

# Variation of Indoor/Outdoor Particulates in Tallinn, Estonia – the Role of Ventilation, Heating Systems and Lifestyle

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**Abstract** As people spend up to 90% of their time indoors, indoor air pollution plays a crucial role in their air pollution exposure. Particulate matter (PM<sub>10</sub>) and fine particles (PM<sub>2.5</sub>) were measured with optical particle counters during three days in summer and winter inside and outside four homes with different ventilation, heating systems and lifestyles in Tallinn. It appeared that during the period outdoor concentrations of PM<sub>10</sub> were relatively low, even though three of the measuring sites were situated near busy streets (15.8 and 25.9 µg/m<sup>3</sup> as summer and winter period average). At the same time the mean indoor PM<sub>10</sub> values were 15.0 µg/m<sup>3</sup> in summer and 22.2 µg/m<sup>3</sup> in winter and up to 94% of the particles were fine particles. The average I/O ratios varied from 0.6 to 1.2 depending on the location and season. The highest indoor concentrations appeared during cooking; however, these peaks did not appear in a flat with a portable air filter. Moreover, residential heating affected both indoor and outdoor air quality causing significantly higher levels in winter and there was also some effect of outdoor fires in summer. Mechanical ventilation somewhat improved the air quality, but during high indoor emission episodes (cooking) it was not sufficient.

**Keywords:** particulate matter, indoor air pollution, ventilation, heating

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## 1. Introduction

As people spend most of the time indoors, indoor particle pollution exposure is important for understanding the effects of particulate pollution on human health. It has been shown that the outdoor particles are a major contributor to indoor particulate concentrations as they are supplied indoors through ventilation and infiltration [1,2]. Even if the mechanical ventilation equipment is provided with filters that decrease the pollution levels, it cannot fully bind the smallest fractions of the particles [3,4,5,6]. Also there appears an uncontrolled flow of air through cracks and leaks into the building (infiltration). Even though compared to ventilation, infiltration results in a relatively low air exchange rate, it can still be an important pathway for the particles entering the buildings [2,7].

Indoor exposure to airborne pollutants will not only depend on emissions from various outdoor sources, but also on indoor sources that might increase the particulate levels so that they become even higher than those outdoors. Heating and cooking as well as lifestyle are some of the key sources of indoor particulate matter [8-13].

There is strong and inclusive epidemiological and experimental evidence that particulate matter causes

various health effects from premature mortality, cardiovascular and respiratory disease and cancer to asthma attacks, COPD, chronic bronchitis, rhinitis, birth effects to degenerative disease, neuropsychological effects etc. [14,15,16,17]. Recent results show that bad indoor air quality is annually causing 2.1 million DALYs (disability adjusted life years) in EU26 countries, 13% of which are caused by PM<sub>2.5</sub> of indoor origin and 62% by PM<sub>2.5</sub> of outdoor origin [1]. The previous risk assessments have assessed indoor air to be responsible for the 19 % cardiovascular and 9 % for the respiratory diseases caused DALYs in EU27, of which 2/3 is caused by PM<sub>2.5</sub> [18]. This makes indoor fine particle pollution an essential factor influencing public health. Moreover, bad indoor air quality can also trigger discomfort and annoyance [19].

The aim of this pilot study was to explore the levels and variation of indoor and outdoor particulate levels and investigate the role of ventilation, heating systems and lifestyle in Northern climate.

## 2. Ease of Use

### 2.1. Study Sites

Altogether four study sites with different characteristics were selected. The details of the study sites are given in

**Table 1.** Flat 1 with a young resident was situated in a new house with mechanical ventilation. Flat 2 with older residents was situated in a more polluted city centre, had natural ventilation but equipped with a portable air filter. Flat 3 with a young resident was situated in a typical

Soviet block of flats with natural ventilation. House 1 with older residents was situated in a residential area with moderate traffic pollution, but residential heating and natural ventilation. All of the study sites had non-smoking residents.

**Table 1. Description of the study sites**

	Neighbourhood	Renovation	Heating systems	Ventilation	Residents
Flat 1	Residential area, close to busy streets	New house	District heating with radiators	Mechanical ventilation	One resident, studio flat
Flat 2	City centre	Recently renovated and insulated	District heating with radiators	Natural ventilation and an indoor portable air filter	Two residents, two bedrooms
Flat 3	Residential area, near busy streets	Minor renovation	District heating with radiators	Natural ventilation	One resident, one bedroom
House 1	Residential area	No renovation	Wood stoves + sauna stove	Natural ventilation	Two residents, two bedrooms

## 2.2. Measurement of Particulates and Statistical Analysis

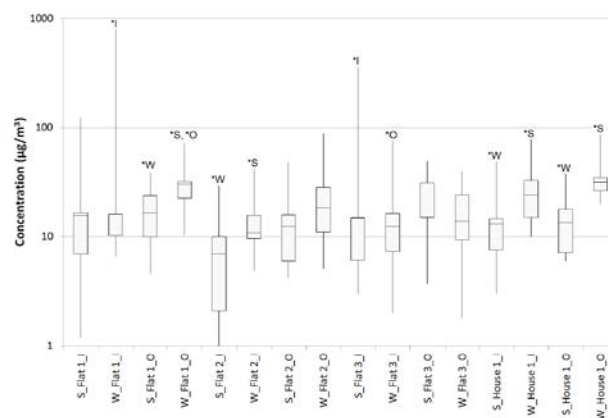
The concentration of particulate matter (both indoors and outdoors) and fine particles (only indoors) were measured with light-scattering laser photometer TSI DustTrak 8533 indoors and with TSI DustTrak 8520 outdoors. Indoors, both particulate matter and fine particles were measured, whereas outdoors only PM<sub>10</sub> was recorded due to the technical availability of the equipment. Three-day measuring campaigns were carried out, both in summer and winter. The levels were measured after every 10 s and based on that hourly average levels were calculated for further analyses.

Based on the hourly data, the indoor/outdoor (I/O) ratios and the proportion of fine particles (PM<sub>2.5</sub>) in the indoor particulate pollution (PM<sub>10</sub>) fraction were calculated for each study site. Moreover, correlations between the indoor and outdoor levels were found. The statistical differences between the indoor and outdoor levels on each study site as well as summer and winter indoor concentrations were tested with a t-test in STATA.

## 3. Results and Discussion

In general, during the study period the concentrations of particulate matter outdoors were 15.8 and 25.9 µg/m<sup>3</sup> as the summer and winter period average, respectively. In the air quality measuring stations, the annual average particulate matter concentrations in 2013 were 17.4 µg/m<sup>3</sup> in the city centre, 11.7 µg/m<sup>3</sup> in the semi-industrial area and 13.2 µg/m<sup>3</sup> in the residential area [20]. During the study period, the average summer concentration of indoor particulate matter was 15.0 µg/m<sup>3</sup> and the average winter concentration was 22.2 µg/m<sup>3</sup>.

During the study period, several very high levels of indoor particulate episodes appeared (Figure 1-Figure 3), mostly caused by cooking. Several studies have shown that cooking can be a very significant contributor to indoor particulate pollution; especially in studio flats [12]. It also appeared that most of the particulate matter during these episodes were fine particles (Figure 2, Figure 3). The episodes appeared both in winter and summer, being worst in small flats. Even though Flat 1 had mechanical ventilation and Flat 3 only natural ventilation, no statistically significant difference between the levels of particulates was detected in the two flats.



**Figure 1.** Mean, min, max, 25 and 75 percentile values of particulate matter in summer (S), winter (W), indoors (I) and outdoors (O) in different study locations

\*I - different ( $p < 0.05$ ) from indoor levels, \*O – different ( $p < 0.05$ ) from outdoor levels, \*W - different ( $p < 0.05$ ) from winter levels, \*S – different ( $p < 0.05$ ) from summer levels

In House 1 the high indoor and outdoor levels in summer were caused by heating fireplaces, and the sauna stove and outdoor fires in summer evenings (Figure 2). As at the same time also indoor levels increased, it indicates that the penetration of that kind of outdoor pollution can significantly contribute to the increases in the overall particulate matter level during a warm season. In winter, due to active heating, several high peaks appeared, both indoors and outdoors. First, this indicates that part of the indoor exposure is of outdoor origin, mainly due to the infiltration of outdoor air pollution (primarily caused by residential heating as the highest peaks appeared during heating times).

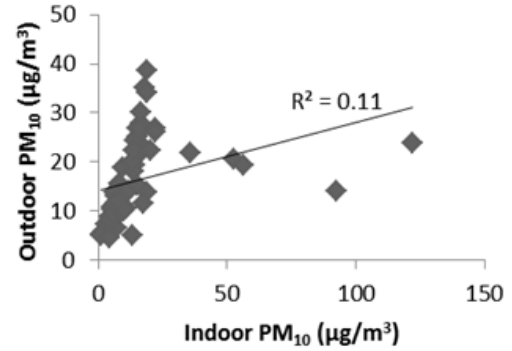
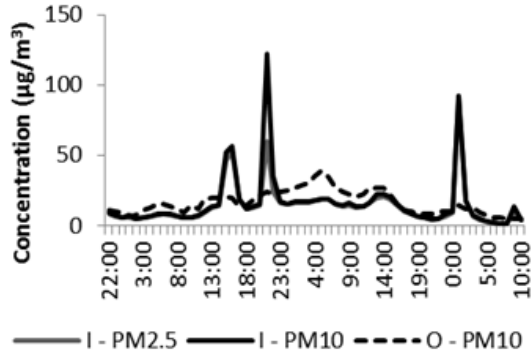
In general the indoor levels were lowest in Flat 2. Although located in the city centre, it had no windows on the street side. Moreover, as that flat was equipped with a portable indoor air filter, this may have decreased the pollution levels. This confirms the findings from several earlier studies that these kinds of filters can substantially decrease the indoor particle levels in houses by about 4–8 µg/m<sup>3</sup> [21], as well as in houses with residential heating up to 85% [22,23]. Moreover, due to the differences in cooking habits (no frying), cooking did not play as crucial a role as in Flats 1 and 3.

The highest correlation ( $R^2 = 0.79-0.85$ ) between the indoor and outdoor concentration also appeared in Flat 2. This is probably caused by a higher proportion of particles of outdoor origin compared to other sites and hence the

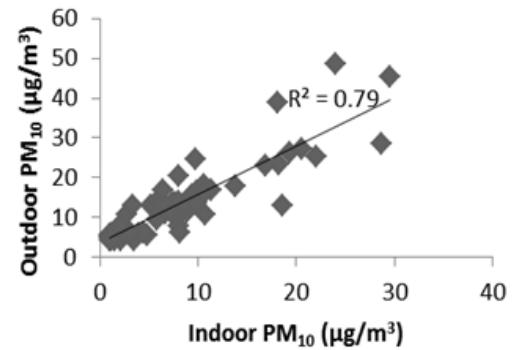
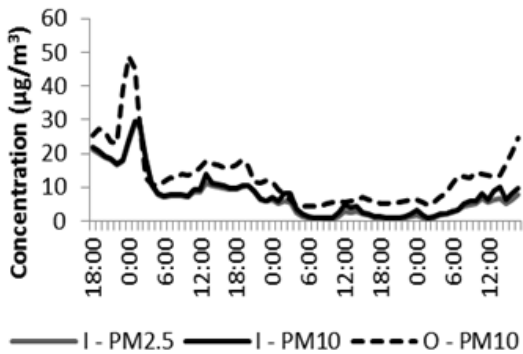
lower role of indoor sources (Figure 2, Figure 3). In House 1 the correlation was relatively good ( $R^2=0.52$ ) in summer (infiltration from open windows), but very poor in winter, where again indoor sources played a significant role. In Flats 1 and 3 the correlations were poor due to significant indoor sources (mainly cooking). However, when we excluded the extreme values, the correlation increased up

to 0.68 in Flat 1. As in Flat 3 the correlation coefficient stayed low, despite excluding the extreme values, it might give some indication of the role of mechanical ventilation in Flat 1. Hence, during extreme indoor emissions this might not be sufficient for regulating indoor air quality. In a recent review Fisk [23] has concluded that particle filtration could reduce health effects by 7–25%.

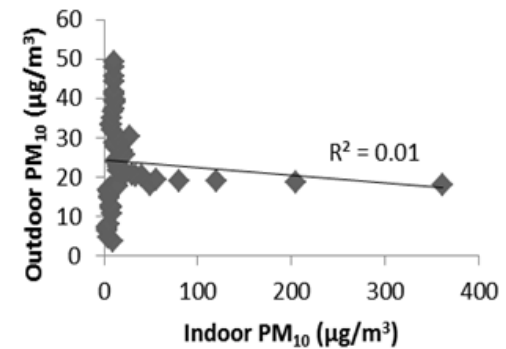
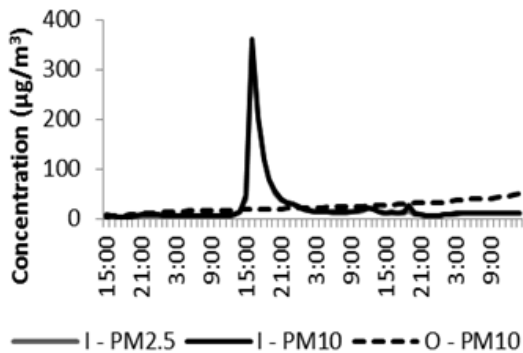
**Flat 1, 29.06-02.07.13**



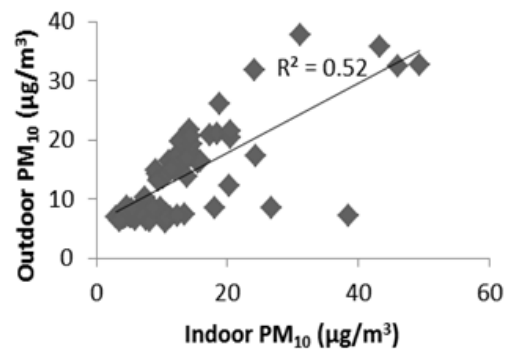
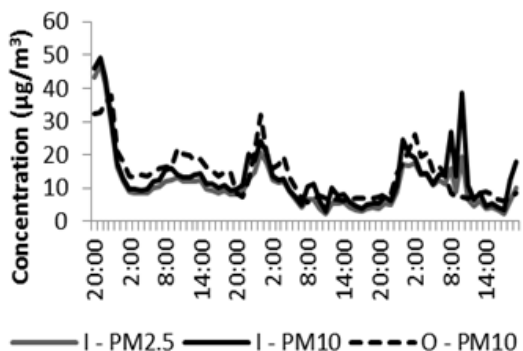
**Flat 2, 5-8.07.13**



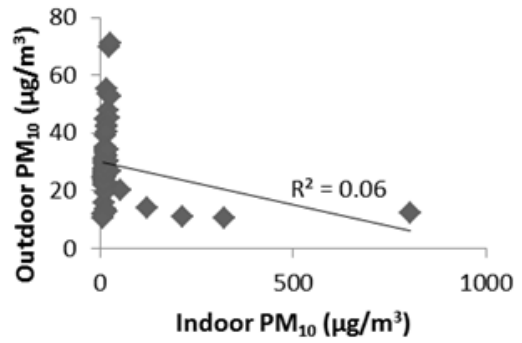
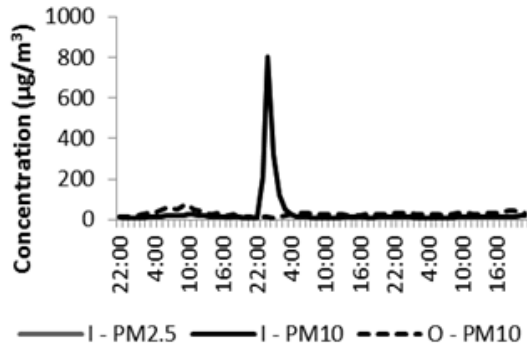
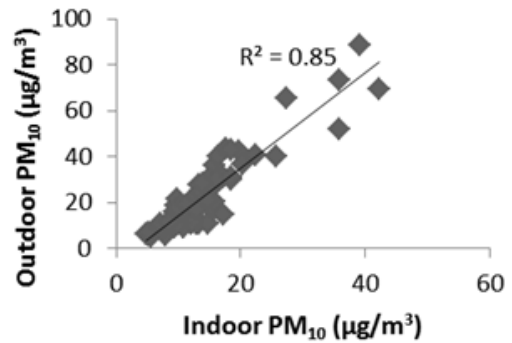
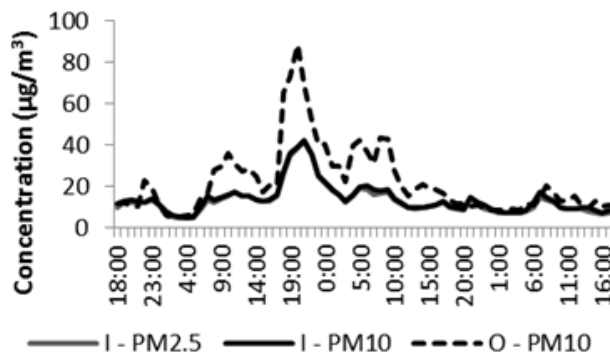
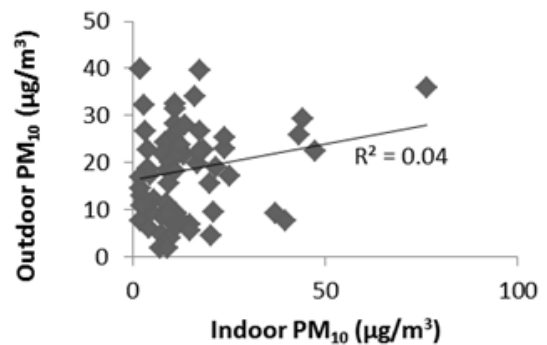
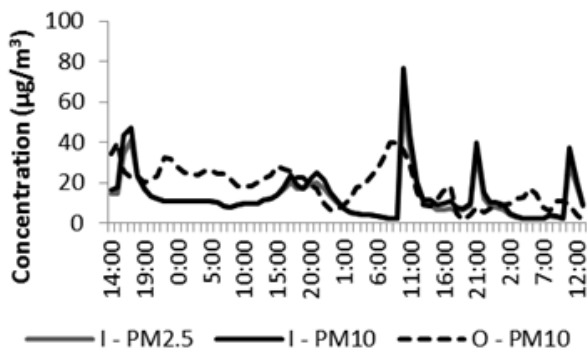
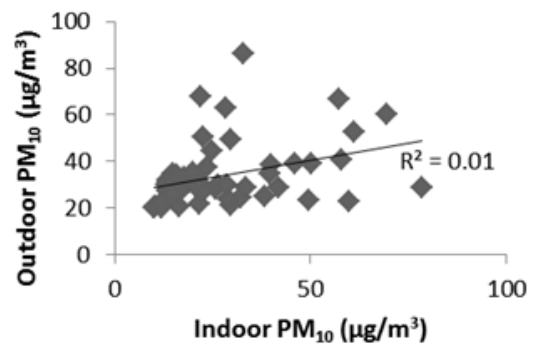
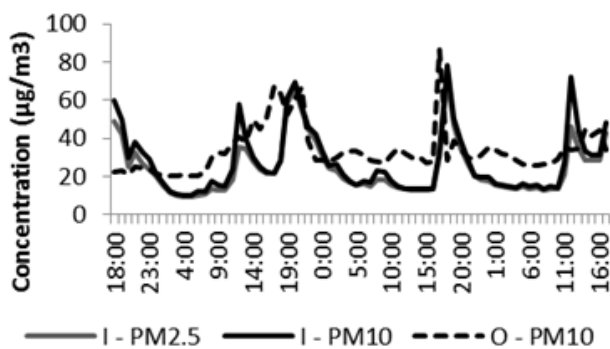
**Flat 3, 20-23.06.13**



**House 1, 10-13.07.13**



**Figure 2.** Concentrations of fine particles ( $PM_{2.5}$ ), and particulate matter ( $PM_{10}$ ) and indoor (I) and outdoor (O) levels in different study locations during the summer period

**Flat 1, 21-24.02.14****Flat 2, 18-21.02.14****Flat 3, 15-18.02.14****House 1, 26.02-01.03.14**

**Figure 3.** Concentrations of fine particles (PM<sub>2.5</sub>), and particulate matter (PM<sub>10</sub>) and indoor (I) and outdoor (O) levels in different study locations during the winter period

During the study period the indoor and outdoor ratios varied from 0.6 to 1.2, being lowest in Flat 2 and highest in Flat 1. In general the I/O ratios were higher in summer and lower in winter, when the windows were closed.

When we compare these I/O ratios with other results, according to the Chen and Zha [24] meta-analysis, the ratios vary from 0.5 to 2.5. In general in Nordic countries the I/O ratios have been around 1 [25], with the low

infiltration factor [26]. There is also some indication of higher ratios in wintertime [25].

When the differences between summer and winter, and indoor and outdoor levels were tested in different locations, statistically significant differences ( $p < 0.05$ ) between different locations were noticed. Most often the differences appeared between the summer and winter values as was seen in Flat 1 outdoors, Flat 2 indoors and House 1 both indoors and outdoors (Figure 1). The differences between summer and winter levels have also been shown in some earlier studies [27] as well as in outdoor levels in Estonia [28]. Moreover, we saw differences between the indoor/outdoor levels in winter in Flat 1 and in summer in Flat 3 (Figure 1). There is also some indication of that in earlier studies; however, results vary among the study sites [25].

Nevertheless, the data collected during the current study are limited and we should be careful with interpreting the results. Thus there is a need for further investigations and measures to verify the indicated relationships between ventilation, heating systems and lifestyle in the Northern climate.

## 4. Conclusions

The current study indicated that indoor particulate levels are affected both by outdoor air quality and indoor sources, such as residential heating. In a studied house with wood stoves significantly higher levels appeared in winter, with high peaks during evening heating times. The indoor/outdoor ratios varied from 0.6 to 1.2 in some locations, being often close to 1. The indoor air quality was even more affected by indoor cooking, which in some cases caused extremely high levels of fine particles (up to  $800 \mu\text{g}/\text{m}^3$  as hourly average). Even though that flat had mechanical ventilation, during these cooking episodes it was not sufficient to guarantee good indoor air quality. In a flat with a HEPA filter, we did not see such peaks; however, there were also differences in lifestyle (no cooking party). Even though several high peaks appeared, the particulate matter levels during a 3-day period were still relatively low:  $15.0/22.2 \mu\text{g}/\text{m}^3$  as a summer/winter period average indoors and  $15.8/25.9 \mu\text{g}/\text{m}^3$  outdoors. This study indicates the need for further elucidating the variability in the rates of indoor air pollution in relation to infiltration rates, heating systems, ventilation and filtering mechanisms and the role of lifestyle.

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## Statement of Competing Interests

Authors have no competing interests.

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