Variables affecting indoor air quality in newly finished buildings- a multivariate evaluation

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SUMMARY

This paper presents results from a principal component analysis (PCA) on variables affecting indoor air quality in newly established buildings, in which low-emitting, classified building materials were used. The concentrations of TVOC, VOCs, formaldehyde and ammonia) were determined for the newly finished and 6-, and 12-month-old buildings. Temperature, relative humidity and air exchange rates were determined simultaneously. These values were included in the PCA models, which were used to reveal which variables affected indoor air quality (IAQ). The variables included floor covering, air exchange system and the time of its operation (in the newly finished building), floor structure / leveling agent, walls, time of construction and season and time point from last construction work.

The IAQ was by most affected by the air exchange system and ceiling product. Lowest concentration levels and classification of VOCs occurred for the buildings with mechanical supply and exhaust air system. IAQ was highly affected by indoor air humidity, especially in the 6 and 12-month-old building.

INTRODUCTION

Indoor air quality (IAQ) is affected by both indoor and outdoor sources of pollutants. Indoors, building materials are important emission sources of pollutants, especially in new buildings [1]. Occupancy (activities of the inhabitants, furniture etc.) and chemical reactions may further increase concentration levels of harmful pollutants, which in some cases can lead sick building syndromes (SBS). Besides source control, ventilation is one effective way to control pollutant levels indoors.

The evaluation of the contribution from different sources and the effect of outer conditions (ventilation, temperature, humidity) on IAQ is difficult due to the complexity of indoor environments. This study investigates the potential of multivariate methods for the evaluation of variables affecting IAQ in newly finished buildings.

METHODS

Study buildings and measurement scheme

Fourteen apartments in eight residential buildings (seven apartment buildings and one two-family house), built according to the current Finnish Building Regulation Code, were
investigated. Seven of the buildings were located in Helsinki and one in Turku. Low emitting, M1-classified materials were used in all the buildings. That is, the laboratory tests performed for 4 week-old samples have given TVOC-, ammonia- and formaldehyde emissions lower than 200, 30, and 50 µg/m²h, respectively [2]. The relative humidity (RH) of the structure was determined to be <85% before the floor covering was installed. In seven buildings, the walls were finished with screed and painted. Wallpaper was laid on the screed in the building 4. Ceilings were finished with screed (2 different products). The floors were finished with fine screed (dispersal 2-5 mm) in the site built buildings and with gross screed (dispersal 10-30 mm) in the manufactured buildings. Different types of PVC materials and parquets were used as floor covering materials. The installation of the floor covering material was the last construction work occurring 2-28 weeks prior to occupation, except in building 4, where painting was performed 12 weeks prior to occupation.

Indoor air measurements were performed first in the newly finished building, when the ventilation was operating, but before the occupants had moved in. The measurements were repeated after 6 and 12 months. In one apartment (Building 7, apartment 2), a water leak took place a few weeks before the apartment was finished. The apartment was heated and ventilated for about two weeks after which the indoor air was measured. These VOC results were not included in the statistical analysis.

**Sampling and analysis**

Indoor air samples were taken in a closed room (usually the bedroom) at the height of approximately 1.40 m before noon. The follow-up measurements were done every time in the same room and in the same place. The air exchange rates were determined simultaneously. The inhabitants were asked to avoid cleaning, smoking, and the use of fragrances in the morning prior to the measurements. Additional ventilation through doors or windows 24 h before the measurement was discouraged. No smoking or pets were observed during the measurements.

Air samples of VOCs were collected on Tenax TA adsorbent [3]. The sampling of ammonia and formaldehyde was performed into a 0.005 M sulphuric acid- solution at 2-4 l/min. The temperature and RH were registered using a Vaisala HMP41 moisture detector. The air exchange rate was determined simultaneously based on ventilation duct measurements with an Alnor AXD-530 thermo anemometer.

Tenax tubes were thermally desorbed and analysed with a HP 5890 series 2 gas chromatograph connected to a HP 5972 mass spectrometer and FID detector. MSD in SCAN mode was used to identify single VOCs and the FID response was used for quantification. TVOC was calculated as toluene equivalents from the total integrated FID signal between hexane and hexadecane. The ammonia concentration was determined with an ion-selective electrode and the analysis of formaldehyde was done with the spectrometric acetyl-acetone method.

**Data handling**

Statistical tests were performed with Simca-P 7.0 for Windows software. Principal component analysis (PCA) was performed to reveal which variables affected IAQ most.

The values for TVOC, formaldehyde, ammonia and single VOC concentration as well as the temperature, humidity, and air exchange rate were included in the models. Due to water damage in building 7, apartment 2, these results were excluded from the analysis. Models
were calculated for the 0-, 6- and 12- month-old buildings. Automatic UV scaling was performed by the Simca software. Table 1 summarizes details for the models for the 0-, 6- and 12-month-old buildings. The variables investigated were as follows:

- Structure (on site built+ fine screed/ manufactured concrete cast slab+ gross screed)
- Floor covering (parquet/PVC)
- Wall material (paint/ wall paper)
- Ceiling material (screed, different manufacturer)
- Air exchange system (mechanical exhaust/ mechanical supply and exhaust air system)
- ACH system operation time (0.5-8 weeks, newly finished building)
- Time of construction (7-10 months, from the time point )
- Season (month finished, indoor air humidity)
- Time point from last construction work prior to use (4-28 weeks)

Table 1. PCA models details for the 0-, 6- and 12-month-old buildings.

<table>
<thead>
<tr>
<th>Model</th>
<th>0 month-old building</th>
<th>6 month-old building</th>
<th>12 month-old building</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC, ammonia, formaldehyde</td>
<td>13 measurements (apartments), R²: 0.695 (2 components)</td>
<td>14 measurements (apartments), R²: 0.812 (2 components)</td>
<td>14 measurements (apartments), R²: 0.799 (2 components)</td>
</tr>
<tr>
<td>VOCs</td>
<td>VOCs occurring at n≥3 sites (76/ 238 compounds), R²: 0.631 (3 components)</td>
<td>VOCs occurring at n≥4 sites (56/ 167 compounds), R²: 0.576 (3 components)</td>
<td>VOCs occurring at n≥4 sites (61/189 compounds), R²: 0.576 (3 components)</td>
</tr>
</tbody>
</table>

RESULTS

Selected examples of PCA results are presented in figures 1 and 2. Lower TVOC concentration was observed in the newly finished buildings with a mechanical supply and exhaust air system (Figure 1a and b). The same leveling agent (product 2) was also used on the ceiling structure in these buildings and the RH was low, less than 40%. The floor covering was parquet and walls were painted. The lowest TVOC, ammonia, and formaldehyde concentrations in the 6-month-old buildings were measured in the building where product 2 was used as ceiling surface product and when the RH was less than 40%. The floor covering was parquet and walls were painted. The lowest TVOC, ammonia, and formaldehyde concentrations in the 6-month-old buildings were measured in the building where product 2 was used as ceiling surface product and when the RH was less than 30%. The clustering of VOCs also occurred at these apartments. The same was observed in the 12-month-old buildings, where the clustering of VOCs according to air exchange system (mechanical supply), ceiling surface (product 2), and indoor air humidity (<40%) was quite clear (Figure 2). Lowest pollutant levels/ VOC classification in the 0-, 6- and 12-month-old buildings are summarized in Table 2.
Figure 1 a-f: Example of PCA results: IAQ in the newly finished building. The score plots (a-e) shows how the 13 measurement sites and the model contribution of the measured parameters is shown in the corresponding loadings plot (f). The contribution of the measured parameter decreases as the distance of the parameter to the observation increases (TVOC=total volatile organic compounds, FA= formaldehyde, NH3= ammonia, temp=temperature, hum= relative humidity, ach= air exchange rate).
a) structure: on site built=1, manufactured=2

b) floor covering material: parquet=1, PVC=2

c) walls: paint=1, wall paper=2

d) ceiling: product 1=1, product 2=2

e) air exchange system: mechanical exhaust=1, mechanical supply & exhaust=2

f) season: month number

Figure 2. Classification of VOCs in the 12-month-old-buildings.
Table 2. Summary of PCA results in the 0-, 6- and 12-month-old buildings.

<table>
<thead>
<tr>
<th>0-month-old building</th>
<th>6-month-old building</th>
<th>12-month-old building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest TVOC concentration:</td>
<td>Lowest TVOC, ammonia and formaldehyde concentration:</td>
<td>Lowest TVOC, ammonia and formaldehyde concentration:</td>
</tr>
<tr>
<td>air exchange system:</td>
<td>ceiling surface: product 2</td>
<td>air exchange system:</td>
</tr>
<tr>
<td>mechanical supply and exhaust air</td>
<td>indoor air humidity: &lt;30%!</td>
<td>mechanical supply air system:</td>
</tr>
<tr>
<td>system</td>
<td></td>
<td>ceiling surface: product 2</td>
</tr>
<tr>
<td>ceiling surface: product 2</td>
<td></td>
<td>indoor air humidity: &lt;40%</td>
</tr>
<tr>
<td>walls: painted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>indoor air humidity: &lt;40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOC classification (clustering):</td>
<td>VOC classification (clustering):</td>
<td>VOC classification (clustering):</td>
</tr>
<tr>
<td>Air exchange system:</td>
<td>ceiling surface: product 2</td>
<td>air exchange system:</td>
</tr>
<tr>
<td>mechanical supply</td>
<td>indoor air humidity: &lt;40%</td>
<td>mechanical supply air system:</td>
</tr>
<tr>
<td>ceiling surface: product 2</td>
<td></td>
<td>ceiling surface: product 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>walls: painted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>indoor air humidity: &lt;30%!</td>
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</table>

DISCUSSION

The best IAQ was achieved in the 0-12-month-old buildings with mechanical supply and exhaust air system, screed product nr 2 as ceiling surface, and painted walls. These buildings had parquet as floor covering material. IAQ was highly affected by indoor air humidity, especially in the 6 and 12-month-old building. As the summary of (10) PCA, variables affecting the concentrations of indoor air gaseous pollutants in the buildings were season, relative humidity and temperature of indoor air, air exchange system, floor covering material, ceiling surface product, wall surface product, and occupancy. The multivariate analysis proved to be a very useful tool in revealing the most significant variables affecting IAQ.

ACKNOWLEDGEMENT

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REFERENCES