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Residential indoor pollution by nitrogen dioxide: conference series

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Abstract. According to the Environmental Protection Agency, indoor air quality (IAQ) is defined as air quality within and around buildings and structures and it is related to the health and comfort of building occupants. A better understanding of IAQ is essential, since people spend more than 90 percent of their time indoors. The greatest amount of time spent indoors is at home, so it is important to control indoor air pollution and to reduce the risk of health effects related with indoor air pollutants exposure. The aim of this study was to determine indoor air pollution of nitrogen dioxide (NO₂) in different seasons and to compare indoor and outdoor NO₂ concentrations. The sampling of NO₂ was performed in cold, warm and intermediate seasons using passive sampling technique inside and outside of the residential houses. The results of the study showed that the average NO₂ concentration in cold season was 10.5 µg/m³ and 20.0 µg/m³, respectively in indoor and outdoor air. The lowest indoor and outdoor levels of NO₂ were observed in warm season, 9.7 and 11.3 µg/m³, respectively. The strongest positive relationship between indoor and outdoor concentrations of NO₂ was determined in warm season.

1. Introduction

Indoor air pollution is one of the major environmental health concerns for developed and developing countries that is responsible for many adverse health effects [1,2]. Indoor air quality (IAQ) becomes even more important considering that people spend about 90 percent of their daily time in indoor environments (home, work, schools, shopping centers, etc.) [3,4]. Children, the elderly, individuals with chronic diseases are the most vulnerable to the effects of air pollution [5]. The concentration of air pollutants is emitted from indoor (burning fuel for cooking and heating) and outdoor sources. Studies have shown that indoor air pollution can be 2-5 times higher than outdoors. According to the World Health Organization (WHO) most recent report, approximately 3.8 million people each year die prematurely from illness attributable to the household (indoor) air pollution caused by the inefficient use of solid fuels and kerosene for cooking. Epidemiological studies have shown that indoor air pollution is associated with increased respiratory symptoms, the prevalence of asthma and rhinitis in children and adults [6-8]. Nitrogen dioxide (NO₂) is one of the main air pollutants, which is significant in outdoor and indoor environments and its emissions are produced during road traffic and other fossil fuel combustion processes [9]. Road traffic is the most important outdoor sources of NO₂. Studies have shown that the levels of NO₂ are significantly higher near high traffic streets and decrease with increasing distance from roads [10]. Gas, wood and kerosene appliances used for cooking and heating are the most important indoor source of NO₂. There is evidence that indoor NO₂ concentrations in houses with gas stoves are usually higher than the outdoor concentrations. A study by Cyrus et al. [11] conducted in Germany showed that the use of gas for cooking increased indoor NO₂ levels by 41%. Other studies have also found similar results [12,13]. Meanwhile, in residential places, in which electric stoves are used for cooking, IAQ depends on the concentration of pollutants in the outdoor air [14]. There is evidence that short-term and long-term exposure to NO₂ is associated with health risk [15,16].



Another important factor influencing IAQ in buildings is ventilation rate [2]. Natural ventilation is the most common ventilation system in most European countries [17]. Passive ventilation is a natural ventilation system driven by pressure differences between the inside and outside without the use of any mechanic system [18]. The main purpose of ventilation is to create optimal conditions in indoor environments (living or working) by regulating the internal air temperature and bringing fresh air inside. A lack of ventilation can be responsible for poor IAQ. In many European countries, ventilation is included in the building regulations. In some of the countries, there are minimum requirements for ventilation rates, while in another countries there is only a recommendation for minimum ventilation rates which vary between countries and are generally different from EU standards [19]. At present, In Lithuania, the minimum amount of fresh air per person required by the normative documents is 14.4 m³/h and for a comfortable microclimate of about 30 m³/h. Design ventilation rates are set out in the Construction Technical Regulation. The Energy Performance of Buildings Directive (EPBD, 2010/31/EU; new revised directive 2018/844/EU) and the Energy Efficiency Directive (2012/27/EU) are the EU's main legislative instruments promoting nearly zero-energy buildings (NZEBs) and the improvement of the energy performance of buildings within the EU. According to the EPBD, all new buildings should be nearly zero-energy by the end of 2020 and EU countries must draw up national plans to increase the number of NZEBs. Lithuania has set transitional requirements for newly constructed buildings in 2014, 2016, 2018 and 2021 under building energy performance classes: from 2018 new buildings or their parts shall comply with the requirements for class A+ buildings and from 2021 new buildings or their parts shall comply with the requirements for class A++ buildings. Air tightness requirements for buildings vary according to the energy efficiency classes. Class A requirement for the air change rate of residential buildings is 1 l/h and for A + and A ++ classes is 0.6 l/h [20].

Currently, the focus is on improving the energy efficiency of buildings, but attention on IAQ should also be addressed. A review study by Dimitroulopoulou [17] showed that ventilation rates are poor in many European countries that result in increased levels of indoor air pollutants. The aim of this study was to assess residential pollution of NO₂ and compare indoor and outdoor concentrations.

2. Methods

2.1. Study area

The study was conducted in Kaunas city, Lithuania (North latitude 54° 56' and East longitude 24° 51'). Kaunas is the second-largest city of the country with a population of 286,763 (in 2019) and the area of 157 km². Kaunas Municipality consists of 11 districts. Kaunas city is a large centre of business and industry and it is served by a number of major highways. Kaunas has the second-busiest airport in Lithuania and fourth-busiest airport in the Baltic States.

2.2. NO₂ measurements

The measurements of NO₂ were conducted for intervals of two weeks in five randomly selected residential houses in Kaunas city. All houses were connected to the local district heating network and were in the same type of buildings with natural ventilation system. Two passive samplers were installed in each site to have a representative sample of measured locations. NO₂ measurements were carried out in three seasons: cold, warm and intermediate (spring, autumn) from February to October 2014. Residential houses were selected without any indoor sources of NO₂. Passive sampling method was used to measure indoor and outdoor NO₂ concentrations. This method is based on the diffusion of gases from the atmosphere onto an absorbent (triethanolamine). Passive samplers were prepared in the laboratory and then exposed for 14 days in selected sites. Passive samplers were located in three places (kitchen, bedroom and living room) about 1.8-2 m high from the floor and at least 1m away from the any wall obstructions to measure indoor NO₂ concentrations. For outdoor measurements, passive samplers were placed at the outdoor balcony. After exposure, passive samplers were capped, taken to the laboratory and stored in the refrigerator until analysis. NO₂ was determined after extraction using a spectrophotometric Saltzman's reaction. The concentration of NO₂ was calculated based on the recorded sampling time, meteorology and the diffusion coefficient [21,22].

2.3. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp. Released 2016. Armonk, NY: IBM Corp.). Descriptive statistics were calculated for indoor and outdoor concentrations of NO₂ in different seasons. We compared the means of indoor and outdoor levels of NO₂ and indoor / outdoor (I/O) ratios of NO₂ concentration in cold, warm and intermediate seasons and performed an independent t-test. Pearson's correlation coefficient (r) and p-value were calculated to assess linear association between indoor and outdoor NO₂ concentrations.

3. Results and discussion

The results of the study showed that the highest indoor and outdoor levels of NO₂ were observed in cold season. The average indoor NO₂ concentration was 10.4 µg/m³ and the outdoor NO₂ concentration was 20.0 µg/m³. Statistical test showed significant difference between indoor and outdoor NO₂ concentrations. The lowest concentration of NO₂ both in indoor and outdoor air was determined in warm season, respectively 9.6 and 11.2 µg/m³. There was no statistically significant difference between indoor and outdoor concentration of NO₂ (p < 0.05). The results of measurements of NO₂ in intermediate season showed that the average indoor NO₂ concentration was 10.3 µg/m³. We observed that the average outdoor level of NO₂ in intermediate season was 14.2 µg/m³. The results indicated that there was statistically significant difference in the mean concentration of NO₂ (p = 0.015). Compared with the highest indoor NO₂ concentration, the indoor levels of NO₂ decreased by 8 % in warm season and by 1 % in intermediate season. Our findings showed that the average indoor NO₂ concentration between cold and intermediate seasons was very similar and slightly varied. The average outdoor NO₂ levels in warm and intermediate seasons were 1.8 and 1.4 times lower compared to cold season. The results of the correlation analyses showed that the strongest positive relationship between indoor and outdoor concentrations of NO₂ was determined in warm season (r=0.85).

Table 1. The mean value and other statistics of indoor and outdoor NO₂ concentrations in three seasons

Season	Mean NO ₂ concentration	SD	Minimum value	Maximum value	P-value *	r, p-value
Cold						
Indoor	10.4	1.85	8.5	12.4	0.000	0.08 p=0.905
Outdoor	20.0	1.22	18.5	21.2		
Warm						
Indoor	9.6	1.95	7.2	11.9	0.183	0.85 p=0.067
Outdoor	11.2	1.48	9.6	12.7		
Intermediate						
Indoor	10.3	1.88	8.0	12.4	0.015	0.45 p=0.452
Outdoor	14.2	2.09	11.8	16.2		

* p-value obtained from an independent samples t-test

A study conducted by Kornartit et al. [9] confirmed our study findings that outdoor NO₂ concentrations were higher compared with indoor concentrations for the winter period. Indoor NO₂ concentrations are affected by outdoor levels, air-exchange rates and the presence of indoor sources.

The results from a national survey of air pollutants in homes in England [13] showed that the geometric mean of indoor NO₂ in houses without any fossil fuel cooking was comparable with our study results. In contrast to the results of our study, Raw et al. [13] found that in homes with no fossil fuel cooking appliances the highest levels of NO₂ were found in summer and autumn and stated that these results could be due to a higher ventilation rate in summer and increased NO₂ concentrations from outdoors. The average indoor and outdoor NO₂ concentrations in our study were lower than those measured in the EXPOLIS study where the residential indoor NO₂ level varied from 18 to 43 µg/m³ and the outdoor NO₂ from 24 to 61 µg/m³ in Basel, Helsinki and Prague with lowest NO₂ concentrations in Helsinki and highest in Prague [23]. Wichmann et al. [24] measured NO₂ concentrations in winter and

spring/early summer periods in Stockholm, Sweden, where the residential indoor NO₂ level was significantly lower than the outdoor level (12.1 and 14.2 µg/m³, respectively). In winter season, indoor and outdoor NO₂ concentrations were 14.2 and 16.6 µg/m³ and in spring/early summer season, 9.9 and 11.8 µg/m³, respectively. Our NO₂ values are close to these levels.

The I/O ratio directly represents the relationship between indoor and outdoor NO₂ concentrations (Figure 1). The lowest mean I/O ratio for NO₂ was determined in cold season and it was 0.52. These results showed that indoor NO₂ concentration was lower than the outdoor and indicated the influence of outdoor sources of NO₂. We found that during warm season I/O ratio for NO₂ was 0.86 indicating that indoor and outdoor levels was nearly equal [25]. This finding might be due to frequent window opening. The I/O ratio for NO₂ in intermediate season was 0.74. The values of I/O ratio lower than 1 indicate the absence of indoor sources of NO₂ and show that indoor NO₂ levels are influenced by the outdoor NO₂ concentrations. Higher I/O ratios are related to the increased infiltration of outdoor NO₂ in the indoor environment and this is very evident during the warm season [26].

Similar I/O ratio patterns during summer were obtained in a study in residential houses in Switzerland [27]. The I/O NO₂ ratio results from our study are in line with other similar studies. for vary between different studies. A study in Detroit, Michigan [28] determined a median I/O ratio for NO₂ of 0.6 in residential households. The overall mean I/O ratio was 0.99 for NO₂ during all seasons at homes, pre-schools and schools in Sweden [29]. A study in Birmingham, UK [30] found that in naturally ventilated buildings the I/O NO₂ ratio was 0.9.

An experimental study of apartment buildings' ventilation parameters carried out in Lithuania [31] showed that, on average, when the temperature difference between indoor air and outdoor air is about 10 °C, the air change rate was 0.20 air changes per hour and when the difference is 25 °C, the average air change rate increases to 0.26 times per hour. The results of this research indicated that the average value of ventilation in existing residential buildings is often lower than regulated in the Construction Technical Regulation.

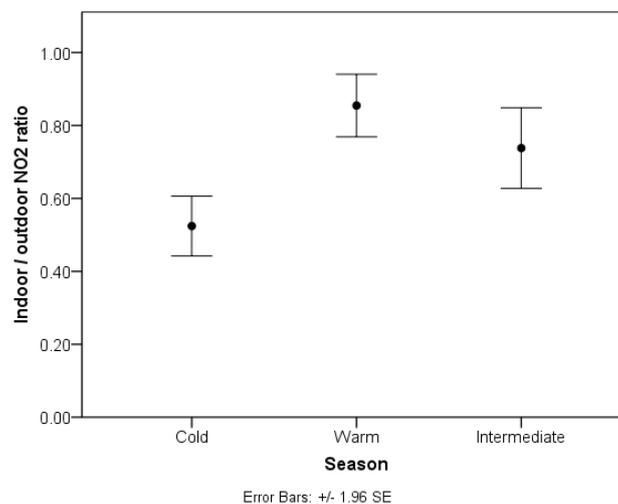


Figure 1. Indoor / outdoor (I/O) ratios of NO₂ concentration during different seasons

Ventilation in buildings is an important component of a healthy dwelling and it can be considered as one of the public health measures for the prevention and control of adverse health effects related to indoor air pollution [32]. However, a review of the European regulations for ventilation rates [33] showed that the values of ventilation rate are inconsistent and vary largely throughout Europe and there is a need for harmonisation of the ventilation regulations on the European level [19].

4. Conclusions

The study investigated residential pollution by NO₂ and compared indoor and outdoor concentrations of NO₂ in different seasons. Our findings revealed significant differences in NO₂ levels between indoor and outdoor environments in cold and intermediate seasons. The average indoor NO₂ concentration in cold and intermediate seasons was similar, meanwhile the outdoor concentration varied significantly between these seasons, indicating that, in the absence of indoor sources of pollution and a minimum ventilation rates, the indoor levels of NO₂ remain similar even with a significant difference in the outdoor levels. The smallest difference between indoor and outdoor NO₂ concentrations was measured in the warm period. Our study highlights the importance of reducing indoor sources of air pollution which have the greatest impact on the levels of pollutants inside the building and focusing on adequate ventilation in buildings to control IAQ and to reduce the exposure to indoor air pollutants. Even though the present study showed significant differences between indoor and outdoor NO₂ concentrations, future research using a larger sample size are needed to provide more precise results and conclusions about the relationship between indoor and outdoor concentrations of air pollutants in different seasons.

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