

## Indoor TVOCs and CO<sub>2</sub> levels in selected clinics of the Athens Dentistry School, Greece

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### Abstract

In this study an attempt is made to assess the indoor air quality status of clinics of the Athens University School of Dentistry with respect to VOCs and CO<sub>2</sub>. Measurements were collected for a period of approximately three months in three clinics with the aid of portable instrumentation. It was found that the levels of VOCs concentrations are high, being attributed to the use of acrylic substances and dental materials but also to the detergent products for cleaning the working surfaces. The VOCs levels depend on the number of occupants and the material use as well as on the number of open windows. The corresponding background values remain high in all clinics. The levels of the concentrations of CO<sub>2</sub> are considered in general satisfactory as compared to the international standards, however, they can exceed the intervention limit at certain hours of the day, suggesting poor air renewal. The opening of the windows was found to improve the air quality status.

*Keywords: volatile organic compounds, carbon dioxide, indoor measurements, dentistry clinics.*

### 1 Introduction

In recent years the scientific community is increasingly interested in indoor areas of hospitals, where the mixture of pollutants and microorganisms present a dangerous environment for both doctors and patients. This issue becomes more



complicated in hospitals located in urban areas, where additional pollution sources, including cars, industries, central heating can affect the indoor air quality status. Previous studies have demonstrated the formation of bad conditions in hospitals and have investigated possible sources (Loizidou et al. [1], San-Jose-Alonso et al. [2], Holcatova et al. [3]).

The present work aims to study the indoor air quality with respect to VOCs and CO<sub>2</sub> in three selected undergraduate and postgraduate clinics of the University School of Dentistry, which is located in an urban area of Athens. More specifically, the objective of the study is: a) to examine the diurnal and inter-diurnal variations of VOCs and CO<sub>2</sub> during working days b) to assess the background levels during weekends and holidays when the clinics are closed c) to identify possible sources.

## 2 Experimental site and instrumentation

### 2.1 Sampling sites and descriptions

This study was conducted in the Dentistry Faculty of the University of Athens, which is located in a densely populated area of the city, with very high buildings and heavy traffic roads, due to the four nearby hospitals in the perimeter of the Faculty. The building, where the clinics of the Undergraduate Studies are held, was constructed in 1969, while the building where the Postgraduate Studies are held, in 1981. Each Building has five floors and they are connected by internal corridors.

The experiment took place in three clinics. The Total Treatment Clinic (hereafter will be referred to as Clinic A) on the third floor of the Undergraduate Building is of 290 m<sup>2</sup>, with 70–100 occupants on a daily basis. The Endodontics, Periodontics and Operative Dentistry Clinic (hereafter will be referred to as Clinic B) is of 150 m<sup>2</sup> on the second floor of the Postgraduate Building with 30 occupants every day. The Prosthodontics Clinic (hereafter will be referred to as Clinic C) is of 150 m<sup>2</sup> and is located in the same building on the fourth floor with 20 occupants on a daily basis. The clinics operated in two shifts between 08:00 – 12:30 and 13:00 – 17:00, except for Clinic C which has one shift between 09:00 – 16:00.

During the whole experimental period a logbook had been kept recording all the activities taking place in the clinics, including the number of open windows, the used materials and the cleaning processes. Thus, there have been records of the number and the location of the opened windows, the number of the students working, the kind of the tasks that were taking place, the materials that had been used, as well as the hours of the clinics cleaning.

### 2.2 Instrumentation

Portable instrumentation - IAQRAE PID monitor for TVOCs and CO<sub>2</sub> and ppbRAE PID monitor for TVOCs – is employed at all measurement sites. TVOCs and CO<sub>2</sub> concentrations refer to one – hour mean values, as derived from



one-min continuous measurements. Both monitors are of new technology and high sensitivity. The measurements took place during the periods 14 February - 3 March 2005 in Clinic A, 4 March - 18 April 2005 in Clinic B and 18 April - 23 May 2005 in Clinic C during working days and weekends. In Clinic A, TVOCs simultaneous measurements were performed at two locations, K (in the centre of the room) and B (in the northern part of the room, near the door), during the period 17-25 February 2005. Background concentration values were considered as the values recorded during the weekends and non-working hours, when the clinics are not occupied.

### 3 Results and discussion

Table 1 shows the average concentration values of CO<sub>2</sub> and TVOCs during the experimental period, the corresponding average values during working hours and non-working hours (background values) in the three Clinics, along with the range of the maximum hourly values. In general, it can be seen that the concentration levels of TVOCs are substantially high, as compared to the threshold limits set for indoor environment by the international bibliography (Molhave [4], Seifert [5], European Concerted Action [6]). More specifically, taking into account that the warning limits are between 300 and 600 µgr/m<sup>3</sup>, while the limits of interventions are over the 600 µgr/m<sup>3</sup>, it is shown that even the background values are higher than the intervention limits.

Table 1: Average concentration values of TVOCs and CO<sub>2</sub> in the three clinics during the experimental period.

Clinics	Pollutants	Mean background values	Mean working hours	Daily maximum values range	Average value
A	CO <sub>2</sub> (mg/m <sup>3</sup> )	1250	2200	1500-4600	1600
	TVOCs (K) (µg/m <sup>3</sup> )	950	1900	2000-5500	1300
	TVOCs (B) (µg/m <sup>3</sup> )	1500	3000	3000-10500	2500
B	CO <sub>2</sub> (mg/m <sup>3</sup> )	1250	2100	1620-4620	1520
	TVOCs (µg/m <sup>3</sup> )	480	760	1000-14600	720
C	CO <sub>2</sub> (mg/m <sup>3</sup> )	1170	1400	1300-3100	1220
	TVOCs (µg/m <sup>3</sup> )	400	900	900-14900	500

The comparison of the mean CO<sub>2</sub> concentrations with the recommended limits of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE [7]) for indoor spaces (satisfactory air quality: <1000 ppm or 1800 mgr/m<sup>3</sup>), resulted in the fact that the mean values during the operating



hours of the clinics fall into the category of unsatisfactory air quality. The background levels are significantly lower.

### 3.1 Clinic A

#### 3.1.1 CO<sub>2</sub>

The CO<sub>2</sub> concentrations varied between 800 and 4600 mgr/m<sup>3</sup> and the average value was 1600 mgr/m<sup>3</sup>. During the working days, CO<sub>2</sub> concentration presented the average diurnal pattern during the experimental period shown in figure 1: during the first hours of the day, the values remained at low levels, of 1250 mgr/m<sup>3</sup>. A sudden increase was observed at 08:00 LST when the clinic operation starts and a large number of students and patients occupied the room. After that time, further increase was found being attributed to the lack of air renewal and poor ventilation conditions. A peak appeared at around 11:00, of 2800 mgr/m<sup>3</sup>. Then, a small decrease was recorded, due to the break for the change of shifts. When the occupants started to regather, CO<sub>2</sub> tends to increase again. The second peak of the day appeared round 15:00, of 2400 mgr/m<sup>3</sup>. The concentrations decrease gradually as the number of occupants decreases. Finally, at around 19:00 LST, CO<sub>2</sub> reached the same background levels that had been recorded early in the morning. The concentrations remained low until the beginning of the next day's shift.

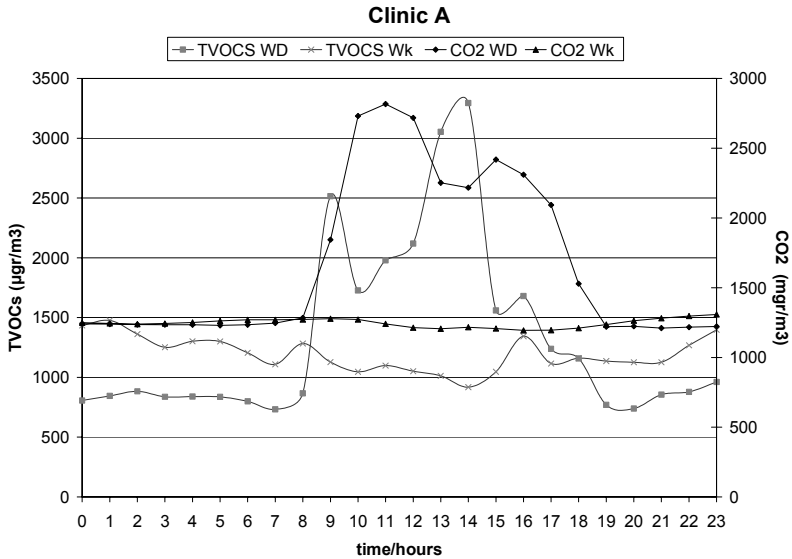


Figure 1: Average diurnal variation of CO<sub>2</sub> and TVOCs concentration during the experimental period in Clinic A during working days (WD) and weekends (Wk).

From figure 2, where the variations of the hourly concentration values during the experimental period are shown, it can be seen that the maximum values

ranged between 1500 – 4600 mgr/m<sup>3</sup>, depending on the number of occupants and the number of open windows. More careful examination of the indoor conditions demonstrated that the maximum concentration values were recorded when the windows were closed, the occupant number was large and the ventilation was poor. When some of the windows are open, the CO<sub>2</sub> values present a significant decrease (30%) due to the air renewal, but still appear the same typical diurnal pattern of Figure 1.

The CO<sub>2</sub> concentration during weekends remained at relatively high levels (see Figure 1), similar to the values recorded during non working hours during the other days, forming a mean background value of 1250 mgr/m<sup>3</sup> (Table 1).

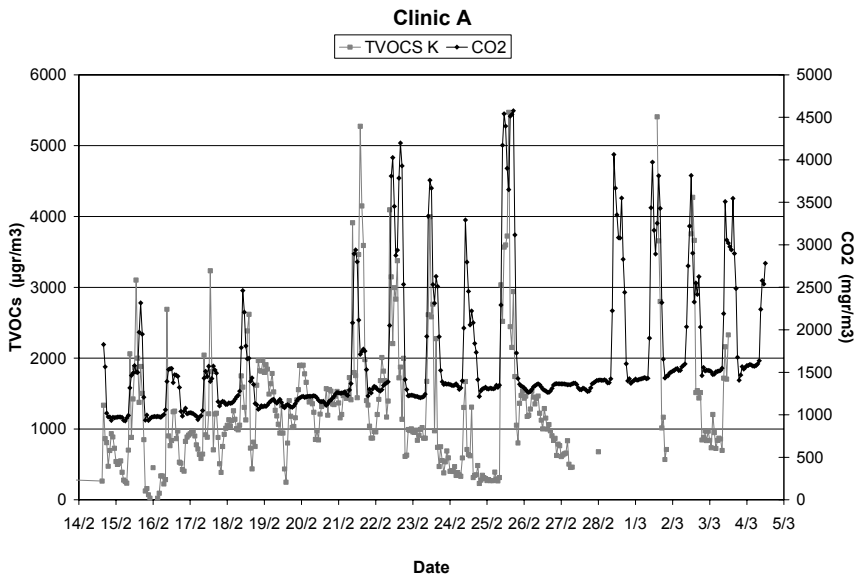


Figure 2: Variation of mean hourly CO<sub>2</sub> and TVOCs concentration values during the experimental period in Clinic A.

### 3.1.2 TVOCs

The concentration values of TVOCs during the experimental period ranged between 20 and 5500 µgr/m<sup>3</sup> and the average value was 1300 µgr/m<sup>3</sup> (Table 1). According to Figure 1, early in the morning the TVOCs concentration is of 950 µgr/m<sup>3</sup>, while it substantially increases after 08:00 LST. It remained at high levels until the afternoon due to the poor ventilation of the room and the use of dental materials and substances, mainly acrylic, which act as VOCs sources. Three peaks are observed: the first one appeared at 09:00 LST (mean value at 2500 µgr/m<sup>3</sup>), the second at round 13:30 LST (mean value at 3300 µgr/m<sup>3</sup>) and the third at 17:00 LST (mean value at 1500 µgr/m<sup>3</sup>). These peaks are attributed to the use of detergent products for cleaning the working surfaces during the beginning and the end of each shift. In the end of the last shift, TVOCs

concentration decreased gradually and reached similar background values to the ones observed early in the morning. During the weekends the concentrations remained at similar background levels.

It is remarkable that exceptionally high values (such as  $5500 \mu\text{gr}/\text{m}^3$ ) during the working hours (see Figure 2) are associated with the use of the substance Kalocryl. Similarly to  $\text{CO}_2$ , TVOCs values appear the same decrease when some of the windows are open.

The examination of the TVOCs variations at the two different locations K and B demonstrated that that even though the concentrations follow the same diurnal variation at both sites (see Figure 1), the values at B were higher than the K. More specifically, the mean value is of  $1400 \mu\text{gr}/\text{m}^3$  and  $2500 \mu\text{gr}/\text{m}^3$  at sites K and B, respectively, while the maximum values become as high as  $10500$  and  $5500 \mu\text{gr}/\text{m}^3$  respectively. This difference is attributed to the different VOCs sources: the emissions are much higher at B due to the operation of machines for grinding, smoothening and polishing acrylic materials.

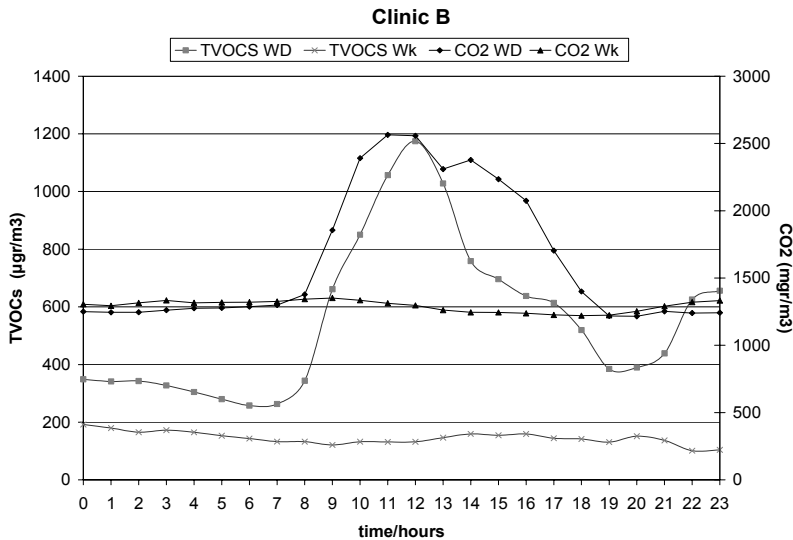


Figure 3: As in Figure 1, but for Clinic B.

## 3.2 Clinic B

### 3.2.1 $\text{CO}_2$

The  $\text{CO}_2$  concentrations varied between the values of  $765$  and  $4620 \text{ mgr}/\text{m}^3$ , while the mean value was slightly lower ( $1520 \text{ mgr}/\text{m}^3$ ), as compared to Clinic A. However, a similar diurnal variation to that in Clinic A was found (Figure 3) since the same operational timetable is followed in both clinics. According to Figure 4, the maximum concentrations of the two peaks that were daily recorded ranged from  $1620$  to  $4620 \text{ mgr}/\text{m}^3$  and appeared at  $11:00$  and  $14:00$  LST (mean value at  $2550$  and  $2400 \text{ mgr}/\text{m}^3$ , respectively). The average value of the working hours was at  $2100 \text{ mgr}/\text{m}^3$  (see Table 1).



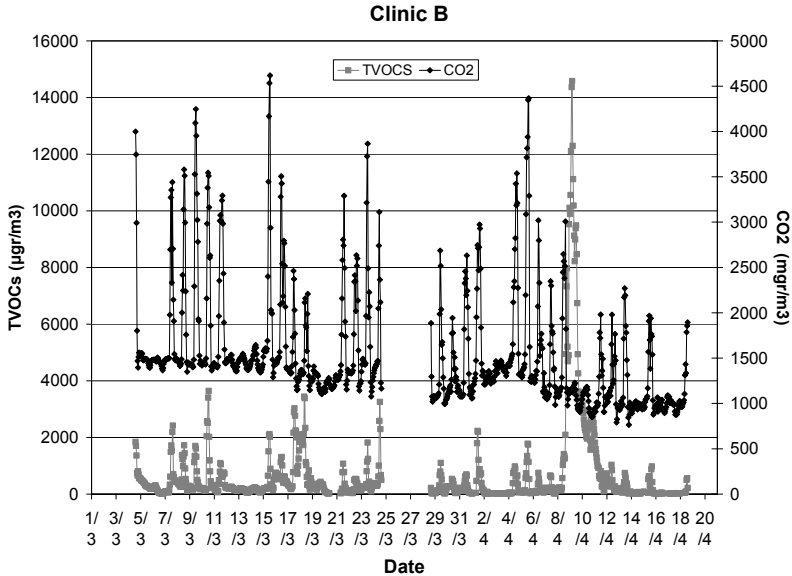


Figure 4: As in Figure 2, but for Clinic B.

### 3.2.2 TVOCs

The TVOCs concentration levels are high in Clinic B, ranging between 23 and 14600  $\mu\text{gr}/\text{m}^3$  with average value of 720  $\mu\text{gr}/\text{m}^3$ , which is, however, significantly lower as compared to Clinic A. This is due to the fact that the dental substances and materials emitting VOCs are employed only during the first shift in Clinic B, when periodontics operations take place. It is characteristic that the TVOCs concentration reduces after 12:00-12:30 LST, immediately after the termination of these operations. For the same reason, only one peak is observed (Figure 3) with mean value of 1200  $\mu\text{gr}/\text{m}^3$ . Detergent cleaning products in use during the break are also responsible for the enhancement of VOCs concentrations. The average concentration during working hours is of 760  $\mu\text{gr}/\text{m}^3$ , the corresponding values during non-working hours are lower (610  $\mu\text{gr}/\text{m}^3$ ) while they are even lower (150  $\mu\text{gr}/\text{m}^3$ ) during the weekends. Thus, the background levels are as half as the corresponding in Clinic A (480  $\mu\text{gr}/\text{m}^3$ ).

From Figure 4, it is worth to note that extremely high TVOCs concentrations are recorded on Friday of the 8<sup>th</sup> of April during the nighttime, reaching 14600  $\mu\text{gr}/\text{m}^3$  that remained at high levels during the whole weekend. This can be attributed to the extensive use of cleaning products.

## 3.3 Clinic C

### 3.3.1 CO<sub>2</sub>

In this clinic, the CO<sub>2</sub> levels are not very high as compared to the other two clinics, due the lower number of occupants, the ventilation and the different operational program. The CO<sub>2</sub> concentrations range from 640 to 3100 mgr/m<sup>3</sup>.

The background concentrations were also low, of 1170 mgr/m<sup>3</sup>. Since the tasks were taking place in one shift, the peak in the diurnal distribution (Figure 5) appeared at around 10:30 and varied between 1300 – 3100 mgr/m<sup>3</sup> (mean value at 1550 mgr/m<sup>3</sup>). After that time the CO<sub>2</sub> concentration decreases to significantly lower levels for the rest of the day.

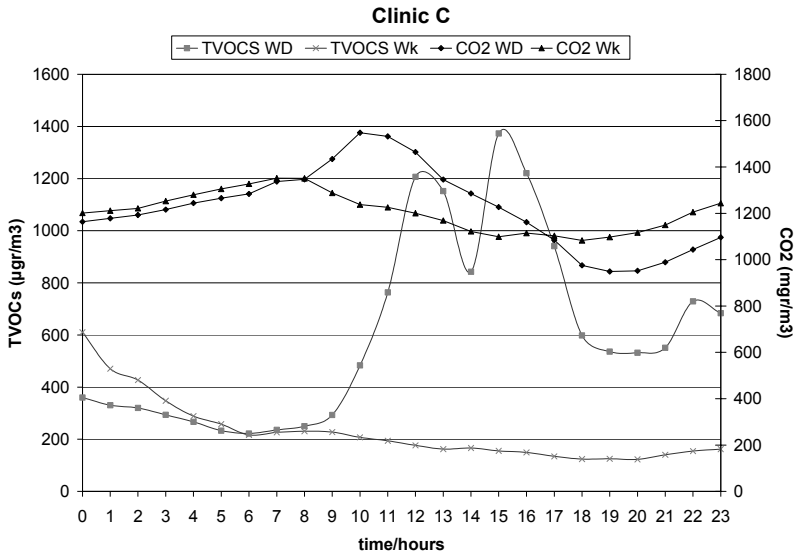


Figure 5: As in Figure 1 but for Clinic C.

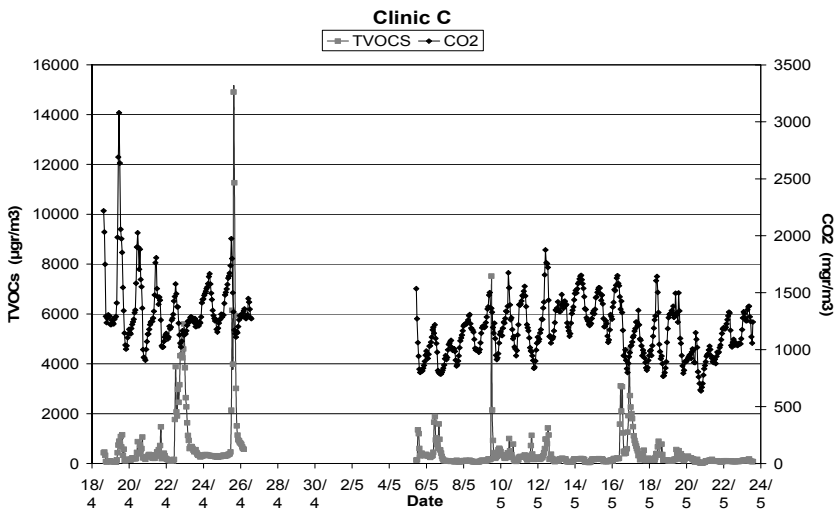


Figure 6: As in Figure 2, but for Clinic C.





### 3.3.2 TVOCs

The TVOCs concentrations ranged at lower levels as compared to clinics A and B from 16 to 14900  $\mu\text{gr}/\text{m}^3$  and the average value was at 500  $\mu\text{gr}/\text{m}^3$  (see Table 1). According to Figure 5, the mean concentration present two peaks that varied between 900 – 14900  $\mu\text{gr}/\text{m}^3$ . The first peak appeared at 12:00 LST and the second at 15:00 LST (mean value at 1200 and 1400  $\mu\text{gr}/\text{m}^3$  respectively). The increased concentrations are attributed to the use of acrylic substances and dental materials and the detergents for the cleaning of the working surfaces in the beginning and the end of each shift. Thus, the average concentration of TVOCs during the operating hours was at 900  $\mu\text{gr}/\text{m}^3$ , and the background values at 400  $\mu\text{gr}/\text{m}^3$ . It should be noted that when the highest TVOCs concentrations occur the  $\text{CO}_2$  levels are minimized. This is due to the windows opening that improved the ventilation conditions as well as to the small number of occupants.

It is once again remarkable the fact that the use of the substance Kalocryl form very high TVOCs concentration values (14900  $\mu\text{gr}/\text{m}^3$ ). Also in this clinic, relatively high values are observed during the weekends because of the use of some kind of detergents on Friday afternoon (Figure 6).

## 4 Concluding remarks

The three clinics of the Dentistry Faculty are characterised by high levels of TVOCs concentrations, which are attributed to the use of acrylic substances and dental materials but also to the detergent products for cleaning the working surfaces. It is remarkable that the concentrations of VOCs reached exceptionally high values such as 14900  $\mu\text{gr}/\text{m}^3$  when the dental substance Kalocryl had been used. Maximum values during the working periods of the day are attained during decontamination of working posts. The concentration values remained increased during non-working hours and weekends. It is characteristic that, the background values are higher than the intervention limits for indoor environment. It is worth to note the increased TVOCs levels in Clinic C during weekends, due to the use of one kind of cleaning detergents in Clinic C on Friday afternoon.

The levels of the concentrations of  $\text{CO}_2$  are considered in general unsatisfactory during the working hours, as compared to the international standards. The opening of the windows contributed to a decrease of the concentration values, suggesting that the ventilation of the clinics should be improved.

Comparing the three clinics in the Faculty of Dentistry, Clinic A is characterised by the poorest indoor air quality status, being followed by the Clinic B and C. This is attributed to the larger number of occupants in Clinic A and the employment of materials that act as VOCs sources during the whole working day.

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## References

- [1] Loizidou, M., Asimakopoulos, D.N., Lagoudi, A. & Petrakis, M., An assessment on the indoor air quality of houses and hospital in Athens. *Quality of the Indoor Environment*, eds. Lester, J.N., Perry, R., Reynolds, G.L., pp. 597-608,1992.
- [2] San Jose-Alonso, J.F., Velasco-Gomez, E., Rey-Martinez, F.J., Alvarez-Guerra, M. & Gallego-Pelaez, C., Study on environmental quality of a surgical block. *Energy and Buildings*, 29, pp. 179-187, 1999.
- [3] Holcatova, I., Beneova, V. & Hartlova, D., Comparison of the Environment in Operating Theatres in two Hospitals. *Indoor and Built Environment*, Vol. 12, No. 1, pp. 121-124 (4), 2003.
- [4] Molhave, L., Evaluations of VOC emissions from materials and products: solid flooring materials. *Proc. of Healthy Buildings '95*, ed. Maroni M., Milano, Vol. 1, pp 145-162,1995.
- [5] Seifert, B., Regulating indoor air. *Proc. of Indoor Air '90*, ed. Walkinshaw, Toronto, Vol. 5, pp 15-33,1990.
- [6] European Concerted Action, Indoor Air Quality and its impact on man, Guidelines for ventilation requirements in buildings. Report No. 11, Commission of the European communities, EUR 14449 EN, Joint Research Centre, 1992.
- [7] ASHRAE, ASHRAE Standard 62-2001 rev. Ventilation for Acceptable Air Quality, ASHRAE, Atlanta, 2003.

