in the building were ventilated naturally or by air conditioners and smoking is prohibited in all Faculty buildings. The building is cleaned every morning before the start of the clinics. It is heated via central heating radiators and rarely by air conditioners. The outpatient clinics and central laboratory operate in two shifts (08.00-12.30 and 13.00-17.00) and the inpatient clinics operate 24 hours a day. →

Sampling: The outpatient clinics (polyclinics) were divided into three categories based on the numbers of patients examined in a day: a) <50, b) 51-500, c) >500. One polyclinic room was randomly selected to represent each category in our sample of places where measurements were to be taken. The common waiting room was included. The inpatient clinics of the departments selected were included in the sample. The patient rooms were grouped according to the numbers of beds occupied as either "one", "two" and "more than two". The common space beyond the entrance and one room from each category in the clinics were selected into our sample. The laboratory rooms are grouped according to the number of staff working in the rooms: "rooms with one person", "rooms with two" and "rooms with more than two". We selected one room from each category and included the waiting room. The sample comprised 20 sites in total; three rooms from the central laboratory and the common waiting area; three rooms from the polyclinics and the common waiting room; three patient rooms from three different in patient clinics,

Measurements of TVOCs, CO and CO_2 levels: Indoor concentration levels of TVOCs, CO and CO_2 were measured for 8 hours during the workday (8.30 a.m. - 4.30 p.m.). An IAQ monitor (IAQ RAE) was used to measure CO_2, CO, VOC, temperature and humidity levels. IAQRAE is the only indoor air quality monitor that combines a Photo-Ionization Detector (PID) with traditional measures. The equipment was placed at 1,5 m above floor level at the center of the sampling site. Data collection was done over 20 consecutive working days from the 4th September to the 6th October 2009 (and excluded weekends and public holidays). We measured the concentrations of air pollutants in ppm, and we converted the results of other authors who measured the concentrations in mg/m^3 or $\mu g/m^3$ to ppm for easier comparison.[14]

Permission: The permission for the study was obtained from the Dean of the Faculty. An application to the University's ethics committee was not submitted because there was no human contact in the study.

RESULTS

The central laboratory and polyclinics are on the lower floors of the hospital building and are not connected to each other but the concentration of TVOCs were the same in both locations. The concentrations of TVOCs were above 1 ppm in the common waiting rooms and below 1 ppm in the operating rooms of the central laboratory and polyclinics except for the cardiology polyclinic (Table 2). The safety limit [3 ppm] set by WHO and EPA was never exceeded at any time during→

Table 2: Measurements of TVOCs, CO and CO_2 concentrations in the central laboratory and polyclinics

Sampling sites	TVOCs (ppm)			CO (ppm)			CO_2 (ppm)			Humidity (%)	Temperature (Celcius)
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Mean
Waiting room of central laboratory	1.97	1.79	2.17	3.25	2.81	3.84	3069	2894	3221	59.3	24.1
Room with 1 personnel working	0.45	0.38	0.57	0.85	0.75	0.97	1355	1324	1386	58.5	23.5
Room with 2 personnel working	0.24	0.14	0.39	0.39	0.3	0.48	1158	1106	1215	58.5	22.9
Room with 4 personnel working	0.18	0.11	0.25	0.62	0.48	0.75	1363	1304	1417	61.5	23.7
Waiting room of polyclinics	1.72	1.55	1.92	0.98	0.77	1.18	2061	1989	2124	56.7	21.1
Geriatrics (<50 Patients)	0.39	0.32	0.48	0.67	0.55	0.82	1203	1124	1274	58.2	24.1
Nephrology (51-500 Patients)	0.65	0.52	0.75	0.99	0.86	1.12	1362	1296	1458	56.5	23.3
Cardiology >500 Patients	1.09	0.94	1.24	1.95	1.72	2.16	3016	2910	3128	60.4	24.3

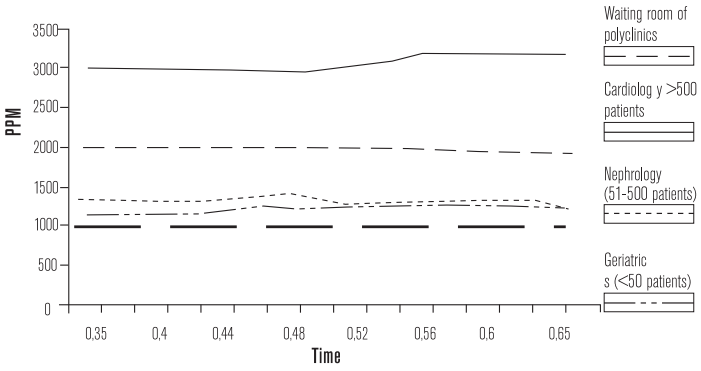

Figure 2. Measurements of CO_2 concentrations in the central polyclinics

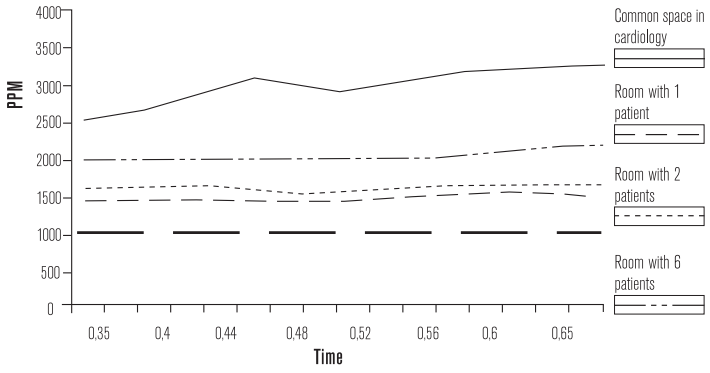

Figure 3. Measurements of CO_2 concentrations in the Cardiology

Table 3: Measurements of TVOCs, CO and CO_2 concentrations in the in-patient clinics

Sampling sites	TVOCs (ppm)			CO (ppm)			CO_2 (ppm)			Humidity (%)	Temperature (Celcius)
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Mean
Common space in geriatrics	0.11	0.04	0.17	0.35	0.17	0.48	1032	954	1128	57.7	22.7
Room with 1 patient	0.36	0.14	0.59	0.37	0.24	0.45	1361	1291	1435	59.8	22.6
Room with 2 patient	1.26	1.05	1.41	0.84	0.69	0.97	1965	1838	2201	61.0	23.6
Room with 3 patient	1.25	1.02	1.41	1.47	1.20	1.69	2057	1927	2124	61.5	23.3
Common space in nephrology	0.61	0.48	0.76	1.56	1.32	1.71	2142	2037	2234	60.5	24.1
Room with 1 patient	0.61	0.54	0.68	0.48	0.32	0.63	1687	1617	1759	61.3	23.6
Room with 2 patient	0.08	0.03	0.17	1.05	0.93	1.24	1604	1423	1706	58.1	22.6
Room with 4 patient	0.97	0.71	1.18	1.61	1.32	1.81	2137	2014	2304	61.5	24.3
Common space in cardiology	2.04	1.75	2.34	2.28	1.84	2.58	3039	2517	3366	58.9	23.5
Room with 1 patient	0.23	0.07	0.38	0.51	0.41	0.63	1400	1357	1438	59.3	23.4
Room with 2 patient	0.28	0.18	0.42	0.57	0.45	0.67	1557	1463	1637	58.9	24.3
Room with 6 patient	0.57	0.38	0.76	1.24	1.06	1.41	1970	1863	2107	61.3	24.0

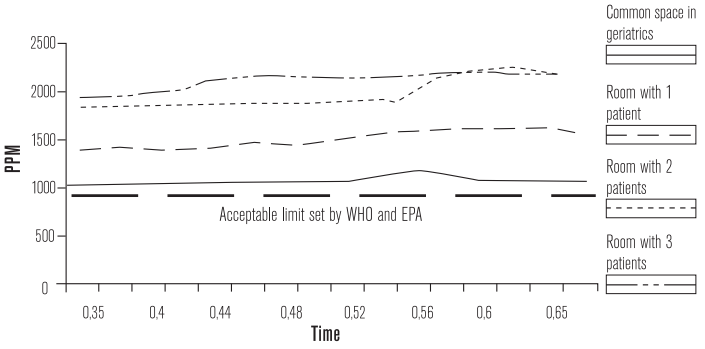

Figure 4. Measurements of CO_2 concentrations in the Geriatrics

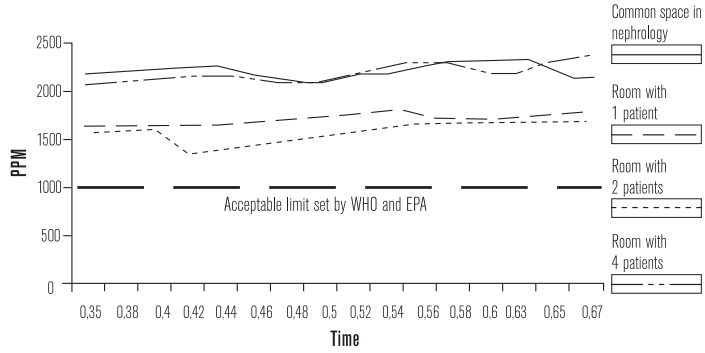

Figure 5. Measurements of CO_2 concentrations in the Nephrology

the day. The seating capacity of the central laboratory waiting room is 150 but this number is often exceeded when people standing are included in the count. The room temperatures at all the sites ranged from 21.1°C to 24.3°C, and the relative humidity ranged from 56.5% to 61.5% (Table 2).

The average CO level was greater the operating rooms that in the central laboratory but did not exceed the critical value of 5 ppm (Table 2). The measurements in the polyclinics and the central laboratory were different as the measurements in the waiting room and geriatrics and nephrology polyclinics did not exceed 1 ppm. The measurement in the cardiology polyclinic averaged 1.95 ppm which was almost twice as high as that in the waiting room.

The CO_2 levels were the only measurements that exceeded the acceptable limits in the central laboratory and polyclinics (Table 2). The CO_2 concentrations were above 1000 ppm at all the sampling sites (Figures 1, 2). The CO_2 measurements were higher in the central laboratory waiting room compared to the operating rooms; but the CO_2 levels in the cardiology polyclinic was higher than those in the waiting room and the other two polyclinics. This finding was similar to the finding for the CO levels. The inpatient cardiology clinic had the highest levels of TVOCs. The TVOCs measurements at the patient rooms were relatively low but the TVOCs measurements were highest in the common space at the centre of the clinic (Table 3). The TVOC measurements were under 1 ppm in the nephrology patient rooms "with two patients" and "with two or more patients". The CO levels in the cardiology clinic were the highest but still did not exceed the acceptable minimum levels. The mean CO level was measured above 2 ppm (Table 3). The mean CO_2 level was measured above 3000 ppm there as could be seen on the Figure 3. The lowest levels were measured in the common space of geriatrics clinic, as it was not the case in terms of patient rooms (Figure 4). The acceptable limits of WHO and EPA for CO_2 were exceeded also in Nephrology clinic (Figure 5). In general the more patients staying in the room the higher levels were. Mean room temperatures in the outpatient clinics ranged between 22.6 °C and 24.3°C, and relative humidity was ranging between 57.7% and 61.5%.

DISCUSSION

This was a cross sectional descriptive study and does not explain causal relationships. We could only speculate about the factors which affected indoor air quality at the hospital. Determining the effects of indoor air pollution on the health of people in the hospital is beyond the scope of this investigation. →

The most widely recognized indoor environmental hazard is the VOCs which usually surpass the baseline outdoor levels. The VOCs consist of hundreds of different organic compounds and is quite complex to analyze and do a risk assessment of individual compounds and therefore, the total concentration of the VOCs is measured. In this study the total concentration of VOCs were measured, and the term "total volatile organic compounds" (TVOCs) was used.

The European Collaborative Action (ECA-IAQ 1992) categorizes TVOCs concentration levels into four exposure ranges: a comfort range (< 0.08 ppm), a multifactorial exposure range (0.08-1.06 ppm), a discomfort range (1.06-8.86 ppm), and a toxic range (> 8.86 ppm). Another categorization ECA uses is that TVOC concentrations should not exceed 0.1 ppm.[15] The TVOCs concentrations in the building are not exceeded if the later categorization is used; however if the former approach is used then the TVOCs concentrations in the waiting rooms of the central laboratory and polyclinics, cardiology polyclinic, the geriatric rooms with two or more patients and the common space of the cardiology clinic are in the discomfort zone. The high levels of TVOCs during the working hours may be attributed to the cleaning products used the type of ventilation in these areas and the large number of the occupants. At the end of the second shift all surfaces included in the study are cleaned and then the central laboratory and polyclinics are kept closed during non-working hours and weekends while the outpatient clinics are kept open 24 hour. The closing of the central laboratory and the polyclinics until the next working day and re-emission of the walls could have contributed to the elevation of TVOCs levels.[16] Vehicle emissions are the largest source for the air pollutant CO in urban areas.[6] CO has been considered representative of urban air pollution in many countries for years and exposure to air pollution was characterized as being the horizontal distance to major roads.[12,17] In the city of Athens almost 100% of the total CO emissions is attributed to mobile sources.[18]

There is no internal source emitting CO in the hospital building such as unvented kerosene and gas space heaters, leaking chimneys and furnaces, gas water heaters, wood or gas stoves, fireplaces and gasoline powered equipment. The high CO level measured in the waiting room of the central laboratory could be attributed to the motor vehicle traffic on the campus area. The waiting room of the central laboratory has no direct connection to the outside and the only connection is through a corridor which opens to one of the main gates of the hospital. In front of the gate is a small side road with a parking lot. The waiting rooms of the polyclinics are connected to the outside through windows on the wall adjacent to the examination rooms and, before this wall there is no motor vehicle traffic. This can explain different levels of CO in both places. The inpatient clinics, showed a different pattern: the more people that stayed in one room the higher the CO levels were. This was not related to motor vehicle traffic, since the crowded common spaces in nephrology and cardiology clinics had higher CO levels than the patient rooms which had a direct connection to the outdoor air. In their study, Jo and Lee (2006) reported a similar situation and concluded that the CO indoor concentrations did not vary significantly according to distance from a major roadway.[6] Although we have not observed any violation of the smoking ban, we kept in mind that disguised smoking is a possibility and could have affected the CO levels.

Indoor CO_2 concentrations are a function of occupancy and ventilation rate, both varying as a function of time.[19] They are associated with human presence, as well as with the ventilation of the indoor environment.[20] As people exhale carbon dioxide, without adequate ventilation to dilute and remove the CO_2 generated by the occupants, it can accumulate. An elevated CO_2 level is an indication of an inadequate amount of outside air being brought into a building.[4] High CO_2 levels do not affect human health but TVOCs and CO do, and high CO_2 levels indicate insufficient ventilation of the room, which causes discomfort to the occupants. When levels exceed the value of 1000 ppm it is suggested that immediate action should be taken to enhance air renewal.[16] In our study the critical limit of 1000 ppm was exceeded in all rooms investigated. In crowded places the levels exceeded 3000 ppm. In the waiting room of the central laboratory, cardiology polyclinic, where more than 500 patients were examined daily, and in the common space of the cardiology clinic 3000 ppm was exceeded. Although these areas were crowded the waiting room of the polyclinics showed lower levels of CO_2 and this may be because of its larger area.

Interestingly the patient rooms in outpatient clinics all had relatively high CO_2 levels in contrary with the need for fresh air for the patients. Natural ventilation poses a problem because it does not provide adequate air exchange and is controlled by the patients. Santamouris et al (2008) found in their study carried out in schools that natural ventilation statistically had a higher average CO_2 concentration than mechanical ventilation.[21]

CONCLUSION:

The results demonstrated that people staying in our hospital were occasionally exposed to indoor air which does not meet minimum standards. It poses an ethical problem as patients are not informed of the quality of→

indoor air at the hospital. Indoor air quality of hospitals should be continually monitored to ensure public health. Therefore, it is necessary to build a system that can deliver clean air efficiently and at low cost to the patients. Mechanical and natural ventilation can be used for renewal of the indoor air at the clinic. Natural ventilation is commonly relied on in mild climates; and this can provide the necessary ventilation rates; but this may result in higher ventilation rates which expose the indoor microenvironment to a higher penetration of outdoor pollutants. Mechanical ventilation systems show a beneficial effect on the improvement of indoor air quality provided these systems are operated properly and well maintained. High concentrations of air pollutants in a building may indicate that either there are strong indoor or outdoor sources or that ventilation is inadequate.

No regulatory standard for indoor TVOCs, CO and CO_2 levels have been established in Turkey and few studies have been done in this field. Results from this study will assist in helping the indoor air quality regulations in Turkey to be revised by the relative authorities.

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