AIVC 11040

PROGRESSION OF FORMALDEHYDE CONCENTRATIONS IN A RECENTLY RENOVATED, NATURALLY VENTILATED BUILDING

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ABSTRACT

Two series of formaldehyde concentration measurements were conducted on the first storey of a medium size, three-storey, naturally ventilated office building. In this building, due to extensive renovations, a variety of formaldehyde containing materials were used. In the first data set, just after the end of work, values of up to 0.4 ppm were recorded. Higher concentrations were encountered in the internal rooms. In the second data set, nearly one month later, formaldehyde concentrations did not exceed 0.2 ppm. This time, many high concentration values were detected in the peripheral rooms. Both times, formaldehyde concentration did not exceed 0.1 ppm on the other storeys of the building, where renovation work had been completed 4 months earlier. These results indicate that after renovation (and possibly construction) work in naturally ventilated buildings there is a rather short period in which formaldehyde concentrations descend rapidly. During this period, it is hygienically advisable for the inhabitants not to use the building.

INTRODUCTION

It is well known that during building construction or renovation works, when construction or application materials with volatile constituents are used, the indoor air is contaminated by a large variety of organic pollutants, like, formaldehyde, aliphatic and aromatic HCs and their derivatives and pinene. Their presence is in most cases evident by their odors and, in more serious situations, by the discomfort or sickness of the people who work or dwell in the building's interior (1, 2). Formaldehyde, as a major or secondary component, is contained in a large variety of materials used in building renovation works. Examples include paints, glues, putties, resins, varnishes, polishes and detergents. It is also present, due to chemicals used for their fabrication, in different wood and other solid products used in buildings as construction, furnishing or fitting materials, such as, particleboard, medium density fiberboard, hardwood plywood, insulation materials, textures, etc. The presence of formaldehyde inside a room is evident by its characteristic odor which becomes noticeable at low concentrations (a few tenths ppm). Exposure to a formaldehyde contaminated environment can potentially cause acute symptoms in the eyes, skin and upper respiratory system, whereas larger concentrations or prolonged exposure may cause eye irritation, dry/sore throat, headaches, sinus irritation, sinus infection, great discomfort and many other problems (3).

Ventilation is a principal mechanism for the removal of indoor air pollutants. Theoretically, the concentrations of contaminants generated in a room's interior are inversely proportional to the air change rate of the room (4). However, this is not always valid, especially for contaminants produced continuously. For formaldehyde, for example, the emission rate is a function of the vapor pressure gradient, namely, the concentration values in the space around the source (5). As these concentrations are reduced by ventilation, the emission rate increases and, as a result, the indoor formaldehyde levels are determined by this dynamic equilibrium. Additionally, formaldehyde releasing products differ in their emission potential. Despite the common-sense belief that indoor formaldehyde levels are due to the combined emissions of all sources present, laboratory and whole-house studies indicate that formaldehyde sources interact and, depending on individual circumstances, such interaction may result in the suppression of emissions from one source by another, complete additivity, or where sources of equal potency are present, a less additive augmentation of formaldehyde levels (6). Consequently, indoor formaldehyde levels will be determined to a considerable extent by the type of formaldehyde sources present and, of course, by the quantity of source materials.

Indoor formaldehyde concentration measurements in Greece are rare. One series of measurements was conducted by the Institute of Inorganic Chemistry, Aristotelian University, Thessaloniki, upon 40 samples coming from houses and faculties. From specimens coming from 10 houses included in this study, the values were between 0.03 and 0.12 ppm. Higher concentrations were detected in three industries producing particleboard (1.1-1.8 ppm) and one industry producing Formica (0.3-1.2 ppm) (7).

METHODS

The formaldehyde concentration measurements included in this paper were conducted on the three-storey office building of the Center of Renewable Energy Sources (CRES), Athens, Greece. This building, with an area of approximately 2200 m^2, was constructed about fifteen years ago (1980) and its first use was as a home and base of an athletic-shoes trade company. A few years ago (1992), it was bought by CRES to be used as the headquarters of the Center at Athens. Necessary repair and renovation work included extensive changes in all the storeys' interiors in order to convert them to offices and other rooms necessary for the center activities. The final stage of work concerned the ground floor. This floor, with an approximate area of 800 m^2, was initially a unified space used as storage. After renovation, it was divided into office and common use rooms (Figs. 1 and 2). Around its periphery there is a continuos zone of windows, and several doors leading to the yard. Almost all of the dividing walls are made of double plaster-board, 12.5 mm thick, with internal fiberglass insulation, 5.5 cm thick. Only in some of the diving walls was the upper part transparent pane and the bottom part, instead of plaster-board, was made of particleboard sheets, 8 mm thick, with melamine coating. All spaces are covered with double-ceiling made of panels of compressed mineral wood, measuring 60x60 cm. The floor is covered with square PVC tiles stuck with petroleum-based glue on top of pseudomosaic. Also, many surface materials were used, such as, paints, glues, putties and polishes. In the formaldehyde emitting materials, we have also to include furniture (desks, cabinets, etc.) many of which are made of particleboard with melamine coating. This furniture was generally old (approximately 5 years) and was used in the previous headquarters of the Center.

The first series of measurements started on 12th October 1992, a few days after the end of the renovation work on the ground floor, when the furniture had already been transferred from the previous offices and the personnel had started working there. The stimulus for the measurements was the symptoms that some of the personnel - the author included - felt. These symptoms included eye irritation, discomfort, headaches and dizziness, whereas the characteristic formaldehyde odor was obvious. The second series of measurements were conducted about one month later, on 17th November 1992, in order to investigate the progress of the formaldehyde concentrations. In both cases an early time was chosen (before 08:00) so that there were no other employees in the building who could distort the values by smoking, opening doors and windows, etc. Before the start of the measurements all the open doors and windows in the building envelope were located and closed. They remained closed for about 1 hour before the measurements in order to establish equilibrium. Afterwards, formaldehyde concentrations were measured at approximately 45 points on the ground floor of the building using the portable analyzer. In smaller rooms one measurement in the center was conducted, whereas in larger rooms and passages two or more measurements at symmetrical points were conducted. In every case the analyzer sampling wand was kept away from furniture (desks, closets, etc.) that possibly consist major sources. So, recordings may be considered to be representative of the corresponding volume (8). Each isolated concentration measurement lasted about 30 s in order to ensure a complete renewal of the air sample inside the analyzer's chamber (5 times/min). Accordingly, each series of measurements were completed in approximately half an hour.

Simultaneously with the formaldehyde concentration measurements, air change rate measurements were conducted inside the building in order to investigate the influence of ventilation upon indoor formaldehyde concentrations. Two points were chosen inside the building, A and B (Figs. 1 and 2), which were considered to be representative of the ventilation rates of the internal and peripheral rooms respectively. For these measurements, the tracer gas decay method was applied. Namely, a small quantity of tracer gas (SF6) was emitted into the room and following a brief period of artificial mixing with the existing air, its concentration was monitored every 5 min (9). The procedure lasted approximately 40 min.

For the formaldehyde concentration measurement, a portable ambient air analyzer (accuracy: ± max [0.05 ppm, 15 %]) was used. This is a microprocessor-controlled infrared spectrometer, suitable for rapid and accurate formaldehyde concentration measurements at levels below 1 ppm. The instrument was set at zero in free atmosphere on the presupposition that the formaldehyde concentration was zero. This fact implies a systematic error in the measurements up to 0.05 ppm, which is considered the outdoor threshold (10). The same instrument, which is electronically precalibrated for a wide range of gases and vapors, was also used for monitoring the tracer gas (SF6) concentration decay during the air change rate measurements inside the building.

RESULTS

Formaldehyde concentration values recorded in the building at both times are shown at corresponding positions in Figures 1 and 2 respectively. Both times formaldehyde concentration measurements were also conducted on the other two storeys of the building, where the restoration works were almost equally extensive and had been completed about 4 months earlier. During these measurements the indication of the instrument was steadily at zero, except in very few cases when it reached 0.1 ppm.

In Figures 1 and 2, values of air change measurements inside the building are also shown.

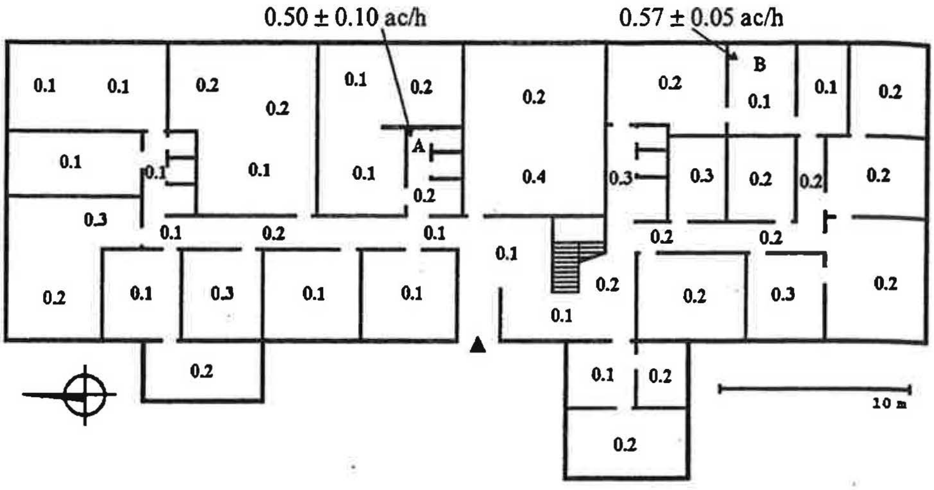

Figure 1: Formaldehyde concentrations, in ppm, measured on 12th October 1992.

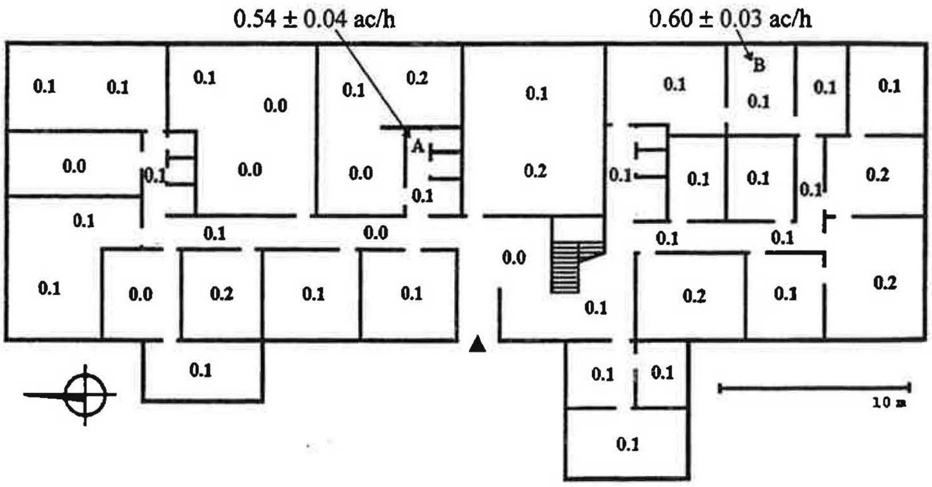

Figure 2: Formaldehyde concentrations, in ppm, measured on 17th November 1992.

From Figure 1 it can been seen that in the first data set, values up of to 0.4 ppm were recorded. Higher concentrations were encountered in the internal rooms of the building, where the representative air change rate was found about 0.5 ac/h. Precisely, the maximum reading (0.4 ppm) was recorded in the library room where new bookshelves, made of particleboard with a melamine coating, were installed. From Figure 2, we can see that values of formaldehyde concentration did not exceed 0.2 ppm in the second data set. However, it is not clear whether the higher values were in the interior rooms or not. Nevertheless, many of the high concentrations were found in the peripheral rooms with access to windows and the external doors of the building. At the same time the air change rate was measured at about 0.57 ac/h at the inner site and 0.60 ac/h at the outer site. The mean outdoor temperature during the first series of measurements was 17.2 °C, whereas during the second series it was 13.0 °C.

DISCUSSION

Based on the experimental results presented in this study, it can be concluded that formaldehyde concentrations decrease rapidly after the completion of renovation works inside the building under study. Although formaldehyde concentrations, like other VOC in general, inside confined spaces are influenced by conditions of temperature, humidity, and air change rates (2, 11), in this particular case, for what it is worth, no such changes important enough in themselves to justify this particular behavior were recorded. Consequently, the behavior of formaldehyde concentrations in the interior of this particular building should be attributed to endogenous factors related to its emission rates from materials in which it is a component. Similarly, it is well-known that in materials which include compounds of formaldehyde in their constitution (mainly as urea, phenolic, melamine and acetal resins) there is also free formaldehyde in small quantities (12, 13). The emission rate of free formaldehyde is more rapid provided that only physical parameters are involved (porosity, surface exposure, etc.) in contrast to chemically bonded formaldehyde which requires chemical reactions (like hydrolysis) for its liberation. Therefore, it can be presumed that the rapid emission of formaldehyde which was observed during the first short period after the completion of the renovation work on the building concerns mainly free formaldehyde. This reflects the favorable conditions which are created by the increase in the surface area of materials containing formaldehyde, especially particleboard and materials in liquid or thick liquid form (paints, glues, varnishes).

The very rapid rate of decrease in the values of formaldehyde concentration in the building's interior (approximately 50 % in one month) does not correspond to the results of similar measurements taken in new buildings, where the half-life of formaldehyde was, as a rule, found to be significantly greater (e.g. 2, 14, 15). This particular fact may be due to the variations in the composition, quality, method of construction, age, etc. of the materials used. Similarly, and independently of this particular case, it is certain that, considering the significant progress in the study of indoor air quality, simply naming the materials and the objects is no longer enough to describe their contribution to the quality of the internal environment of a space, but instead, additional and specially-detailed information and descriptions are required.

The conclusions of this particular study are not only theoretical but also have a practical interest. More specifically, provided that the findings are repeated and confirmed by systematic measurements of the progression of formaldehyde concentrations with time, in combination with measurements of the variable factors which influence them, the findings will have to make some inhabitants aware of related health effects. These inhabitants include those from a wide range of newly-constructed buildings and from buildings which, due to a change of use, have undergo extensive reconstruction or renovation work and changes to their interior. Particularly, in such situation, a brief delay in using these buildings would be advisable so as to reduce the danger of exposure to high formaldehyde-amongst others-concentrations. However, if there is greater ventilation within the interior spaces of the building, which will accelerate the diffusion of the rapidly emitted free formaldehyde, the length of this delay can possibly be reduced.

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