# MEASUREMENTS OF INDOOR AIR POLLUTANT LEVELS IN A UNIVERSITY OFFICE BUILDING

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## ABSTRACT

*This work consisted of a series of determinations performed in typical rooms of a building belonging to the Technical University of Lisbon, which is located in a central urban area of Lisbon. The main objective was to evaluate the Indoor Air Quality (IAQ) of the rooms so that further corrective measures could be taken if unsatisfactory IAQ levels were to be found. Correlations were derived, between indoor and outdoor pollutant concentrations, in order to assess the existence of contaminations coming from outside. Also, correlations were derived between total volatile organic compounds (VOC) concentrations and specific individual organic species measured in the same room. The methodology recorded in this paper is effective to assess compliance analysis of total VOCs, however, it seems somewhat limited to determine specific individual chemical species responsible for obtaining high total VOC concentrations.*

## KEYWORDS

Indoor Air Quality; Hazardous Substances; Ventilation

## INTRODUCTION

The actual knowledge of the levels of concentration of specific pollutants such as volatile organic compounds inside buildings, together with the knowledge on the effects of those compounds on human health, is essential to define specific protection measures for building occupants. Several studies (Jurvelin et al., 2003; Moschandreas and Sofuoglu, 2004) have shown the dominant role of indoor air in personal exposure to many air pollutants. These findings are important given the high proportion of time that people spend indoors (85–95%) and by the high concentrations of many air pollutants found in the indoor environment.

Assessment of the risk to the community resulting from exposure to airborne pollutants should ideally include measurements of concentration levels of the pollutants in all microenvironments where people spend their time (Stieb et al, 2003). Due to the multiplicity of different microenvironments, it is usually, however, not possible to conduct measurements in all of them (Morawska et al, 2001). The main consideration in designing exposure assessment studies is, which of the microenvironments should be studied to provide data allowing for most accurate assessments, while limiting the costs and efforts relating to the studies. In many cases, the subdivision is between the indoor and outdoor environment, with questions posed as to what extent indoor exposures could be predicted from measured concentrations of pollutants in outdoor air (Chang, 2002).

Understanding the relationship of indoor and outdoor aerosol particles, as well as other airborne pollutants such as CO, $CO_2$ and VOCs, under different environmental conditions is of importance for improving exposure estimates and, in turn, for developing efficient control strategies to reduce human exposure and thus health risk (Zhao et al, 2003; Gomes, 2006; Wilson et al, 2006). Previously developed exposure assessment models are often based on the outdoor pollutant concentration used as the input parameter for predicting total human exposure (Colls and Micallef, 1997). However, the indoor concentrations may be different than the outdoor ones even in the absence of any significant indoor pollution sources (Morawska et al., 2001).

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## STUDY OBJECTIVE AND SUBJECT

The main objective of this study was to evaluate the Indoor Air Quality (IAQ) of rooms to observe correlations between indoor and outdoor pollution levels. The subject of the study is a number of rooms in a building belonging to the Technical University of Lisbon, which is located in a central urban area of Lisbon. Table 1 shows the main characteristics of the rooms analysed this study.

## EXPERIMENTAL DETERMINATION OF POLLUTANTS

$CO_2$ and CO were determined with a portable analyser GFM100 (Gas Data, UK), using an infrared spectroscopy detector for $CO_2$ and an electrochemical detector for CO. The analyser is also equipped with thermocouple probes for determination of air temperature and relative humidity. Total VOC was measured with a portable analyser PhoCheck+ 2000Ex (Phocheck, UK) which uses a ultraviolet detector. Particulate matter was sampled using a SKC Universal Air Sampling Pump 224-PCTX8 (SKC, USA) sampling pump equipped with a cascade impactor, according to the NIOSH 500 standard method (NIOSH, 1994), and determined gravimetrically using an analytical balance Mettler AX205DR. BTEX was sampled using Tenax tubes, according to the NIOSH 2549 standard method (NIOSH, 1994), followed by gas chromatographic determination using a Clarus 500 (Perkin-Elmer, USA) gas chromatograph equipment, equipped with a mass spectroscopy detector, coupled to a thermal desorption apparatus.

## OBTAINED RESULTS

Table 2 shows the measured pollutant concentrations in the rooms of the University office building. This table shows the average obtained concentration results during one working day, based on hourly observations. No particular variability was observed for pollutants other than for $CO_2$, where the minimum/maximum observed interval is presented.

In order to try to understand the origin of contamination in those rooms, linear correlations were drawn between outdoor and indoor concentrations concerning VOC. The comparison between both values is presented in figures 1 to 5. It should be noticed

**TABLE 1.** Main features of analysed rooms.

| Sample reference | Room | Main activity | Number of occupants | Air conditioning system | Smoking | Area ($m^2$) |
|---|---|---|---|---|---|---|
| 1 | DEM cabinet | Office | 14 | Yes | No | 80 |
| 2 | QA021 | Amphitheatre | 130 | Yes | No | 107 |
| 3 | DEC | Reprography | 1 | Yes | No | 65 |
| 4 | PAV | Cafeteria | 56 | No | Yes | 90 |
| 5 | SJD | Reprography | 20 | Yes | Yes | 42 |
| 6 | Outside | — | — | — | — | — |

**TABLE 2.** Measured pollutants concentrations in the University office building.

| Parameter | Room 1 | Room 2 | Room 3 | Room 4 | Room 5 | Outside |
|---|---|---|---|---|---|---|
| $CO_2$ ($mg/m^3$) | 1004–1908 | 741.7–794.7 | 1346.9–1706.1 | 1706.1–2564.4 | 1259.7–1304.3 | 629.9–647.9 |
| CO ($mg/m^3$) | nd | nd | nd | nd | nd | nd |
| VOC ($mg/m^3$) | 0.2 | nd | nd | 0.5/0.7 | 0.9/1.5 | nd |
| PM ($mg/m^3$) | 0.66 | nd | 1.33 | 0.12 | 1.58 | 1.92 |
| Benzene ($\mu g/m^3$) | <0.66 | 0.66 | 1.33 | 2.00 | 2.00 | 2.00 |
| Toluene ($\mu g/m^3$) | 2.66 | 8.66 | 38.66 | 8.66 | 25.33 | 9.33 |
| Ethylbenzene ($\mu g/m^3$) | 1.33 | 2.00 | 3.33 | 1.33 | 2.00 | 2.00 |
| Xylene ($\mu g/m^3$) | 2.00 | 5.99 | 7.33 | 5.33 | 8.00 | 8.00 |
| Temperature (°C) | 26 | 23 | 24 | 27 | 26 | 25 |
| Relative humidity (%) | 59 | 64 | 48 | 43 | 40 | 42 |

Note: nd = non-detected

**TABLE 3.** Comparison between measured values for total VOC and total BTEX.

| Room | Σ BTEX (μg/m$^3$) | VOC (μg/m$^3$) | BTEX/VOC | % |
|---|---|---|---|---|
| 1 | 7.3 | 200 | 0.0365 | 3.5 |
| 2 | 17.33 | nd | — | — |
| 3 | 50.66 | nd | — | — |
| 4 | 17.33 | 600 | 0.03466 | 3.5 |
| 5 | 37.33 | 1200 | 0.02488 | 2.5 |
| 6 | 21.33 | nd | — | — |

Note: nd = non-detected

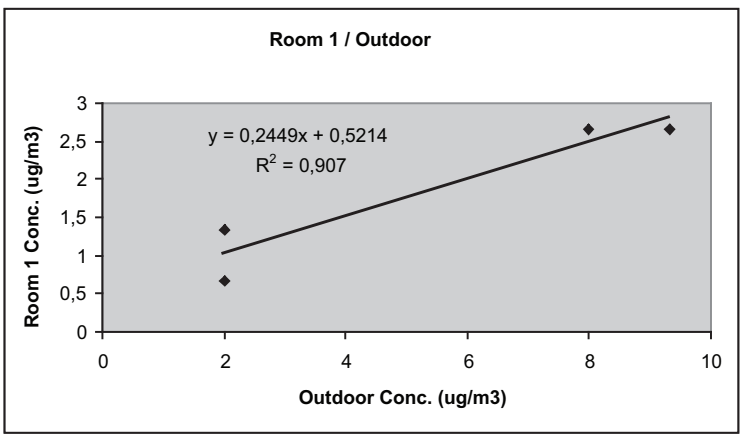


**FIGURE 1.** Correlation between VOC observed concentrations outside and in Room 1.

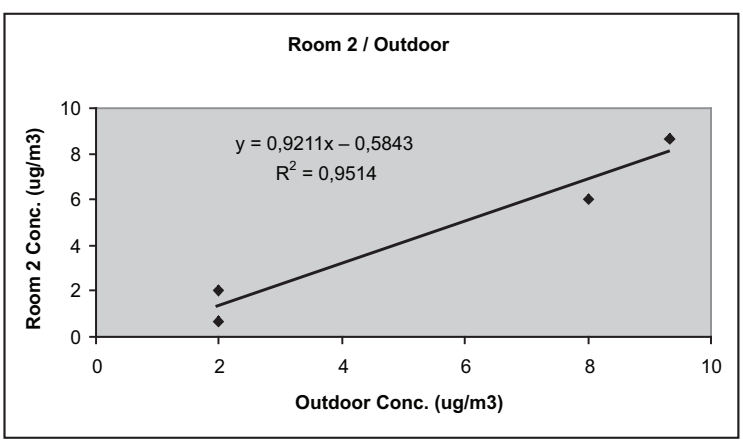


**FIGURE 2.** Correlation between VOC observed concentrations outside and in Room 2.

that in certain VOC measurements, the observed value was below the instrument detection limit of 2 mg/Nm$^3$. In these cases, the graphic show the concentration of 2 mg/Nm$^3$. Linear correlations were chosen, instead of quadratic ones, because of simplicity of analysis. Another important correlation was obtained by comparing the total VOC levels measured by using the portable analyser and the BTEX levels measured by gas chromatography, in the same room. This comparison is shown in table 3, together with calculated ratio of total BTEX to VOC., and a graphical linear correlation is presented on figure 6.

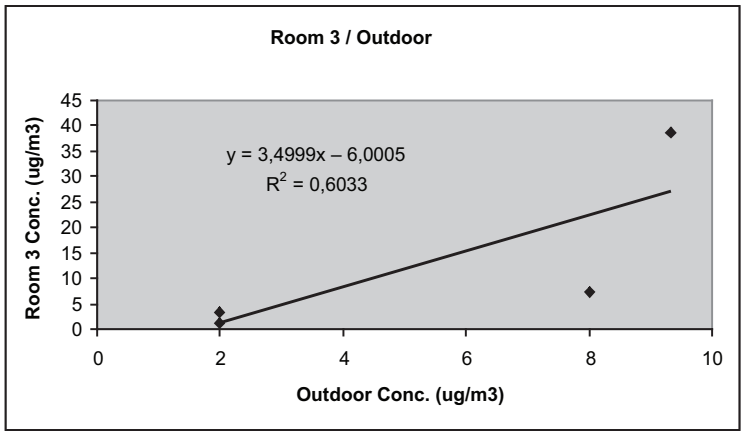


**FIGURE 3.** Correlation between VOC observed concentrations outside and in Room 3.

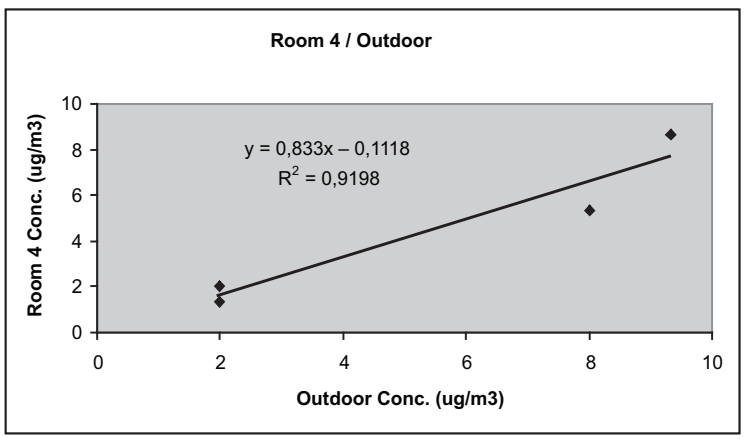


**FIGURE 4.** Correlation between VOC observed concentrations outside and in Room 4.

## DISCUSSION

From the obtained values, it can be noticed that, as a whole, pollutant concentrations are somewhat higher inside the analysed rooms from the University building than outside determined levels. This trend could be expected considering that indoor atmospheres can derive from outdoor pollutant concentration, which are trapped inside walls, thus resulting in higher bulk concentrations, mainly due to the effect of air conditioning. Exceptions are made to particulate matter as well as certain aromatic compounds such as benzene, as could be noticed in Figures 1, 2 and 4, referring to VOC levels measured in rooms 1, 2 and 4, respectively.

The previous observation is particularly true regarding $CO_2$, which is generated by human occupancy of rooms.

It should be also noted that the observed levels of outdoor pollutant concentrations are due to the fact that the University is located in a central area of Lisbon, surrounded by heavy traffic. Measurements were made during weekdays, in September 2006, in a mild climate season, with no rain.

These measured values are in accordance with pollutant levels measured by the air quality stations in nearby Lisbon area.

As expected, the highest measured concentrations for the BTEX pollutant series were observed in rooms 3 and 5, which are used for reprographies. In fact, the highest observed concentrations were measured in room 3, which has a work load considerably higher than room 5. Apart from that, room 5, has more occupants, a lower area and smoking is allowed, which

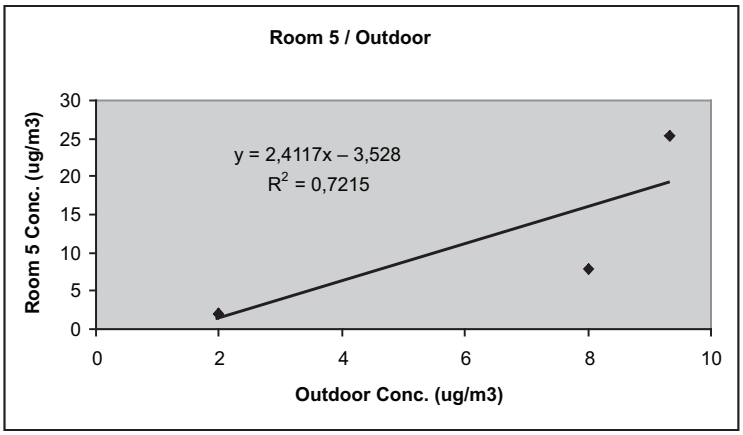


**FIGURE 5.** Correlation between VOC observed concentrations outside and in Room 5.

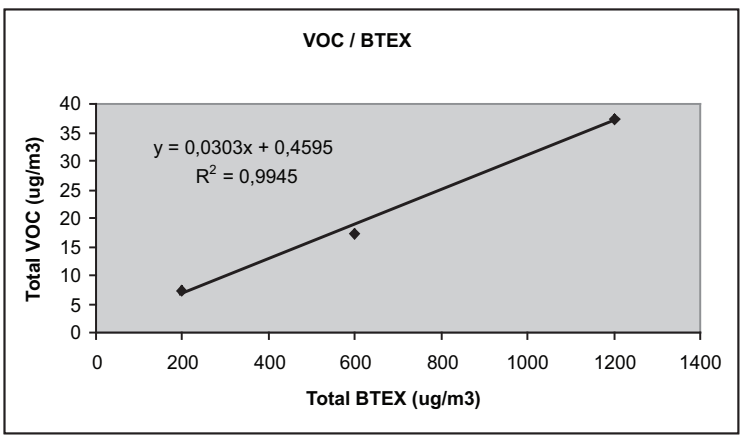


**FIGURE 6.** Correlation between VOC and BTEX observed concentrations.

can also explain the observed differences. The most significant aromatic compound detected is toluene, which is used as a component of developing fluid in both reprographies, and reaches a concentration of 38.7 ($g/m^3$ in room 3.

Also in rooms 3 and 5, higher levels of particulate matter, when compared with other rooms, were observed, which could be justified by the load of paper existing in reprographies.

Regarding VOC concentrations measured inside rooms versus outside, linear correlations between both measured concentrations seem to exist, as shown in figures 1 to 5. However, observed concentrations are lower inside rooms than in the outside environment, except for rooms 3 and 5 (reprographies) which denotes the existence of indoor sources, resulting on toluene emissions. Therefore, for these particular two rooms, the obtained correlation parameter $R^2$ is considerably lower, than for the other rooms. Only in rooms 3 and 5, $R^2$ is lower than 0.90. It should be noted that, in these two cases, if the toluene concentration is disregarded, the obtained correlation coefficient will increase up above 0.90.

As shown in figure 6, a correlation also appears to exist between measured VOCs and total BTEX, although only a very small percentage of BTEX (from 2.5 to 3.5%) was found, which calls for further investigations on the nature of the existing indoor VOC compounds, as this is quite a low value.

The European Commission issued a Directive in 2002 (EC, 2002) aiming to reduce the energy consumption of buildings, which was adopted by the

**TABLE 4.** Indoor Air Pollutant Limit Values (according to the Portuguese Regulations).

| Indoor Air Pollutant | Limit Value | Measured values |
|---|---|---|
| $PM_{10}$ | 0,15 mg/m$^3$ | 629,9-2564,4 mg/m$^3$ |
| $CO_2$ | 1800 mg/m$^3$ | nd |
| CO | 12,5 mg/m$^3$ | nd-1,5 mg/m$^3$ |
| $O_3$ | 0,2 mg/m$^3$ | nd-1,92 mg/m$^3$ |
| HCHO | 0,1 mg/m$^3$ | not measured |
| TVOC | 0,6 mg/m$^3$ | not measured |

Note: nd = non-detected

European Union member states and came into force in 2006. Portugal adopted it by issuing law decrees in 2006 (INCM, 2006a ; INCM, 2006b ; INCM, 2006c) which considered not only the energy saving aspects but also additional specific measures aiming to protect indoor air quality (IAQ). This new legislation is now being enforced and indoor air concentration limits for certain pollutants are already defined and are presented in table 4. A simple comparison with the prescribed limit values and the measured ones shows several concentrations exceeding limits such as CO2 in rooms 1, 4 and 5; VOC in rooms 4 and 5 and particle matter (PM) in rooms 1, 3 and 5.

## CONCLUSIONS

The results of the study show, as a whole, pollutant concentrations are somewhat higher inside the analysed rooms from the University building than outside determined levels. As discussed, this is an expected result given the uses of the rooms analyzed in this study.

The methodology recorded in this paper is effective to assess compliance analysis of total VOCs, however, it seems somewhat limited to determine specific individual chemical species responsible for obtaining high total VOC concentrations. This could be an important issue in order to define remediation measures related with specific VOC sources. Therefore, the followed methodology could be considered as a preliminary one, prior to finer analysis and subsequent scanning determinations.

The information resulting from these measurements is of paramount importance to proceed with corrections in the building ventilation system itself and would help to achieve better indoor air quality which is a central tenet of sustainable building.

Although the Portuguese legislation defines the indoor concentration limit values for certain specific pollutants, no indication of pollutant sampling and analysis methods is yet referenced in the regulations. Nevertheless, the applied methodology recorded in this paper is useful for a preliminary diagnosis of the situation in an office building. In fact, the measurements completed resulted in observed concentration of pollutants which allowed compliance analysis with the prescribed limit values. In this particular case, low quality levels of indoor air were detected in some of the analysed rooms which call for the necessity to define further remediation measures that may include the increase of ventilation flow rates. It should be noted that the remediation measures to be applied certainly depend on the nature of observed pollutant exceeding the respective limit value.

## REFERENCES


Chang, T. Numerical evaluation of the effect of traffic pollution on indoor air quality of a naturally ventilated building, J. Air & Waste Management Association, 52, 1043 (2002).

Colls, J.J., Micallef, A. Towards better human exposure estimates for setting of air quality standards, Atmospheric Environment, 31, 4253 (1997).

European Comission. European Directive 2002/91/CE, 16/12/2002.

INCM. Law Decree DL Nº 78/2006, 4/4/2006.

INCM. Law Decree DL Nº 79/2006, 4/4/2006.

INCM. Law Decree DL Nº 80/2006, 4/4/2006.

Jurvelin, J.A., Edwards, R.D., Vartiainen, M., Pasanen, P., Jantunen, M.J. Residential Indoor, Outdoor and Workplace Concentrations of Carbonyl Compounds: Relationships with personal Exposure Concentrations and Correlation with Sources, J. Air & Waste Management Association, 53, 560 (2003).

Gomes, J.F.P. Métodos expeditos de estimative da concentração de poluentes gasosos no interior de edifícios, Rev. Port. Penumologia, 12-4, 447 (2006).

Morawska, L., He, C., Hitchins, J., Gilbert,D., Parappukkaran, S. The Relationship between indoor and outdoor airborne particles in the residential environment, Atmospheric Environment, 35, 3463 (2001).

Moschandreas, D.J., Sofuoglu, S.C. The indoor environmental index and its relationship with symptoms of office building occupants, J. Air & Waste Management Association, 54, 1440 (2004).

NIOSH. Manual of Analytical Methods, 4th Edition, 1994.

Stieb, D.M., Judek, S., Burnett, R.T. Meta-analysis of time-series studies of air pollution and mortality: update in relation to the use of generalized additive models, J. Air & Waste Management Association, 53, 258 (2003).

Wilson, J.G., Kingham, S., Sturman, A.P. Intraurban variations of PM10 air pollution in Christchurch, New Zealand: implications for epidemiological studies, Science of Total Environment, 367, 559 (2006).

Zhao, B., Li, X., Li, D., Yang, J. Revised air-exchange efficiency considering occupant distribution in ventilated rooms, J. Air & Waste Management Association, 53, 759 (2003).