Formaldehyde in indoor air of new apartments in Greece

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ABSTRACT

This work aimed at evaluating the indoor concentrations of formaldehyde in thirty new apartments in Karditsa, Greece. By using a formaldehyde meter, two series of measurements were made in July 2006 and January 2007. Early morning measurements were made in the living rooms and bedrooms as well as in the kitchen and bedroom cabinets. Initial measurements showed that average concentrations of formaldehyde exceeded 1.0 ppm in living rooms and bedrooms in ten out of thirty apartments, while concentrations in kitchen and bedroom cabinets were higher than 3.0 ppm in more than 15 out of 30 apartments investigated. After a 30-minute natural ventilation in the apartments, formaldehyde concentrations remained at levels higher than 1.0 ppm only in six apartments. In the following months (July 2006 to January 2007), a systematic ventilation by opening windows took place not only in the morning but also in the late afternoon, while no smoking was taken place within the new apartments. In January 2007, measurements were repeated in the same apartments. It was found then that all thirty apartments investigated had formaldehyde concentrations much lower than 1.0 ppm and obviously the indoor air environment was much cleaner.

INTRODUCTION

Indoor air quality is an important issue because people spend most of their time in indoor environments where there may be more pollutants and at higher concentrations than outdoors (Godish 1989a, US EPA 1991, Li *et al.* 2001). In particular, the levels of volatile organic compounds (VOCs) found indoors are generally reported to be greater than outdoors (Ilgen *et al.* 2001, Pośniak *et al.* 2005, Khoder 2006). Consequently, indoor air quality is liable to influence human health more than outdoor air quality. Poor indoor air quality has been linked to a number of symptoms, which the World Health Organisation has defined together as *Sick Building Syndrome* (US EPA 1991, Kostiainen 1995). It is well known that the most common indoor pollutant is formaldehyde (Dally *et al.* 1981, Breysse 1985, Brown *et al.* 1996, Mantanis and Markessini 1998, Hodgson *et al.* 2000). Formaldehyde is classified to be toxic and irritating to the respiratory tract, eyes and skin (National Research Council 1981) and is carcinogenic to humans at high concentrations (The Japan Society for Occupational Health 2002, IARC 2004).

The sources and levels of the VOCs in indoor air vary depending on the type of building. Major sources are construction materials, furnishings, cosmetics and textiles, paints, carpets, architectural finishes, insulation, fabrics and paper, varnishes and solvents, adhesives, cleaning compounds and combustion by-products (Samfield 1992, Kelly *et al.* 1999, Guo *et al.* 2000, Guo and Murray 2001, Kwok *et al.* 2003). Combustion, particularly tobacco smoking, but also photocopying or laser printing on paper, strongly influences the indoor concentrations of VOCs (Etkin 1996, Baek and Jenkins 2001).

Formaldehyde concentration in new houses has been reported to be at very high levels (Dally *et al.* 1981, Godish 1989b, Kostiainen 1995, Brown 2000, Khoder *et al.* 2000, Mantanis 2007). Evidently, kitchen closets and cabinets in new apartments alone have the potential for causing residential formaldehyde to rise higher than 0.1 ppm (Godish 1989b). Zhao *et al.* (2004) also reported that, in freshly decorated houses, formaldehyde concentrations were up to 0.41 ppm. In Australia, measurements in suburban Melbourne residences more than a year after construction identified twenty seven airborne toxics. These included the carcinogens benzene, formaldehyde and styrene. The study concluded that occupants of new homes can be exposed to up to 20 times the maximum allowable limits of indoor air toxics (Brown 2000). The measurements indicated that long-term indoor air pollution is likely from new building materials emitting formaldehyde such as manufactured wood-based panels used principally in flooring, furniture and cabinets.

Menteşe and Güllü (2006) reported that formaldehyde concentration inside homes, although averaged at around 0.06 ppm, can elevate in some residences as high as 0.71 ppm depending upon indoor and outdoor temperature, age of house and density of the plywood furniture. Khoder *et al.* (2000) found that in new flats, the maximum formaldehyde concentration was up to 0.35 ppm in residential homes in Cairo noting that air temperature, relative humidity and age of the flat were the main factors affecting the emission and concentration of formaldehyde. Minami *et al.* (2002) reported that in a new private house, formaldehyde concentrations ranged between 0.07 and 0.23 ppm during the first months, while natural ventilation by opening windows was effective for decreasing the formaldehyde concentration in the indoor air.

Previous studies on indoor air quality in Greece have focused on volatile organic compounds and formaldehyde in schools and occupational environments (Tsitouridou and Papachristou 1991, Siskos *et al.* 2001, Synnefa *et al.* 2003, Valavanidis and Vatista 2006). Therefore, there is a lack of information on the indoor air formaldehyde levels in new houses and apartments in Greece. This study thus aimed at reducing that lack by evaluating the indoor concentrations of formaldehyde in thirty brand new apartments.

EXPERIMENTAL METHODS

Formaldehyde measurements in the indoor air were made in thirty brand new apartments in the city of Karditsa, Greece. The apartments had been very recently occupied (one to three months already) by their residents and were freshly painted. The majority of materials, i.e. cabinets, closets, buffets, were all made of melamine paper or veneer laminated particleboard or fibreboard panels. Most of the insulation materials, carpets and fabrics were also brand new. Indoor air formaldehyde measurements were made in the following areas: (a) living room, (b) bedroom, (c) kitchen cabinets and (d) bedroom cabinets.

A formaldehyde meter model *Triple Plus+* was used in this study (Fig. 1). With this meter, it was possible to estimate formaldehyde concentrations in the indoor air with a relatively limited accuracy. Before each measurement, a calibration of the meter was taking place in the outdoor environment, where the formaldehyde concentration was zero.

For the measurements in living rooms and bedrooms, the meter was turned on for three minutes and the formaldehyde concentration in each room (in parts per million, ppm) was recorded. In addition, a temperature meter was used to record the air temperature during each measurement. For the measurements inside the kitchen and bedroom cabinets, the meter was set on and left within each cabinet for a five-minute time, before each measurement was recorded. The temperature inside each cabinet was also measured.

Figure 1: Formaldehyde meter model Triple Plus+ used in this work

Two series of formaldehyde measurements were carried out in this work. The first series of measurements was made in July 2006. Attention was given so that a set of measurements was made during early morning hours prior to any ventilation within the apartments. Following, windows were left open in each apartment for a ventilation time of 30 minutes and after that a second set of measurements was taken.

In the next six months (July 2006 to January 2007), occupants were advised to undertake systematic ventilation every day in the new apartments not only in the morning but also in the late afternoon. In addition, no smoking was taken place within the apartments. In January 2007, the second series of formaldehyde measurements was carried out likewise in the selected apartments, as described previously.

RESULTS AND DISCUSSION

Table 1 summarises the results obtained in July 2006. First measurements as shown in Table 1 revealed that formaldehyde concentrations in rooms like living room and bedroom were at high levels (>1.0 ppm). It becomes obvious that these levels exceed by far the limit of 0.1 ppm set in most of the European countries for formaldehyde concentration in residential environments.

Table 1: Formaldehyde concentrations in indoor air of 30 new apartments (as in July 2006)

	Distribution of formaldehyde concentrations as measured in 30 new apartments			
Area	***< 1 ppm***	***1 – 3 ppm***	***3 – 5 ppm***	***> 5 ppm***
	Before ventilation *(avg. temperature: 27.8^{o}C)*			
Living room	*19*	*10*	*1*	*0*
Bedroom	*20*	*10*	*0*	*0*
Kitchen cabinets	*8*	*7*	*7*	*8*
Bedroom cabinets	*1*	*3*	*6*	*20*
	After 30-minute ventilation *(avg. temperature: 25.5^{o}C)*			
Living room	*24*	*6*	*0*	*0*
Bedroom	*26*	*4*	*0*	*0*

More specifically, for the measurements made in living rooms (July 2006), the following were observed in all 30 apartments investigated: (i) in 10 apartments, formaldehyde concentrations ranged between 1 and 3 ppm, (ii) in one apartment, formaldehyde concentration was 4 ppm, and (iii) in 19 apartments, formaldehyde concentrations were lower than 1 ppm, while in 3 of them, this concentration was zero.

From the measurements made in bedrooms (July 2006), the following were observed in all 30 apartments investigated: (i) in 10 apartments, formaldehyde concentrations ranged between 1 and 3 ppm, and (ii) in 20 apartments, formaldehyde concentrations were lower than 1 ppm, while in 4 of them, this concentration was zero.

Measurements made in the kitchen cabinets revealed dramatically high formaldehyde levels. In particular, the following were observed in all 30 apartments: (i) in 7 apartments, formaldehyde concentrations ranged between 1 and 3 ppm, (ii) in 7 apartments, concentrations ranged between 4 and 5 ppm, (iii) in 6 apartments, concentrations ranged between 9 and 12 ppm, (iv) in 2 apartments, formaldehyde concentration reached the levels of 21 and 25 ppm, and (v) in 8 apartments, formaldehyde concentrations were lower than 1 ppm.

As far as it concerns the measurements made in the bedroom cabinets (July 2006), even higher formaldehyde levels were observed. In specific, the formaldehyde concentrations were lower than 5 ppm in 10 out of the 30 apartments. In the rest of the apartments (20), the formaldehyde concentrations ranged between 5 and 20 ppm.

Following the first set of measurements, a 30-minute natural ventilation by opening windows took place in the apartments. A remarkable decrease in the concentrations of formaldehyde was noted. For living rooms, in 6 apartments, formaldehyde concentrations were found between 1 and 3 ppm. In the rest (24), formaldehyde concentrations were lower than 1 ppm, while in 9 of them, a zero concentration was measured. Similarly for bedrooms, in 4 apartments, formaldehyde concentrations were measured between 1 and 3 ppm. In the rest (26), formaldehyde concentrations were lower than 1 ppm, while in 11 of them, a zero concentration was recorded.

Table 2: Formaldehyde concentrations in indoor air of 30 new apartments (as in January 2007)

	Distribution of formaldehyde concentrations as measured in 30 new apartments			
Area	***< 1 ppm***	***1 – 3 ppm***	***3 – 5 ppm***	***> 5 ppm***
	Before ventilation *(avg. temperature: 18.7^{o}C)*			
Living room	*28*	*2*	*0*	*0*
Bedroom	*29*	*1*	*0*	*0*
Kitchen cabinets	*28*	*2*	*0*	*0*
Bedroom cabinets	*26*	*4*	*0*	*0*
	After 30-minute ventilation *(avg. temperature: 16.5^{o}C)*			
Living room	*30*	*0*	*0*	*0*
Bedroom	*30*	*0*	*0*	*0*

The results obtained in January 2007 are shown in Table 2. It is noted that a systematic ventilation was carried out in the apartments throughout the period July 2006 to January 2007. Indoor air formaldehyde concentrations in living rooms and bedrooms dropped down dramatically, in most cases at levels below 1 ppm.

In specific, measurements made in living rooms (January 2007) showed that only in 2 apartments, the formaldehyde concentrations lied between 1 and 3 ppm. The formaldehyde concentrations in 22 out of the rest 28 apartments were zero. Correspondingly in bedrooms, these levels were zero in 22 apartments and 1 ppm in 7 apartments. Only in one case the concentration was 2 ppm.

As far as it concerns the measurements made in the kitchen cabinets (January 2007), concentrations higher than 1 ppm were recorded only in 2 cases. The formaldehyde concentration in 15 cases was zero. The whole situation therefore was remarkably improved. Measurements made in bedroom cabinets in January 2007 showed only 4 apartments in which the formaldehyde concentrations were between 1 and 3 ppm.

Zero formaldehyde concentrations were recorded in the mentioned areas in all of the 30 apartments after a 30-minute natural ventilation. It is apparent that the results obtained in January 2007 show a much cleaner environment in all rooms and cabinets investigated in these new apartments, as compared with the results of Table 1.

CONCLUSIONS

It was found that indoor air formaldehyde concentrations in 30 brand new apartments in Karditsa, Greece were exceptionally high. In most cases, concentrations exceeded by far the level of 1 ppm. Noticeably, formaldehyde concentrations were found to be higher than 1 ppm in nearly one-third of the investigated rooms like living room and bedroom. Formaldehyde concentrations within the kitchen and bedroom cabinets were recorded to be much higher than 5 ppm. Although this phenomenon is quite common in new houses, the formaldehyde levels observed in this work are extraordinarily high exceeding by far the established non-occupational limits. A repetition of this work owing to the above-mentioned results is due in the next year.

Moreover, it is concluded that systematic ventilation by opening windows in new apartments on a daily basis can decrease formaldehyde concentrations dramatically after a period of six months. In that respect, residents are also advised not to smoke in the new apartments helping to diminish this phenomenon sooner. Thus, systematic ventilation of new houses (apartments) during the first 6 to 12 months of residence is undeniably crucial.

In addition, this work helped so as local customers be informed about the facts that:

- melamine paper or veneer laminated wood-based panels (and subsequently furniture products) of classes E1 and E0 emit much lesser amounts of formaldehyde, and therefore special attention should be given when new apartments are furnished,
- natural ventilation of rooms in brand new apartments is necessary, especially in the summer when high temperatures favour formaldehyde emission, and
- smoking inside the new houses should be avoided.

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