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ScienceDirect

Energy Procedia 85 (2016) 288 – 294

Energy Procedia

Sustainable Solutions for Energy and Environment, EENVIRO - YRC 2015, 18-20 November 2015, Bucharest, Romania

Experimental measurements of VOC and Radon in two Romanian classrooms

Marian – Andrei Istrate[a]*, Tiberiu Catalina[a], Alexandra Cucos[b], Tiberius Dicu[b]

[a]*Faculty of Engineering for Building Services, Technical University of Civil Engineering Bucharest, 66, Pache Protopopescu Blvd. Bucharest, 021414, Romania*

[b]*Faculty of Environmental Science and Engineering, Babes-Bolyai University, 30 Fântânele Street, RO-400294, Cluj-Napoca, România*

Abstract

The present study reports by experimental measurements the levels of volatile organic compounds (VOC) and radon concentrations in two high school classrooms. The difference between the two classrooms abbreviated as S7 and S8 is the presence of a mechanical ventilation system in one of them (S8). The topic is of high importance as the indoor air quality (IAQ) can affect the health and learning performance of the pupils. VOC and RADON have a substantial weight of IAQ and a study of theirs level can help us to better understand at what levels the children are exposed daily. The two mentioned classroom have suffered recently a massive renovation. The classroom with the ventilation system was mounted with variable flow of fresh air, while the other one relies only on natural ventilation by opening the windows. In S8 several test were done for different fresh air ventilation rates. The conclusions were that in the classroom S7 there were measured high levels of VOC and radon, higher than the maximum admissible which is a serious problem. On the other hand, in the classroom S8 for all the different air rates the values were very low, thus creating a healthy and comfortable environment for the learning process. In this article we raise again the problem of lack of a mechanical ventilation system in all Romanian schools. Due to thermal rehabilitation of the buildings the building is air sealed with negative impact on the introduced fresh air. Moreover, the high number of occupants in the classroom and the renovation of classroom have negative influence on all indoor pollutants levels. The only solution to these problems is a correct design of a school or to install other ways to mechanically introduce the fresh air.

Peer-review under responsibility of the organizing committee EENVIRO 2015

Keywords: VOC; RADON; IAQ; ventilation rate; classrooms.

* Corresponding author. Tel.: +40.721.769.294
E-mail address: istrate_marianandrei@yahoo.com

1876-6102
Peer-review under responsibility of the organizing committee EENVIRO 2015
doi:10.1016/j.egypro.2015.12.254

1. Introduction

If in many cases most people are aware that outdoor air pollution can impact their health, as concerns the indoor air pollution they are not aware that can have significant and harmful effects. Schools are occupational environments characterized by a high occupancy rate (number of students reported the occupied area). The occupants are responsible for significant carbon dioxide emission (CO_2), moisture, odors and dust (e.g. chalk dust). In addition, the construction materials of the building, interior finishes, furniture and office equipment (computers, printers) are responsible for the emission of hazardous substances into the indoor air, such as volatile organic compounds (VOCs) , formaldehyde (HCHO) and contaminants airborne biological (germs, viruses and bacteria).

Indoor air quality in schools and kindergartens lately has become a global concern. This is because the main actors, the children, are extremely sensitive to unhealthy indoor environments with high concentrations of pollutants. Their bodies protection system is still underdeveloped and is more fragile if put in contact with low air quality and may cause serious health problems. Numerous epidemiological studies have demonstrated poor indoor air quality in schools worldwide [1]. Other authors have shown a direct relationship between poor academic performance of pupils and students and thermal comfort and indoor air quality in schools [2].

Among the many indoor pollutants the volatile organic compounds (VOCs) are emitted as gases from certain materials: solids or liquids. The VOCs comprise a large diversity of chemicals, which have short- or long-term adverse health effects on the occupants. The concentration of these organic compounds depends on many factors (type of activity in the room, ventilation rate, number of occupants, type of furniture, etc.), which makes it extremely difficult to estimate unless they are continuously monitored. One of the most toxic air pollutants indoor is formaldehyde. It is emitted from sources such as building materials, materials used for insulation (foam based on urea and formaldehyde, UFFI), furniture, flooring, wall wallpaper, cellulosic materials etc. making it one of the most common pollutants of indoor air. The effects of exposure to formaldehyde are the most serious and may be associated with nasal irritation, chronic respiratory diseases, asthma, neuropsychological deficit, adverse effects on the central nervous system and reproductive system [3]. The carcinogenic effect was experimentally demonstrated, formaldehyde being responsible for buccal carcinoma. Also in the US National Cancer Institute states that overexposure to formaldehyde increases the risk of leukaemia and brain cancer.

Another pollutant with negative impact on health is the exposure to radon. The news IAEA's Basic Safety Standards put radon issue in a significant position concerning the identification and management of population risks derived from exposure to radon inside buildings [4 - 6]. The carcinogenic impact of radon and its decay products has been proven in cohort studies of miners and case-control studies on exposure to residential radon. In the last 25 years, 22 major studies were conducted on the impact of residential radon on lung cancer, the main conclusion being that the risk of developing lung cancer due to radon increases by 16% per 100 Bq/m^3 [7,8]. Studies show that in Europe between 8 and 15% of all lung cancer cases may be attributable to radon in homes, aspect that makes it the main environmental factor causing lung cancer [9].

The population exposure to radon and other pollutants inside buildings can be controlled and reduced with relative minimal investments. A range of techniques are available to reduce high indoor concentration and to minimize the risk. Indoor air quality in schools can be secured properly by implementing appropriate mechanical ventilation systems with air flow rates sufficiently high to maintain low values of the most dangerous pollutants. These solutions should be adopted as early as the design stage of the school in order to implement correctly the ventilation systems. In already built schools, the possibility of implementing a mechanical ventilation system is difficult because of architectural restrictions but a compromise must be done.

In this article we present the impact of a new ventilation system on the indoor air quality of a classroom and we compare the results with an identical classroom without any ventilation. Indoor radon measurements were performed by using Radon Scout device (SARAD, Dresden, Germany) exposed one week in each classroom of a high school from Bucharest during the July-August 2015, according to the NRPB Measurements Protocol [4,6,10]. To study the effect of ventilation system, measuring of radon concentration was performed after the installation, with the active system working. The impact of indoor exposure to radon on public health in Romania was estimated at 1800 deaths annually from lung cancer, representing a rate of 7-25% of all deaths from lung cancer [11,12]. The indoor radon concentrations for Romania range from 30 to 3653 Bq/m^3 with an average exposure of 126 Bq/m^3, based on approximately 2000 indoor radon measurements [4,6]. The annual mean is considerably higher than similar values reported for other countries and also than the indoor radon average (98 Bq/m^3) reported for Europe [13].

2. Study case

This study was done on two classroom of a high school situated in Nicolae Grigorescu Bdvl., Bucharest and has a “U” construction shape like most of the schools in the country. In the figure below it is presented a photo of the school, the position of the classrooms and the dimensions of the room.

Fig. 1. High school photo and sketch of the two studied classrooms

The chosen classrooms are situated at the last floor, side by side, with similar exposure situations. The two identical classrooms have 7.84m in length, 6.2m in width, 3.3m in height with a surface of 48.61 m2 and a volume of 160.4 m3. The exterior walls are made of 24 cm brick, recently thermal insulated with 10cm of polystyrene and the windows are double glazed. Classroom number 7 (S7) hasn’t any ventilation system and rely only on opening manually the windows, on the other hand, classroom number 8 (S8) has a ventilation system. The ventilation system is a unit composed of an evaporative cooler, a fan, an electric heat coil and distribution ducts to introduce the fresh air in the classroom. The fresh air is introduced through the evaporative cooler pads; these pads are designed to filter the air (leaves, dirt etc.) and to moisten the air (cooling it during hot days). Then, the filtered fresh air is distributed in the classroom using a modulated fan. If the air temperature falls below 20°C, the heating coil is activated in order to maintain a comfortable temperature both for winter and summer.

Figure 2 presents the ventilation system in classroom number 8 and a 3D view for better comprehension of the system fresh air distribution.

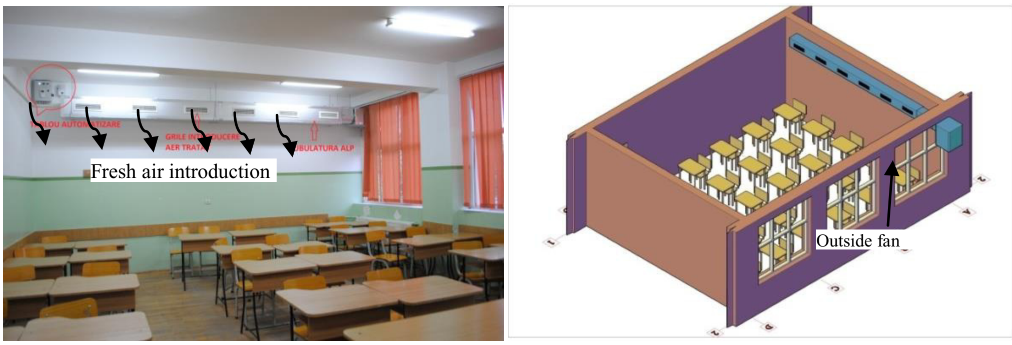

Fig. 2. Classroom S8 with the ventilation system mounted in the back of the classroom and 3D view

Measuring indoor air pollutants after the installation of a mechanical ventilation system is the only accurate indication of the success of the protective measures.

The measurements of VOC and radon levels inside the indoor air were realized simultaneously in the two rooms for the same period. The VOC measurement sampler is realized of a porous polyethylene tube, which is acting as the diffusive membrane. To this membrane is connected a small polypropylene syringe used for the elution of the analyses from the adsorbent. The system allows exposure from all sides because the diffusive membrane is round. The adsorbent is silica gel coated with 2,4-dinitrophenylhydrazine (DNPH) and moves from the diffusive end during sample collection to the syringe end for sample extraction, by inverting the device. Aldehydes and ketones diffuse through the membrane reacting with DNPH to form stable derivatives. The DNPH-derivatives are then eluted with acetonitrile and analysed by high performance liquid chromatography (HPLC) [14]. In order to measure the indoor radon concentrations, Radon Scout device was used. This instrument presents a measurement chamber, equipped with a semiconductor detector and high voltage collection. Gross alpha detection technique is used and the sensitivity of the detector is 1.8 CPM/kBq/m3. The detector response is insensitive to any environmental changes in the atmosphere [15].

3. Results and discussions

Result of experimental measurements of the investigated indoor air pollutants in two classrooms of a high school from Bucharest before and after the installation of a mechanical ventilation system are presented in Figure 3, Table 1 and also Table 2.

Using the Radon Scout device we have realized multiple experimental tests in the two classrooms during a period of 595 hours. The data from the equipment were visualized and analysed using the SARAD software compatible with the measurement apparatus. The recorded data consisted of radon levels but also air temperature and humidity. From the Figure 3 presented below we can observe that the radon levels are highest in the case of classroom S7 with values reaching up to 400 Bq/m3. The indoor radon average in the case of S7 was found to be 320 Bq/m3. On the opposite side, we found that the classroom where we had the ventilation system functioning the radon levels were low (<50 Bq/m3) for different fresh air ventilation rates. The most energy efficient and good way to ensure air quality is to use a fresh air rate of 25 m3/h/person. We have also tested the classroom S8 without the ventilation system active and still we have found lower values than the ones from S7. We remind that the two classrooms were renovated 4 months before the tests and the chemicals were still present in the materials. In classroom S8, during the functioning hours, the ventilation system has eliminating a large part of the pollutants and when it was turned off the indoor levels were not so high as in the case of classroom S7 which didn't benefit from any fresh air except the rare opening of windows and some infiltrations.

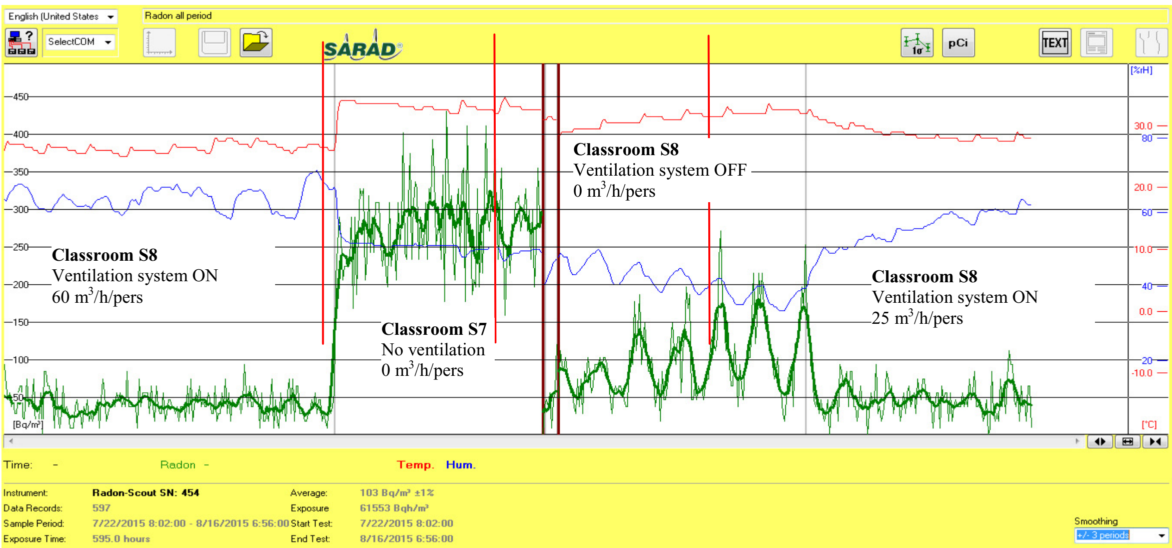

Fig. 3. Radon, temperature and humidity measured levels for the two tested classrooms during 595 hours

Table 1. Comparison of VOC and radon concentrations between the two studied classrooms

Location	Type of ventilation	Formaldehyde (μg/m3)	Acetaldehyde (μg/m3)	Acetone (μg/m3)	Radon (Bq/m3)
Classroom S7	No ventilation	86.68	45.16	59.37	320
Classroom S8	Mechanical ventilation	5.32	1.65	1.95	40

As can be seen from Table 1, the results for indoor air quality in S7 are higher than the EU recommendations or published guideline values for investigated pollutants -radon and formaldehyde [5, 16]. The measured values are slightly higher than the recommendations for the offices, with the measured formaldehyde concentrations range between 5.3 and 86.7 μg/m^3 and the respective values for acetaldehyde range from 1.7 to 45.2 μg/m^3. Published indoor air quality guideline values for formaldehyde and acetaldehyde can be found only in Flanders - 10 μg/m^3 and 46 μg/m^3, respectively [16].

To assess the effectiveness of ventilation system installed in the classroom no. 8, the criteria of efficiency are used. One of the main criterions is a reduction efficiency R in %. It is estimated as follows [17]:

$$R = \frac{C_{before} - C_{after}}{C_{before}} \times 100, [\%] \quad (1)$$

where C_{before} and C_{after} are indoor radon concentrations (Bq/m^3) with the mechanical ventilation system off, respectively on. The reduction efficiency is sometimes reported as a reduction factor RF defined by [17]:

$$RF = \frac{C_{before}}{C_{after}} \quad (2)$$

where Cbefore and Cafter are indoor radon concentrations (Bq/m3) before and after remediation.

The results of measurement of indoor radon concentration before and after mitigation, and also the calculated reduction efficiency and reduction factor are presented in table below. The both measured values for radon concentration were above the recommended reference level of 300 Bq/m3 for existing public buildings [5].

Table 2. Results of radon concentration before and after mitigation and reduction factors.

Location	Cbefore (Bq/m3)	Cafter (Bq/m3)	R (%)	RF (-)
Classroom S8	150	40	73	3.8

Similar values can be observed in terms of efficiency for remedial actions against radon based on ventilation systems implemented in Romania (see Table 3), in the framework of the POSCCE 586-12487 "IRART" project [18]. The following table presents a comparison of the main remediation methods developed experimentally and the results on the reduction efficiency (%) of the radon concentration achieved in the IRART project compared with results accomplished in European countries [19]. All remediation methods developed and applied in the IRART project resulted in high reduction factors with an average efficiency of 81% [6] for all 21 houses with high risk of radon from the Băiţa-Ştei uranium mining area. The implemented methods are based on active and passive pressurization and depressurization of indoor spaces [6].

From our results, it could be concluded that in thermally rehabilitated buildings, increased tightness often leads to a decrease of indoor air quality. Minimum legislative requirements recommend avoiding deterioration of indoor air quality, i.e. increasing the levels of radon and other household air pollutants after applying energy-saving technologies. Dynamic criteria of the air should be considered and applied accordingly.

Table 3. Remediation techniques based on ventilation systems applied in the IRART project compared with those applied in 14 European countries within the European project RADPAR.

No.	Remediation technique	Short description	R (%)	
			IRART	RADPAR
1	Soil depressurization (active and passive methods)	It works by reversing the pressure difference between the space under the floor and the room above. The contaminated air is expelled through a ventilator, thus preventing its infiltration indoors. By coupling the collector with a fan is known as the active collector.	68-95	60-95
2	Improving natural ventilation	Determines mixing of radon-rich indoor air with the outdoor air, thus decreasing the indoor radon concentration but also slightly increasing the pressure inside the house which helps reduces the tendency of radon to be sucked indoors.	30-59	10-50
3	Improving mechanical ventilation	It involves introducing air inside the house through a fan, thus creating a slight positive pressure relative to the outside air. This reduces radon entry and forces the air out through cracks, windows and other openings.	65-78	10-60
4	Ventilation methods combined with soil depressurisation	It requires installation of additional under-floor ventilation paths to force evacuate radon using an active fan. These ventilation paths are crossed by longitudinal slotted PVC pipes.	88-95	60-99

4. Conclusions

The new motivated requirements regarding assessing the energy performance of buildings in the European Union, including Romania, through the implementation of Directive 2010/31 of the European Commission impose a series of major changes associated with energy certification of buildings and a low to zero energy consumption for heating and air conditioning systems. A productive economic sector must adapt to the conditions imposed by the new legislation through design and production of technical systems for buildings and of heating and cooling equipment compliant with low energy consumption [20] but in the same time we must neglect the true purpose of a building: providing an healthy and comfortable environment for the occupants.

The experimental study of the two classroom showed that the indoor concentrations of formaldehyde, acetaldehyde and acetone are much higher if there is no ventilation. In the classroom S8 the concentrations were 16 to 30 times lower than in the classroom S7. The most of measured values were above the recommended guidelines which may represent a serious health problem for the exposed students. As concerns the radon levels, in classroom S8 with the ventilation system functioning the levels were 8 times lower than in S7 where the occupants relied only on opening manually the windows to refresh the air.

The conclusions of this article are important because they show that in most of the Romanian schools the indoor air quality lacks and can have long term repercussions on children health. We have proposed a ventilation system mounted on the façade of the building and by using it all the indoor pollutants levels were very good, thus creating a healthy and productive environment for the pupils.

Acknowledgement

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, project number PN-II-RU-TE-2012-3-0108. The study was also supported by a postdoctoral research made possible by the financial support of the Sectoral Operational Programme for Human Resources Development 2007-2013, co-financed by the European Social Fund, under the project POSDRU/159/1.5/S/133391 - "Doctoral and postdoctoral excellence programs for training highly qualified human resources for research in the fields of Life Sciences, Environment and Earth".

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