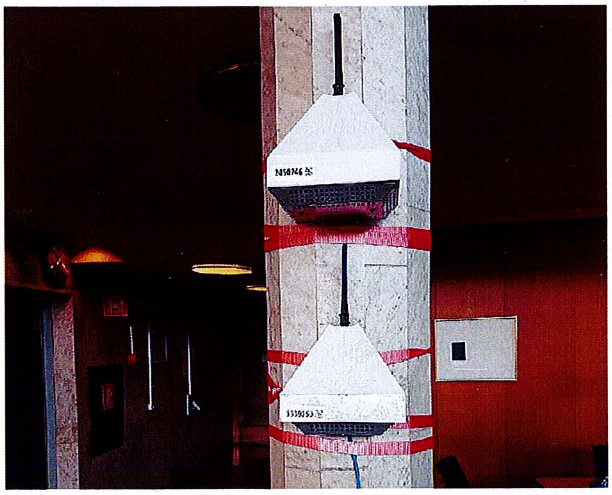
AIR QUALITY, INDOOR AND OUTDOOR

A study of connections between indoor and outdoor concentrations: NO_2, CO_2, PM_{10} and $PM_{2.5}$



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Abstract

Air pollution is a hazard to human health and especially vulnerable are those who live in urban areas. Urban areas are undergoing fast driven urbanization which often results in increased air pollution. Since different types of air pollutions have various impact on human health, the knowledge of how these air pollutants behave is important in the context of reducing air pollutant and aiming toward a sustained environment with clean air. Today, focus is often on outdoor air quality, we will with this study highlight the importance of studying indoor environment since it is showed that people in general spend 90 % of their time indoors. This study investigates how the indoor air quality is affected by outdoor concentrations of air pollutant. Further we will examine the variability of outdoor air quality depending on prevailing meteorological factors such as air pressure, air temperature, precipitation, solar radiation and wind speed. The study is based on measurements taken at Mölndal municipality building and complemented with measurement data of pollutants and meteorology from monitoring stations in the Gothenburg and Onsala area.

Result showed that outdoor NO_2 and PM_{10} concentrations at Mölndal municipally building is mainly an effect of urban sources while $PM_{2.5}$ originates from both the regional background and urban sources. The indoor PM and CO_2 concentrations increase with occupancy in the building which can be seen when looking at differences between weekdays/weekends and day/night concentrations. Further, when studying the indoor/outdoor (I/O) CO_2 ratio the connection to activity in the building seems clear. Both NO_2 and PM seems to be dependent on the activity of ventilation, during times with indoor ventilation the outdoor concentrations of the compounds is mirrored in the indoor environment but with a lag time. NO_2, PM_{10} and $PM_{2.5}$ could not be highly correlated between indoor and outdoor environment, the absence of correlation is rather a result by lag times than a lack of connection to each other. Indoor PM is shown to be dependent on both occupancy and ventilation, but to which degree ventilation and occupancy affects indoor PM is hard to determine.

Inversions where found to be the main influencer on outdoor monthly mean values while outdoor concentrations of CO_2, NO_2, PM_{10} and $PM_{2.5}$ generated no clear connection to the prevailing meteorology. The reason could be the dependency of interaction between meteorological parameters or because a lag time might be present.

Further investigating in the topic is needed to be able to bring out indoor air quality regulations to promote healthy indoor environment. Also, to understand the outdoor variations in air pollution concentrations to a greater extent.

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1 Introduction

1.1 Air pollution

Air pollution in the environment causes more than 2 million premature deaths worldwide and approximately 7600 deaths in Sweden alone (Gustafsson et al., 2018; World Health Organization [WHO], 2010). Clean air in the environment is essential for human wellbeing. Urbanization is strongly linked to increased concentration of air pollution that is present in a society. Fast driven urbanization generates a rapid increase of motor vehicles in the urban area as well as exacerbates the urban heat island effect which in turn contributes to poor air quality (Hassan, Hashim, & Hashim, 2016). Further, the ongoing densification of urban areas results in more people per square meter and usually also worsen the air quality. This results in poor dispersion of emissions at street level, thus reducing the availability of fresh air entering a building through the ventilation (Yassin, 2013) and further increases the risk of exposure to indoor air pollutants. Motor vehicles cause deteriorating air quality in urban areas through emittance of primary pollutants such as carbon monoxide, nitrogen dioxide, black carbon and particulate matter (PM) originating from high traffic roads. Exposure to air pollutants is constantly present and strategies to reduce the impact of air pollution change as research progresses. Gaining awareness of how people are affected by poor air quality both indoors and outdoors is given the opportunity to reduce the effects and work towards a clean air environment (World Health Organization [WHO], 2006b).

Fossil fuel depletion caused by human activity is triggering the deteriorating air quality globally as well as locally. The dispersion and thus the concentrations of air pollutants are determined by wind speed, through controlling the mass concentration, and wind direction, through placement (Oke, Mills, Christen, & Voogt, 2017). Air stability is also an important aspect in determining the concentration of near ground air pollutants (Haeger-Eugensson, 1999; Laurin & Färnlöf, 1994; Oke et al., 2017). During ground inversions events, the air pollution at ground level gets exacerbated due to the stability of the atmosphere when temperatures at ground is colder than higher up in the atmosphere causing poor ventilation, especially vertically but usually also horizontally (Laurin & Färnlöf, 1994). IPCC (2014) mentions that good air quality is important to be able to reach sustainable development and further to mitigate climate change. Due to people spending around 90 % of their time indoors, indoor air quality (IAQ) is an important area to study (Hwang & Park, 2019; Jantunen, 2007; McCreddin, Gill, Broderick, &

McNabola, 2013). However, IAQ is not as well evaluated as outdoor air pollutant and need to be further studied to understand the consequences of poor IAQ (World Health Organization [WHO], 2010).

1.1.1 Indoor air quality affecting health

Poor IAQ has been shown to reduce productivity in workplaces as well as contributing to a multitude of health risks (Lee & Chang, 2000). Common air pollutants such as nitrogen dioxide (NO_2), carbon dioxide (CO_2) and particulate matter (PM) all entail some health risks. Although the effects of NO_2 are not completely understood, reduced development of lung function in children has been linked to higher concentrations of NO_2. PM is divided depending on the size of the particulates. Particles up to 10 µm (PM_{10}) are defined as coarse particles, < 2.5 µm ($PM_{2.5}$) are defined as fine and finally < 0.1 µm are defined as ultrafine particles. Of these types of PM, fine particles have shown to have the most impact on health (Jantunen, 2007). $PM_{2.5}$ induces respiratory diseases such as aggravated asthma and, furthermore, alters the cell microenvironment which correlates with carcinogenic responses in lung tissue (Li, Zhou, & Zhang, 2018). CO_2 has been shown to cause negative health effects such as inflammation as well as reducing higher-level cognitive abilities (Jacobson et al., 2019)

1.1.2 Regulations

To be able to reduce health related issues formed by reduced air quality, the World Health Organisation (WHO) has stated some guidelines for limiting exposure rates of different air pollutants. These guidelines are used for both outdoor and indoor environments concerning NO_2, PM_{10} and $PM_{2.5}$ (Table 1) (World Health Organization [WHO], 2006b, 2010). Naturvårdsverket in Sweden is responsible for the outdoor air quality targets, *miljömål,* environmental goal, to favour a sustainable future. This environmental goal is set by the Swedish government and aims to be reached within a generation (Naturvårdsverket, 2020a). The outdoor air quality legislation used in Sweden today is called environmental standards (MKN) (Naturvårdsverket, 2020b), these are less ambitious than the environmental goal and is undertaken by the Swedish governmental law in luftkvalitetsförordningen (SFS 2010:477) (Table 1). MKN is set by regulations from the European Union (EU) to favour a clean and healthy environment (Naturvårdsverket, 2020a). Unfortunately, general IAQ limits are missing, causing *arbetsmiljönivåer,* ‘environmental working-levels’, to commonly be used as quantitative levels of exposure (Arbetsmiljöverket, 2018) (Table 1). This study will have its focus in Mölndal which has its own local sub outdoor environmental goal, *Miljömål Mölndal*, aiming to be reached within year 2022 (Mölndals stad, 2014) (Table 1).

Table 1. Guidelines and legislations for air quality

Pollutant	*Mean time*	*MKN* (µg/m^3)	*MKN-Permitted overruns each year*	*WHO* (µg/m^3)	*Miljömål Mölndal* (µg/m^3)	*Miljömål Mölndal Permitted overruns each year*	*Arbetsmiljö-nivåer*
NO_2	1 h	90	175 h**	200	60*	175 h	-
	24 h	60	7 days	-	-	-	960 µg/m^3
	Year	40	-	40	20*	-	-
PM_{10}	24 h	50	35 days	50	30	37 days	-
	Year	40	-	20	15*	-	-
$PM_{2,5}$	24 h	-	-	25	-	-	-
	Year	25	-	10	-	-	-
CO_2	8 h	-	-	-	-	-	5000 ppm

*Note** goals for schools, homes and kindergartens.
*Note*** not allowed to transcend 200 µg/m^3 during an hour more than 18 times a year.
Sources: (Arbetsmiljöverket, 2018; Mölndals stad, 2014; Sveriges Riksdag, 2010; World Health Organization [WHO], 2006b)

1.1.3 Indoor and outdoor relationships

There are various studies on the so-called indoor/outdoor (I/O) relationship which highlight the I/O ratio of pollutants (Blondeau, 2005; Challoner & Gill, 2014; Martins & Carrilho da Graça, 2018; Miller, Facciola, Toohey, & Zhai, 2017). IAQ is highly dependent on the outdoor air quality, which in turn is dependent on meteorological conditions (Challoner & Gill, 2014; Hassan et al., 2016). The levels of emissions in the vicinity to the building is another important factor, combined with the ventilation which will be explained more in detail further on.

The I/O ratios of PM_{10} have been connected to human activity in a building, indicating that movement inside a building can be a source of PM_{10} (Braniš, Řezáčová, & Domasová, 2005). The movement of humans inside a building cause resuspension or delayed deposition of PM_{10} which impacts the I/O ratio (Goyal & Khare, 2011). The I/O ratios during weekends and weekdays also show distinct differences. Indoor concentrations during weekdays are higher than those of weekends which Goyal and Khare (2011) attributes to there being more occupants in the building. This ties into the I/O ratios of CO_2 which is strongly tied to how many occupants are in a building. Blondeau (2005) could use I/O ratios of CO_2 as an indicator of occupancy in his study because of this correlation. Thus, CO_2 has the capability to act as an air quality controller and ventilation indicator in indoor spaces because of its reflection of indoor air quality (Ben-David & Waring, 2016; Hwang & Park, 2019).

The NO_2 I/O ratios are often lower than 1, thus, indicating that outdoor sources are the main influencer of indoor NO_2 (Jantunen, 2007; World Health Organization [WHO], 2010). Jantunen (2007) explains these I/O ratio with the reactive nature of NO_2 in indoor environment. Ozone (O_3) levels in urban areas are usually low due to traffic releasing NO. This causes a chemical reaction where NO together with sunlight breaks down O_3 to create NO_2 (Jantunen, 2007; World Health Organization [WHO], 2006a).

1.1.4 Indoor air quality and ventilation

Earlier studies emphasize the need for indoor ventilation to increase the IAQ (Challoner & Gill, 2014; Hwang & Park, 2019; Jantunen, 2007). Challoner and Gill (2014) found that indoor NO_2 concentrations correspond to outdoor concentrations at ground level. They suggested that the ventilation could be switched-on at midnight to increase the IAQ which would reduce the indoor concentration of NO_2 and $PM_{2.5}$. Martins and Carrilho da Graça (2018) and Othman et al. (2020) mentioned that the indoor PM is mainly affected by indoor activities while ventilation can reduce the amount of pollutants entering the building. Pacitto et al. (2020) arrived at the same conclusion when he studied the indoor PM_1 to PM_{10} concentrations in a gym and compared it with outside concentrations.

1.2 Aim

This study aims to investigate the connection between indoor and outdoor air quality in an office building surrounded by high traffic roads. Focus lies on how the IAQ varies with outdoor sources and meteorological conditions together with the aspect of ventilation steering. Air pollutants considered are NO_2, $PM_{2.5}$ and PM_{10} due to it substantial effect on human health related issues. CO_2 is measured as an indicator of human occupancy in the building. Raised questions in this matter are:

- How does the indoor air quality vary over time?
- Is the IAQ connected to outdoor air quality and further to meteorology?
- What effect does the indoor ventilation have on the indoor air quality?
- Is there a need to improve the indoor air quality?

1.3 Study area

The investigated office building is the Mölndal municipality hall located in an urban environment (Fig. 1, 2). The municipality hall is made of brick and was built in 1962 and consists of four floors (Wikipedia, 2019). It contains an atrium hall where the outflow ventilation is located. The main inflow ventilation is located on the roof in the northeast corner of the building. Ventilation in the offices is on during Monday to Thursday 04:30-18:30 and Fridays 04:30-16:30. The ventilation in the meeting rooms is active on Monday to Thursday 06:00-22:00 and Fridays 06:00-18:30.

Figure 1. Roof-view from Mölndal municipality building where our measurements took place. The high traffic roads Göteborgsvägen and E6 can be seen in the background together with train and tram stops.

The air quality in Mölndal municipality has steadily been improved since the 1970's. Air pollutants that exceed the MKN are still an issue in some areas where traffic roads are the dominating source for PM and NO_x (Mölndals stad, 2014). Mölndals stad is actively working to integrate green areas in the city to reduce particles and toxic substances in the air (Mölndals stad, 2018). The area surrounding the municipality hall is diverse, high traffic road in the east, city centre in the south and *Stadshusparken*, the biggest park in Mölndal, located just behind the municipality hall to the west (Mölndals stad, 2020).

The air quality in the area is dependent on the regional background and the urban scale, NO_2 and CO_2 are mainly pollutants from urban scale while $PM_{2.5}$ is mainly a result of regional background due to the ability to travel and be suspended in the atmosphere for a long time (World Health Organization [WHO], 2006a). Since the concentrations of air pollutants is dependent on the prevailing regional background transportation and urban scale, it will vary year to year. Two different years where chosen as reference years for evaluation of year 2020 (February and March) dispersion patterns. One year (2016) with bad dispersion wintertime and one year (2018) with good dispersion wintertime (Table 2) (M. Haeger-Eugensson, personal communication, April 16, 2020). Year 2018 (February and March) in Gothenburg, Skansen Lejonet, was colder than usually with 1.1 degrees lower mean temperature than normal in

February and 2.4 degrees lower mean temperature in March. March 2018 was drier and less windy than normal. Only one inversion was detected in February 2018, in March there were some inversions (9th of March and the period 19th of March to 21st of March). The NO_2 concentration was at a normal level in Femman and Gårda in February 2018 on average but there where outliers, high concentration was seen in the beginning and the end of February when the temperature decreased. In March 2018, the NO_2 concentrations were lower in Femman but higher in Gårda than normal concentrations. Particle levels were normal at Femman station but was higher in Gårda during February 2018, unfortunately March 2018 had to little data coverage to be able to calculate a mean of particle levels and is therefore lacking (Göteborgs stad, 2018a, 2018b). In comparison, year 2016 (February and March) in Gothenburg, Skansen Lejonet, was warmer than usually with mean temperatures around 1 degree higher than usually. This year, 2016, in February was also slightly wetter than normal, and March was much wetter than normal. Inversions were present in February 2016 both in the beginning, middle and at the end while it in March 2016 there was in general two bigger events (15th of March and 26th of March) of inversions and some small inversions spread out between these two events. February and March 2016 had NO_2 concentrations above normal and MKN where transcended several times both at Femman and Gårda. Particle-levels were in both February and March 2016 lower than normal at Femman but normal at Gårda (Göteborgs stad, 2016a, 2016b).

Table 2. Air pollution concentration for February and March 2016 and 2018

Station	*Air pollutant*	*Mean month value* (µg/m^3)			
		February 2016	*February 2018*	*March 2016*	*March 2018*
Gårda	NO_2	55.4	46.8	40.2	44.6
	PM_{10}	32.7	36.2	36.1	*
Femman	NO_2	28.6	19.7	25.2	20.9
	PM_{10}	14.3	15.7	17.4	*

*Note** Too low data coverage to be able to calculate a mean value. Source: (Göteborgs stad, 2016a, 2016b, 2018a, 2018b)

2 Method

2.1 Measuring station

Portable air sampling measurement stations (so called AQMesh pods) placed at Mölndal municipality hall were used as primary measurements. Measurements were taken both indoors and outdoors.

2.1.1 Placement and measurement parameters

Air sampling stations were placed inside the building on the third floor close to the ventilation outtake in the atrium hall. The outdoor measuring station was placed on the roof close to the air intake of the ventilation, located in the northeast corner of the building. At each place two measuring pods were running where one measured PM_{10}, $PM_{2.5}$, air temperature and humidity while the other measured NO_2, CO_2, air temperature and humidity. The focus of the analysis will be on NO_2, PM_{10} and $PM_{2.5}$ because of the health implications connected with them, CO_2 will also be analysed to a lesser degree. Measurements were taken every 15 sec during the measuring period from 14th February to 7th of April. The pods measuring gases used lithium batteries while the pods measuring particles were plugged directly into an outlet.

2.1.2 Calibration

The air samplings pods were calibrated against each other for two weeks before the actual measuring period took place. During the calibration period all pods were placed next to each other on the roof. After successfully calibrating the pods, two pods were moved inside. Before using data from the indoor measurements, the pods needed to be active for three days to stabilize. The same method was applied when the indoor measurements were stopped due to battery loss and were turned back on after 11 days of inactivity. When the measuring period ended, it was followed by a two-week calibration where all pods were once again placed on the roof to see if the pods still measured accurately.

2.1.3 Used monitoring sites

Meteorological data was gathered from Göteborgs stad *Öppna data*, this site collects all public data for the Gothenburg region. Meteorological parameters of interest were air temperature, wind speed, solar radiation, precipitation and air pressure. These parameters were taken from two meteorological stations in the Gothenburg area: Skansen Lejonet and Femman except from the meteorological measurements taken at Mölndal municipality building. Femman, Gårda and

Råö are used as reference stations for air pollutants. Femman, Gårda and Skansen Lejonet is in the Gothenburg area while Råö station is located in Onsala (Fig. 2)

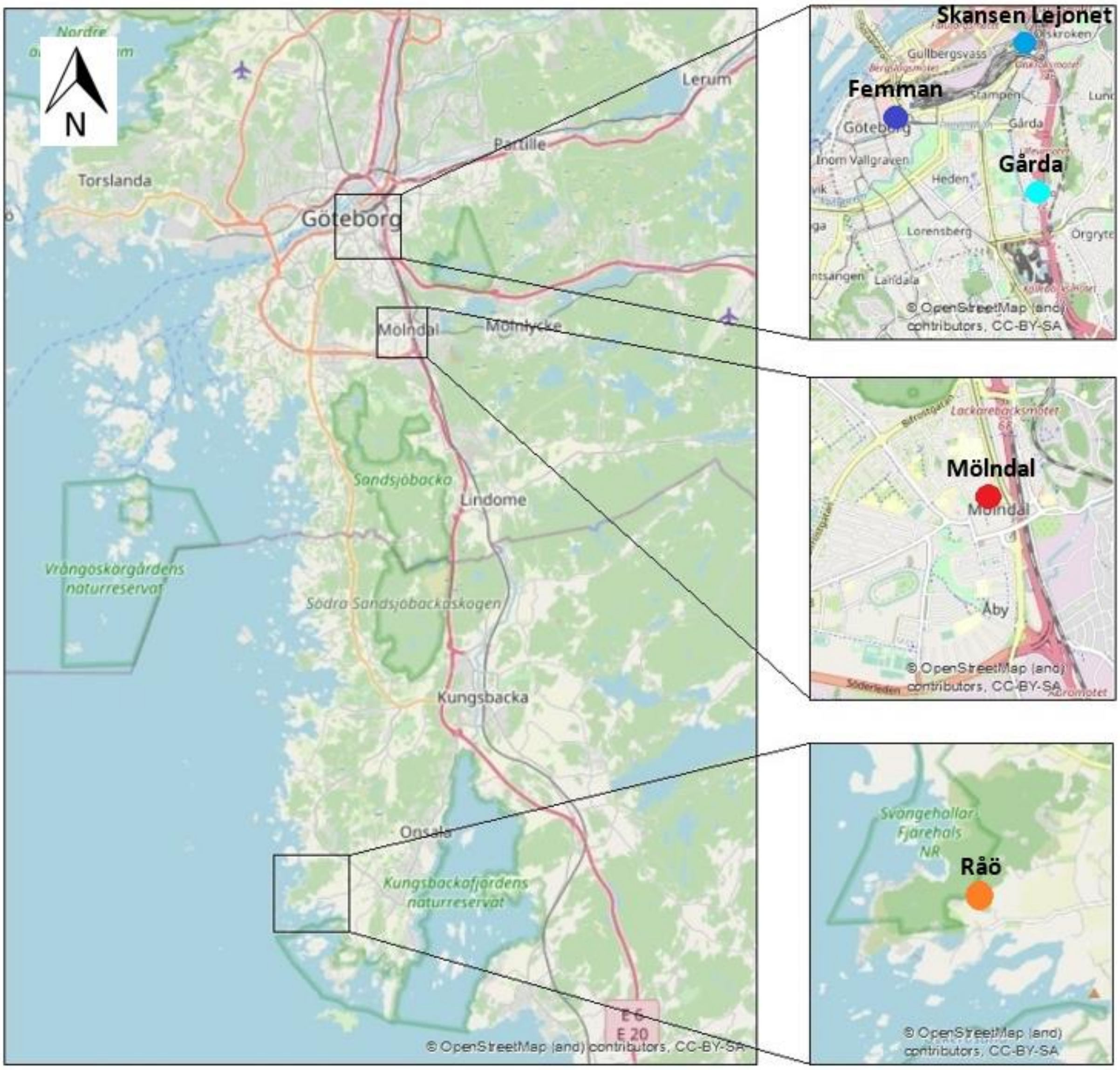

Figure 2. Location of measuring stations used in this study

2.2 Analysing data

Meteorological data taken under the measuring period (Fig. 3) were studied in AQMesh web portal to be able to choose periods where the meteorological conditions were different from each other. Inversions could be detected through analysing the temperature variations with height. This was done through comparing the temperature in Gothenburg at the monitoring station Skansen Lejonet between two- and eight-meters height. If a positive value above 0.5 was observed (Göteborgs stad, 2018b), an inversion was detected, indicating that the air temperature gets warmer with height.

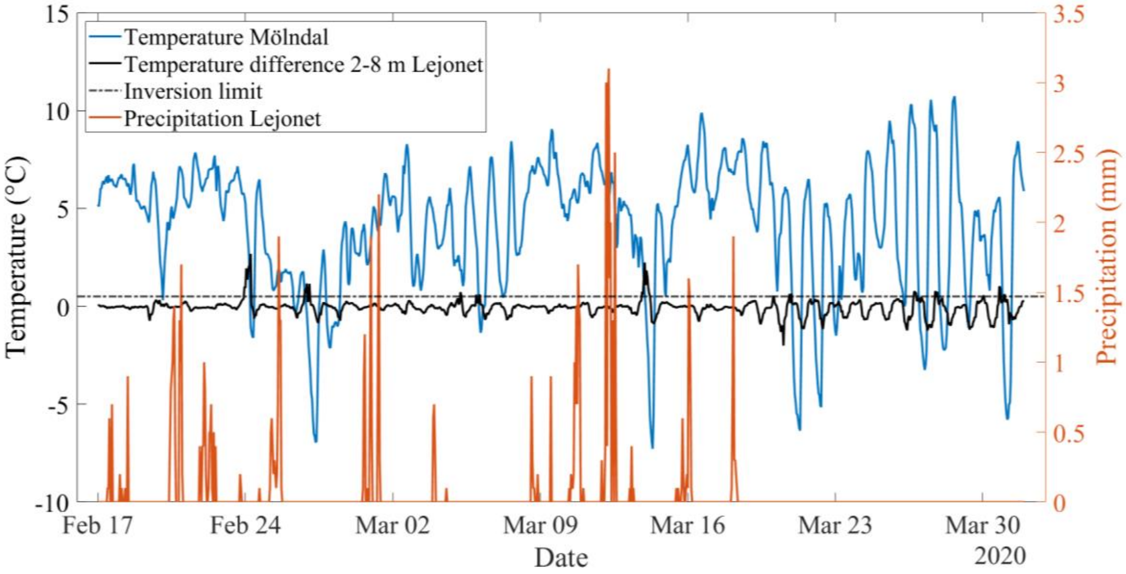

Figure 3. Meteorological conditions during measuring period, times with inversions is seen where the temperature difference 2-8 m at Skansen Lejonet is above the inversion limit.

2.2.1 Periods of interest

These periods were chosen with respect to the prevailing meteorological conditions (Table 3). Our aim was to find periods with high pressure, low pressure, inversion, precipitation and high wind speed to detect how the concentrations vary depending on the different meteorological state. High pressure is often highlighted by sunny sky, little wind, high temperature variation during day and night and no precipitation. On the other hand, low pressure weather is often connected to clouds, small temperature variations and some precipitation.

Table 3. Interesting periods that were chosen to be further investigated

Period	*Meteorological description*
24th February	Ground inversion during 01:00 to 06:00.
27th February	Weak ground inversion during 22:00 to 01:00.
3rd to 5th March	Wind speeds of 0-5 m/s, cloudy, under 1 mm of precipitation
8th to 15th March	Heaviest precipitation during measurement period.
26th to 29th March	Warm, sunny, wind speeds of 0-4 m/s, high pressure

2.2.2 Yearly distribution comparison

Mean concentration values of air pollutants in Mölndal for February and March were calculated in MATLAB. The mean value for February included 17th to 29th and the mean value for March included the periods 1st to 8th and 22nd to 31st due to lack of data between the periods. These mean values were compared with earlier years, 2016 and 2018 in Femman and Gårda to see how this year behaved in comparison to a year with good wintertime dispersion and a year with bad wintertime dispersion.

2.2.3 Urban scale or regional background

For the investigated periods in Mölndal 2020, the air pollution distribution on an urban and regional scale was investigated. The urban scale was investigated by comparing concentrations at Mölndal with Femman station in Gothenburg. Pearson’s correlation was used to indicate if there were the same patterns at the both sites and two sample Kolmogorov-Smirnov tests (KS2-test) were used to see if the data from Femman and Mölndal came from the same continuous distribution. For particles, Råö station in Onsala was used to see the regional background and detect long range transport. If particle levels are high at Råö as well as in Mölndal and Gothenburg, then it can be due to long range transport. If the opposite is true, low particle concentration at Råö and high concentrations in Mölndal and Gothenburg indicates that the source is likely urban.

2.2.4 Meteorology and I/O correlations

For each investigated period, Pearson's correlation was performed. This was done to highlight clear connections between meteorological parameters (wind speed, temperature, precipitation, air pressure and solar radiation) and I/O air quality (NO_2, CO_2, PM_{10} and $PM_{2.5}$). There was also a period during the 8th to 15th of March where a correlation analysis was performed regarding precipitation and outdoor PM, to see if precipitation affects the concentration of PM.

2.2.5 Hourly and daily comparison indoor/outdoor

The indoor and outdoor measurements at Mölndal were divided into weekdays, weekends, day, and night to be analysed separately. Sundays were chosen as weekends and Tuesdays as weekdays. Plots were created where the gas and particle data were analysed independently depending on day of the week and time of day. I/O ratios were calculated by dividing indoor concentrations with those outside. These was done from the 17th of February to the 7th of March using a mean value of eight hours from 08:00 to 16:00.

2.2.6 Indoor and outdoor variations

To understand the variations between indoor and outdoor air pollutant concentration of PM_{10}, $PM_{2.5}$ and NO_2, an hourly mean concentration analysis was performed. Data used for this analysis is from the measuring site Mölndal. Pivot tables were created in Excel to be able to calculate mean concentrations for every hour of the measuring period (17th of February to 31st of March). This analysis made it possible to get an overview of the average hourly concentration during the measuring period. The hourly mean concentration value for each of the investigated particles and gases were imported and plotted in MATLAB. This was done to visualize variations and be able to detect if there was a time lag by comparing peak values. The first peak in the morning was assumed to be the morning peak for every investigated air pollutant. If there were any time lag in between the peaks for indoor and outdoor, this time was assumed to be the lag time.

2.2.7 Indoor air quality affecting health

For all investigated particles and gases at Mölndal, an analysis of exceeded legislation (MKN), recommendations and the goal *Miljömål Mölndal* was conducted. For each of the measured particles and gases, mean values of concentrations were calculated. The chosen mean value was dependent on current legislation, recommendations or goals and varied between the different air pollutants (Table 1). For outdoor NO_2 concentrations, the mean value of 1 hour was plotted together with the limiting exposure rates set by the different organisations or legislations. Values that exceeded this limiting exposure rate were considered as overridden. Same procedure was performed for each differing mean value needed depending on what the legislation/limit called for. This was done for both indoor and outdoor concentrations of NO_2, CO_2, PM_{10} and $PM_{2.5}$.

3 Result

3.1 Yearly distribution comparison

Mean outdoor concentrations of NO_2 and PM_{10} vary depending on the month (Fig. 4) and meteorological conditions. Mean values from February and March 2020 at Mölndal show an increase of NO_2 from February to March while PM_{10} is stable in the same period. In comparison to earlier years, the year 2020 has low values similar to year 2018 at Femman measuring station and is seen as a good dispersion period which is highlighted by the low concentration levels of

NO_2 and PM_{10}. Meteorological conditions during 2020 is above normal considering temperature, wind speed and precipitation during both February and March. These patterns are not consistent with neither 2016 nor 2018 for February and March. 2016 was warm and wetter than normal but had more inversions and normal wind speed. 2018 was cold and slightly drier with calmer wind, on the other hand it had few inversions.

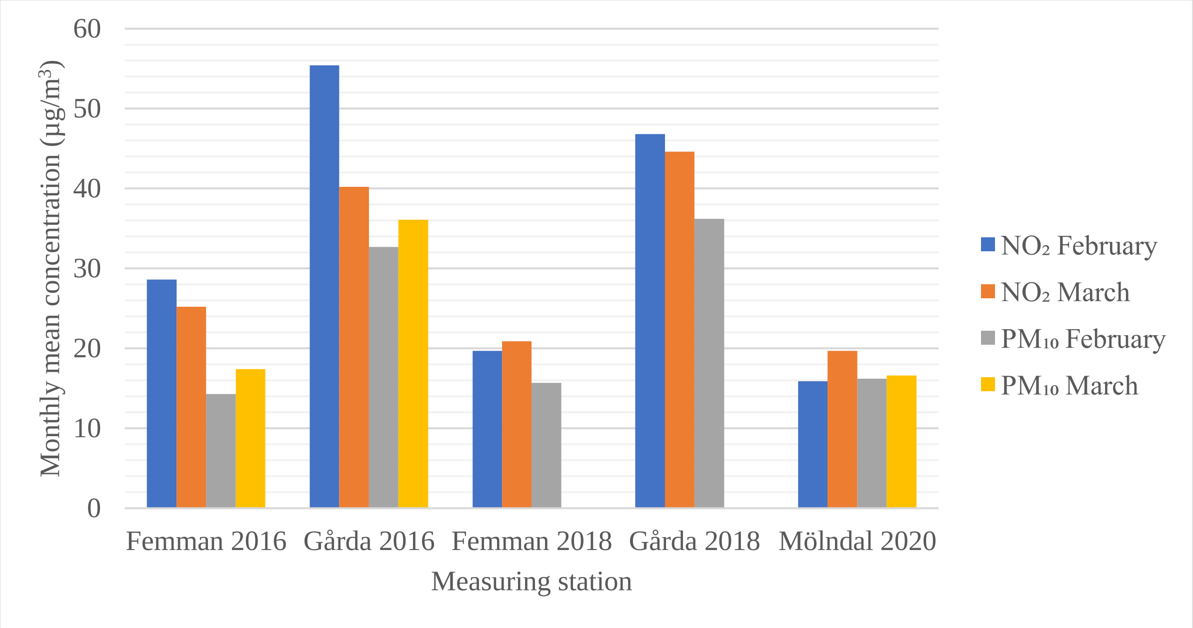

Figure 4. Mean values for different air pollutants, NO_2 and PM_{10}, during measuring period in February and March together with the mean concentration values for earlier year, 2016 and 2018, in February and March. 2016 is a year with bad dispersion wintertime (February and March) while 2018 is a year with good wintertime (February and March) dispersion.

3.2 Urban scale or regional background

The comparison between Mölndal and Femman reveals a KS2-test that indicates a tendency of beholding the null hypothesis for gases while it for particulate matter tends to reject the null hypothesis at a significance level of 95% (Table 4). This indicates that NO_2 has the same distribution pattern at the Mölndal measuring station as well as at the Femman monitoring station. The results however indicate that $PM_{2.5}$ is a result of the regional background since it rejects the null hypothesis, which indicates that the distribution patterns are different from each other. The pattern of PM_{10} is not as clear as the pattern for $PM_{2.5}$. The results show that PM_{10} is dependent on a combination of both regional background transportation and urban sources. The correlation is overall high for gases and low for PM. However, for $PM_{2.5}$ there are two periods with unusually high correlations, the 8th to 15th and 26th to 29th of March. This high correlation can also be seen for PM_{10} during the period 8th to 15th of March.

Table 4. Kolmogorov-Smirnow-two-sample test for different air pollutants together with correlation coefficient, comparing outdoor concentrations at station Femman in Gothenburg with measurements taken in Mölndal at Mölndal municipality building.

Date	*Test type*	*Femman/Mölndal NO_2*	*Femman/Mölndal $PM_{2.5}$*	*Femman/Mölndal PM_{10}*
24th of February	Correlation (R)	0,76	0,30	0,46
	KS2	0	1	0
27th of February	Correlation (R)	0,87	0,43	0,29
	KS2	0	1	1
3rd to 5th of March	Correlation (R)	0,60	0,16*	-0,13*
	KS2	0	1	1
8th to 15th of March	Correlation (R)	-	0,78	0,68
	KS2	-	1	1
26th to 29th of March	Correlation (R)	0,60	0,80	0,43
	KS2	1	1	0

*not significant value with significant limit of $P < 0.05$

The outdoor comparison of Råö and Mölndal concentrations of PM (Fig. 5) show mostly higher values at Mölndal, indicating an urban source of PM_{10}. $PM_{2.5}$ has sometimes higher concentrations at Råö than Mölndal. This usually indicates that there have been situations with long range transport of $PM_{2.5}$. This is further demonstrated by the results of the KS2-test which reject that they come from the same distribution. Outdoor mean concentrations at Råö for PM_{10} and $PM_{2.5}$ follow the same pattern with the difference of lower values of $PM_{2.5}$ (Fig. 6). Since

$PM_{2.5}$ is a part of the PM_{10} fraction, this difference is expected. However, the amount of fine fractions, $PM_{2.5}$, is high for Råö (Fig. 6) which indicates that the long range transport mostly consists of $PM_{2.5}$ and further strengthen the result from the KS2-test.

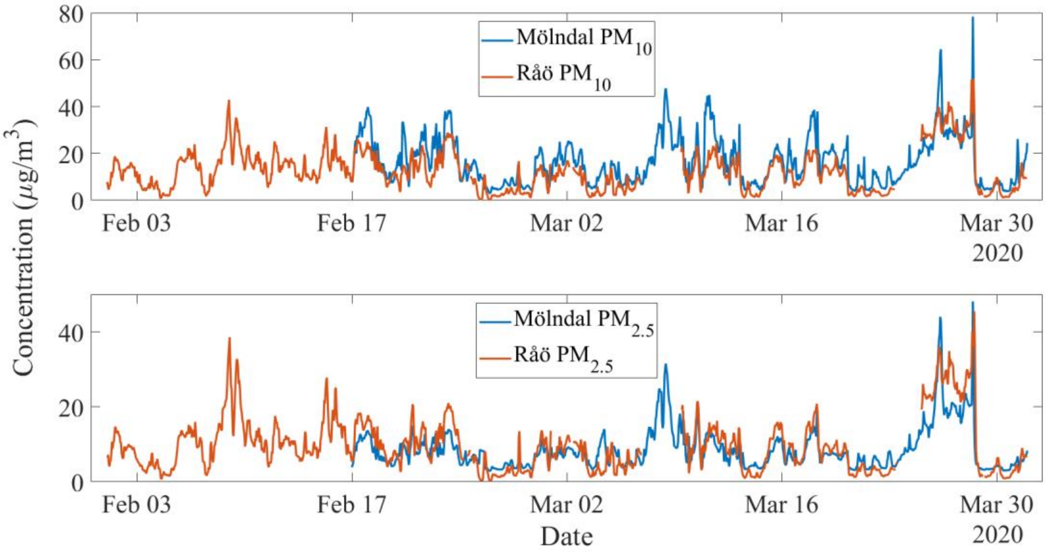

Figure 5. Concentration comparison of particles (PM_{10} and $PM_{2.5}$) taken at Råö station in Onsala with measurements taken in Mölndal at the roof of Mölndal municipality building.

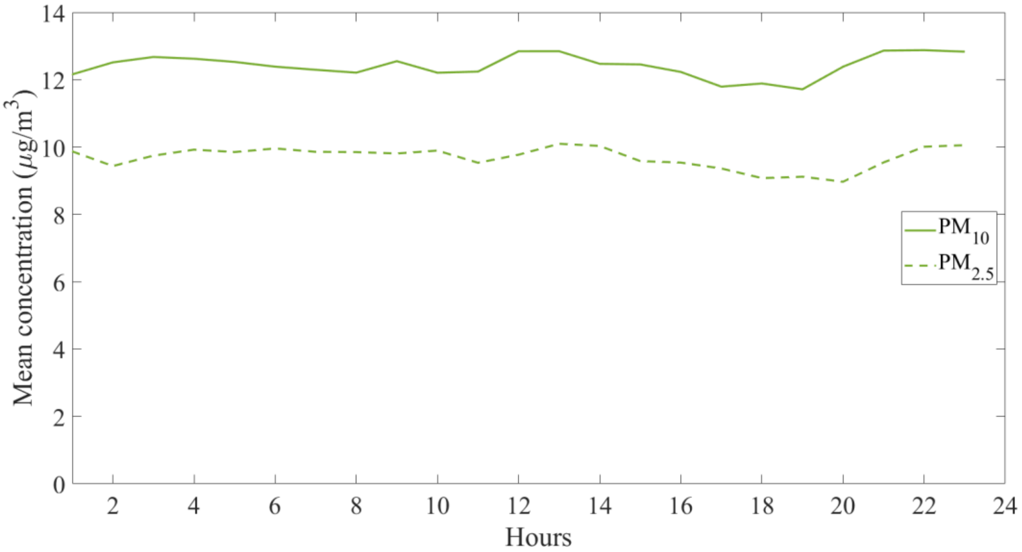

Figure 6. Concentration comparison of particles levels between PM_{10} and $PM_{2.5}$ at the regional background station Råö located in Onsala.

3.3 Meteorology and I/O correlations

Indoor CO_2 is the only air pollutant that has a correlation with any of the investigated meteorological parameters (wind speed, temperature, precipitation, air pressure and solar radiation) for the investigated periods. Indoor CO_2 was for three out of four periods correlated with both outdoor temperature and solar radiation (Table 5). A noticeable result is the 27th of February, this date has a weak ground inversion and is highly correlated between temperature and different air pollutants. The correlation between different air pollutants (NO_2, CO_2, PM_{10} and $PM_{2.5}$) indoor and outdoor revealed that indoor CO_2 is correlated with PM_{10} for all periods, while indoor PM $_{2.5}$ is correlated with indoor CO_2 in two cases (Appendix C1). PM_{10} and $PM_{2.5}$ seem to be well related to each other with high correlations for both indoor PM respectively outdoor PM, for all periods except for one correlation (Appendix C1). Interestingly, PM has low correlation when comparing indoor PM with outdoor PM. Precipitation during the period 8th to 15th of March indicates no clear visual connection to PM (Fig. 7).

Table 5. Temperature and solar radiation correlates well to indoor CO_2 for three out of four measuring periods, indicated by green mark. Non-significant values are marked with red colour.

Date		*Meteorological parameter*	*Air pollutant*							
			CO_2 Out	*CO_2 In*	*NO_2 Out*	*NO_2 In*	*$PM_{2.5}$ Out*	*$PM_{2.5}$ In*	*PM_{10} Out*	*PM_{10} In*
February	24	Temperature	0,00	0,73	0,01	0,38	0,00	0,13	0,01	0,26
	27	Temperature	0,61	0,71	0,41	0,02	0,09	0,59	0,02	0,68
March	3–5	Temperature	0,17	0,61	0,04	0,22	0,03	0,14	0,05	0,36
	26–29	Temperature	0,15	0,39	0,26	0,05	0,00	0,25	0,01	0,40
February	24	Solar radiation	0,00	0,50	0,01	0,57	0,06	0,07	0,00	0,11
	27	Solar radiation	0,03	0,56	0,06	0,10	0,00	0,52	0,00	0,37
March	3–5	Solar radiation	0,09	0,50	0,08	0,22	0,00	0,19	0,00	0,26
	26–29	Solar radiation	0,00	0,35	0,01	0,29	0,14	0,33	0,17	0,44

Note correlation coefficient significance of 95 %

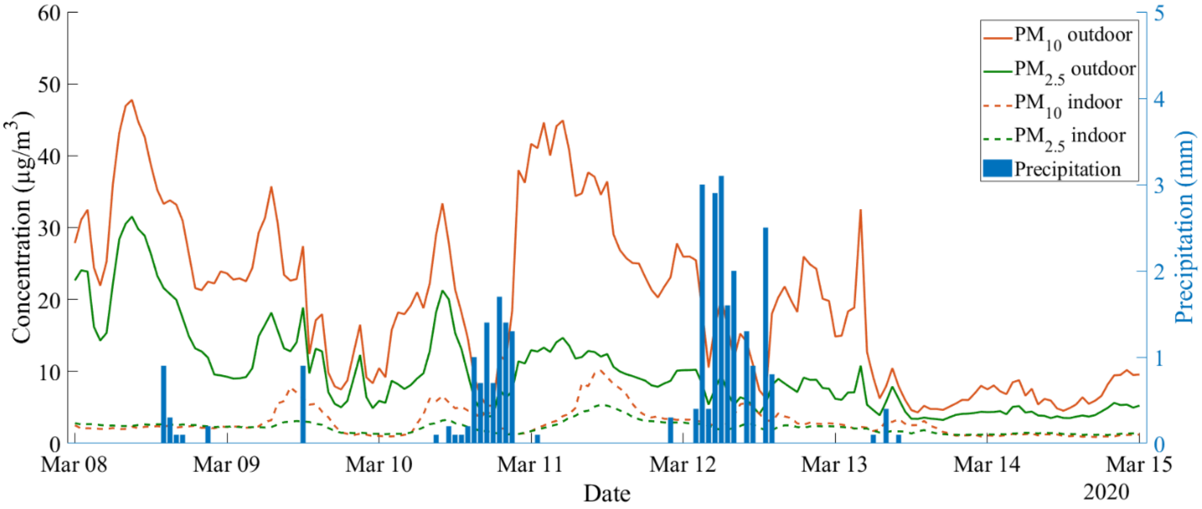

Figure 7. Precipitation and PM comparison during the period with most precipitation at the time of measurement.

3.4 Hourly and daily comparison indoor/outdoor

The I/O ratios (Table 6) calculated from 17th of February to 7th of March (weekends and weekdays included), show lower values when looking at $PM_{2.5}$ and PM_{10} compared to NO_2 and CO_2, indicating a reliance on outdoor concentrations. An I/O ratio above 1 indicates the presence of an indoor source of pollution. The I/O ratios show the highest values with CO_2, staying above 1 in all but three instances and with a mean of 1.1. The three instances with lower I/O ratios were all during weekends.

Table 6. Mean values for I/O-ratios based on daily 8-hour mean concentration values inside and outside Mölndal municipality building for different air pollutants.

	Air pollutant			
	$PM_{2.5}$	*PM_{10}*	*NO_2*	*CO_2*
Mean I/O	0,4	0,4	0,8	1,1

Hourly NO_2 values were shown to be slightly more stable inside compared to the outside during both night and day. NO_2 concentrations are slightly higher during weekdays compared to weekends in all but the nightly outside concentrations where the pattern is not as clear (Fig. 8a, 8b, 8c, 8d). A clear trend can be seen in the indoor CO_2 variation with peak values around noon during weekdays. The same trend is not visible during weekends or at any time in the outside measurements (Appendix A1).

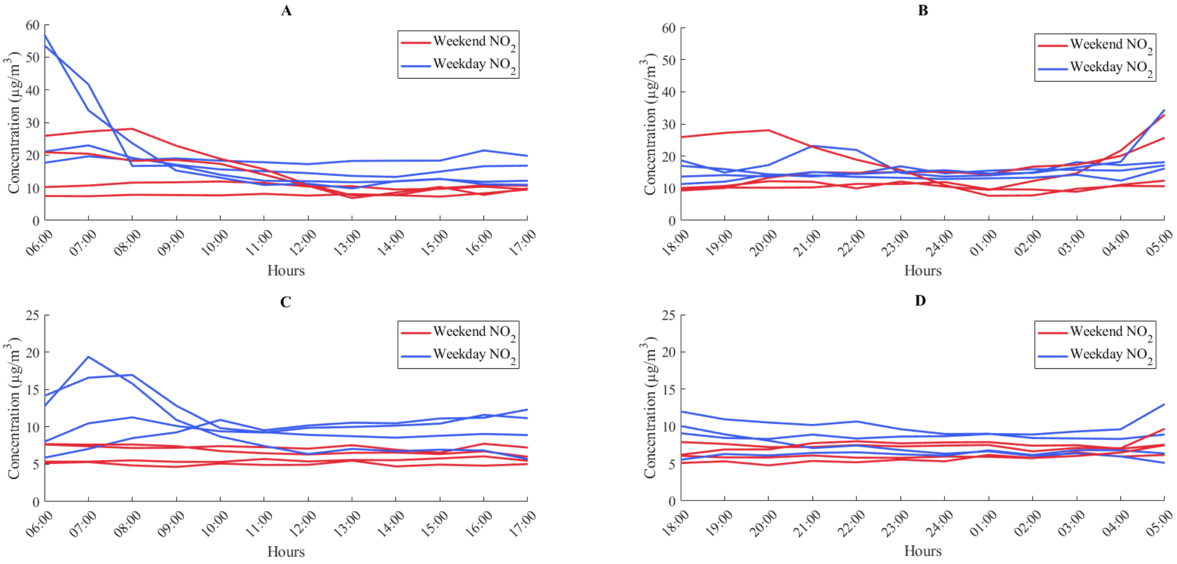

Figure 8. Hourly concentrations of NO_2 during weekends and weekdays divided by day and night, reflecting four different weekends and four different weekdays. Plots show; A: outside concentration during the day, B: outside concentration during the night, C: inside concentration during the day, D: inside concentration during the night. Note the different values on the Y-axis between the plots.

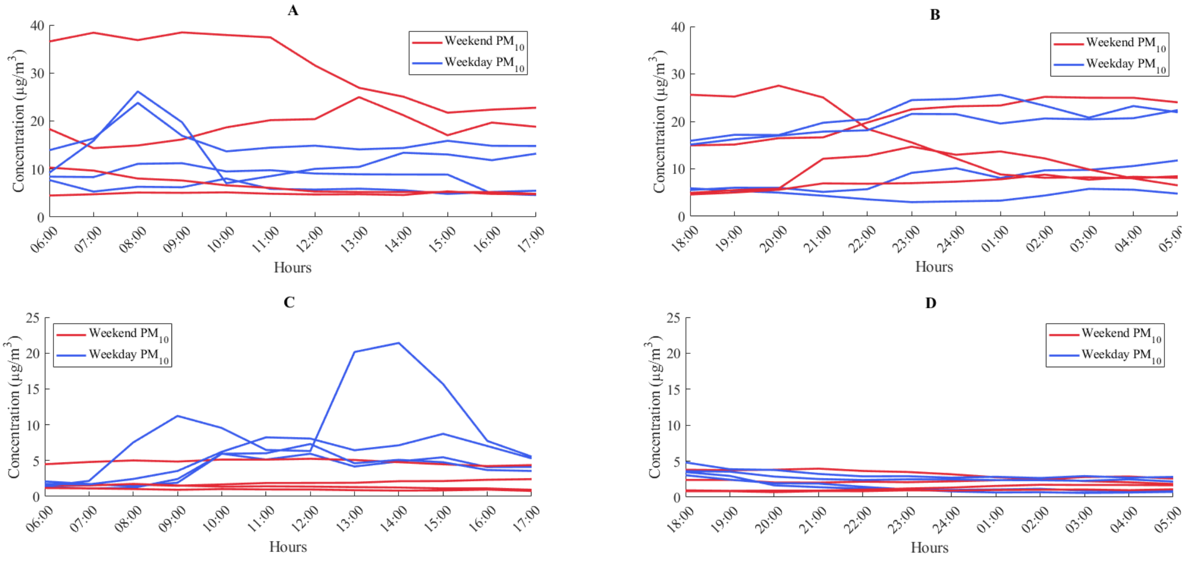

Figure 9. Hourly concentrations of PM_{10} during weekends and weekdays divided by day and night, reflecting four different weekends and four different weekdays. Plots show; A: outside concentration during the day, B: outside concentration during the night, C: inside concentration during the day, D: inside concentration during the night. Note the different values on the Y-axis between the plots.

3.5 Indoor and outdoor variations

A lag time of 1 hour can be seen in the NO_2 concentrations when comparing the indoor environment with the outdoor (Fig. 10). Particles have a slower time response with a lag for PM_{10} of 3 hours (Fig. 11) and for $PM_{2.5}$ of 4 hours (Fig. 12). An outdoor NO_2 peak can be seen at 20:00 which cannot be seen indoors (Fig. 10). Outdoor PM_{10} and $PM_{2.5}$ both show a peak in the evening at 22:00 which is not reflected in the indoor environment (Fig. 11, 12).

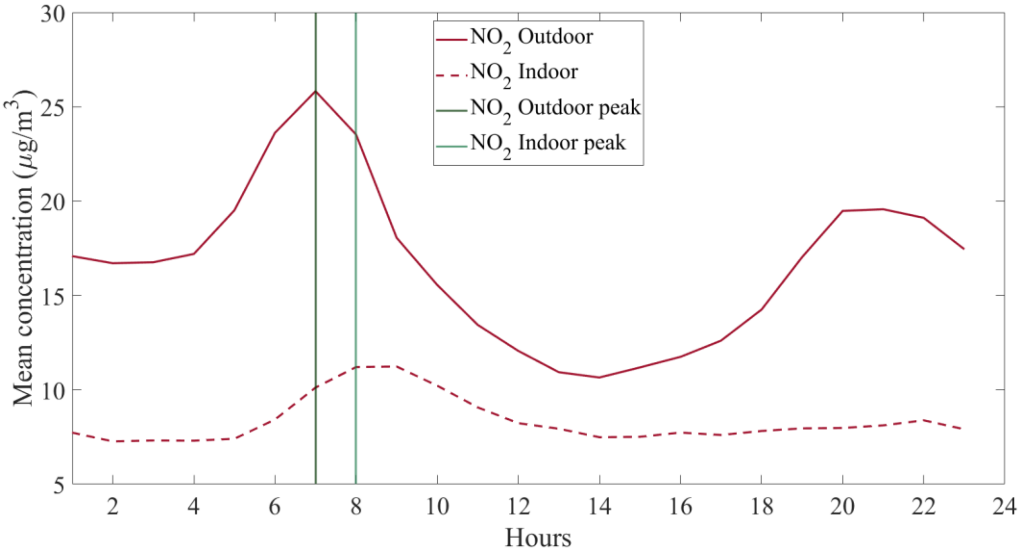

Figure 10. Visualisation of hourly mean concentration and lag time during measuring period concerning NO_2 at Mölndal municipality building.

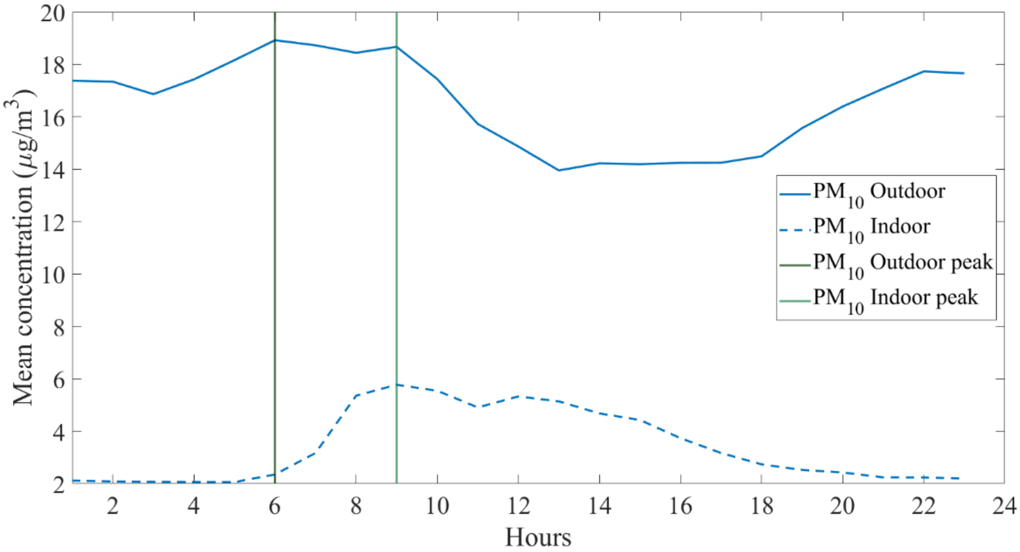

Figure 11. Visualisation of hourly mean concentration and lag time during measuring period concerning PM_{10} at Mölndal municipality building.

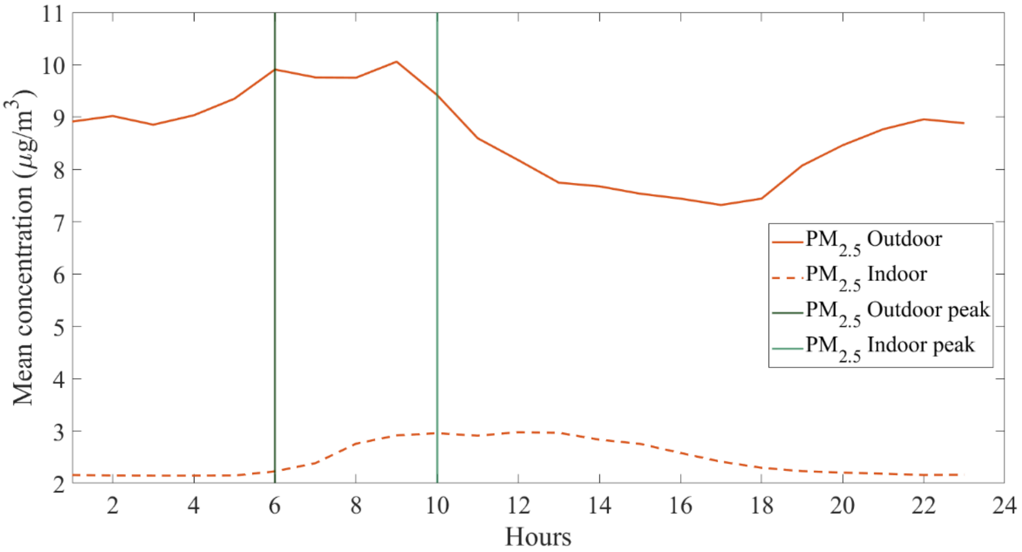

Figure 12. Visualisation of hourly mean concentration and lag time during measuring period concerning $PM_{2.5}$ at Mölndal municipality building.

3.6 Indoor air quality affecting health

Arbetsmiljöverket has a high limit of acceptance and the levels of NO_2 and CO_2 indoor is well below limit. The WHO threshold is slightly transcended one time during the measuring time for $PM_{2.5}$ the 26th of March (Appendix B1). All air pollutants are below the limit of MKN. The *Miljömål Mölndal* is passed for two different pollutants, NO_2 in February and PM_{10} in March (Appendix B2, B3).

4 Discussion

4.1 Yearly distribution comparison

The dispersion results from Mölndal are most similar to the Femman station during the year 2018, when looking at NO_2, PM_{10} and $PM_{2.5}$ (Fig. 4). Gårda has overall higher values for the three aforementioned parameters. This could be explained by the highly trafficked *E6* road close to the station with increasing combustion and friction caused by vehicles, releasing pollutants (Hassan et al., 2016). Another factor could be that data from both Femman and the measuring site in Mölndal are taken at roof-level while Gårda measurements are taken on street-level. Year 2018 (February and March) had mean temperatures below normal while year 2020 (February and March) is a warm period. The reason why the measurement for 2020 has more similarities to the measurement of 2018 cannot be explained simply in the context of mean temperatures.

Since the meteorological conditions are different regarding temperature, wind speed and precipitation between the periods in 2016, 2018 and 2020, the cause of dispersion pattern seems to be a combination of different meteorological conditions. The meteorological conditions seem to affect the dispersion differently and their interaction might enhance or decrease the dispersion. Overall, the dispersion 2020 is good in an air quality perspective, similar to that of 2018, with low concentrations of NO_2 and PM_{10}. The meteorological cause behind the dispersion patterns for 2018 and 2020 is different from each other. Earlier studies have shown meteorological parameters to be a sufficient marker of air pollution (Dahari, Latif, Muda, & Hussein, 2020; Nicolás et al., 2020), which we think are right, but the interaction between the different parameters and in which degree they affect the dispersion is hard to identify. 2018 is characterised by low temperature, low precipitation amount and low wind speed together with few inversions. Since low temperature was seen to increase the NO_2 concentration (Göteborgs stad, 2018a) and little precipitation as well as less wind speed are thought to enhance the probability of high air pollution concentration (Martins & Carrilho da Graça, 2018), the reason for the low dispersion values during 2018 seem to be because of the few inversion events. Haeger-Eugensson (1999) found that dispersion patterns were highly dependent on the atmospheric stability, inversions were seen as the main influencer on dispersion patterns of air pollutants in urban environments. This connection between inversions and dispersion patterns can explain the low dispersion during measuring period 2020 in Mölndal because there were few inversions, comparable to 2018.

4.2 Urban scale or regional background

NO_2 is an urban source, indicated by the KS2-test with mostly the same distribution pattern between Femman and Mölndal. There was one period (26th to 29th of March) where the distribution pattern of NO_2 differed between Femman and Mölndal. This can be explained by the meteorological state, this period was overcast and had a small inversion. Since inversions limits the dispersion possibility of pollutants (Haeger-Eugensson, 1999), the air pollutants primarily reflect the local scale, which may result in different dispersion patterns at Mölndal and Femman.

The period 8th to 15th of March show high correlation between Femman and Mölndal for PM with behold of the null hypothesis. This indicates that the concentrations at each site belongs to the same data and further implies that the particles behave in the same way. The other periods are harder to draw any conclusions about since the correlation coefficient is highly variable and that the KS2-test points in different directions, some rejecting and some beholding the null hypothesis. This can be because of local variations in resuspension and further dependent on the closeness to roads. Martins and Carrilho da Graça (2018) states that local combustion is the main source of $PM_{2.5}$ in urban environments. The comparison of PM between Råö station and Mölndal (Fig. 5) showed PM_{10} to be an urban scale air pollutant while $PM_{2.5}$ is harder to tell whether it act as a regional background or urban scale air pollutant. Martins and Carrilho da Graça (2018) further points at precipitation and wind velocity to be sources of removal for $PM_{2.5}$. Precipitation acts as a sink for $PM_{2.5}$ and might have the capability of evening out the concentrations of $PM_{2.5}$ in the urban environment. However, wind velocity at Femman and Mölndal has not been compared but could be interesting to study to further be able to understand the variations in concentration of outdoor $PM_{2.5}$.

4.3 Meteorology and I/O correlations

The correlation between meteorology and indoor and outdoor air pollutant was overall weak. This can be because air pollutants are dependent on more than one meteorological factor for its dispersion pattern. Further, a strong correlation might not be possible through this type of correlation analysis where one meteorological factor was correlated to one air pollutant. However, some correlations where present. Indoor CO_2 was correlated with solar radiation and temperature which both had outdoor origin (Table 5). Hashemi and Passe (2019) found that indoor CO_2 was negatively correlated to outdoor temperature, which is the opposite of what we found. An explanation to this finding can be due to the fact that their study location was in a subtropical region while Mölndal is in a warm temperate region. Hashemi and Passe (2019) argued that with lower outside temperature there is no need for ventilation and therefore, indoor CO_2 can accumulate. Same argument cannot be applied at Mölndal since the temperature is low and the ventilation is mechanically operating during weekdays. Neither can the opposite be true because of the positive correlation between indoor CO_2 and outdoor temperature. Jantunen (2007) points out that the behaviour of the air pollutants varies greatly between climate zones and buildings. It is more likely that this relationship is a result of the daily pattern of occupancy. The office gets occupied at the same time as the solar radiation heats the air, resulting in further increase in temperature. Thus, indoor CO_2 and outdoor temperature might not be dependent on each other, rather by a coincidental daily pattern. This could explain the two positive correlated meteorological variables to indoor CO_2. The concentration of indoor CO_2 is mainly a result of increased human attendance.

Solar radiation was assumed to be well correlated to NO_2, but this connection could not be seen in the results (Table 5). Challoner and Gill (2014) found NO_2 levels to have a peak in the morning during rush hour. They explained this as being a result of the high intensity in traffic which releases NO_2, combined with the sun rising which further converts O_3 to NO_2. Our study shows the same pattern with peaks during morning rush, but outdoor NO_2 is correlated to neither solar radiation nor temperature. This could be because the main source of NO_2 is the traffic and not the meteorological conditions themselves, even though solar radiation might increase the concentration through the reformation of O_3 to NO_2. This theory is further convincing when looking at the KS2-test between Mölndal and Femman (Table 4), which mostly rejects the null hypothesis for NO_2. This indicates that the source of NO_2 is regional to local, which corresponds with the statements from the World Health Organization [WHO] (2010).

Precipitation minimizes the resuspension of PM through the process of wet deposition counteracting the ability for particles to be suspended in the air (Martins & Carrilho da Graça, 2018; Nicolás et al., 2020). Results from Mölndal cannot clarify these statements since there were both a low correlation between PM and precipitation and unclear visual pattern in the graph (Fig. 7). However, our study could only investigate one period with precipitation since there were few periods containing precipitation where the data was usable. Further research on the connection between PM and precipitation needs to be done.

4.4 Hourly and daily comparison indoor/outdoor

The results from our analysis of night and day show clear differences concerning all gases and particle sizes. Concentrations for both gases and particles seem to decrease during night-time, or at least showing a flattening of the curve. This could easily be seen, not unexpectedly, in the CO_2 plot (Appendix A1). The daytime CO_2 concentrations peak inside the building during work hours and decrease after about 15:00 when people would begin to leave the building. This is the same pattern seen when looking at the meteorological correlations for indoor CO_2 concentrations, which were thought to be a consequence of occupancy. This indicates that a higher amount of people in a building increases the indoor CO_2 concentrations.

Indoor $PM_{2.5}$ and PM_{10} follow a similar pattern during the weekday. $PM_{2.5}$ does however have lower variability than PM_{10} which keeps the indoor $PM_{2.5}$ concentrations between night and day around the same levels (Fig. 8, Appendix A2). Goyal and Khare (2011) attributed resuspension by occupants in a building as a source for PM_{10} which we believe to be accurate in our study as well (Fig. 8a). This is further explained by the high correlation between CO_2 and PM_{10} (Appendix C1). Because both PM_{10} and CO_2 respond to occupancy, they act similarly, which could explain the correlation between the two. Our study shows a clear difference in PM concentrations between night and day, but also between weekdays and weekends, which the study by Braniš et al. (2005) supports. Another factor affecting the indoor concentrations of PM_{10} and $PM_{2.5}$ is the ventilation (Martins & Carrilho da Graça, 2018; Othman et al., 2020; Pacitto et al., 2020). A clear difference can be seen between weekends and weekdays with lower PM concentrations indoors when the ventilation is turned off and there are no people in the building (Fig. 8). Earlier studies also found that PM is a product of occupancy in a building and that ventilation could decrease the amount of PM entering a building (Othman et al. 2020, Pacitto et al. 2020). This indicates a connection between ventilation and the I/O relationship of PM. However, to separate occupancy and ventilation is hard, there is probably a combination of them both that affect the indoor concentrations.

The analysis of NO_2 showed a peak in concentration at 08:00 indoors and a lag time of one hour could be seen between the indoor and outdoor NO_2 concentrations (Fig. 8a, 10). This peak of indoor NO_2 cannot be seen inside during the weekend, most likely due to the ventilation being turned off and less cars driving in the morning on weekends. A second peak in the outdoor NO_2 concentrations can be seen around 20:00, which is not mirrored in the indoor concentrations (Fig. 10). This could be because the ventilation is turned off and because the outdoor measurement station at Mölndal is located on the roof of the building, not at street level.

Our NO_2 I/O ratios (Appendix D1) show an increase in I/O ratio during the night which is similar to that found by Challoner and Gill (2014). Challoner and Gill (2014) mentioned the rapid decrease in outside concentrations of NO_2 compared to the slower decrease in inside NO_2 as an explanation, this could be seen in our data as well. World Health Organization [WHO] (2010) mentioned that with normal ventilated buildings the I/O ratios of NO_2 varies between 0.88-1. In our study, the mean I/O ratio was found to be 0.8 (Table 6), which can be seen as a normal ventilated building. World Health Organization [WHO] (2010) points out that indoor levels of NO_2 are normally higher during wintertime due to indoor sources such as heating and a decreased need for ventilation. They conclude that the distance to roadways is an important factor in determining indoor levels of NO_2. The Mölndal CO_2 I/O ratios being slightly above 1 was expected since the CO_2 increase is connected to humans and not an outdoor source. It would be meaningful to study different seasons since there are indications that the variability with seasons highly affects compounds concentrations (World Health Organization [WHO], 2010).

4.5 Indoor and outdoor variations

Indoor NO_2 patterns follow that of the outside NO_2 but with a lower concentration and a lag time of about one hour (Fig. 10). This indicates a dependency of the indoor NO_2 concentrations on the outdoor NO_2 concentrations. WHO concludes in their report *"WHO Guidelines for indoor air quality: selected pollutants"* (World Health Organization [WHO], 2010) that indoor concentrations of NO_2 mainly originates from outdoor sources such as traffic and combustion. But World Health Organization [WHO] (2010) and Jantunen (2007) points out that NO_2 is a very reactive compound. In an indoor environment, NO_2 is either quickly absorbed by materials or reacts chemically with other compounds and is further dependent on ventilation flow. However, through looking at the correlations between indoor and outdoor NO_2, significant values between indoor and outdoor NO_2 can only be revealed during the 27th of February, during a weak ground inversion. A reason for this could be because the correlation is on an hourly basis and in normal conditions have a lag time (Fig. 10). During conditions with inversion, the stability of the atmosphere will likely enhance a stagnation of the concentration amount and consequently, a correlation could be seen due to the absent of lag time. NO_2 can vary greatly depending on the availability of other compounds to react with rather than the amount of outdoor NO_2 that infiltrates indoor, or there might be a combination of the two. The connection between NO_2 outdoor and NO_2 indoor needs to be further studied to understand the indoor variations in concentration. World Health Organization [WHO] (2010) states that the air exchange rate of the ventilation plays an important role in determining the levels of NO_2 entering a building. They further conclude that high outdoor levels will influence the indoor concentration of NO_2.

Just as with indoor NO_2, indoor PM_{10} and $PM_{2.5}$ follow the outdoor PM concentrations but with longer lag times of three and four hours respectively (Fig. 11, 12). This lag time indicates a connection between the indoor and outdoor PM concentrations and can further explain why a correlation was not present. The lag time could be connected to how efficient the ventilation is at recycling the air in the building. Miller et al. (2017) found an 11-minute lag time between indoor and outdoor PM_{10} while the ventilation system had an air exchange rate of 12 minutes. This could be indicative to how efficient the ventilation system is in the investigated municipally building in Mölndal, however, exchange rates have not been studied.

Both PM_{10} and $PM_{2.5}$ show outdoor peaks at 06:00 which is followed by an indoor peak in PM. A later peak in the outdoor PM around 22:00-23:00 is however not followed by the indoor PM values which we believe is due to the ventilation being shut off or the occupancy being low (Fig. 11, 12). Although a peak in either PM or NO_2 concentration at this hour would normally be seen as an anomaly, it is most likely due to the fact that the measurements are taken at a higher elevation than street level. This shows a reflection of a larger area instead of only the traffic peak hour (M. Haeger-Eugensson, personal communication, May 25, 2020). Braniš et al. (2005) indicate that human activity contributes the most to indoor PM_{10} concentrations. This could be the reason that the highest PM values indoors are around 10:00 when activity in the building could possibly increase. Activity and movement in the building could be an important factor to consider in future studies to investigate exactly how much occupancy affects indoor PM concentrations.

4.6 Indoor air quality affecting health

It is important to restrict the level of air pollutants to favour healthy air and aim towards reaching the EU goal of clean air. This study shows that more needs to be done to be well below limit, especially for *Miljömål Mölndal*, that aims to be reached by year 2022. Mölndal municipality needs to undertake strategies to be able to reduce air pollutants level to reach these goals. The most highlighted problem for Mölndal seems to be PM_{10} (Appendix B2). Our measurements were placed near two high traffic roads, *E6* and *Göteborgsvägen*, which could be the source of PM_{10}. PM_{10} is mainly added to the atmosphere by resuspension and through friction between ground and vehicles (World Health Organization [WHO], 2006b).

Outdoor exposure levels are well investigated, and limits are steadily being studied. On the other hand, indoor exposure levels are hardly mentioned, even though we on average spend 90% of our time indoors (Hwang & Park, 2019; Jantunen, 2007; McCreddin et al., 2013). The environmental working-levels are meant to decrease the levels of bad air quality during construction. This does however not say anything about normal, everyday environments.

5 Conclusion

This report aimed to investigate the connection between indoor and outdoor air quality of the Mölndal municipal building by investigating a variety of factors. Comparing years with good and bad wintertime dispersion patterns yielded inversions to be the main indicator of dispersion patterns, since the measuring period had few inversions and was comparable to levels of the year 2018.

The increased concentrations of CO_2 inside the building during the day is attributed to human activity. A three-hour lag time between indoor- and outdoor peaks of NO_2 could be seen which indicates that the indoor NO_2 concentrations are dependent on those outside and further to the efficiency of the ventilation. A strong correlation between inside and outside NO_2 could however not be seen which could be due to the reactive nature of NO_2 or the lag time affecting the hourly comparison in the correlation analysis. Evidence in the hourly mean concentration study revealed a connection to the ventilation system with low indoor NO_2 concentrations whenever the ventilation was turned off. All gases and particle sizes show clear differences during night and day, demonstrating the need to take time of day into account when looking at both indoor and outdoor air quality. The I/O ratio of PM_{10} seems to be connected to the occupancy of the building, which in turn coincides with the timing of the ventilation. Because of this, indoor PM_{10} concentrations vary greatly depending on if it is a weekday or weekend. This study presents a need to improve IAQ at the Mölndal municipally building to promote a healthier work environment. One step towards better IAQ could be optimizing the ventilation by decreasing airflow during peak outdoor concentration hours and increasing airflow during low outdoor concentration hours.

During correlations between both indoor and outdoor air pollutant as well as to meteorological conditions, the overall correlations were weak. A problem is likely encountered when correlating meteorological factors to different air pollutants. Because air pollutant concentrations are often dependent on more than one meteorological factor as well as the lag times between the indoor and outdoor environment, the resulting correlations are weak.

Through conducting this study, we found a few areas that would be interesting for future studies; Movement by people in the building where measurements are being taken would increase understanding of the mixing of air and resuspension of PM. The ventilation rate is another area of interest where more research might provide useful insights regarding I/O ratio. A future study focusing more on lag times between indoor and outdoor air quality could likely find better correlations by shifting the indoor measurements depending on lag times. Lastly, the effect of seasonal variability on IAQ would be interesting to investigate since air quality is dependent on the prevailing meteorology.

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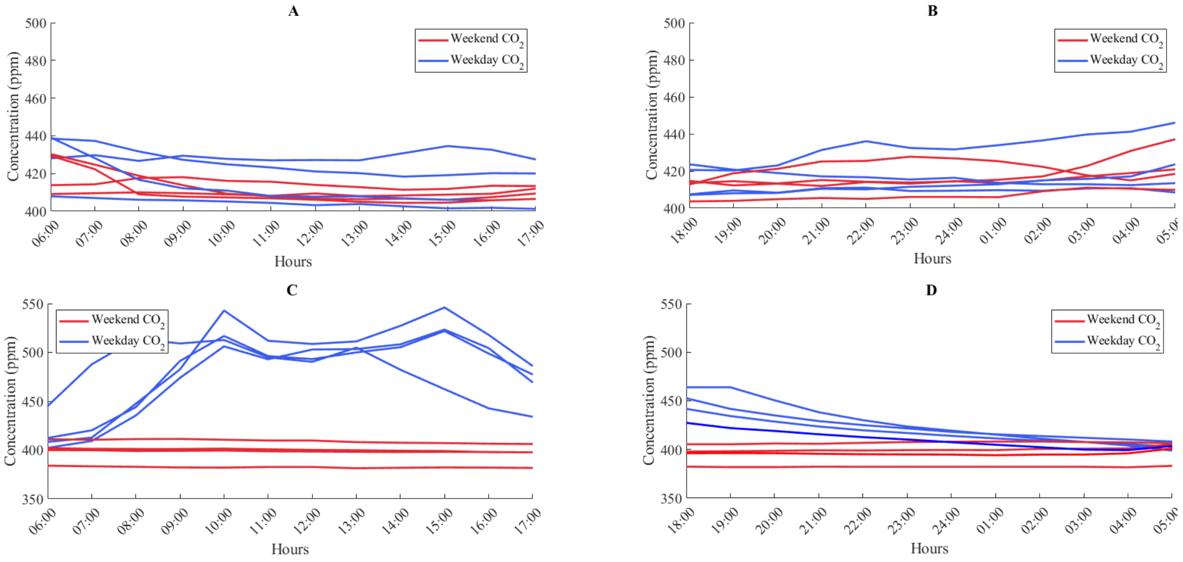
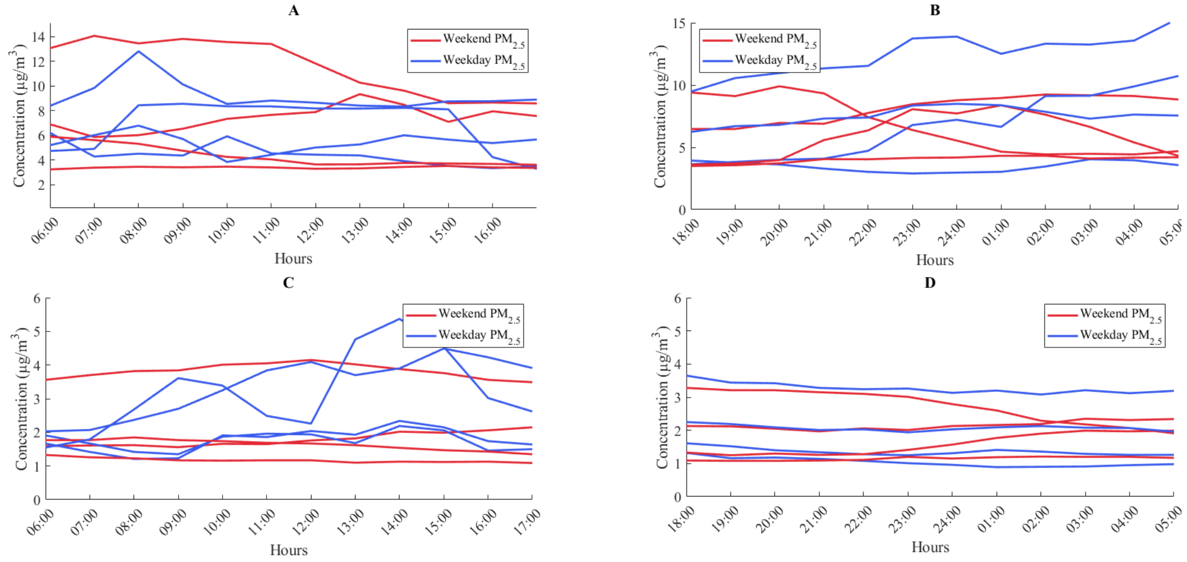
Appendix A

Visually detectable trends for comparing weekdays with weekends and days with nights of different air pollutants.



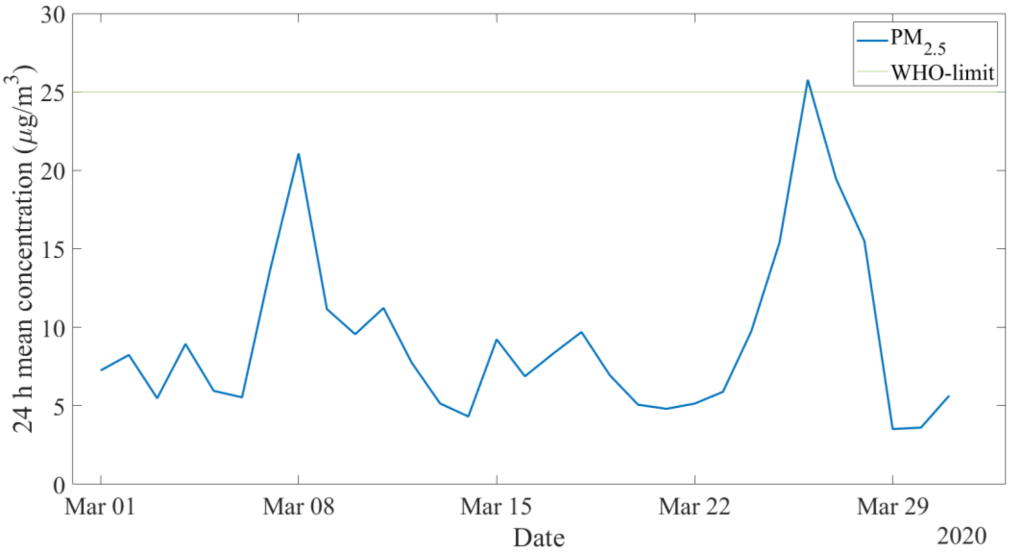
A 1. Hourly concentrations of CO_2 during weekends and weekdays divided by day and night, reflecting four different weekends and four different weekdays. Plots show; A: outside concentration during the day, B: outside concentration during the night, C: inside concentration during the day, D: inside concentration during the night. Note the different values on the Y-axis between the plots.



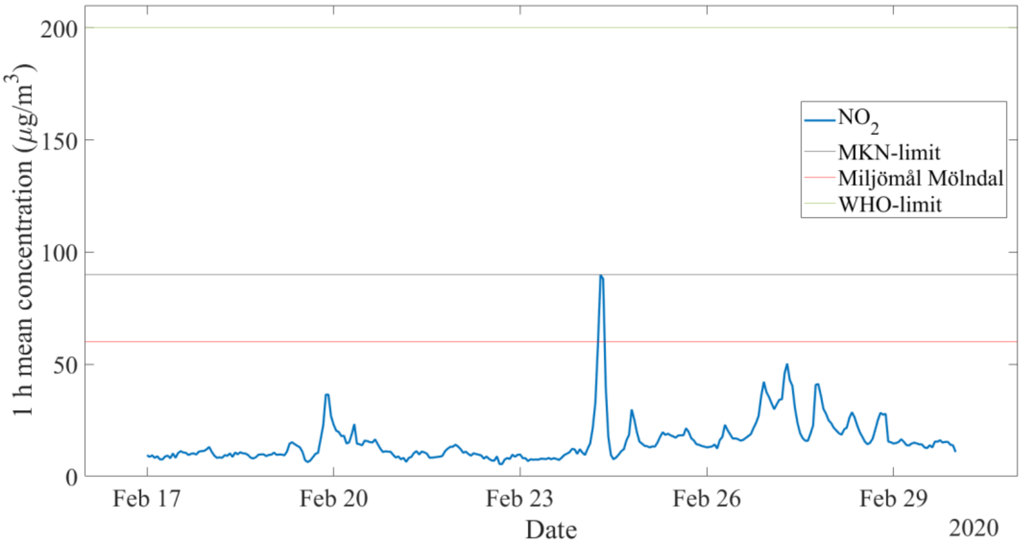
A 2. Hourly concentrations of $PM_{2.5}$ during weekends and weekdays divided by day and night, reflecting four different weekends and four different weekdays. Plots show; A: outside concentration during the day, B: outside concentration during the night, C: inside concentration during the day, D: inside concentration during the night. Note the different values on the Y-axis between the plots.

Appendix B

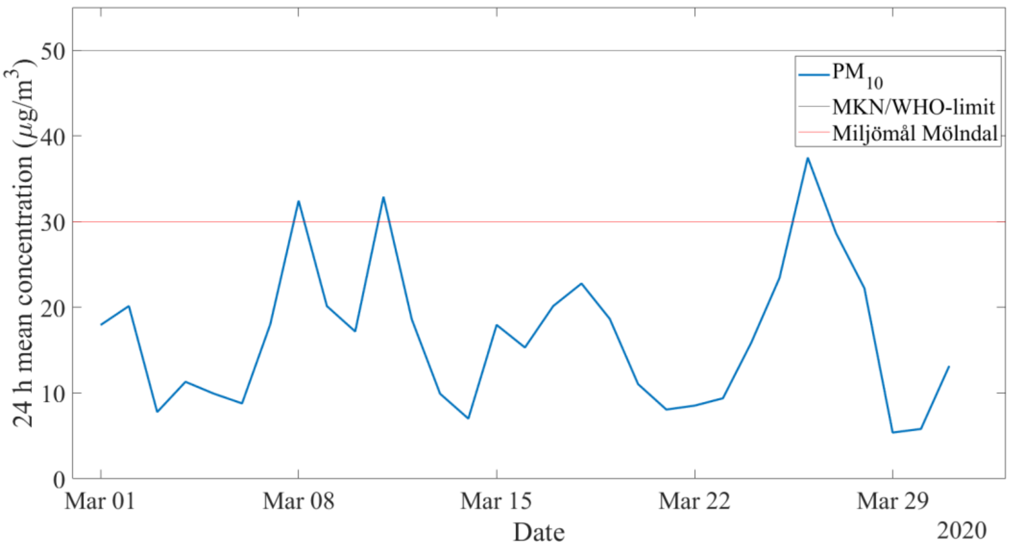
Visually detectable trends of air pollutants concentrations and transcendence of limit set by regulation, recommendations, or goal.



B 1. Variations of $PM_{2.5}$ during the month of March together with limitations.



B 2. Variations of NO_2 during the month of March together with limitations.



B 3. Variations of PM$_{10}$ during the month of March together with limitations.

Appendix C

Correlations between different parameters

C 1. Correlation for all investigated periods in February and March. Green mark indicates that at least 3 out of 4 periods is correlated to each other. Yellow mark indicates correlation of 0.45 or higher. Blue mark indicates correlation higher than 0.5. Red mark indicates non-significant value.

			Air pollutant							
Date		*Air pollution Parameter*	*CO_2 Out*	*CO_2 In*	*NO_2 Out*	*NO_2 In*	*$PM_{2.5}$ Out*	*$PM_{2.5}$ In*	*PM_{10} Out*	*PM_{10} In*
February	24		1,00	0,04	0,95	0,29	0,04	0,53	0,00	0,29
	27		1,00	0,30	0,77	0,32	0,09	0,45	0,02	0,54
March	3-5		1,00	0,44	0,57	0,06	0,38	0,10	0,43	0,44
	26-29	CO_2 Out	1,00	0,02	0,56	0,34	0,45	0,00	0,36	0,03
February	24		0,04	1,00	0,02	0,24	0,10	0,16	0,06	0,55
	27		0,30	1,00	0,20	0,03	0,02	0,68	0,01	0,72
March	3-5		0,44	1,00	0,27	0,08	0,07	0,37	0,08	0,76
	26-29	CO_2 In	0,02	1,00	0,06	0,10	0,03	0,73	0,05	0,89
February	24		0,95	0,02	1,00	0,37	0,02	0,49	0,00	0,29
	27		0,77	0,20	1,00	0,52	0,09	0,33	0,02	0,36
March	3-5		0,57	0,27	1,00	0,12	0,03	0,17	0,08	0,29
	26-29	NO_2 Out	0,56	0,06	1,00	0,20	0,21	0,00	0,17	0,06
February	24		0,29	0,24	0,37	1,00	0,27	0,02	0,07	0,00
	27		0,32	0,03	0,52	1,00	0,22	0,00	0,11	0,00
March	3-5		0,06	0,08	0,12	1,00	0,12	0,01	0,15	0,00
	26-29	NO_2 In	0,34	0,10	0,20	1,00	0,21	0,07	0,23	0,05
February	24		0,04	0,10	0,02	0,27	1,00	0,00	0,79	0,06
	27		0,09	0,02	0,09	0,22	1,00	0,00	0,29	0,05
March	3-5		0,38	0,07	0,03	0,12	1,00	0,00	0,71	0,12
	26-29	$PM_{2.5}$ Out	0,45	0,03	0,21	0,21	1,00	0,12	0,97	0,05
February	24		0,53	0,16	0,49	0,02	0,00	1,00	0,00	0,59
	27		0,45	0,68	0,33	0,00	0,00	1,00	0,02	0,88
March	3-5		0,10	0,37	0,17	0,01	0,00	1,00	0,00	0,55
	26-29	$PM_{2.5}$ In	0,00	0,73	0,00	0,07	0,12	1,00	0,14	0,81
February	24		0,00	0,06	0,00	0,07	0,79	0,00	1,00	0,07
	27		0,02	0,01	0,02	0,11	0,29	0,02	1,00	0,03
March	3-5		0,43	0,08	0,08	0,15	0,71	0,00	1,00	0,12
	26-29	PM_{10} Out	0,36	0,05	0,17	0,23	0,97	0,14	1,00	0,06

February	24		0,29	0,55	0,29	0,00	0,06	0,59	0,07	1,00
	27		0,54	0,72	0,36	0,00	0,05	0,88	0,03	1,00
March	3-5		0,44	0,76	0,29	0,00	0,12	0,55	0,12	1,00
	26-29	PM_{10} In	0,03	0,89	0,06	0,05	0,05	0,81	0,06	1,00

Note correlation coefficient significance of 95 %

Appendix D

D 1. Daily I/O ratios calculated with an 8 hour mean value between Feb 17th to March 7th.

Date	*PM 2.5*	*PM 10*	*NO2*	*CO2*
17-feb-2020 08:00:00	0,41	0,29	1,11	1,22
18-feb-2020 00:00:00	0,31	0,14	1,06	1,03
18-feb-2020 08:00:00	0,42	0,30	1,04	1,23
19-feb-2020 00:00:00	0,33	0,16	0,80	1,00
19-feb-2020 08:00:00	0,46	0,48	0,98	1,20
20-feb-2020 00:00:00	0,25	0,12	0,61	1,08
20-feb-2020 08:00:00	0,35	0,25	0,88	1,22
21-feb-2020 00:00:00	0,23	0,10	0,95	1,02
21-feb-2020 08:00:00	0,37	0,24	0,93	1,21
22-feb-2020 00:00:00	0,27	0,15	0,83	1,00
22-feb-2020 08:00:00	0,27	0,13	1,07	0,98
23-feb-2020 00:00:00	0,24	0,11	0,97	0,98

23-feb-2020 08:00:00	0,35	0,16	0,92	0,98
24-feb-2020 00:00:00	0,41	0,22	0,29	0,94
24-feb-2020 08:00:00	0,44	0,40	1,01	1,20
25-feb-2020 00:00:00	0,31	0,17	0,47	0,98
25-feb-2020 08:00:00	0,23	0,55	0,56	1,19
26-feb-2020 00:00:00	0,27	0,15	0,35	0,98
26-feb-2020 08:00:00	0,49	0,82	0,29	1,22
27-feb-2020 00:00:00	0,29	0,18	0,24	0,94
27-feb-2020 08:00:00	0,49	0,64	0,36	1,22
28-feb-2020 00:00:00	0,37	0,24	0,22	0,98
28-feb-2020 08:00:00	0,45	0,64	0,36	1,13
29-feb-2020 00:00:00	0,23	0,09	0,36	0,96
29-feb-2020 08:00:00	0,22	0,13	0,38	0,94

01-mar-2020 00:00:00	0,23	0,09	0,51	0,93
01-mar-2020 08:00:00	0,23	0,10	0,52	0,92
02-mar-2020 00:00:00	0,26	0,11	0,55	0,92
02-mar-2020 08:00:00	0,40	0,39	0,76	1,18
03-mar-2020 00:00:00	0,24	0,15	0,54	0,94
03-mar-2020 08:00:00	0,44	0,80	0,67	1,17
04-mar-2020 00:00:00	0,13	0,09	0,55	0,92
04-mar-2020 08:00:00	0,19	0,32	0,89	1,13
05-mar-2020 00:00:00	0,21	0,12	0,45	0,90
05-mar-2020 08:00:00	0,41	0,53	1,14	1,26
06-mar-2020 00:00:00	0,29	0,16	0,42	0,93
06-mar-2020 08:00:00	0,40	0,46	0,78	1,16
07-mar-2020 00:00:00	0,16	0,10	0,42	0,95

07-mar-2020 08:00:00	0,13	0,07	0,65	0,95