Building and Environment 108 (2016) 63–72

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Indoor air quality in low energy residential buildings in Lithuania

Violeta Kaunelienė [a, *], Tadas Prasauskas [a], Edvinas Krugly [a], Inga Stasiulaitienė [a], Darius Čiužas [a], Lina Šeduikytė [b], Dainius Martuzevičius [a]

[a] *Department of Environmental Technology, Kaunas University of Technology, Radvilėnų str. 19, LT-50254, Kaunas, Lithuania*
[b] *Department of Building Energy Systems, Kaunas University of Technology, Studentų str. 48, LT-51367, Kaunas, Lithuania*

ARTICLE INFO

Article history:
Received 1 July 2016
Received in revised form
16 August 2016
Accepted 18 August 2016
Available online 20 August 2016

Keywords:
Indoor air
Low energy buildings
VOCs
Formaldehyde
PAHs
SPMDs

ABSTRACT

The indoor environment was investigated in 11 newly built low energy residential buildings. Temperature, relative humidity, the concentrations of CO_2, NO_2, formaldehyde, volatile organic compounds (VOC), and semi-volatile organic compounds (SVOC, i.e. PAHs, PCBs, HCB) were measured. Despite of the low air exchange rate in most buildings (0.08–0.69 h^{-1}), CO_2 and many monitored VOC and SVOC concentrations were at typical indoor levels, while the concentration of formaldehyde (3.3–52.3 $\mu g/m^3$) was elevated above the Lithuanian limit value. In several buildings, extremely high concentrations of VOCs were observed where the installation of interior surfaces and furnishing were done shortly prior the measurement campaign. Decrease of benzene, toluene, ethylbenzene and xylene (BTEX) sum concentrations was rapid and fell below Lithuanian limit values in one month. This study demonstrates the importance of checking indoor air quality before occupancy and avoiding moving into buildings before the complete installation of the interior. Selection of low-emitting building and finishing materials, furniture, cleaning products and ensuring effective work of mechanical ventilation will contribute to good indoor air quality in low energy buildings.

1. Introduction

There is a general consensus that humans are predominantly exposed to air pollutants in indoor environments. Major pollution sources include building materials, combustion processes, furniture, various household and personal care products and plastic utensils. During extensive study of air quality in residential buildings in Arizona and Mexico, USA, hundreds of individual chemical compounds were identified, ranging from pesticides to a wide array of hydrocarbons, including aldehydes, alcohols, esters and phthalate esters, fragrances, and other miscellaneous types of chemicals [1].

The concentration of an indoor air pollutant depends not only on its indoor emission rate, but also on the rate at which it is being transported from outdoors to indoors (if applicable), and the rates at which it is scavenged by indoor surfaces, consumed by indoor chemistry, and removed by ventilation or air cleaning [2]. Recently, the removal of pollutants via ventilation is being challenged due to increasing occurrence of energy efficient buildings due to increasing demand in energy saving. Tightening of buildings and presumably decreasing ventilation may have negative impact on indoor air quality (IAQ), however little attention has been paid to the IAQ in low-energy buildings in comparison to conventional buildings [3].

Hodgson et al. [4] investigated concentrations of 54 volatile organic compounds (VOCs) and ventilation rates in four new manufactured buildings in the USA over 2–9.5 months following installation and in seven new site-built buildings 1–2 months after completion. The buildings were located in hot-humid and mixed-humid climates. The predominant airborne compounds were a-pinene, formaldehyde, hexanal, and acetic acid. Formaldehyde concentrations were below or near 50 $\mu g/m^3$. Major identified sources included plywood flooring, latex paint, and sheet vinyl flooring. Brown et al. [5] investigated IAQ in new and established buildings in Melbourne, Australia, and showed that the airborne VOC levels were one to two orders of magnitude higher in new or renovated buildings than in established dwellings. The concentration decay rate correlated with VOC molecular volume, indicating emissions were limited by material diffusion processes. Eight buildings, representing the present construction practice in Finland and used low-emitting materials in the construction, were investigated to create numeric reference data for IAQ in new residential

* Corresponding author.
E-mail address: violeta.kauneliene@ktu.lt (V. Kaunelienė).

http://dx.doi.org/10.1016/j.buildenv.2016.08.018
0360-1323/

buildings [6]. The airborne VOCs, formaldehyde, ammonia concentrations as well as temperature, relative humidity, and air exchange rate were determined in the newly finished buildings and after 6 and 12 months. Target values for the indoor air concentrations were not generally reached in newly finished buildings. The concentrations of individual VOCs decreased most strongly during the first 6 months and the final mean concentration levels were generally less than 15 $\mu g/m^3$. As the occupancy period got longer, the VOCs originating from the construction phase were increasingly replaced by new ones. Langer et al. [7] investigated IAQ in the Swedish housing stock and its dependence on building characteristics and concluded that air exchange rate is a significant predictor of air pollutants. Increased ventilation rate appeared to decrease the indoor concentrations of formaldehyde and total volatile organic compounds (TVOCs). In a subsequent study Langer et al. [3] assessed air quality in 20 new passive buildings and 21 new conventionally built buildings in Sweden. Median concentrations in the passive and the conventional buildings were respectively 10 and 12 $\mu g/m^3$ for NO_2, 9.7 and 11 $\mu g/m^3$ for ozone, 11 and 16 $\mu g/m^3$ for formaldehyde, and 270 and 150 $\mu g/m^3$ for TVOC. Significant differences in the TVOC and formaldehyde concentrations between the two groups of buildings indicated substantial sources of TVOC present in the passive buildings. Derbez et al. [8] investigated IAQ and comfort in seven newly built energy-efficient buildings in France. The authors reported that compared to standard French buildings, the concentrations of benzene, ethylbenzene, m- and p-xylenes, $PM_{2.5}$, and radon were low, whereas the CO_2 and formaldehyde levels were not significantly different. In contrast, the levels of acetaldehyde, hexaldehyde, n-decane, n-undecane, o-xylene, and styrene were higher in these new homes, possibly because of the emissions from products and materials. Kolarik et al. [9] investigated concentrations of formaldehyde in 20 new Danish residential buildings and reported that in two buildings formaldehyde concentrations exceeded WHO guideline value (100 $\mu g/m^3$).

There are fundamental differences between VOC and semi volatile compound (SVOC) emissions. For VOCs found within the matrix of a material at the time of manufacture, emissions tend to occur independent of their external environment and decrease over the life of the material. Such emissions often deplete the reservoir of VOCs present within a material during the initial weeks or months that the material is present in an indoor setting. In contrast, SVOCs found within the matrix of a material tend to be emitted at rates that depend on external factors such as partitioning into the gas phase, the convective mass transfer coefficient and sorption onto indoor surfaces [2]. Among SVOCs, polyaromatic hydrocarbons (PAHs), their alkylated species, polychlorinated biphenyls (PCBs) and organochlorine pesticides (e.g., hexaclorbenzene (HCB)) are target analytes in many studies [1]. PAHs originate from unvented combustion appliances, PCBs, besides their main use as heat transfer fluids in transformers, had many other indoor uses including stabilisers, additives in sealants, adhesives, paints and floor finishes [2]. Although use of PCBs as well as most of organochlorine pesticides has been banned they are still measured in indoor air [2].

Construction practices and indoor sources differ among countries depending on the socio-economic conditions of the occupants. The aim of this study was to investigate IAQ and the occupant's comfort in new energy-efficient buildings in Lithuania. The country represents a region with high differentiation in quality of building materials. Moving in to a building with partial completion of the interior works is also a common practice. 11 low-energy buildings were investigated for general IAQ and one building with high VOC levels was researched for the decrease of organic compound concentration in time.

2. Methodology

2.1. Buildings

The first round of investigation was performed during the period from April to August 2014. It aimed at collecting air quality information from 11 single-family detached low energy buildings (representing A and B energy performance class as defined by the national standard STR 2.01.09:2002 [10] implementing the European directive 2010/31/EU) and located in Kaunas (8 buildings) and Vilnius (3 buildings), see Table 1.

The age of the most buildings ranged from 2 months to one year, whilst two unfinished buildings (B5 and B10) and one ten-year-old building (B8) was taken for comparison. All buildings had a mechanical ventilation system with a heat recovery installed and operating except for the two unoccupied buildings. Although the mechanical ventilation systems were present, very few residents were aware of their running schedule or balancing. During the investigation the mechanical ventilation systems were operating in all occupied buildings.

Questionnaires were distributed to the residents for gathering of the information concerning building construction characteristics and occupant activities during the measurement period. The main data from the questionnaires used in this study included background building information (age of a dwelling, building material), building ventilation and heating system, typical number of people living, etc. (Table 1).

The second round of investigation was carried out in September of 2014 in B5. This was aimed to estimate the decline of VOC concentration over time after construction. Sampling was started the next day after complete installation of all interior surfaces and conducted during five consecutive weeks. Air exchange rate was kept constant at 0.5 h^{-1} by means of the mechanical ventilation system. The building was unoccupied during the experiment.

2.2. Sampling and chemical analysis

Weekly (7 days) indoor air samples were collected in the living room, or in the hallway of the building. The measured gaseous pollutants indoors in the first round included formaldehyde (HCHO), selected VOCs (as listed in Table 2), semi-volatile organic compounds (16 PAHs as defined by US Environmental protection Agency (EPA) [2], alkylated PAHs, PCBs, HCB), NO_2, and CO_2. In the second round of sampling only concentration of selected VOCs (as listed in Table 4) was measured. Samplers of formaldehyde, VOCs, and NO_2 were exposed for seven consecutive days.

Formaldehyde was collected with passive sampler tubes (Radiello, Fondazione Salvatore Maugeri, Italy). The tubes were positioned at a distance exceeding one meter from windows, door or other surfaces at a height of about 1.5–2 m above the floor. Formaldehyde sorbent tubes matrix contains a 2,4-dinitrophenylhydrazine coated Florisil adsorbent. After exposition, compounds were analysed with ultra-fast liquid chromatography coupled with UV/VIS and diode matrix detectors system (Prominence UFLC, Shimadzu, Japan).

The positioning and sampling procedure of VOC samplers was similar as for formaldehyde. VOCs sorbent tubes were preloaded with an active charcoal adsorbent (Radiello). Analysis was performed by gas chromatography (GC MS-QP2010 Ultra, Japan) coupled to mass spectrometer (GC/MS) using helium (He) as a carrier gas. The equipment was calibrated before the analyses by injecting standard solutions of compounds: BTEX (benzene, toluene, ethylbenzene, xylenes). The explicit procedure of analysis is presented in our earlier studies [11,12].