A comparison of indoor air quality in two buildings of different construction.

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Abstract: Two buildings were compared in terms of incoming natural light levels, indoor temperature, indoor relative humidity and I/O concentration ratios of some criteria photochemical air pollutants (O_3, NO, NO_2*). One building is built with traditional materials, whilst the other was constructed with modern, mainly man-made materials. Both have natural ventilation, natural light and similar use. An intensive campaign, during which the aforementioned parameters were quantified, revealed that the modern building has inferior indoor air quality in comparison to the older building.

Key words: indoor air quality, indoor chemistry, construction materials.

1 Introduction

Recent scientific information indicates that indoor air pollution poses substantial health risks in many indoor environments [1, 2]. The total quantity of air pollutants emitted indoors is less than that emitted by outdoor sources. However, once emitted, indoor air pollutants are much less diluted, due to the partial trapping effect of the building shell. Additionally, indoor emissions occur in closer proximity to people, and people in developed countries spend most of their time indoors. Indoor-air contaminants are many and varied. So, too, are their effects, which include respiratory irritation, sick-building syndrome and building-related illness, respiratory disease, allergic reactions, and carcinogenesis [3, 4].

In Greece, over recent decades, there have been many changes in the way buildings are constructed and operated. The increase in the need for housing and workplaces, the increased cost of materials, energy and labor, combined with advances in construction technology, have led to buildings that are constructed with cheaper alternatives to the traditional building materials, more insulated, with more man-made construction materials. However, many of these modern buildings provide an environment in which airborne contaminants are readily produced and may build up to substantially higher concentrations than are typically encountered outside [4, 5, 6].

The scientific research on the indoor air pollutant levels, on material and device emissions, on health effects of indoor pollutants is increasing [7].

In this work, two buildings are compared, in terms of natural light levels, temperature, relative humidity and criteria photochemical air pollutants (O_3, NO, NO_2*). One is built with traditional materials, whilst the other was constructed with modern, mainly man-made materials.

The similarity of these two buildings is that, like the majority of the buildings in Greece, they have natural ventilation and natural lighting. Construction techniques and building design affect the ventilation rate and indoor lighting levels. These two parameters affect indoor climatic conditions as well as atmospheric pollutant concentrations in several ways. This work investigates the influence of ventilation and indoor daylight levels on the concentrations of indoor air pollutants which in turn are strongly depended on indoor chemical reactions and the ventilation rate [6, 8].

2 Problem Formulation

2.1 Description of the buildings.

The rooms where the measurements were conducted were part of two completely different buildings, concerning their construction materials. These rooms were rarely used as offices.

One building was traditionally built (hereafter referred to as old). The exterior walls are 1 m thick, built with stone. The floor is covered with ceramic tiles and the room has natural light from 4 large windows with wooden frame and single pane glass. In the north side there are no windows. The other building was constructed with modern materials (hereafter referred to as new). It has a metallic frame, the ceiling and walls are covered with colored corrugated plastic sheeting with enameled metal trim acting as external covers of polyurethane insulating material. The floor coverings are plastic tile. Three aluminum framed double-glazed windows covered approximately the half of the north, east and south wall. In the west side there was no windows, but a door which connected the room under study with the rest of the building. In these buildings there were no heating or forced ventilation or air-conditioning systems.

2.2 Sampling procedure and instrumentation.

Two programs of simultaneous indoor and outdoor measurements were conducted for a week at the two buildings. The first campaign was, in March 2001 and the second in March 2002.

Ozone concentrations were measured with a UV photometric ozone monitor (a Dasibi model 1008-RS). A chemiluminescence NO_x monitor was used to measure NO and NO_2* (an AC 30M Environment S.A.). CO_2 was measured with a real-time infrared CO_2 analyzer (Gas Card II, Infra red gas monitor, Edinburgh sensors, UK). These analyzers were outfitted with two ¼ in diameter Teflon sampling lines, one sampling indoor air and the other outdoor air, via a time controlled three-way valve. Data were recorded every 10 min, yielding alternatively indoor and outdoor air concentrations. The NO_2* measurements reported in this study are the sum of NO_2+HONO+HNO_3+PAN [9].

Temperature and relative humidity were recorded with a Vaisala solid state sensor and total and UV radiation with a pair of pyranometers (KIPP and ZONEN). All the data were stored in a data logger (Campbell Scientific CR10X).

The air exchange rate of the buildings was calculated by using CO_2 as tracer gas, as explained below.

There were not known indoor sources for O_3, NO and NO_2* inside the rooms. The only sources of pollutants were the cleaning procedures, once per week, and the presence of one or two persons [10].

3 Problem solution

3.1 Air exchange rate

During the time of measurements, the windows remained closed and the doors were rarely opened. The air exchange rate of each building was estimated with a simple mass balance model:

$$\frac{dC_{in}}{dt} = \lambda\, C_{out} - \lambda\, C_{in} + S - k_d\, C_{in} \qquad (1)$$

where C_{in} and C_{out} is the indoor and outdoor CO_2 concentration, λ is the air exchange rate (h^{-1}), S is indoor CO_2 direct emission rate ppmv h^{-1}, k_d=u_dxA/V is the CO_2 deposition rate (h^{-1}), where u_d is the average deposition velocity (m h-^{1}), A is the total interior surface area (m^2) and V is the volume of the building (m^3). If the variables other than C are constant for a given situation, then the solution of Eq. 1 is:

$$C_{in}(t) = \frac{S+\lambda C_{out}}{\lambda + u_d \frac{A}{V}}\{1-\exp[-(\lambda+u_d\frac{A}{V})t]\} +$$

$$+ C_{in}(0)\exp[-(\lambda+u_d\frac{A}{V})t] \qquad (2)$$

Assuming that CO_2 deposition velocity u_d=0, the Eq. 2 became:

$$C_{in}(t) = \frac{S+\lambda C_{out}}{\lambda}\{1-\exp(-\lambda t)\} +$$

$$+ C_{in}(0)\exp(-\lambda t) \qquad (3)$$

The equation (3) was solved, for a time step of one hour, to obtain λ. The source emission rate used was 0.31 $Lmin^{-1}$ CO_2 for each person present [11].

In the old building the air exchange rate ranged between 1.9-5.5 h^{-1} during daytime. During nighttime the air change per hour (ach) fell to 0.45 h^{-1}. In the new building, during daytime the air exchange rate varied between 0.76-2.5 h^{-1}, whilst in nighttime it fell to 0.2-0.3 h^{-1}.

3.2 Light levels

Representative diurnal profiles of indoor UV and total solar radiation are presented in figures 1 and 2, respectively. The daily profiles which are given, corresponded to identical outdoor irradiance levels, as depicted in figure 3. Note that in the old building the two pyranometers were located very close to the window in the west side, whilst in the new one the instruments were located at 1 m distance from the west facing window.

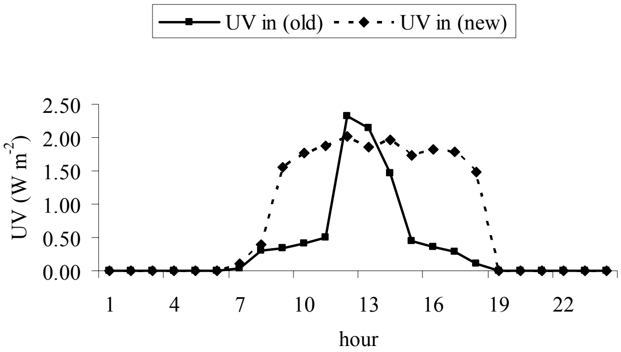

Fig. 1: Comparison of UV solar radiation levels in the two buildings.

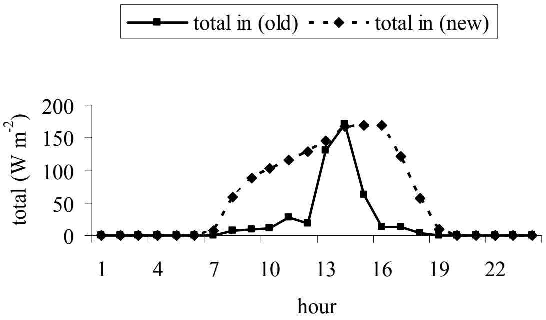

Fig. 2: Comparison of total solar radiation levels in the two buildings.

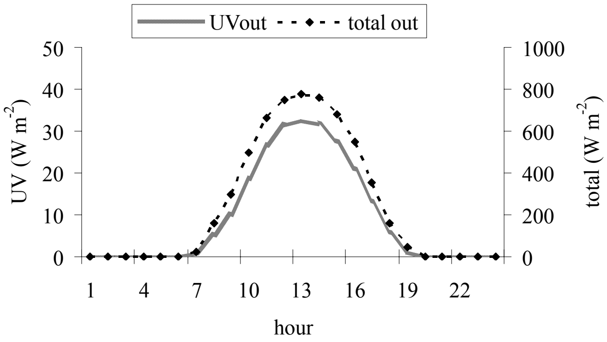

Fig.3: Outdoor UV and total solar radiation.

As can be seen from the figures 1 and 2, the interior of the new building experienced much more solar radiation than the old one, despite the double glazing. Indoor light-energy fluxes in both buildings were by far larger than 1 Wm^{-2}, the value reported from Nazaroff et al., 2003, as an average value for indoor environments [12].

3.3 Climatic conditions

In figures 4, 5, 6, 7 indoor and outdoor temperature and relative humidity in the two buildings are compared. The thick walls in the old building damped the outdoor climatic variations. The indoor climatic conditions, especially the temperature, were very little affected by the outdoor variations. On the contrary, in the new one, temperature tracked more closely the outdoor variations, whilst indoor RH seems unaffected and remained, during all day, elevated. The interplay among the temperature and RH was based on evaporation (in times of high temperature) and on condensation (in times of low temperature) of moisture, which was released or absorbed by the indoor surfaces.

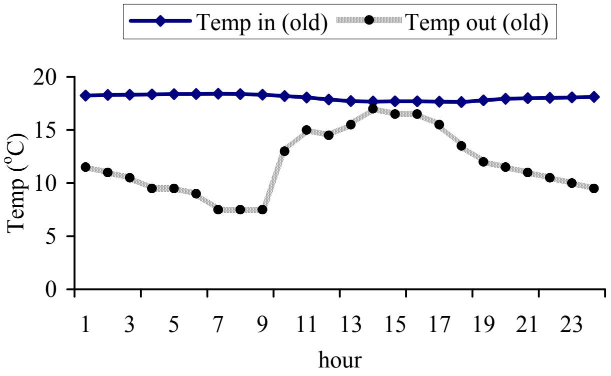

Fig.4: Indoor and outdoor temperature in the old building.

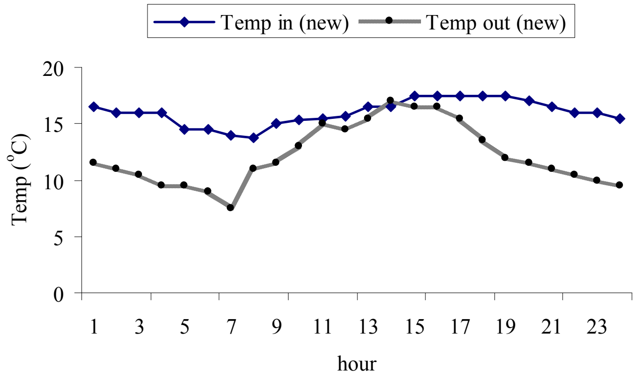

Fig.5: Indoor and outdoor temperature in the new building.

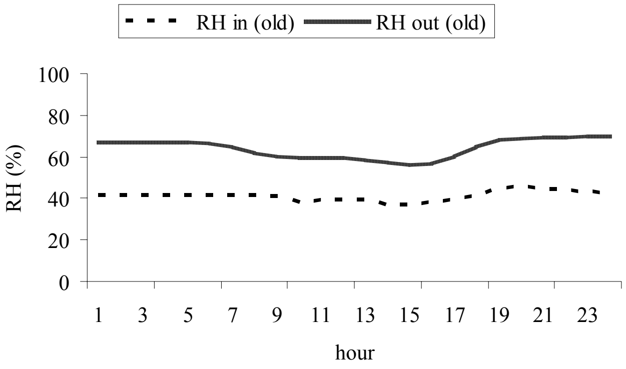

Fig.6: Indoor and outdoor RH in the old building.

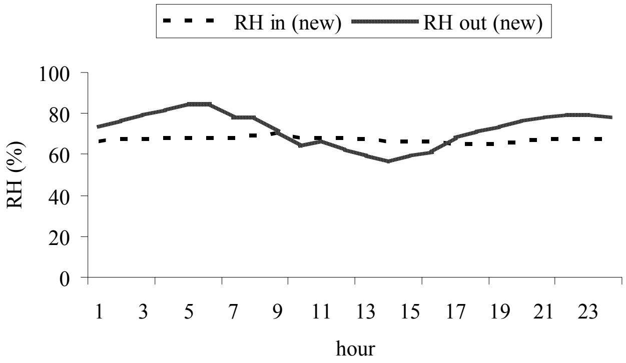

Fig.7: Indoor and outdoor RH in the new building.

3.4 Photo -chemically related air pollutants

Figure 8 represents the indoor/outdoor 7-day averaged pollutant concentration ratios (I/O) for both locations. The I/O ratios are accepted in the relevant literature to be representative of the building's design and operation and give a measure of the indoor air quality [6, 8]. This ratio is depending on building ventilation rate, its volume and its interior surface area and type. The existence of indoor sources that emit pollutants strongly affects this ratio. Also, it is affected by lighting, temperature, relative humidity and air flow near surfaces. These parameters, plus the indoor air pollutant mixing ratios, influence the heterogeneous or homogeneous reactions between indoor pollutants and between air pollutants and interior surfaces. Indoor chemistry in turn influences the I/O ratio of the air pollutants [13].

Usually, pollutants with indoor sources increase in concentration as the ventilation rate decreases. Pollutants which have outdoor origin, in our case O_3, NO, NO_2*, have lower concentration indoors when the ventilation rate decreases (their intrusion rate is small). The ventilation rate determines the rate of their intrusion inside the buildings [8]. In these two buildings under study the opposite was found. The old building, with the higher ventilation rate, exhibited lower O_3, NO, NO_2* I/O ratios than the new one. One possible explanation is that the measured pollutants have a very low deposition rate on the specific plastic and glass surfaces of the new building, when compared with the deposition rate on the indoor materials of the old building [6, 14, 15].

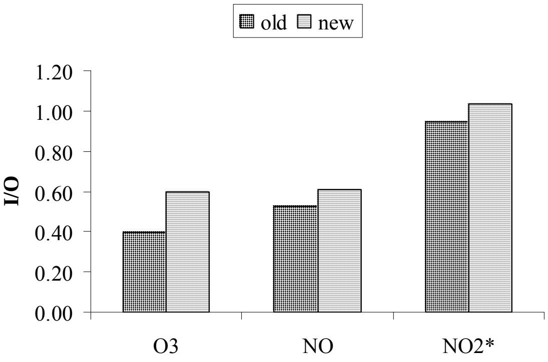

Fig.8: Comparison of 7-day average I/O air pollutant concentration ratios in the two buildings.

A simplified expression of O_3 I/O ratio is given by the following equation:

$$\frac{I}{O} = \frac{\lambda}{\lambda + \kappa_d \dfrac{A}{V}} \tag{4}$$

where $I=C_{in}$ and $O=C_{out}$ is the indoor and outdoor O_3 concentration, λ is the air exchange rate (h^{-1}), $k_d = u_d \times A/V$ the ozone deposition rate (h^{-1}), where u_d is the average deposition velocity ($m\ h^{-1}$), A is the total interior surface area (m^2) and V is the volume of the building (m^3). This model can be applied if steady-state conditions are assumed [8].

The A/V ratio was 1.46 m^{-1} for the old building and 1.75 m^{-1} for the new one. Note that the floor area was equal in the two buildings, the height was larger in the old one and this resulted to a smaller A/V ratio in the old room.

Given a literature value for ozone deposition velocity of 0.04 cm s^{-1} for the old building and 0.0035 cm s^{-1} for the new building, the calculated I/O O_3 ratio is 0.67 (measured 0.70) and 0.52 (measured 0.54) respectively, during times that indoor and outdoor O_3 concentrations were almost constant [14, 15]. Average air exchange rate was 1.5 h^{-1} for the old building and 0.5 h^{-1} for the new one. Model results inferred that O_3 deposition velocity on surfaces encountered in the new building is 10% of its deposition velocity on indoor surfaces which are found in the old one, as it was reported in other similar works [6, 15].

In the case of NO_2*, the decreased deposition rate in the new building can not fully explain the results. The I/O NO_2* ratio was larger than unity. It appears that the indoor chemistry involved such reactions which produced NO_2 or other nitrogen containing species, which concentrations were added to NO_2 values. During nighttime HONO could be produced, through heterogeneous reactions, assisted by the elevated relative humidity [13, 15].

In daytime, due to the strong solar radiation, the enhanced photochemistry could produce significant HNO_3, through the reaction:

$OH^{\bullet}+NO_2 \rightarrow HNO_3$

Also, NO_2 can be produced directly through PAN decomposition indoors or through the reactions:

$O_3+NO \rightarrow NO_2+O_2$,

$HO_2^{\bullet} + NO \rightarrow NO_2 + OH^{\bullet}$

The concentrations of free radicals are essentially unknown in indoor environments, however it is accepted that they play a key role in indoor chemistry [16, 17]. The $OH^{\bullet}$ and $HO_2^{\bullet}$ radicals should be found in higher concentrations in Greek indoor environments which experience strong sunlight and elevated ozone levels. Note that in this work no VOCs or acids measurements were conducted, species which if measured could make the indoor chemistry better understood. Furthermore, indoor air quality depends on particulate matter which was not recorded in these studied cases.

4 Conclusions

The indoor air quality in two buildings, located in North Greece, which were constructed with different techniques, but they have similar use and operation, was investigated. Indoor climatic conditions, ventilation rate, natural lighting and criteria photochemical air pollutants (O_3, NO, NO_2*) were compared in these two buildings. In the new building constructed with modern materials, the decreased ventilation rate, the strong natural daylight and the low pollutant deposition rates lead to elevated indoor photo- oxidants concentrations. Also, it is very probable that inside both buildings, enhanced photochemistry may have produced secondary compounds that potentially are more deleterious to human health or to sensitive materials [13, 16].

Nowadays, the implementation of natural ventilation and natural lighting in construction industry is promoted all over the world, for energy saving and for better indoor environmental quality [18]. These measures have to be combined carefully with modern materials, such as glass or metal or plastic surfaces, especially under the environmental conditions prevailing in Mediterranean area.

Public perception, current codes and regulations, and rapid introduction of new building materials and commercial products, as well as the prevailing design-building practices, pose challenges to the integration of natural ventilation and lighting in the design, construction and operation phases of modern buildings.

More data have to be acquired to propose guidelines for a healthy indoor environment, i.e. for a "healthy building," by design [19].

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