# Reduction in $NO_2$-concentration across ventilation filters in an office building located close to heavy traffic

**By**

**Alexander Reyes-Lingjerde**

**Department of Global Public Health and Primary Care**

**Occupational and Environmental Medicine**

**University of Bergen, Norway**

**August 2016**

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**Alexander Reyes-Lingjerde**

This thesis is submitted in partial fulfilment of the requirements for the degree of Master in Health Sciences at the University of Bergen.

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# Abstract

In Scandinavia, people live in climatic conditions that makes it favorable to stay indoors at wintertime. Norway has a relatively small population, even so Bergen and Oslo reaches annual average nitrogen dioxide concentrations equal to or above the levels in large European cities. Newspapers in Bergen recommend the population to stay indoors in urban areas that are highly polluted. Bergen municipality takes measurements of the outdoor pollution continuously, but more knowledge is needed on the propagation of the pollution from the outdoor and to the indoor environment.

Danmarksplass intersection is one of the most trafficked and polluted areas in Bergen, Norway. Surrounding terrain and meteorological conditions during wintertime results in accumulation of local air pollution, locally known as the “lid”. Bergen municipality is then often obligated to implement mitigating actions. Particles and nitrogen oxides from traffic emissions has been recognized as a major contribution source to local air pollution. Nitrogen oxides are formed during combustion. Among the different nitrogen oxide components mainly nitrogen dioxide ($NO_2$) is associated with negative health effects.

This study was set up to compare the effectiveness at reducing $NO_2$-concentration from outdoor to indoor environment at an office building by a combination filter (active coal + particle) and a regular particle filter. In addition, $NO_2$ propagation from the location of the municipality instrument and mentioned office building was examined.

Two Teledyne API 200E direct reading instruments were used for measuring $NO_2$. The instruments were deployed outdoors and indoors at an office building. The measurements took place in January to March 2014, when the highest concentration of air pollution was expected. A total of 625 1-hour mean values of $NO_2$ were included in the study.

The results show that the $NO_2$-concentrations are approximately 30% lower at the location of the office building than the municipality deployed instrument. The results show that when a regular particle filter was used there was no reduction of the $NO_2$-concentration. However, the combination-filter reduced the average indoor $NO_2$-concentrations by approximately 70% compared to outdoor level. Thus, when local historical data show that the outdoor $NO_2$-concentration can reach levels close to or above the Norwegian Institute of Public Health recommendations, the present study indicates that it is advisable to install a combination filter.

# Content


1 Acknowledgement ........ 10

2 Introduction ........ 12

2.1 Pollution ........ 12

2.2 Nitrogen dioxide ........ 13

2.3 Outdoor to indoor $NO_2$ propagation – literature review ........ 14

2.4 $NO_2$-concentrations in Norway ........ 17

2.5 Regulations ........ 17

2.6 Bergen – pollution ........ 19

2.6.1 Danmarksplass overall description ........ 21

3 Rationale ........ 23

4 Objectives ........ 24

4.1 Main Objectives ........ 24

4.2 Specific Objectives ........ 24

5 Hypothesis ........ 25

6 Method ........ 26

6.1 Office building – site of the study ........ 27

6.1.1 Filters ........ 29

6.2 Data collection ........ 30

6.2.1 Instruments ........ 31

6.2.2 Data Processing ........ 33

6.2.3 Additional data ........ 34

6.3 Practical measurements ........ 35

6.3.1 Roof measurements ........ 35

6.3.2 Office measurements ........ 36

6.4 Result preparation and statistical analysis ........ 37

6.4.1 Trend charts ........ 37

6.4.2 Comparative data tables ........ 38

6.4.3 Scatter plots ........ 38

6.4.4 Development of $NO_2$ concentration models for the Roof Instrument location 38

6.5 Ethics ........ 39

7 Results ........ 40

7.1 Background information ........ 40

7.2 Comparison between the two API ........ 42

7.3 Objective A; Comparison between MI and RI ........ 43

7.3.1 Correlation analysis ........ 46

7.4 Objective B; Outdoor and indoor comparison ... 49
7.4.1 Objective $B_1$; Comparison between $RI_1$ and $CF_1$ ... 49
7.4.2 Objective $B_2$; Comparison between RI and RF ... 52
7.5 Objective C; Comparison between the Regular-Filter and Combination-Filter areas 54
8 Discussion ... 57
8.1 $NO_2$-concentrations at the Municipality Instrument ... 57
8.2 Relationship between the Municipality Instrument and Roof Instrument ... 58
8.3 Office Building outdoor to indoor concentration comparison ... 59
8.3.1 Regular-Filter area ... 59
8.3.2 Combination-Filter area ... 60
8.4 Methodological discussion ... 60
9 Conclusions and recommendations ... 62
10 Future studies ... 63
10.1 Location propagation ... 63
10.1.1 Analytical models ... 63
10.1.2 Additional data analysis ... 63
10.2 Outdoor to indoor propagation ... 64
10.2.1 Ventilation system ... 64
10.2.2 Filters ... 64
11 Reference list ... 65
12 Appendix ... 68
12.1 Detailed timeline description ... 68
12.2 Example sheet for obtaining scaling data ... 69
12.3 Example $NO_x$ – Scaling calculation ... 70
12.3.1 Data treatment ... 70
12.3.2 Example based on real measurements ... 71
12.4 Filter specifications ... 72

# Acronyms and Abbreviations

| | |
|---|---|
| API | Advanced Pollution Instrumentation |
| CF | Combination Filter |
| CI | Confidence Interval |
| CO | Carbon Monoxide |
| IC | Instrument Comparison |
| MI | Municipality Instrument |
| NEA | Norwegian Environment Agency |
| NIAR | Norwegian Institute for Air Research |
| NIPH | Norwegian Institute of Public Health |
| NO | Nitrogen Monoxide |
| $NO_x$ | Nitrogen Oxides |
| N-O | Nitrogen oxygen bond |
| $NO_2$ | Nitrogen Dioxide |
| $O_3$ | Ozone |
| OB | Office Building |
| PM | Particulate Matter |
| ppmV | Parts per million by Volume |
| RF | Regular-Filter |
| RI | Roof Instrument |
| $SO_2$ | Sulphur Dioxide |
| SPSS | Statistical Package for the Social Sciences |
| SRA | State Road Administration |
| VOC | Volatile Organic Compounds |
| WHO | World Health Organization |

# Figure list


1 Size range of airborne particles, showing the health-related ultrafine, PM2.5 and PM10 fractions and the typical size range of some major components.

2 Annual mean $NO_2$-concentrations at major cities around Europe.

3 Picture of Bergen. "…Air quality in Bergen and other big cities are at times very poor…

4 Bergen overview landscape map, describing air pollution red zone and wind directions with arrows…

5 Danmarksplass intersection in purple. Office Building where measurements have been performed in the study in blue. Municipalities stationary instrument, blue circle down to the right…

6 Hourly mean $NO_2$-concentrations at Danmarksplass stationary monitoring station. Period 1.7.2009-1.7.2015…

7 Overview of the office building. The flight photo illustrates where the…

8 Viledon NanoPleat, regular-filter for filtering particles.

9 SuperPleat Duo, combination filter for filtering both particles and gaseous. pollutants.

10 Timeline for the different study periods described in chapter 4, specific objective of the study…

11 Picture of the Advanced Pollution Instrumentation M200E.

12 Illustration of measuring principle for API-instrument...

13 API instrument setup with all related components like, external data logger, external pump, span-gas and Zero-gas.

14 At the roof of the office building. Picture illustrates…

15 Sampling at the roof of the office building, near the roof-air inlet as illustrated in Figure 11 and Figure 7.

16 Small corridor, between main corridor at the Combination-Filter areas. Up on the left is where the inlet tube comes out from the maintenance room.

17 Advanced Pollution Instrumentation (API) instrument with pump and tubes installed in maintenance room at the Regular Filter area.

18 Advanced Pollution Instrumentation (API) instrument with pump and zero-gas generator installed in the maintenance room at the Combination Filter area.

19 Background chart trend illustration, representing 1-hour mean value changes for wind speed (m/s), temperature (˚C), vehicle frequency (vehicles/h).

20 Trend chart illustrating both Advanced Pollution Instrumentation (API) instrument in the Regular-Filter (RF) area for quality association control…

21 Municipality (MI) and Roof Instrument (RI) trend chart illustrating Nitrogen Dioxide ($NO_2$) concentration changes for both instruments…

22 Scatter plot between the Nitrogen Dioxide ($NO_2$) concentrations at the Municipality Instrument (MI) and Roof Instrument (RI), illustrating the relationship…

23 Scatter plot between Nitrogen Dioxide ($NO_2$) concentrations at the Roof Instrument (RI) and Municipality Instrument (MI) illustrating the relationship between the RI and MI…

24 Scatter plot similar to figure 22 with the addition of regression line for each of the four scenarios predicted in Table 10…

25 Trend chart illustrating Roof Instrument (RI) and Combination-Filter (CF) area $NO_2$-concentrations…

26 Scatter plot illustrating the relationship between Roof Instrument (RI) and Combination-Filter (CF) area Nitrogen Dioxide ($NO_2$) concentrations through…

27 Scatter plot illustrating the relationship between the Roof Instrument (RI) and Combination-Filter (CF) area through a regression line and a line representing a 1:1 CF slope…

28 Trend chart illustrating the daily Nitrogen Dioxide ($NO_2$) concentrations changes between the Roof Instrument (RI) and the Regular-Filter (RF) area…

29 Scatter plot illustrating the relationship between the Roof Instrument (RI) and the Regular-Filter (RF) area Nitrogen Dioxide ($NO_2$) concentrations through…

30 Trend chart illustrates the daily Nitrogen Dioxide (NO) concentrations variation between a Regular-Filter (RF) and a Combination-Filter (CF)…

31 Scatter plot illustrates the relationship between Regular-Filter (RF) and Combination-Filter (CF) through a…

32 Scatter plot illustrating the relationship between a Regular-Filter (RF) and a Combination-Filter (CF) regression line and a line representing a 1:1 slope…

# Table list


1 Literature comparison of average $NO_2$ concentration reduction between the outdoor to indoor environment.

2 Current $NO_2$-concentrations limits, ambitions and air quality criteria recommendations.

3 Overview and sources description of external data.

4 Background information data table representing 1-hour mean values (0-24h) between the 13 to 31 January…

5 Relationship and 1-hour mean $NO_2$-concentrations between the two Advanced Pollution Instrumentation (API) instruments…

6 Relationship and mean data illustration between the Municipality Instrument (MI) and Roof Instrument (RI).

7 Bivariate correlation analysis with the Municipality Instrument (MI) and Roof Instrument (RI) as dependent variables and temperature, wind speed and vehicle frequency as independent variables.

8 Multiple linear regression coefficient table; Municipality Instrument (MI) as dependent and temperature, wind speed and vehicle frequency as independent variables.

9 Linear regression coefficient table; Roof Instrument (RI) as dependent and Municipality Instrument (MI), temperature and wind speed as independent variables.

10 Example on predicted values based on the prediction model, when inserting different values into the model…

11 Comparative data table for part 1 and 2. Comparison is between outdoor Roof Instrument (RI), the Combination-Filter (CF) area and Regular-Filter (RF) area $NO_2$-concentrations.

12 Overall and comparative data between the Regular-Filter (RF) and the Combination-Filter (CF), period 31st of January to the 28th of February.

13 Detailed timeline description, describing objectives in relation to the comparing objectives and dates for data scaling.

14 Raw-data preparation.

15 Scaling of raw-data.

16 Factors for converting $NO_x$ from ppb to µg/m$^3$.

# 1 Acknowledgement

No specific person or incident triggered this study, rather several circumstances and coincidences led to its present form. In hindsight, it seems that everything just happened at the right time. I will now go through some of the background and use the opportunity to give thanks to specific persons, workplaces, institutions and collaborators for helping me to complete this work.

My work as an occupational hygienist started in august 2010 for Proactima AS. At the end of 2010, Proactima received an inquiry regarding nitrogen dioxide measurements. The task was to analyse an office building's indoor atmosphere for $NO_2$-concentrations. The reason was that the building is situated near one of the most heavily trafficked and polluted areas in Bergen.

At that time, Proactima and the landlord (GC Rieber) planned for a simple sampling strategy due to costs and the strategy was to perform a few full day mean samplings with prepared filters for $NO_2$ measurements.

The project was postponed because the meteorological conditions were not appropriate at the time. Two years passed and in August 2012 I started a master study at the Department of Global Public Health and Primary Care. Incidentally I was contacted by GC Rieber the same autumn, with a request to take up the thread regarding the same $NO_2$ measurements.

At that time, I was in dialog with my university supervisor professor Magne Bråtveit concerning the topic of my thesis. After some reflection, I mentioned the $NO_2$ sampling as a possible subject for my thesis. Initially it was not clear if it was possible to expand the $NO_2$ assignment into a master thesis.

After much back and forth regarding coordination, meeting arrangements, time estimations and costs calculations it was decided to go ahead with the project. A worrying factor for me was that I had to combine the study with full time work at TCM DA, and fulfilling my obligations as a husband and father of three.

None of this would have been possible without the support of my best friend and lovely wife Natalie Reyes-Lingjerde. I will always be grateful for her patience and help, giving me the time needed to make this study possible.

Beside my wife one special person that has been a huge support is my supervisor professor Magne Bråtveit. I want to thank him for all his advice and knowledge and for challenging me to present my work at the IOHA conference in London, 2015. In addition, I want to thank professor Bente Moen for following me up on several occasions.

I want to thank Bodvar Duesund, main GC Rieber representative for facilitating the study and helping with rental of instruments. The cooperation with GC Rieber was very positive experience.

I want to thank Jo Tidemann (Proactima Bergen office representative) for helping me with financial issues and much personal support during the study. In addition, Hans Thore Smedbold (Proactima supervisor and disciplinary adviser) helped and supported me during the study.
I am grateful to the University of Bergen, or giving me the opportunity to further my education.

I am also grateful to the TCM DA management for being lenient about my study needs at any time. Special thanks to Randi Gundersen for all support during the study.

It is also important to mention all support that I have received from Nils Einar Ladegård at NILU.

Finally, I want to thank my dear friend and sister Isabel Reyes Andersson and my friends Harald Elvatun and Kai Kristoffer Lie for helping me with proofreading, day time discussions and late night reflections on my work.

# 2 Introduction

Air pollution is a huge challenge in many cities and vehicle traffic has been recognized as a major source of air pollution (NIPH 2013; Rijnders 2001). For instance, the World Health Organization (WHO) attributes more than 2 million premature deaths each year to the effects of urban outdoor and indoor air pollution (WHO, 2005). The United Nations estimates that 1 million premature deaths annually are associated to urban air pollution and over 90% of the air pollution in developing cities links with poor quality vehicles (United Nations Environment Programme, u.d.) and the increasing amount of diesel vehicles in the vehicle fleet (NIPH, 2013). Combustion of petrol or diesel fuel leads to the production of exhaust gases containing a range of potentially harmful pollutants (WHO, 2005). Diesel cars emit 10-40 times more $NO_2$ per km than the equivalent gasoline vehicle (NIPH, 2013).

## 2.1 Pollution

Pollutants are divided into primary and secondary groups. Primary pollutants are those emitted directly from a source and are easy to measure. Secondary air pollutants are those formed naturally within the atmosphere itself.

The primary pollutants both outdoors and indoors includes sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), carbon monoxide (CO), Volatile Organic Compounds (VOC), and carbonaceous and non-carbonaceous primary particles. Pollutants are present both as gaseous and Particulate Matter (PM). The gaseous pollutants are normally very small, down to around 1 Ångstrom (0,1nm), for example the nitrogen oxygen bond (N-O) is around 1,2 Ångstrom (Anon., u.d.). The small size of the molecule means that ventilation systems with conventional filters for inlet air in buildings do not normally capture gaseous pollutants.

The PM begins at approximately an aerodynamic diameter of 1nm and are normally captured by conventional air filters. In the literature, it is most common to refer to specific PM sizes in subscript, for instance $PM_{2.5}$, $PM_{10}$. (Figure 1)(WHO, 2005).

Particle size is a property that is extremely important. Particle shape and size will have influence on PM behavior. Perhaps the most important in the occupational hygiene context is aerodynamic diameter as it governs the airborne behavior. The PM cutoff values of 2.5 and 10 also indicates how deep particles penetrate the respiratory system

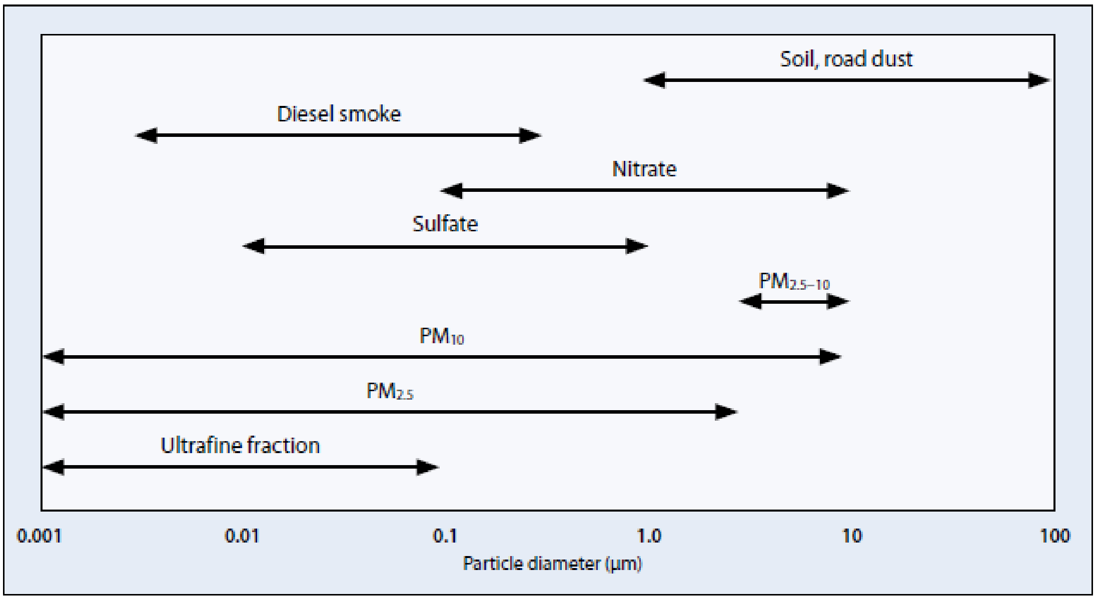


*Figure 1. Size range of airborne particles, showing the health-related ultrafine, PM2.5 and PM10 fractions and the typical size range of some major components (WHO, 2005).*

When considering ventilation systems for inlet air in office buildings most buildings have some kind of conventional air filter installed. These filters reduce the indoor PM depending on particle size and filter specifications. However, these filters will only reduce PM and not the gaseous pollutants such as $NO_x$. This is why it is important to carry out studies on how to also reduce indoor $NO_x$-concentrations through filter absorption.

## 2.2 Nitrogen dioxide

Atmospheric nitrogen and oxygen are combined into $NO_x$ during high-temperature combustion in e.g. gasoline and diesel vehicles engines (WHO, 2005). Combustion produced $NO_x$ is considered as a primary pollutant, and will react chemically with the surroundings. $NO_x$ is a generic term for nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$). It is mainly NO that is produced during combustion. The majority of $NO_x$ is mainly emitted as NO while only a small part, typically 5% is $NO_2$.

The main pathway for conversion of NO into $NO_2$ is through an oxidation reaction of NO and atmospheric ozone ($O_3$), as shown in the formula below

$$NO + O_3 \rightarrow NO_2 + O_2 \text{ (WHO, 2005).}$$

Background $O_3$ has several well documented sources both natural and man-made. These include downward transported stratospheric $O_3$, methane reacting with naturally occurring NOx, naturally occurring NOx reacting with biogenic VOC and long range transported $O_3$ from distant pollutant sources (Agency, Environmental Protection, 2006)

Among the $NO_x$ components, mostly $NO_2$ is associated with negative health effects. According to epidemiological and clinical studies described by WHO document *Air quality guidelines* (WHO, 2005), this includes:

- Impaired lung function
- Eye irritation
- Increased susceptibility for infections
- Irritation and inflammatory responses in the respiratory system
- Respiratory symptoms (cough, increased mucous production, wheezing)

### 2.3 Outdoor to indoor $NO_2$ propagation – literature review

Many people reside or have their working place in urban areas, in direct proximity to a main road and intersections. Due to current EU legislation, major cities in Europe are obligated to measure outdoor air pollution concentrations in densely populated areas. (Norwegian Environment Agency, 2004). The existing Norwegian and EU legislation covers both the indoor and outdoor environment $NO_2$ concentration limits. $NO_2$-concentrations are towards the authorities mandatory to document and report. This is not the case for indoor concentrations despite that the regulation is clear on permitted concentrations.

According to Norwegian Institute of Public Health (NIPH), the reduction of $NO_2$-concentrations is expected to be approximately 20-60% when transported from outdoor to the indoor environment (NIPH, 2013). They suggest that the reason for this reduction is that $NO_2$ will rapidly react with reactive surfaces. A previous meta study reviewing available literature indicated an ~40-50% reduction of $NO_2$-concentrations between the outdoor and indoor environment (Milner, et al., 2004).

The main transport route of $NO_2$ into buildings indoor environment is through the ventilation. Consequently, the type of ventilation system will have an impact on the indoor concentrations. In addition, the type of building and potential indoor sources are also important for indoor pollution levels. A review of the current literature (Table 1) indicates that the outdoor to indoor $NO_2$-concentrations reduction varies between studies.

Ventilation systems are generally divided into natural and mechanical. Naturally is when openings in a building let air in and out without a mechanically moving the air. Mechanical ventilation is when a buildings air supply or extraction is forced through a fan. Previous studies indicate that the overall reduction in $NO_2$ from outdoor to indoor environment have a range of 2-60% (Table 1) depending on which type of ventilation is tested.

Five of six found studies on natural ventilation indicates approximately 10-47% $NO_2$-concentration reduction between the outdoor to indoor environment (Challonger 2014; Lawson 2011; Rijnders 2001; Esplugues 2010; Stranger 2007). Only one study (Baxter, et al., 2006) found higher indoor concentrations than outdoors. Among the five studies found on mechanical ventilation three indicates a reduction of approximately 10-62% (Shuai 2013; Rijnders 2001; Stranger 2007). However, two previous studies (Challonger & Gill, 2014, Parti-Pellinen, et al., 2000) indicate no reduction, instead the concentrations are almost equal (2%) or higher (-79%) indoors than outdoors. Among previous studies only one was identified to compare different types of filters. The results showed an average $NO_2$-concnetration reduction of 47% with a chemically prepared filter (Parti-Pellinen, et al., 2000).

*Table 1. Literature comparison of average $NO_2$ concentration reduction between the outdoor to indoor environment.*

| Study area | $NO_2$ sampling Method | Ventilation system/Filter type | O/I[1] | Approximate average % red[2] | Reference |
|---|---|---|---|---|---|
| 4 shops and 6 offices | Direct reading | Natural/n.a<br>Mechanical/n.a | Nat.19.0/11.3<br>Mec.22.0/21.6 | Nat.40<br>Mec.2 | (Challonger & Gill, 2014) |
| 15 shops[3]<br>**1.** 5<br>**2.** 5<br>**3.** 5 | 21 days of average measurements | Mechanical / n.a | **1**. 44.5/33.6<br>**2.** 49.7/33.9<br>**3**. 41.5/74.4 | **1**. 25<br>**2**. 32<br>**3**. -79 | (Shuai, et al., 2013) |
| 27 dwellings[4]<br>**1.** 15<br>**2.** 12 | 7 days' passive badges per place | Natural/n.a | **1.** 11.2/10.0<br>**2.** 8.5/6.8 | **1**. 11<br>**2**. 20 | (Lawson, et al., 2011) |
| 6 primary schools (241 children). Home(outdoor-indoor). School (outdoor-indoor)[5] | Personal Passive badges and outdoor badges. (week average measurements) | Natural/n.a | **1a.** 58.3/36.0<br>**2a.** 56.1/29.7<br>**3a.** 44.9/25.1 | **1a.** 38<br>**2a.** 47<br>**3a.** 44 | (Rijnders, et al., 2001) |
| | | Mechanical/n.a | **1b.** 59.0/29.4<br>**2b.** 41.6/16.0<br>**3b.** 33.2/12.4 | **1b.** 50<br>**2b.** 62<br>**3b.** 63 | |
| 352 homes | Passive badges 14 days/sample | Natural/n.a | 27.4/19.7 | 28 | (Esplugues, et al., 2010) |
| 40 homes | Passive badges 3-4 days/sample | Natural/n.a | 17.2/19.6 | -14 | (Baxter, et al., 2006) |
| 27 primary Schools (S), 19 Dwellings (D) | Passive cartridge sampling | Mechanical/n.a<br>Natural/n.a | S. 63.7/57.0<br>D. 38.9/32.6 | S. 11<br>D. 16 | (Stranger, et al., 2007) |
| Children's day-care | Direct reading instrument | Mechanical/Mechanical<br>Mechanical/Mechanical and chemical | 21.9/23.8<br>23.7/12.5 | -9<br>47 | (Parti-Pellinen, et al., 2000) |
| Meta study 12 studies between 1986-2005 | | | | ~40 -50 | (Milner, et al., 2004) |

[1]Outdoor (O)/indoor (I) $NO_2$-concentrations

[2]$\boldsymbol{Average\ \%\ reduction} = \frac{\boldsymbol{Outdoor - Indoor}}{\boldsymbol{Outdoor}} \boldsymbol{x100}$

[3]1. Convenience; 2. Coffee; 3. Restaurants

[4]Study was divided in near/far from main road. 1. Near(<50m), 2. Far (>300m)

[5]Study divided in different seasons and traffic density (a) and urbanization (b). **Home**: 1a. Very busy, 2a. fairly busy and 3a.non busy. **School**: 1b. Very urban, 2b. Fairly urban and 3b. Nonurban. Study results are divided in different seasons, selected as representative was winter season.

## 2.4 $NO_2$-concentrations in Norway

Norway has a relatively small population of approximately 5 million people. The two major cities Oslo and Bergen have a total population around 900.000 people (Oslo ~650000 and Bergen ~270000). Despite having a small population compared to many other European cities the average annual outdoor environmental $NO_2$-concentrations are relatively high in both Bergen and Oslo compared to other major cities in Europe (European Environment Agency, 2015), and match annual average concentrations of 40-50µg/m$^3$ (*Figure 2*).

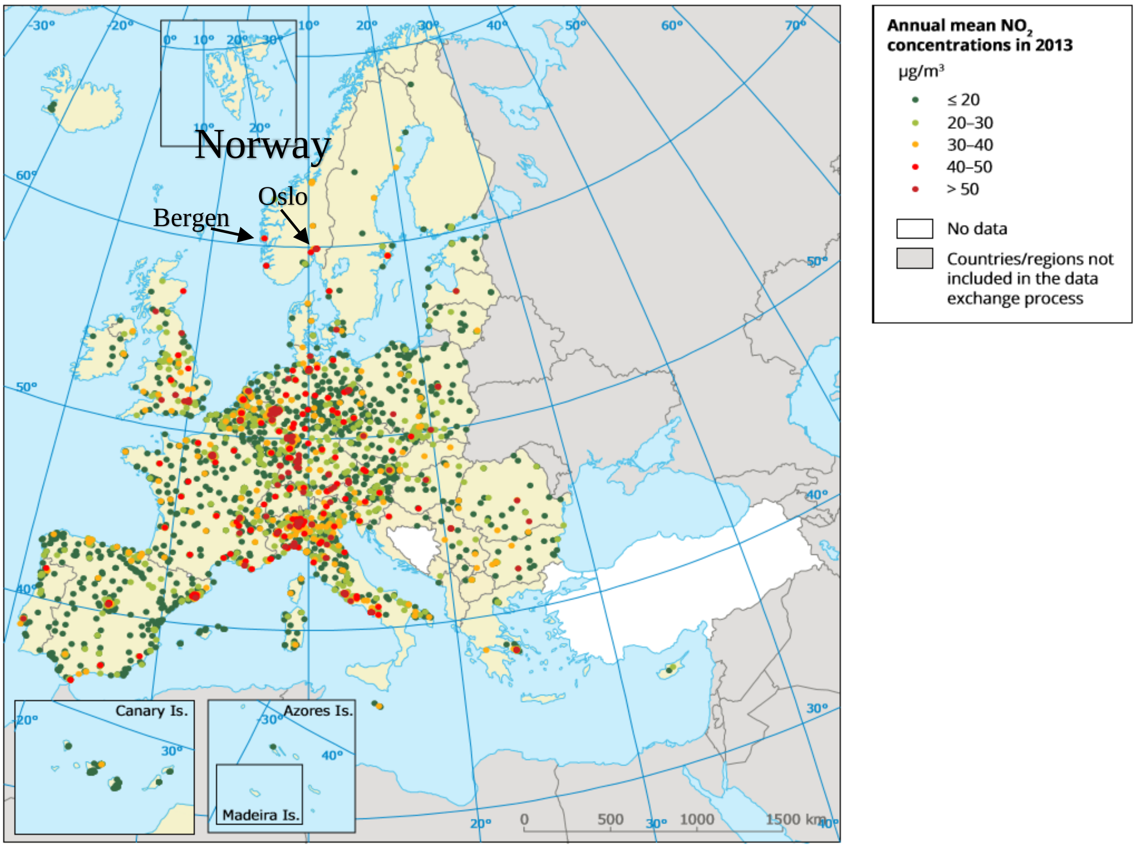


*Figure 2. Annual mean NO2-concentrations at major cities around Europe (European Environment Agency, 2015).*

## 2.5 Regulations

In Norway a number of regulations and recommendations are designed to protect the population and the environment from pollutions potential negative health effects. A short summary of regulations and recommendations related to $NO_2$ are described below. The main act concerning protection against pollution and waste is the, Pollution Control Act.

This overall and mandatory act was promoted in 1983 by the Ministry of Climate and Environment. According to §1:

*This act aims to protect the environment from pollution and to reduce existing pollution, to reduce the amount of waste and to promote a better waste management. The law should ensure a proper environmental quality so that pollution and waste do not lead to injury, the well-being or harm nature and its capacity for self-renewal.* (Ministry of Climate and Environment, 1981)

The Norwegian Environment Agency (NEA) is responsible to administrate the Pollution Control act and aims to reduce local air pollution to promote human health and well-being. The pollution regulation, *regulation concerning the limitation of pollution* was first established the 4th of October 2002 by NEA. According to the regulation, Part 3 – Chapter 7, the regulation describes the requirements for placement, procedures, methodologies and documentation of monitoring instruments. This is to ensure that the data meets quality requirements of EU air quality directives (Norwegian Environment Agency, 2004).

The Norwegian Institute of Public Health (NIPH) have addressed the *air quality standards – health effects of air pollution* with the purpose to prevent adverse health effects based on outdoor air pollution. The criteria are set to a concentration level that permit all people to be exposed to these levels without causing adverse health effects. The document describes the health impact of different pollutants and a guideline to exposure levels (*Table* 2) (NIPH, 2013). For indoor criteria the NIPH have published the *Recommended technical standards for indoor air quality*, which are based on the same criteria's as the outdoors standards (Table 2) (NIPH, 2015).

NEA, Norwegian Public Roads Administration (NPRA), Norwegian Directorate of Health (NDH) and NIPH have, as commissioned by The Ministry of Climate established long-term health-based national targets. The pollution regulation limits are revised and summarized in the document "*Limit values and national ambitions"*. The ambition is to reduce air pollution in Norway in both short- and long-term aspects and reduce the health problems in the population associated with air pollution. For $NO_2$ the air quality criteria are stated in table 2. The limit values indicate that mitigating actions should be implemented to reduce local pollution (Norwegian Environmental Agency, M-129-2014).

*Table 2. Current $NO_2$-concentrations limits, ambitions and air quality criteria recommendations.*

| Averaging period | Limit | National ambitions | Air quality criteria |
|---|---|---|---|
| Hour | 200µg/m$^3$ | 150 µg/m$^3$ | 100µg/m$^3$ (300 µg/m$^3$ 15min) |
| Yearly | 40µg/m$^3$ | -- | 40µg/m$^3$ |

To accomplish and meet the national requirements and regulations and comply with the EU directives (EU-directive2008/50/EC and 2004/107/EC). The NEA have addressed the *Handbook for quality system for measurements of air quality*. The handbook is provided as a common framework that shall form the basis for the establishment and operation of the national monitoring and reporting system. It describes the specific requirements for measuring stations, data collection, data quality, measurement methods, operating procedures and responsibilities (NEA, 2014).

## 2.6 Bergen – pollution

«*… Against the strong air pollution the advice is to mostly stay indoors,* says Stensletten» (Hov. R, 2010).

During winter, the media has focus on the accumulation of traffic-related pollution in Bergen. Poor air quality as described in Figure 3 or news headings like, "*urban air is a shared responsibility"* (Schelderup. H, 2016), "*harmful city air – again"* (Bergens Tidende, 2013), "*air pollution"* (Esau, 2011) are common to read every year.

*Figure 3. Picture of Bergen. "…Air quality in Bergen and other big cities are at times very poor. Among the reasons for that is the increasing proportion of diesel cars in your fleet that emit more out of gas NO2". Ref: Bergens Tidende (Schelderup. H, 2016).*

As described in a Bergen newspaper article (Esau, 2011) and illustrated in Figure 4, Bergen is surrounded by mountains. During cold and wind still winter periods air pollution increases dramatically over Bergen. One reason for this is inversion also described as the "lid" locally. This occurs when cold cloudless days let ground heat escape through the atmosphere (Bergens Tidende, 2014). The second main reason is when east/northeast winds enter slowly through *Byfjorden*, at the same time as cold air moves downstream the Bergen's valley from south to north. These two air streams block each other and leads to wind still conditions in the city centre, especially around Danmarksplass (*Figure* 4) (Esau, 2011). At these conditions temperature can be lower near the sea level than at higher altitudes. When such conditions occur the newspapers often have headings like "…now is the lid back over the city" (Bergens Tidende, 2014)

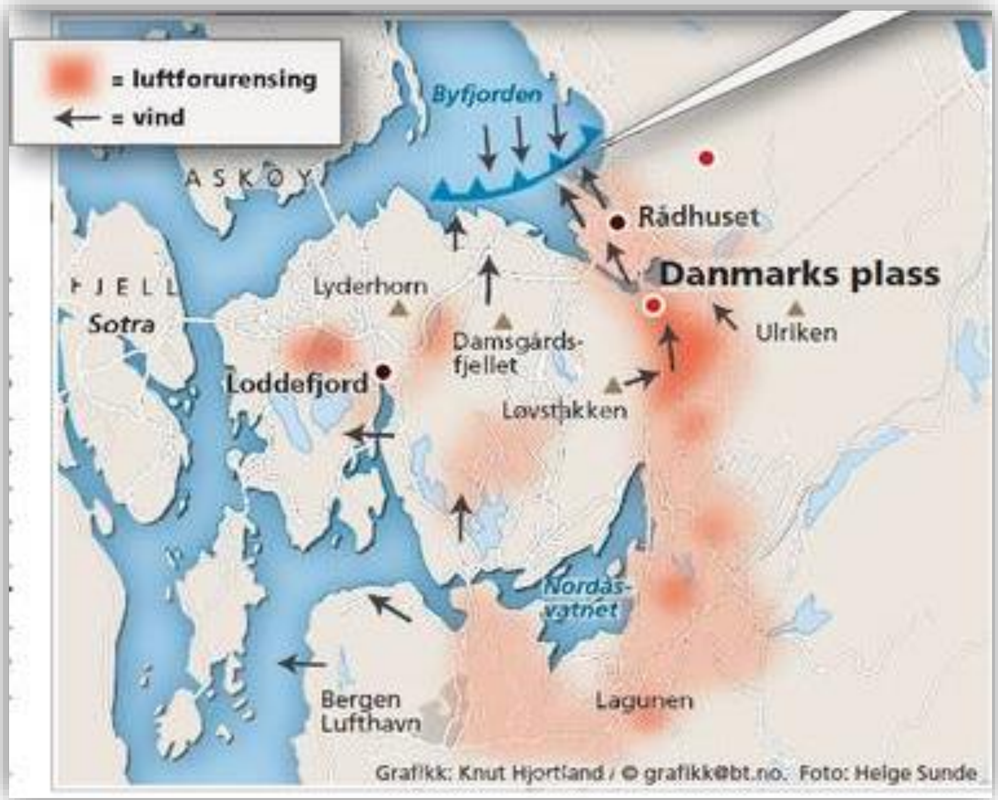


*Figure 4. Bergen landscape map, describing air pollution red zone and wind directions with arrows. Danmarksplass is highlighted as a high polluted spot (Esau, 2011).*

### 2.6.1 Danmarksplass overall description

Danmarksplass was previously a shipyard industrial area, today it is a residential and office area in Bergen. Danmarksplass, which means the place of Denmark, got its official name in 1946 as an expression of gratitude for the humanitarian assistance from Denmark during the 2nd World War (Nielsen, 2011)

Danmarksplass is one of the most polluted areas in Bergen due to several reasons. Most noted is the intersection with a high traffic density during daytime (Figure 5). The reason is that almost all traffic going in and out of Bergen has to cross this intersection. This also includes traffic passing to and from the airport. In addition to the heavy traffic load during rush hours the traffic stands almost still in periods during rush hours.

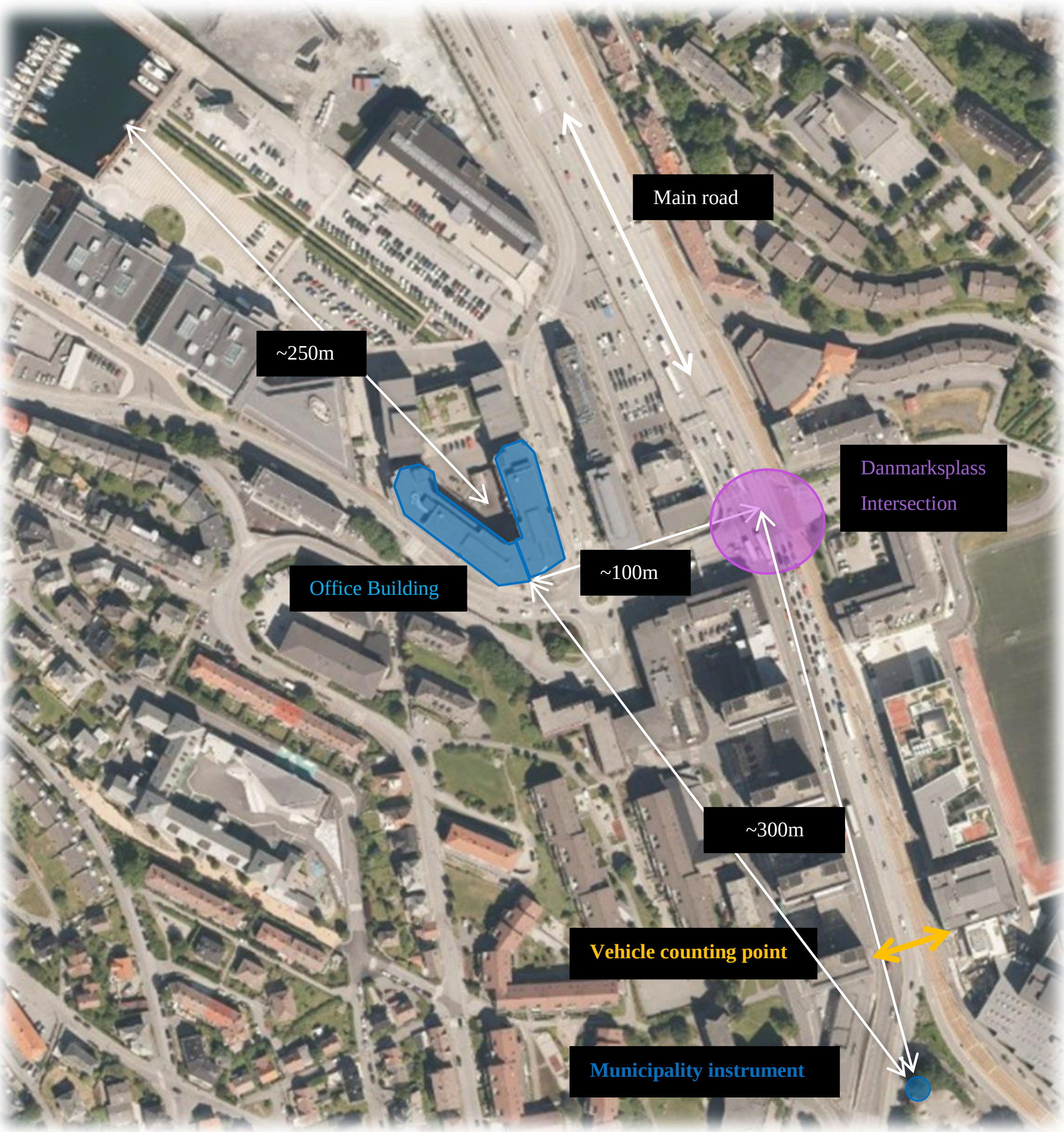


*Figure 5. Danmarksplass intersection in purple. Office Building where measurements have been performed in the study in blue. Municipalities stationary instrument, blue circle down to the right. Vehicle counting spot marked as an orange arrow.SG15 air picture (ref., Norway in picture (Norge I bilder). https://www.norgeibilder.no/ ).*

Figure 6 shows that the concentrations of $NO_2$ at Danmarksplass, Bergen rises during wintertime. The mean hourly $NO_2$-concentrations seems to have been varying between 100-200µg/m$^3$ the last 5-6 years. However, previous years' worst-case scenarios have reached levels up to 400µg/m$^3$ and higher. Values that high exceeds both the limit value of 200 µg/m$^3$ and the short term value of 300µg/m$^3$ (Table 2). These levels can have serious impact on the most sensitive part of the population. According to the regulation of *limit values and national ambitions*, mitigating actions shall be implemented at 200µg/m$^3$.

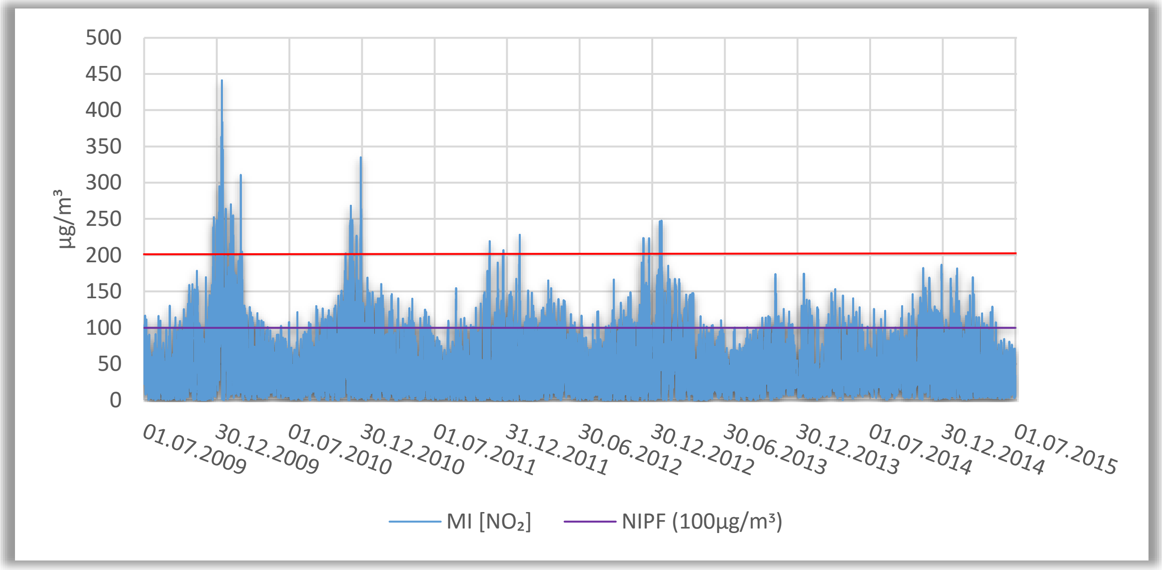


*Figure 6. Hourly mean $NO_2$-concentrations at Danmarksplass stationary monitoring station. Period 1.7.2009-1.7.2015. The purple line indicates the recommended maximum 1-hour mean value which shall not be exceeded. The red line indicates when municipalities are required to implement mitigating actions.*

# 3 Rationale

Combustion vehicles emit harmful pollutants. Parameters such as traffic density, meteorological conditions as well as other local conditions, may intensify local pollution. Many studies have shown that like NOx and especially $NO_2$ can have adverse health effects.

Norway has a relatively small population, even so major Norwegian cities reaches annual average $NO_2$-concentrations equal or above other large european cities. There is pollution “alarm” over Bergen more or less every year during wintertime, media headlines regarding the air pollution are common to read.

Through $NO_2$ measurements, it might be possible to determine the correlation in concentrations between different locations as well as effectiveness of different mechanical ventilation filters in buildings. There are many studies done on outdoor pollution but there is still a knowledge gap when it comes to describing how $NO_2$ from the external environment is distributed into buildings.

Bergen municipality has two instruments measuring $NO_2$, one is located in direct proximity to one of the most polluted and traffic dense main roads in Bergen. Data from this location is publicly available through the web and gives an indication on local concentrations. Thus, it would be useful if this data also could be used for other purposes, e.g. predicting $NO_2$-concentrations in other areas or specific locations.

During wintertime the instrument frequently measures outdoor $NO_2$-concentrations higher than the recommended levels. More knowledge is needed on how the outdoor concentrations of $NO_2$ affects the indoor environment.

Most buildings use conventional filters, but in highly polluted areas it is important to evaluate if other types of filters might be more appropriate to reduce both particles and gaseous pollutants.

# 4 Objectives

## 4.1 Main Objectives

The main objective of this study is to gain more knowledge on how indoor $NO_2$-concentrations is reduced when using different types of air purifying filters. These filters are installed in two independent mechanical ventilation system in an OB, located in an area with high airborne pollution from vehicle traffic.

## 4.2 Specific Objectives

A. Compare the $NO_2$-concentrations at the roof of the OB location with the concentrations measured outdoors using the municipality instrument placed 300m away (*Figure* 6).

B. Compare the $NO_2$-concentration at the roof of the OB, with the indoor $NO_2$-concentrations when using a combination-filter and subsequently a regular-filter.

C. Compare simultaneously indoor $NO_2$-concentrations in two independently mechanically ventilated office-building areas where a combination-filter and a regular-filter is filtering inlet air, respectively.

# 5 Hypothesis

**$H_1$** The outdoor $NO_2$-concentrations on the roof of the OB are lower than at the stationary instrument run by the municipality.
**$H_2$** The OB indoor $NO_2$-concentrations in the combo-filter area, is lower than the outdoor $NO_2$-concentrations next to the air inlet at the roof of the OB.
**$H_3$** The OB indoor $NO_2$-concentrations in the regular-filter area is lower than the outdoor $NO_2$-concentrations next to the air inlet at the roof of the OB.
**$H_4$** The percent concentration reduction of $NO_2$ across the combo-filter is greater than across the regular-filter.

**$H_{01}$** The OB outdoor $NO_2$-concentrations are not different from the $NO_2$-concentrations at the municipalities' instrument.
**$H_{02}$** The OB combination-filter area indoor $NO_2$-concentration is not different from the OB outdoor $NO_2$ concentrations.
**$H_{03}$** The OB regular-filter area indoor $NO_2$-concentration is not different from the OB outdoor $NO_2$-concentrations.
**$H_{04}$** The percent concentration reduction of $NO_2$ across the combo filter is not different than across the regular-filter.

# 6 Method

A quantitative study over time was carried out during the winter season when the highest concentrations of $NO_2$ were expected. Collection of data took place at the OB (*Figure* 5). Two $NO_x$ monitoring instruments (6.2.1) were acquired from the Norwegian Institute of Air Research (NIAR).

In addition, data was obtained from an instrument deployed by the municipality of Bergen. The instrument is located approximately 300 meters from the OB (Figure 5). The data were prepared according to the guideline (NEA, 2014) and further analyzed statistically (6.4). The study was conducted from January 3rd to March 10th, 2014.

### 6.1 Office building – site of the study

Present study took place at the OB placed 100 meters from The Danmarksplass intersection and around 300 meters from an instrument permanently deployed instrument by the municipality (*Figure* 5), further described as the Municipality Instrument (MI). The OB is a five floor, V-shaped structure. First floor is approximately 1000m$^2$ and the other four floors are approximately 2500m$^2$ each. Each floor is divided into two almost equal sections separated physically by a welcome hall with access to emergency stairs, elevators and two main entrance doors for each office area, east and west (Figure 7).

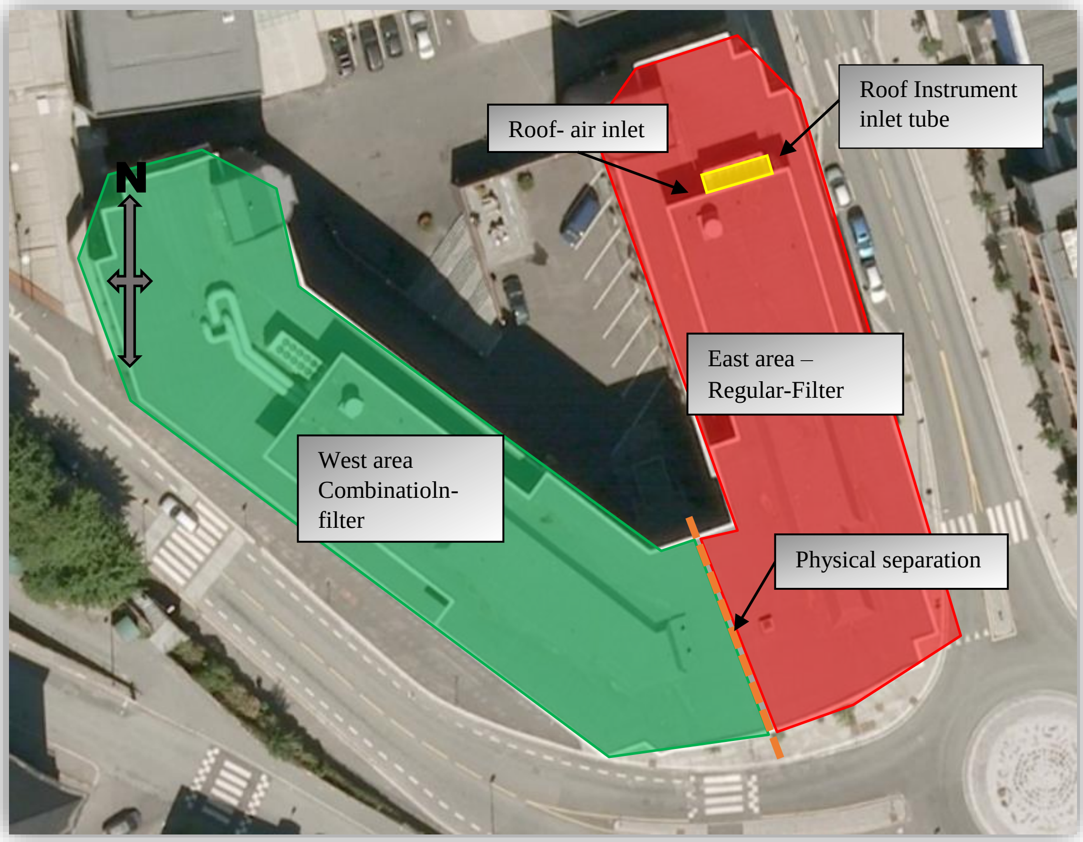


*Figure 7. Overview of the office building. The flight photo illustrates where the combination-filter area is separated from the regular-filter area and also where the roof instrument inlet tube was placed (ref. Norge I bilder. Norgeibilder.no).*

The OB is equipped with two independent mechanical ventilation systems, each with a capacity of 20m$^3$/s. Dividing the ventilation systems capacity in all floor total surface leads to around 3.6l/s for each m$^2$. When the ventilation system was dimensioned the air flow per m$^2$ was set to a minimum of 1.8l/s. According to the Work Environmental Act §4-4 the ventilation capacity need to be assessed and adapted (Inspection, 2005). For the OB it is estimated to be 7l/s for each person, which means that the OB has a capacity for around 2800 people.  Each ventilation system filters the inlet- and outlet-air through 20 inlet- and 20 outlet-filters. During the study the east area ventilation system was equipped with a Regular-Filter (RF) and the west with a Combination-filter (CF) (Figure 7). According to the landlord of the OB both ventilation systems were operating between 06:30-17:00 during working days, Monday to Friday.

### 6.1.1 Filters

The two types of filters used in this study were delivered by Interfil, a Norwegian supplier, and manufactured by Freudenberg, a German company. According to manufactures specifications the filters are composed of 100% thin synthetic fibres and have a very low decompression rate, even in humid environments it remains almost unchanged. The filters are F7 classified according to the EN779:2012 standard. Both filters are suited as main filters in ventilation systems and are resistant to micro bacterial growth and chemicals. (Interfil, u.d.)

Both filters have an approximate surface area of $9.5m^2$. The RF is a Viledon NanoPleat (Figure 8) and the CF a SuperPleat Duo (Figure 9). According to the specifications the major difference between the filters is that the CF synthetic material is treated with a layer of $500g/m^2$ activated charcoal (11.4).

At the OB the filters were replaced every second years. During sampling the filters had been used for approximately 9 months. Intervals between replacements of filters is based on an agreement between supplier and customer.

*Figure 8. Viledon NanoPleat, regular-filter for filtering particles.*

*Figure 9. SuperPleat Duo, combination-filter for filtering both particles and gaseous pollutants, e.g. $NO_2$.*

## 6.2 Data collection

A meeting was arranged with the facility representatives in autumn 2013 to discuss the setup and determine all practicalities. A walk through the facility was carried out to identify where it was appropriate and practical to deploy the instruments.

Technicians from the facility drilled holes through walls, placed tables in maintenance rooms and arranged with power supply before the arrival and installing of the instruments.

In order to address the objectives, the following setup was chosen (Figure 10):

- **A: Difference between outdoor locations**; A Roof deployed Instrument (RI) was continuously measuring $NO_2$-concentrations to compare them with $NO_2$ data obtained from the Municipality Instrument (MI).
- **B: Difference between outdoor and indoor environment**; The same RI data were also used to compare the outdoor with indoor OB $NO_2$-concentrations. Objective B was divided into two parts, the first comparing RI with CF and the second RI with RF.
- **C: Difference between two indoor office areas**; Both instruments were positioned inside the OB for simultaneous measurement of $NO_2$ in the CF- and RF-area.
- At the end of the project both instruments were placed inside the RF-area for a direct instrument comparison, defined as Instrument Comparison (IC).

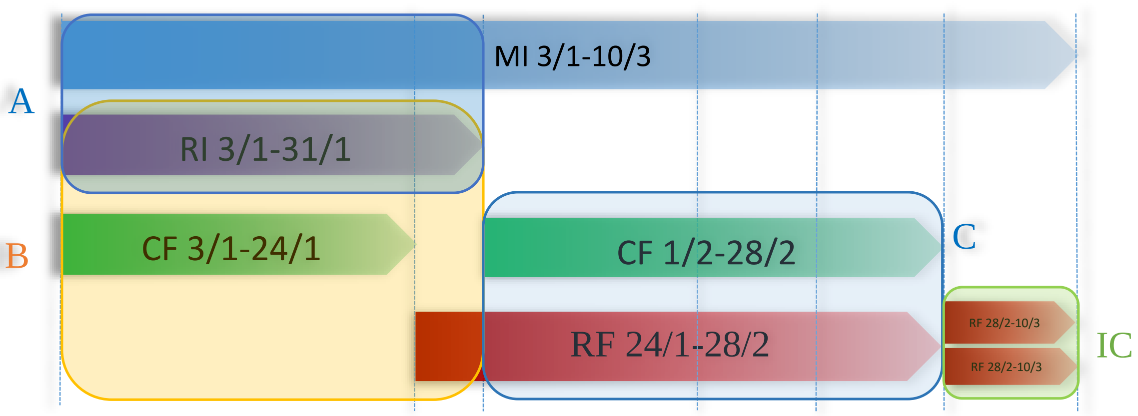


*Figure 10. Timeline for the different study periods described in chapter 4, specific objective of the study. The figure illustrates where the different instruments have been deployed and which data have been included. A. Data from the Municipality Instrument (MI) and Roof Instrument (RI); B. Data from RI and Combination-Filter (CF) area and Regular-Filter (RF) area; C. Data from CF and RF; IC. Comparison between the two API instrument at the RF-area.*

### 6.2.1 Instruments


*Figure 11. Picture of the Advanced Pollution Instrumentation M200E.*

Two instruments of the type Teledyne Advanced Pollution Instrumentation M200E (API) were used for air monitoring of $NO_2$ (Figure 11). The principle behind API's measurement method is chemiluminescence detection, which occurs when NO reacts with $O_3$. The API instrument determines the concentration NO, total $NO_x$ and $NO_2$ in a gas drawn through the instrument. The sample gas is exposed to the instruments self-produced $O_3$ initiating the chemical reaction producing light (chemiluminescence). The instruments measure the amount of light to determine the amount of NO, which is the gas that is actually measured in the instrument, since $NO_2$ does not react with $O_3$.

In order to measure the total $NO_x$ and $NO_2$, the instrument switches periodically gas stream through two different channels. One gas stream goes directly to the $O_3$ reaction cell. The other goes to a converter cartridge filled with heated molybdenum. The heated molybdenum reacts with $NO_2$ in the sample gas and produces a variety molybdenum oxides and NO. Once the $NO_2$ is reduced to NO it is routed to the $O_3$ reaction cell where it will undergo the chemiluminescence reaction (Figure 12) (Akkreditiertes Prüfinstitut, 2007).

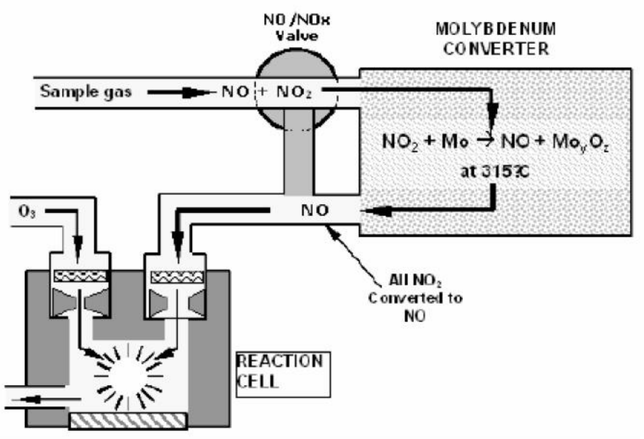


*Figure 12. Illustration of measuring principle for API-instrument. The API measures $NO_2$-concentrations indirectly. Reaction cell reacts only with NO. Sample gas is switched between the molybdenum converter for $NO_2$ reduction to NO and direct NO reading in the reaction cell.*

**Instrument specifications**

| | |
|---|---|
| Measuring range | 0-20000ppbV |
| Lower detectable limit | 0.4ppbV |
| Precision | 0.5ppbV |
| Sample flowrate | 500cm$^3$/min ±10% |
| Dimensions | 178x432x597mm |
| Weight analyzer | 18kg |
| Weight pump | 7kg |

(Teledyne Advanced Pollution Instrumentation, 2010)

### 6.2.2 Data Processing

Data from the $NO_2$-monitoring instruments were analysed according to *Handbook for quality system for measuring air quality* established by NEA (NEA, 2014), and a document describing routinely operation and maintenance of a API200 A/E $NO_x$- monitor established by NIAR (Tørnkvist, 2013).

The raw-data is stored as 1-min average values on an external logger connected to the API by a RS232 serial port (Figure 13). It is possible to select the level of detail on the extracted data. Selected detail level for the study was 1-hour mean values to make possible a direct comparison with the regulations recommendations and requirements (Table 2). The data was also scaled with the help of a zero-gas and a span-gas every 7-10 days according to *Handbook for quality system for measurements of air quality* (NEA, 2014). The scaling is due to the API sensitivity changes slightly over time.

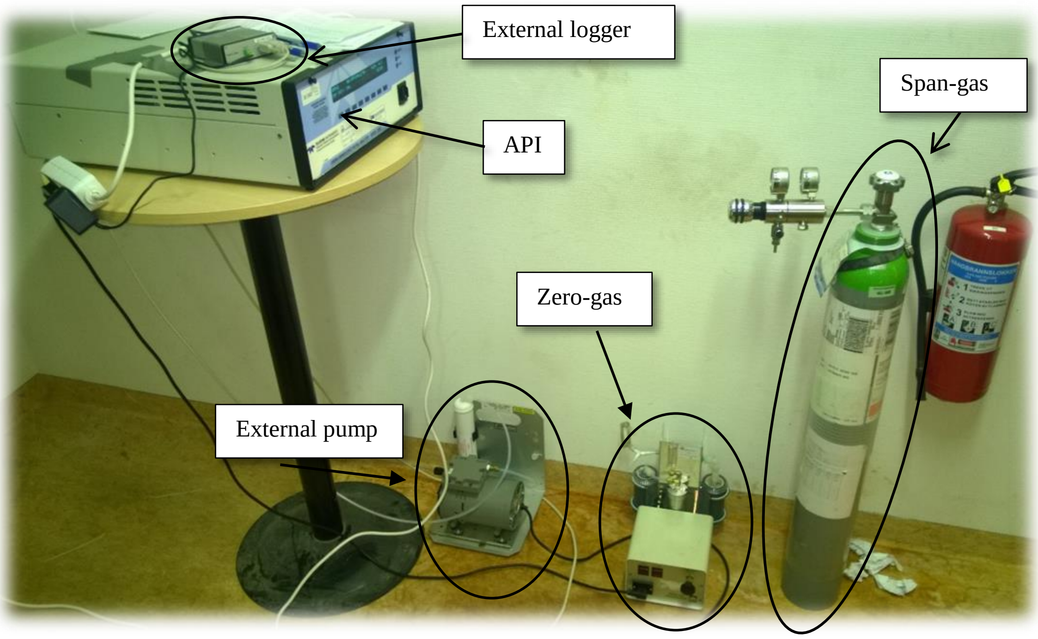


*Figure 13. API instrument setup with all related components like, external data logger, external pump, span-gas and Zero-gas.*

Data was extracted from the logger every 7-10 days and stored on both a personal computer and on OneDrive Cloud to secure that no data were lost. After finished the measurement period data was presented and discussed with the OB landlord and supervisor. A detailed description of scaling timeline, instruments and logger's specific identification is described in Appendix 12.1.

### 6.2.3 Additional data

Additional independent data was acquired with the purpose to study the correlation between RI and MI.

MI data was acquired through NIAR while meteorological data including air temperature and wind speed were collected from one of the major meteorological websites in Norway, YR.no. Traffic data was accessed from the State Road Administration (SRA) (Table 3).

*Table 3. Overview and sources description of external data.*

| *Independent data* | *Administrator/Provider – Source* |
|---|---|
| *Municipality Instrument (MI) nitrogen dioxide concentrations* | Bergen municipality and Norwegian Institute of Air Research (NIAR) – Source data obtained through web page Luftkvalitet.info* |
| *Vehicle frequency data* | State Road Administration – Source data obtained through email correspondence with the State Road Administration (region west) |
| *Meteorological data; wind speed and temperatures* | Norwegian National Television and meteorological department (Norsk Rikskringkasting og Metereologisk institutt, s.f.) |

**To obtain access to the detailed $NO_x$ database it was obtained administration access throughout the study*

As described in 2.5 the *Regulation concerning the limitation of pollution*, monitoring of air pollutants is required on strategic spots depending on city population and pollution concentration around major cities. Different models of $NO_x$-monitoring instruments are deployed in the largest cities in Norway. Bergen has two instruments and one of those is a API M200E instrument which is deployed about ~300m from Danmarksplass (Figure 5).

The municipality of Bergen has the operational responsibility over these instruments. Technicians routinely control the instrument according to *Handbook for quality system for measurements of air quality* (NEA, 2014). API output 1-hour mean data is transferred electronically to NIAR and processed. The last two weeks of processed data is available to the public through the NIAR air quality web page (Bergen Municipality, Norwegian Institute of Air Research, s.f.). For present study administration access to the NIAR historical database was granted. Vehicle frequency data is administrated by the SRA and they have their vehicle counter spot close to MI (Figure 5). Amount of vehicles passing the counter spot was for January send by email in 1-hour mean data values. Norwegian Meteorological Institute and Norwegian Broadcasting Corporation administrate the meteorological data. From their website YR.no, it is possible to obtain both present and historical information. In the present study data was extracted from the meteorological station at Florida, which is located approximately 1.5km north of the OB. The meteorological data were extracted from their website in 1-hour mean values.

## 6.3 Practical measurements

### 6.3.1 Roof measurements

The air inlet tube for the sampling instrument at the roof of the building was placed less than 10 meters from the air inlet at the roof of the building (Figure 14). The instrument itself was installed inside a maintenance room to keep it away from rain and humidity (Figure 14). The inlet tube for air was led through a ventilation channel into the maintenance room (Figure 15).

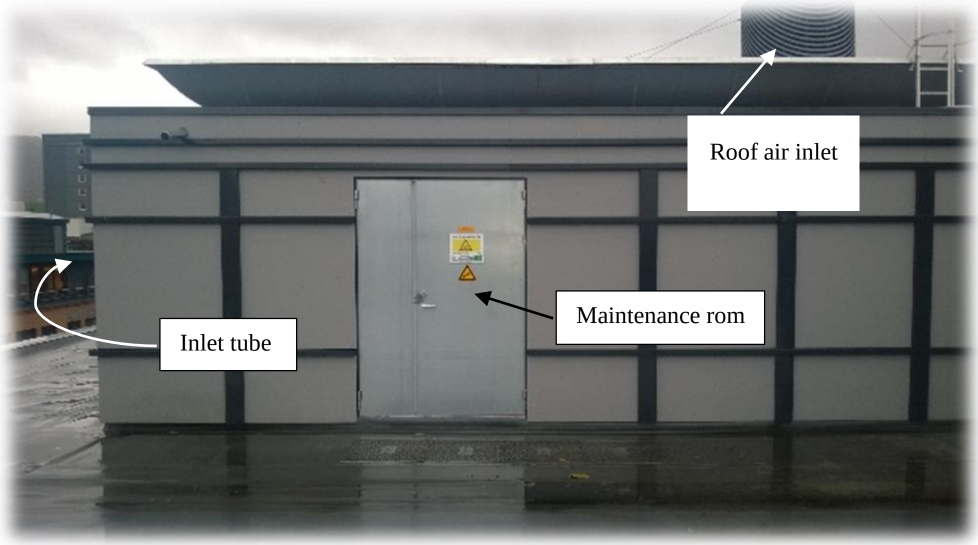


*Figure 14. At the roof of the office building. Picture illustrates the entrance door to the maintenance room and at the right top it is possible to spot part of the ventilation systems air inlet.*

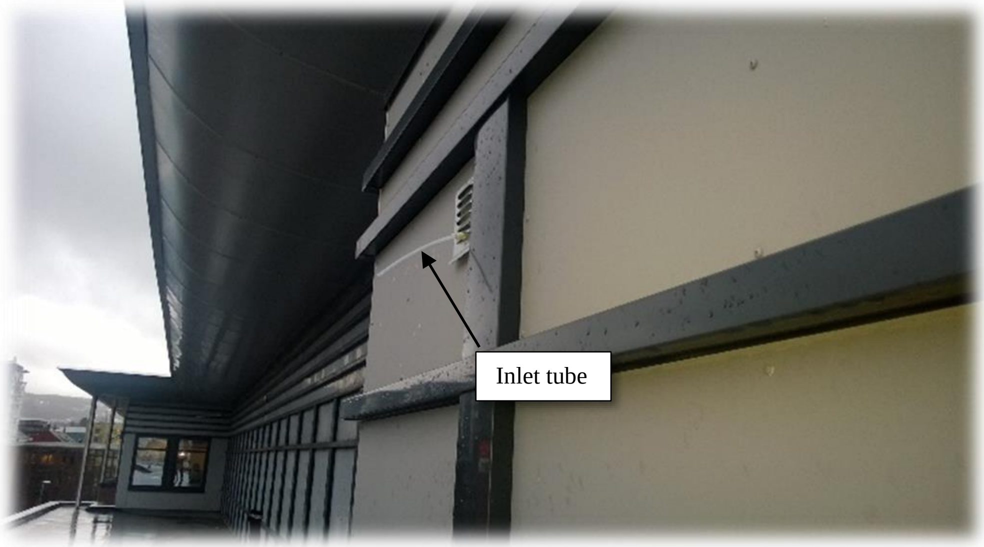


*Figure 15. Sampling at the roof of the office building, near the roof-air inlet as illustrated in Figure 11 and Figure 7.*

The length of the ventilation system was considered to be proportional to the time air was residing inside the ventilation channels, before entering the office area. In order to have as short ventilation channels as possible the $NO_2$-measurements were carried out on the second highest floor. During the study period the highest floor with the shortest ventilation channels was under reconstruction and not available.

### 6.3.2 Office measurements


*Figure 16. Small corridor, between main corridor at the Combination-Filter areas. Up on the left is where the inlet tube comes out from the maintenance room.*

Indoor air monitoring of $NO_2$ was performed in a small corridor between the two main corridors in the office areas (Figure 16). This location was chosen since it was assumed that at this place the supplied air had mixed well with the room air.

The instruments pumps produce an inherent noise, which might be perceived as annoying for tenants. Thus, the instruments with associated equipment, were placed in the maintenance room of each office area (Figure 17 and 18).

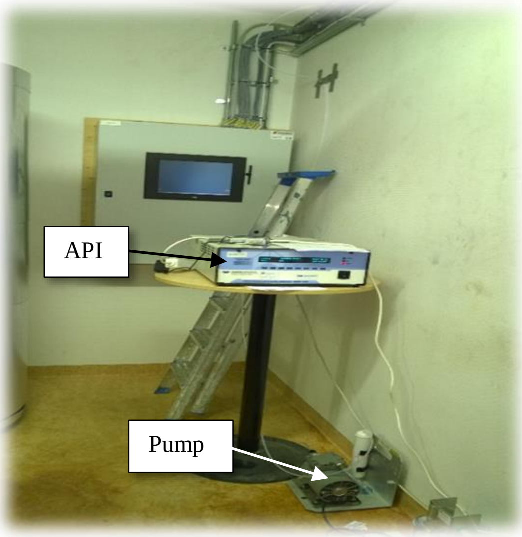


*Figure 17. Advanced Pollution Instrumentation (API) instrument with pump and tubes installed in maintenance room at the Roof Filter area.*

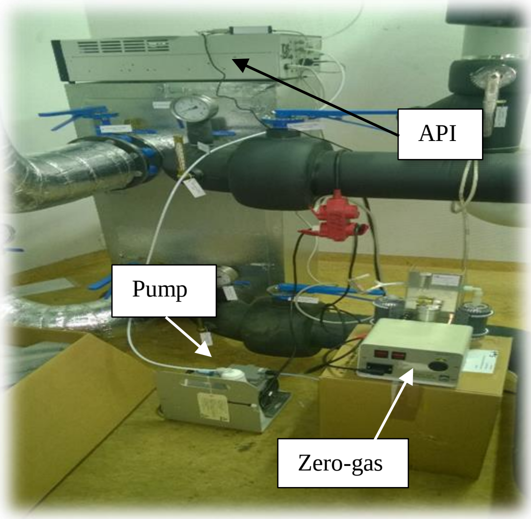


*Figure 18. Advanced Pollution Instrumentation (API) instrument with pump and zero-gas generator installed in the maintenance room at the Combination Filter area.*

## 6.4 Result preparation and statistical analysis

For the result preparation both Microsoft Excel 2013 and SPSSv22.0.0.0 were used. All the trend charts were created with Excel while the comparative data tables, scatter plots, bivariate correlation and multiple linear regression analysis was performed with SPSS. A more detailed description follows in this chapter. For the compilation of the results the data was divided into two sets. One set representing the outdoor measurements between MI and RF, where 1-hour mean data for a whole day from Monday to Sunday was analyzed. The second set was based on 07:00-17:00 1-hour mean data from Monday to Friday, as this relates to the operation time of the ventilation system (06:30-17:00). The second set was used for the outdoor to indoor and in indoor analysis, RI-CF, RI-RF, CF-RF and IC.

### 6.4.1 Trend charts

Trend charts was used to illustrate how data from different instruments changes in relation to each other over time. Included data could be meteorological conditions, vehicle frequency and at least two $NO_2$-monitoring instruments. For all trend charts 24-hour data was used to avoid notches in the trend presentation. Some charts are supplemented with a black horizontal dashed line representing the 100µg/m$^3$ $NO_2$ indoor 1h-average recommended concentration by NIPH.

### 6.4.2 Comparative data tables

For each instrument, the Arithmetic Mean (AM), Standard Deviation (SD), Median, Minimum and Maximum $NO_2$ mean values were analyzed and presented. The difference in $NO_2$-concentrations between two locations (Δa-b) was analyzed through a *Paired Sample T-test*. Statistical significant differences were assessed with a cut-off value of $p<0.05$ for all analyses. The percent difference or reduction in $NO_2$-concentrations at two locations was found by putting the values into the following formula:

$$Average\ \%\ reduction\ or\ difference = \frac{a-b}{a} x100$$

### 6.4.3 Scatter plots

The scatter plots were divided in two different plots. The first plot indicates the relation between the dependent and independent measured values. The plot is attached with a regression line, 95% Confidence Interval (CI) lines, regression equation and the R-squared value explained variance. For none of the plots the regression lines were forced through the origin point. The second plot illustrates how a 1:1 plot for the variables are compared to the regression line for the first plot. This will indicate how the slope of the regression lines are to each other. If the comparative data tables indicated a non-significant correlation, scatter plots were excluded.

### 6.4.4 Development of $NO_2$ concentration models for the Roof Instrument location

A bivariate correlation analysis was used as a first preparatory step to identify which variables have influence on the $NO_2$-concentrations at MI and RI, before conducting a multiple linear regression model.

The multiple linear regression analysis was used to analyse the relationship between dependent and independent variables. Among the outcome data the B-unstandardized data can be used to create a regression line equation, which can be used to predict dependent outcome data based on significant, independent variables. Two multiple regression models were developed in this study.

Model 1. Analyse which variables have influence on the MI data. Parameters inserted in the model are wind speed, temperatures and vehicle frequency.

Model 2. Analyse which variables have influence on RI. Parameters inserted in the model $NO_2$-concentrations at MI, wind speed, temperatures, vehicle frequency.

Variables listed in the MI and RI models, respectively were selected on the basis of a significance levels $p<0.2$ in the preparatory correlation analysis. Variables with significance value $p<0.05$ were retained in the model, which means that if the model indicates that a parameter is not significant it is removed from the model.

B-unstandardized data are used in a prediction equation as follows:

$$\hat{y} = B0(coeficcient) + B1 * Parameter1 + B2 * Parameter2 \dots$$

## 6.5 Ethics

Carrying out studies involving a private actor and the University requires an open dialog regarding expectations for how and to who the results are going to be presented as well as results ownership. Before the startup, it was agreed on that all data presentation has to be consulted with the landlord. The landlords main interest in the study was the filter comparative part, objective B and C.

Tenants were informed before start-up of the project and consented that the study can take place at their location. Tenants agreed on access to their office areas both daytime and outside working time. When results are revealed the landlord has informative responsibilities regarding the revealed results.

The filters used in the study were selected and installed before the study start up. Filter selection was done before the study and was thus not determined by present study, which means that no economic interests lays behind the result preparation of the study.

# 7 Results

The measurements took place over a 66-day period, from 3rd January to 10th March. In the result preparation 625 1-hour mean $NO_2$-concentration values were included. The data was obtained by measurements performed at RI, CF and RF. The results are organized to provide answers to the objectives described in Chapter 4.

For Objective A, representing outdoor measurements, 24-hour data was analysed from Monday to Sunday. Objective B and C, which included both outdoor and indoor measurements, analysed data was from Monday to Friday (07:00-17:00), due to the ventilation systems operational hours described in chapter 6.1.

The elaboration of data was in principle analogous for Objectives A, B and C. The result setup includes preparation and analysis according to chapter 6.4.1-6.4.3. In addition, Objective A also includes the preparation of a prediction model described in chapter 6.4.4.

## 7.1 Background information

Figure 19 illustrates how MI, wind speed, temperatures and vehicle frequency changes over time, between 13th to 31st of January. The chart illustrates that the $NO_2$ levels at MI varies in phase with daily frequency of vehicles passing through Danmarksplass intersection. A comparative data table (Table 4) representing all 1-hour mean values for this period indicates an average outdoor temperature of 1.6 ˚C (range -4.2˚C - 5.3˚C) and average wind speed of 5.1m/s (range 0.2m/s – 14.6 m/s). The daily vehicle frequency was on average 1070 vehicles/hour (range 22-2598 vehicles/hour).

*Table 4. Background information data table representing 1-hour mean values (0-24h) between the 13 to 31 January. The table represents wind speed, temperature and vehicle frequency.*

| | *AM* | *SD* | *Minimum* | *Maximum* |
|---|---|---|---|---|
| ***Wind, m/s*** | 5.1 | 3.4 | 0.2 | 14.6 |
| ***Temp, ˚C*** | 1.6 | 1.8 | -4.2 | 5.3 |
| ***Traffic, (vehicles/h)*** | 1070 | 793 | 22 | 2598 |

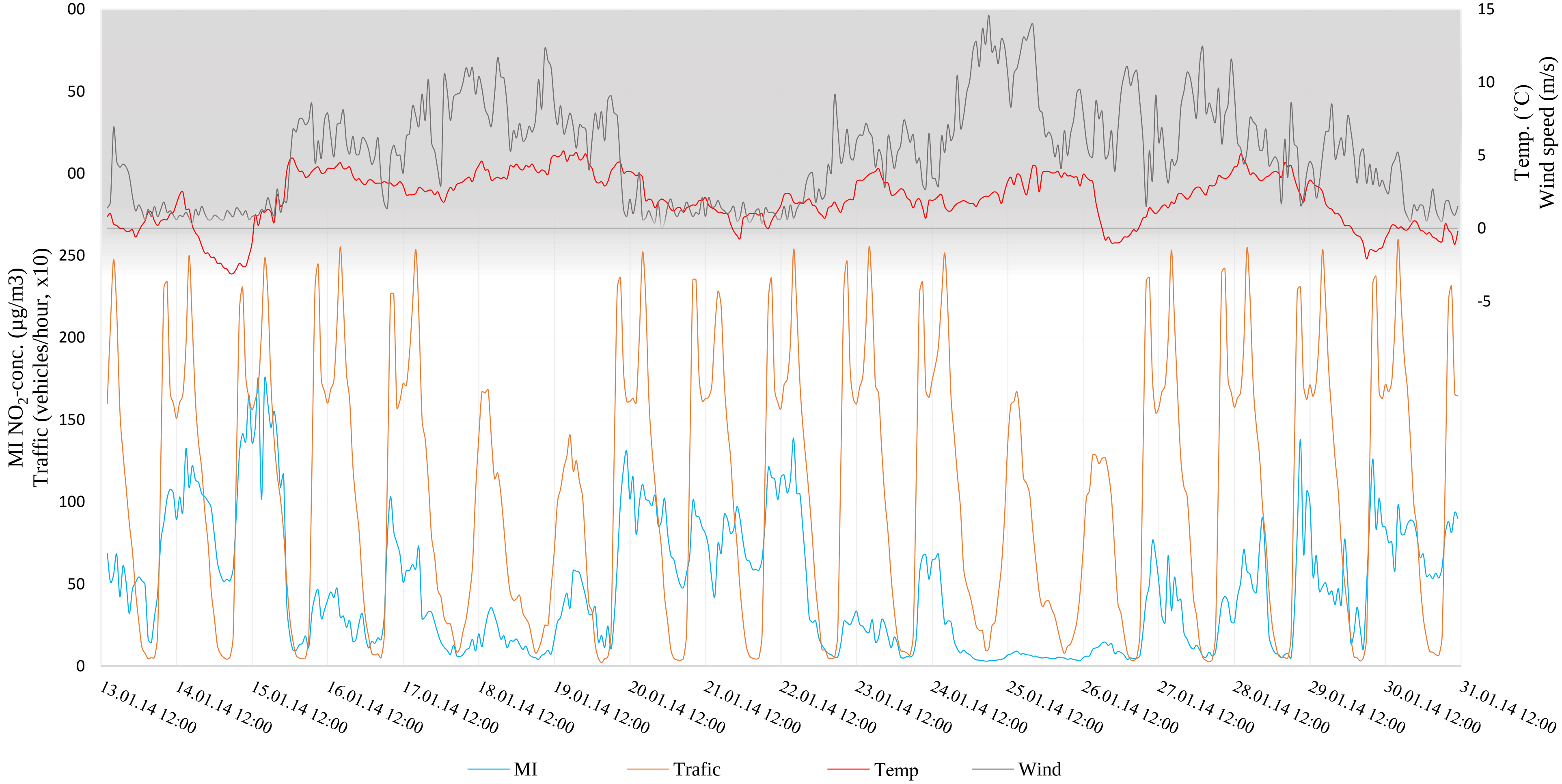


*Figure 19. Background chart trend illustration, representing 1-hour mean value changes for wind speed (m/s), temperature (˚C), vehicle frequency (vehicles/h), and outdoor $NO_2$ (µg/m$^3$) concentrations at the MI. The chart is based on Monday to Sunday values between 00:00-24:00.*

## 7.2 Comparison between the two API

During the comparative period performed from the 28th of February to the 10th of March, both instruments were placed indoors in the RF-area. As illustrated in Figure 20, the $NO_2$-concentrations from instrument 1 ($RF_1$) and 2 ($RF_2$) changes in phase throughout the measurements period. The trends indicate a slight concentration difference (~2-3µg/m³) at low concentrations. The difference seems to disappear as soon the concentration rises above ~10µg/m³.

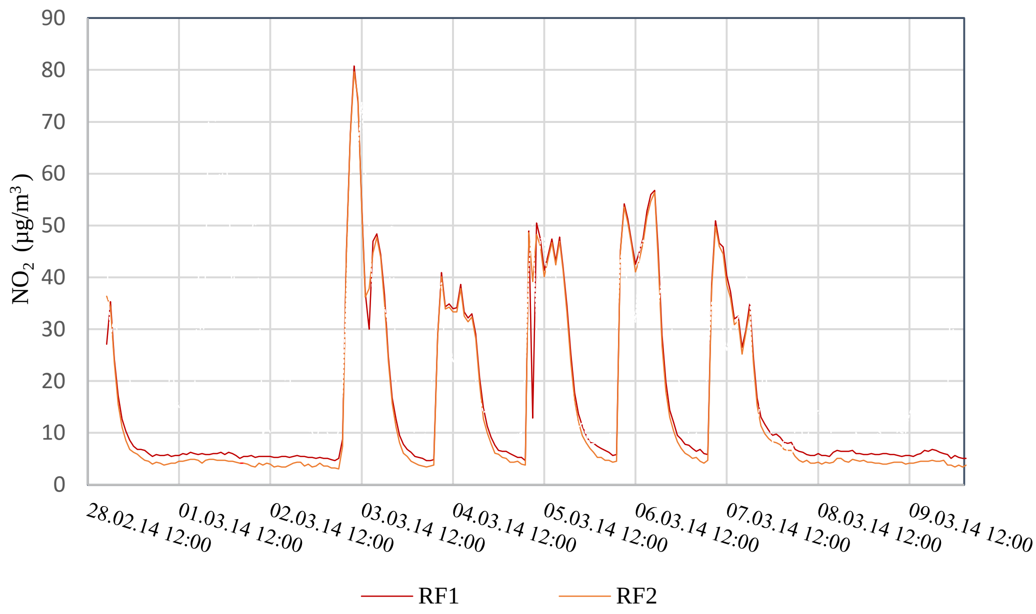


*Figure 20. Trend chart illustrating two Advanced Pollution Instrumentation (API) instrument in the Regular-Filter (RF) area for a quality association control. The chart is based on 1-hour mean Nitrogen Dioxide ($NO_2$) concentration values from Monday to Sunday between 00:00-24:00. Both instruments were running simultaneously.*

The results indicate no significant difference in 1-hour mean values (<0.01%) between the two instruments in this period $RF_1$ (39.9±15.6 µg/m³; range 4.7-80.7 µg/m³) and $RF_2$ (39.8±15.1 µg/m³; range 3.8-79.7 µg/m³) (Table 5).

*Table 5. Relationship and 1-hour mean $NO_2$-concentrations between the two Advanced Pollution Instrumentation (API) instruments when measuring at the Regular-Filter (RF).*

| | ***AM µg/m³(%)*** | ***SD µg/m³*** | ***Median*** | ***Min µg/m³*** | ***Max µg/m³*** |
|---|---|---|---|---|---|
| ***$RF_1$*** | 39.9 | 15.6 | | 4.7 | 80.7 |
| ***$RF_2$*** | 39.8 | 15.1 | | 3.8 | 79.7 |
| | | | **95% CI** | | |
| | | | ***Lower*** | ***Upper*** | **P** |
| ***$\Delta RF_1 - RF_2$*** | 0.08 (<0.01)* | 4.0 | -1.0 | 1.2 | 0.89 |

The sampling period was from February 28th to the 10th of March. The analysed data was based on 6 days (Monday-Friday) and 56 1-hour means (07:00-17:00). *Percentage difference between both instrument.

## 7.3 Objective A; Comparison between MI and RI

The measurements were performed from January 4th to January 31st. However, since the instrument failed from 4th to 13th, only data between 13th to 31st was included in the analysis.

The highest concentrations peaks for the whole study were observed in this period. A total 43 1-hour means at MI and 16 1-hour means at RI exceeded the NIPH recommended concentration limit of 100 µg/m$^3$ 1-hour mean of $NO_2$ (Figure 21).

The hourly $NO_2$-concentrations at MI and RI follow each other in phase throughout the measurements period (Figure 21) and was significantly correlated (r = 0.811, p-value of <0.001, Table 6 and Figure 22).

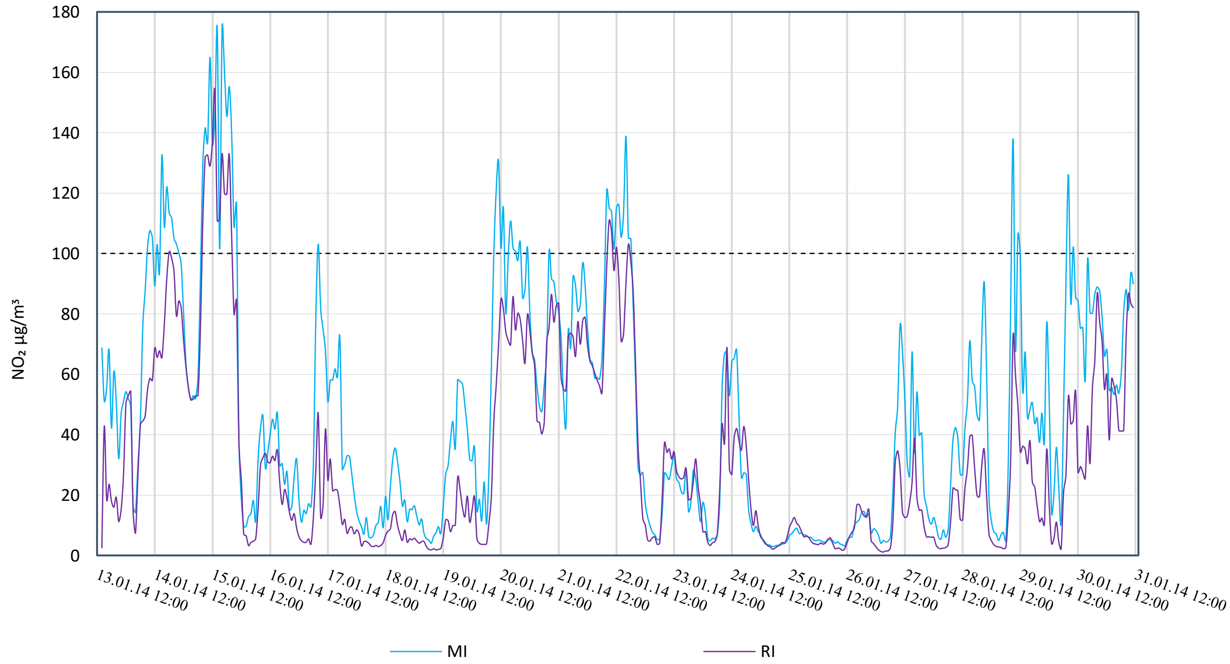


*Figure 21. Municipality (MI) and Roof Instrument (RI) trend chart illustrating Nitrogen Dioxide ($NO_2$) concentration changes for both instruments. The chart is based on Monday to Sunday 1-hour mean $NO_2$-concentrations values between 00:00-24:00.*

During the 18-day sampling period the hourly mean $NO_2$-concentrations was significantly higher at MI (AM 46.8 µg/m$^3$; range 3.0-174.0µg/m$^3$) than at RI (AM 32.5; range 1.0-154.0 µg/m$^3$). The average $NO_2$-concentrations at RI is estimated to be on average 14.3 µg/m$^3$ less than at MI, which corresponds to 30.6% lower $NO_2$ levels at RI compared to MI (Table 6)

*Table 6. Relationship and mean data illustration between the Municipality Instrument (MI) and Roof Instrument (RI).*

| | ***AM µg/m³*** | ***SD µg/m³*** | ***Median*** | ***Min µg/m³*** | ***Max µg/m³*** |
|---|---|---|---|---|---|
| ***MI*** | 46.8 | 38.8 | 37.6 | 3.0 | 174.0 |
| ***RI*** | 32.5 | 31.9 | 20.4 | 1.0 | 154.0 |
| | | | **95% CI** | | |
| | | | ***Lower*** | ***Upper*** | **P** |
| ***ΔMI-RI*** | 14.3 (30.6%)* | 17.1 | 12.6 | 15.9 | <0.001 |

The sampling period was from January 13th to the 31st. The analysed data was based on 18 days (Monday-Sunday) and 430 1-hour means (24-hour data). **Percentage difference between MI and RI.*

A linear regression analysis using $NO_2$-concentrations at RI as dependent variable and $NO_2$-concentration at MI as independent variable, derives the following regression equation:

$RI = -2.19 + 0.74 \times MI$. explained variance $R^2 = 0.76$

The equation indicates that when $NO_2$ at MI increases by for instance 10µg/m$^3$ the $NO_2$ at RI increases 0.74 times less, i.e. by 7.4µg/m$^3$ and that the $NO_2$ concentration at MI explains approximately 76% of the variance in concentration at RI (Figure 22)

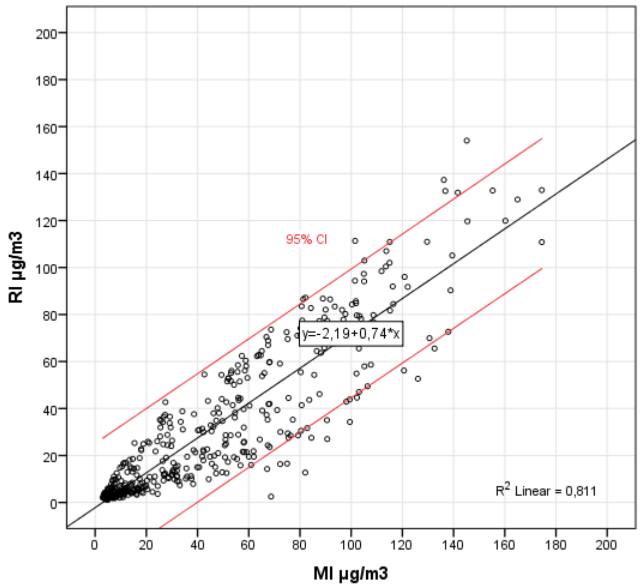


*Figure 22. Scatter plot between the Nitrogen Dioxide ($NO_2$) concentrations at the Municipality Instrument (MI) and Roof Instrument (RI), illustrating the relationship through a regression line, regression equation and 95% CI. The plot is based on 24-hour values from Monday to Sunday.*

When the MI-RI regression line is compared with a 1:1 relationship it indicates that the difference between RI and MI increases with higher MI concentrations (Figure 23).

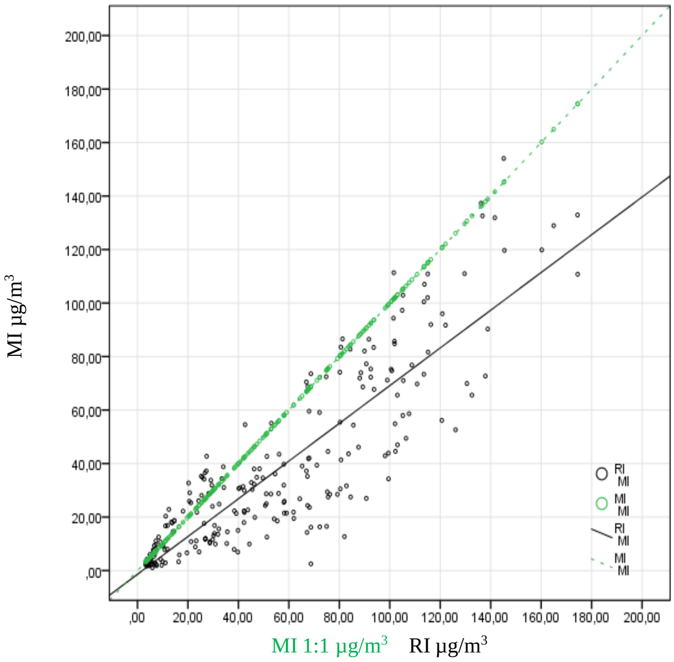


*Figure 23. Scatter plot between Nitrogen Dioxide ($NO_2$) concentrations at the Roof Instrument (RI) and Municipality Instrument (MI) illustrating the relationship between the RI and MI through a regression line and a line representing a 1:1 MI line. The plot is based on Monday to Sunday 1-hour mean $NO_2$ concentration values between 07:00-17:00.*

### 7.3.1 Correlation analysis

A bivariate correlation analysis (Table 7) was performed to identify the relationship between different variables assumed to have an impact on the $NO_2$-concentrations at MI and RI. The highest correlation was between MI and RI (r = 0.901). Vehicle frequency correlated with both MI and RI. MI and RI correlated negatively with both Wind and Temperature. The negative correlation coefficient indicates that MI or RI concentrations rise when temperature and wind speed decrease.

*Table 7. Bivariate correlation analysis with the Municipality Instrument (MI) and Roof Instrument (RI) as dependent variables and temperature, wind speed and vehicle frequency as independent variables.*

| | | *MI* | *RI* | *Temp.* | *Wind* | *Vehicle frequency* |
|---|---|---|---|---|---|---|
| | Pearson Correlation | 1 | 0.901** | -0.405** | -0.706** | 0.539 |
| *MI* | Sig. (2-tailed) | | <0.001 | <0.001 | <0.001 | <0.001 |
| | N | 430 | 430 | 430 | 429 | 430 |
| | Pearson Correlation | 0.901 | 1 | -0.457 | -0.732 | 0.435 |
| *RI* | Sig. (2-tailed) | <0.001 | | <0.001 | <0.001 | <0.001 |
| | N | 430 | 430 | 430 | 429 | 430 |

**. Correlation is significant at the 0.01 level (2-tailed).

A multiple linear regression analysis with MI as dependent variable and wind speed, vehicle frequency and temperature as independent was computed. The analysis indicates that these variables are significantly associated with the MI $NO_2$-concentrations (p-value Wind <0.001, Vehicle frequency <0.001, Temp. 0.001; Table 8).

*Table 8. Multiple linear regression coefficient table; Municipality Instrument (MI) as dependent and temperature, wind speed and vehicle frequency as independent variables.*

| | *Unstandardized Coefficients* | | |
|---|---|---|---|
| *Model* | B | Std. Error | p-value |
| *(Constant)* | 62.339 | 2.659 | <0.001 |
| *Wind* | -6.159 | 0.366 | <0.001 |
| *Vehicle frequency* | 0.021 | 0.001 | <0.001 |
| *Temp.* | -3.215 | 0.681 | <0.001 |
| *Dependent variable MI* | | | |

The MI $NO_2$-concentrations is known at all times as they are available from the municipality instrument. When analysing RI as dependent and MI, temperature, vehicle frequency and wind speed as independent variables the multiple linear regression analysis shows that RI is significantly associated by three of these four variables introduced into the model. When adjusted for MI, temperature, wind speed, the variable vehicle frequency did not enter the model (Table 9).

*Table 9. Linear regression coefficient table; Roof Instrument (RI) as dependent and Municipality Instrument (MI), temperature and wind speed as independent variables.*

| | *Unstandardized Coefficients* | | | |
|---|---|---|---|---|
| *Model* | B | Std. Error | p-value | Adjusted $R^2$ |
| *(Constant)* | 13.770 | 2.385 | <0.001 | 0.832 |
| *MI* | 0.628 | 0.029 | <0.001 | |
| *Temp* | -1.264 | 0.413 | 0.002 | |
| *Wind* | -1.505 | 0.280 | <0.001 | |

From table 9 the linear regression equation is as follows:

$$RI = 13.770 + 0.628MI - 1.505Wind - 1.264Temp$$

This equation can be used to estimate the $NO_2$-concentration at RI. For instance, if values for MI, wind speed and temperatures are inserted into the formula, the outcome indicates the expected concentrations at RI. An example is prepared by inserting different values for the three independent variables in the model (Table 10).

*Table 10. Example on predicted values based on the prediction model, when inserting different values into the model for Municipality Instrument (MI), wind speed and temperature values.*

| | | Example concentration at MI µg/m$^3$ | | | |
|---|---|---|---|---|---|
| | | 50 | 100 | 150 | 400* |
| Wind speed (m/s) | Temperature (˚C) | Estimated values at RI µg/m$^3$ | | | |
| 0.5 | -7 | 53.3 | 84.7 | 116.1 | 273 |
| 3.0 | -3 | 44.5 | 75.9 | 107.3 | 264 |
| 6.0 | -2 | 36.7 | 70.1 | 101.5 | 258 |
| 9.0 | 7 | 22.8 | 54.2 | 86.6 | 243 |

Linear regression equation, $RI = 13.770 + 0.628MI - 1.505Wind - 1.264Temp$

*Values representing worst-case scenario

Figure 24 illustrates how the estimated values from Table 10 fit into a scatter plot of association between measured $NO_2$-concentrations at MI and RI. Worst-case scenario values from Table 10 were not included in the scatter plot, due to that would have required an extrapolation for to 400µg/m$^3$ $NO_2$ values. The estimated values are located within the

95% CI. When executing a regression line for each of the four scenarios described in Table 10, the slope of the lines (blue) are close to the slope of the regression line of the actual measured values (black).

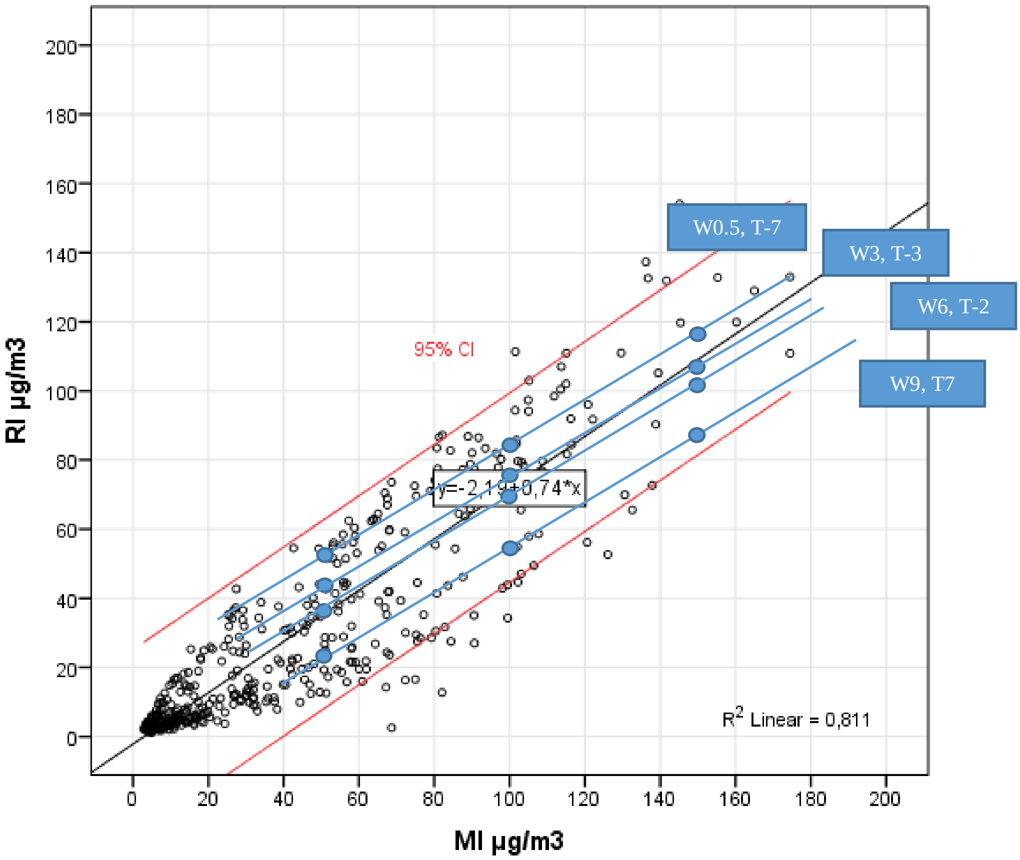


*Figure 24. Scatter plot similar to figure 22 with the addition of regression line for each of the four scenarios predicted in Table 10. Defined temperatures and wind speed for the four scenarios are 0.5m/s: -7 ˚C, 3m/s: -3˚C, 6m/s: -2 ˚C and 9m/s: 7 ˚C.*

## 7.4 Objective B; Outdoor and indoor comparison

Objective B was divided in two parts, first from January 13th to 24th which compares $RI_1$ and $CF_1$ and the second from January 24th to 31st which compares $RI_2$ and $RF_2$.

### 7.4.1 Objective $B_1$; Comparison between $RI_1$ and $CF_1$

A total of 12-days, 102 1-hour mean values were included in the trend chart (Figure 25). The trend lines for $RI_1$ and $CF_1$ indicate that the $NO_2$-concentrations for this period vary in phase and correlates significantly ($r=0.663$, p-value of $<0.001$). However, the concentration is clearly higher outdoors at the roof air inlet of the OB than indoors in the office area.

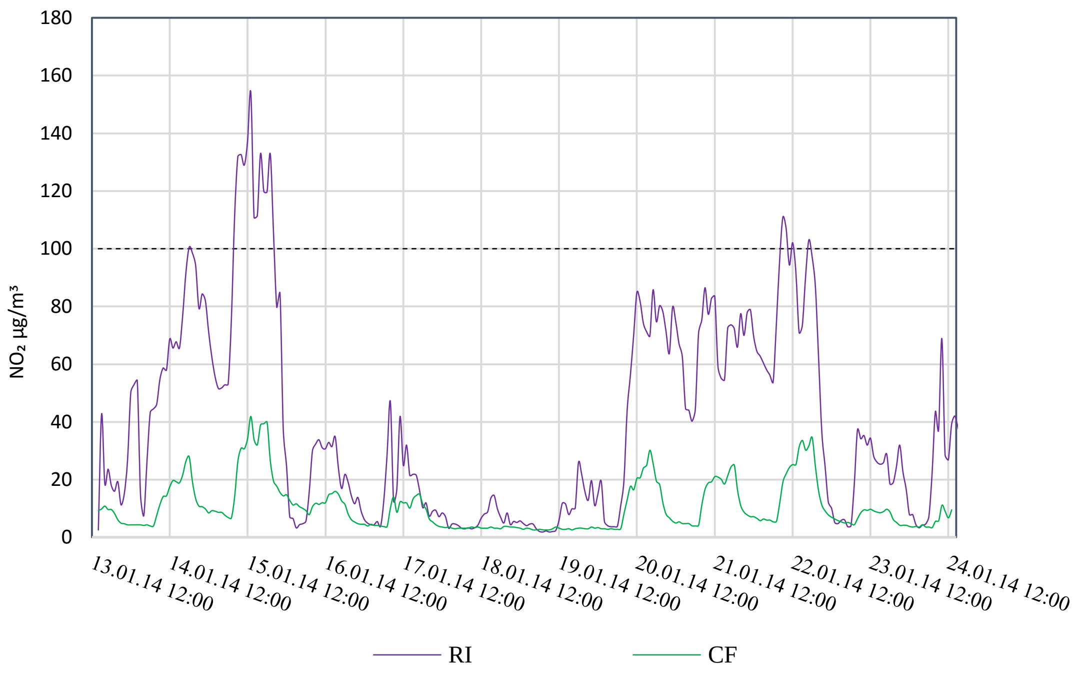


*Figure 25. Trend chart illustrating Roof Instrument (RI) and Combination-Filter (CF) area $NO_2$-concentrations. The chart is based on Monday to Sunday 1-hour mean $NO_2$ concentration values between 00:00-24:00.*

The mean concentration was significantly higher at $RI_1$ (57.3 μg/m$^3$; 2.5-154.0 μg/m$^3$) than at $CF_1$ (16.0 μg/m$^3$; 3.0-42.0 μg/m$^3$). The mean difference between $RI_1$ and $CF_1$ is 41.2 μg/m$^3$, which corresponds to 72% lower concentration at CF than at RI (Table 11).

*Table 11. Comparative data table for part 1 and 2. Comparison is between outdoor Roof Instrument (RI), the Combination-Filter (CF) area and Regular-Filter (RF) area $NO_2$-concentrations.*

| | *AM μg/m³* | *SD μg/m³* | *Median* | *Min μg/m³* | *Max μg/m³* |
|---|---|---|---|---|---|
| ***RI₁*** | 57.3 | 35.1 | 50.7 | 2.5 | 154.0 |
| ***CF₁*** | 16.0 | 9.1 | 13.7 | 3.0 | 42.0 |
| ***RI₂*** | 36.7 | 18.9 | 34.7 | 11.8 | 86.6 |
| ***RF₂*** | 39.6 | 16.4 | 41.2 | 3.2 | 79.1 |
| | | | **95% CI** | | |
| | | | *Lower* | *Upper* | **P** |
| ***Δ RI₁-CF₁*** | 41.2 (72%)* | 28.3 | 35.7 | 46.8 | <0.001 |
| ***Δ RI₂-RF₂*** | -2.9 (8%)* | 13.5 | -7.1 | 1.4 | 0.182 |

The 1st sampling period was from January 13th to 24th and the 2nd from January 24th to 31st. The analysed data was based on 12 and 5 days respectively (Monday to Sunday) and 102 and 41 1-hour mean values (07:00-17:00).
**percentage difference between RI-CF and RI-RF*

A linear regression analysis using $NO_2$-concentrations at CF as dependent variable and RI as independent variable, derives the following regression equation:

$CF = 4.1 + 0.21 \times RI$, explained variance $R^2 = 0.66$

The equation indicates that when $NO_2$ at RI increases for instance 10 μg/m$^3$ the $NO_2$ at CF increases 0.21 times less, i.e. by 2.1 μg/m$^3$ and that the $NO_2$ concentration at RI explains approximately 66% of the variance in concentration at CF (Figure 25).

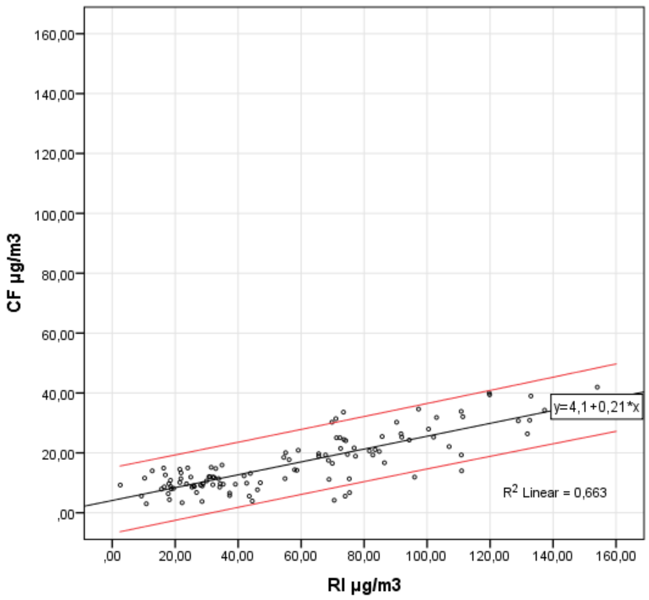


*Figure 26. Scatter plot illustrating the relationship between Roof Instrument (RI) and Combination-Filter (CF) area Nitrogen Dioxide ($NO_2$) concentrations through a regression line, regression equation and a 95% CI. The plot is based on Monday to Friday 1-hour mean $NO_2$-concentrations values between 07:00-17:00.*

When the RI-CF regression line is compared with a 1:1 RI relationship it indicates that that the difference between CF and RI increases with higher RI concentrations (Figure 27).

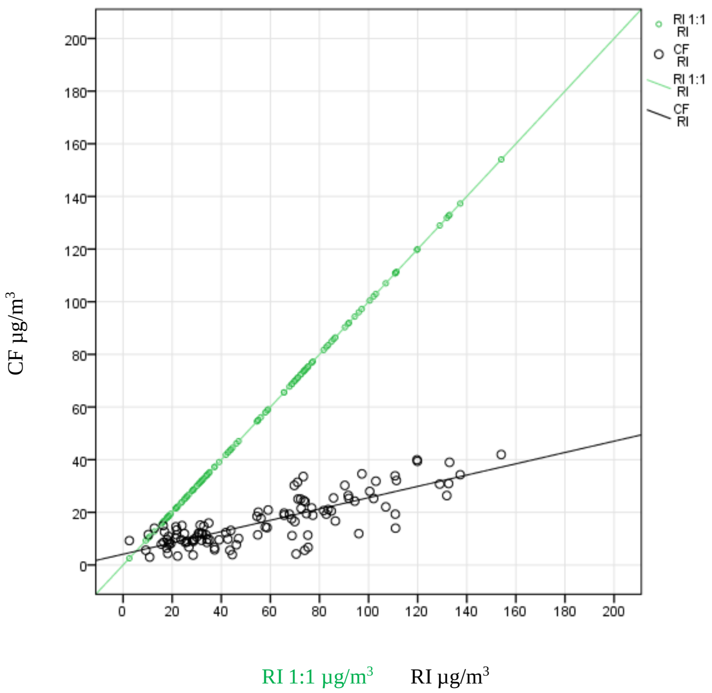


*Figure 27. Scatter plot illustrating the relationship between the Roof Instrument (RI) and Combination-Filter (CF) area through a regression line and a line representing a 1:1 CF slope. The plot is based on Monday to Friday 1-hour mean $NO_2$ concentration values between 07:00-17:00.*

### 7.4.2 Objective $B_2$; Comparison between RI and RF

In this period 5-days, 41 1-hour mean values were included. The trend lines indicate that the $NO_2$-concentrations at $RI_2$ and $RF_2$ in this period vary in phase (Figure 28). During this period the monitoring instrument in $RF_2$ was running only when tenants were present, which clearly appears in Figure 28. The mean hourly $NO_2$-concentration at $RI_2$ (AM 36.7; range 11.8-86.6 µg/m$^3$) was not significantly different from $RF_2$ (AM 39.6; range 3.2-79.1 µg/m$^3$). In periods the $RI_2$ concentrations were slightly higher than $RF_2$.

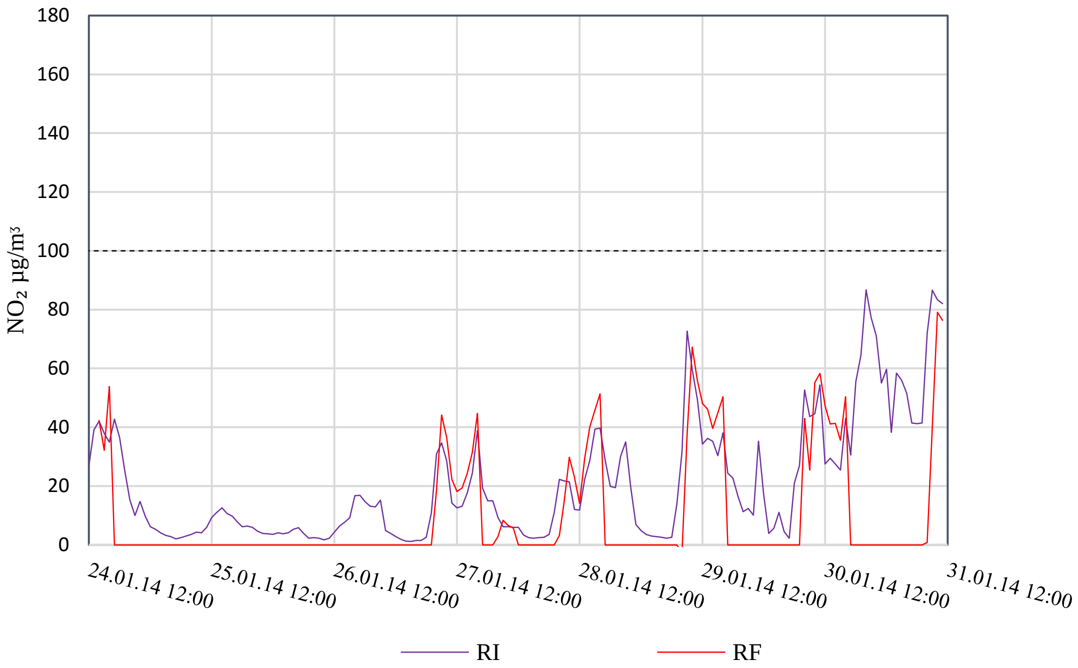


*Figure 28. Trend chart illustrating the daily Nitrogen Dioxide ($NO_2$) concentrations changes between the Roof Instrument (RI) and the Regular-Filter (RF) area. The chart is based on Monday to Sunday 1-hour mean $NO_2$ concentration values between 00:00-24:00.*

The scatter plot (Figure 29) was executed to assess the association between $RI_2$ and $RF_2$. The regression equation was not computed since the correlation between $RF_2$ and $RI_2$ was not significant ($p=0.182$).

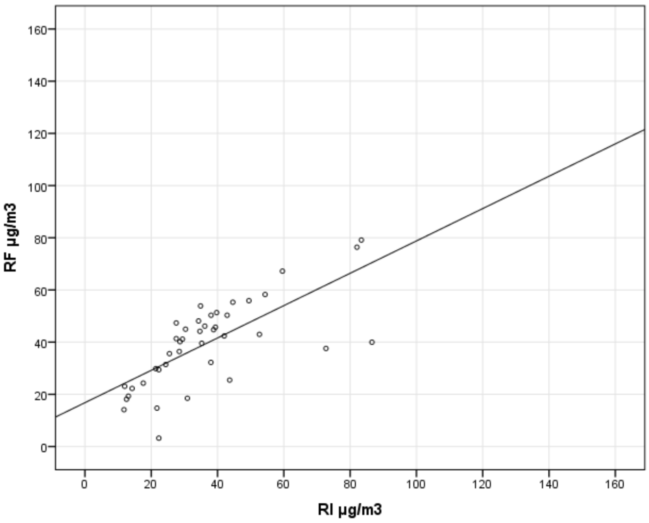


*Figure 29. Scatter plot illustrating the relationship between the Roof Instrument (RI) and the Regular-Filter (RF) area Nitrogen Dioxide ($NO_2$) concentrations through a regression line. The plot is based on Monday to Friday 1-hour mean $NO_2$-concentrations values between 07:00-17:00.*

## 7.5 Objective C; Comparison between the Regular-Filter and Combination-Filter areas

The measurements were performed from the January 31st to February 28th. During this 29-day sampling period a total of 139 1-hour means were included in the analysis. The hourly average $NO_2$-concentrations at RF and CF varies in phase throughout the period (Figure 30) and was significantly correlated (r= 0.649, p-value of <0.001, Table 12 and Figure 31). The RF $NO_2$-concentrations are considerable higher than at CF. The concentration difference seems to change depending on concentration level. For instance, the 4th of February seem so have a top for RF at ~85µg/m$^3$ and CF at ~25µg/m$^3$, indicating a concentration difference of 60µg/m$^3$, while the 3rd of February indicates a RF value of 50µg/m$^3$ and CF 10µg/m$^3$ a difference value of 40µg/m$^3$.

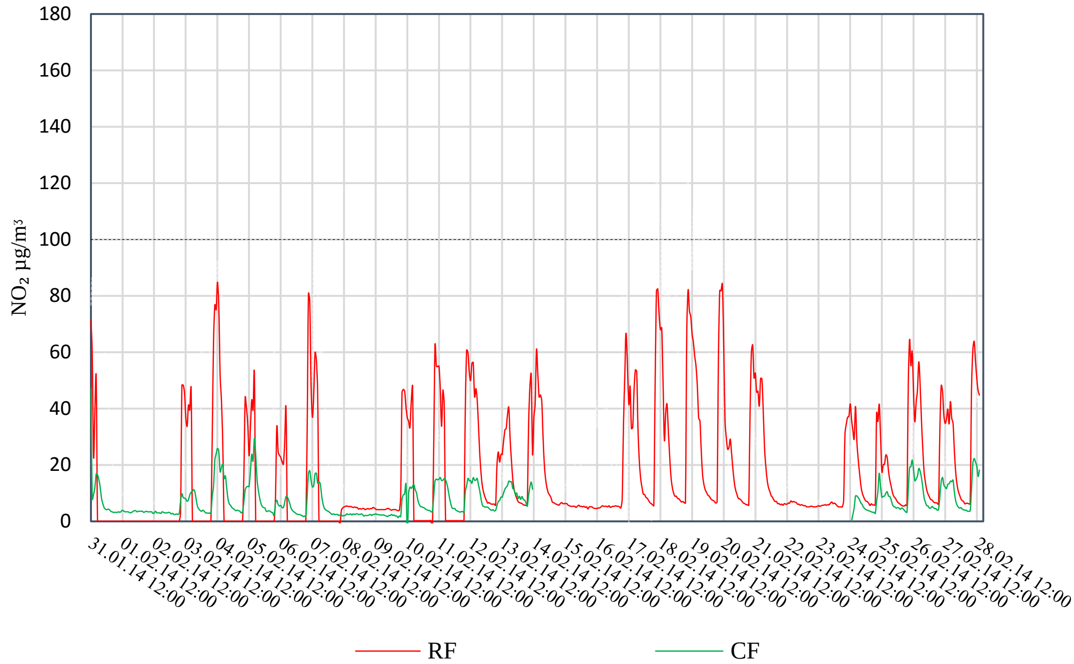


*Figure 30. Trend chart illustrates the daily Nitrogen Dioxide (NO) concentrations variation between a Regular-Filter (RF) and a Combination-Filter (CF). The chart is based on Monday to Sunday 1-mean Nitrogen Dioxide ($NO_2$) concentration values between 00:00-24:00.*

During the 29-day sampling period the hourly mean $NO_2$-concentrations was significantly higher at RF (AM 40.0 µg/m$^3$; range 3.2-84.9µg/m$^3$) than at CF (AM 12.6 µg/m$^3$; range 1.7-47.0 µg/m$^3$). The average $NO_2$-concentrations at CF is on average estimated to be 27.4 µg/m$^3$ less than at RF, which corresponds to 68% lower $NO_2$ levels at CF compared to RF (table 12)

*Table 12. Overall and comparative data between the Regular-Filter (RF) and the Combination-Filter (CF), period 31st of January to the 28th of February.*

| | ***AM µg/m³*** | ***SD µg/m³*** | ***Median*** | ***Min µg/m³*** | ***Max µg/m³*** |
|---|---|---|---|---|---|
| ***RF*** | 40.0 | 16.7 | 48.4 | 3.2 | 84.9 |
| ***CF*** | 12.6 | 6.0 | 28.5 | 1.7 | 47.0 |
| | | | **95% CI** | | |
| | | | ***Lower*** | ***Upper*** | **P** |
| ***ΔRF-CF*** | 27.4 (68%)* | 13.0 | 25.2 | 29.5 | <0.001 |

Sampling period, Period January 31 to February 28. The analysed data was based on 29 days (Monday-Friday) and 139 1-hour mean values (07:00-17:00). **Percentage difference between RF and CF.*

A linear regression analysis using $NO_2$-concentrations at CF as dependent variable and RF as independent variable, derives the following regression equation:

$CF = 1.83 + 0.27 \times RF$, explained variance $R^2 = 0.65$

The equation indicates that when $NO_2$ at RF increases for instance 10 µg/m$^3$ the $NO_2$ at CF increases 0.27 times less, i.e. by 2.7µg/m$^3$ and that the $NO_2$ concentration at RF explains ~65% of the variance in concentration at CF (Figure 31).

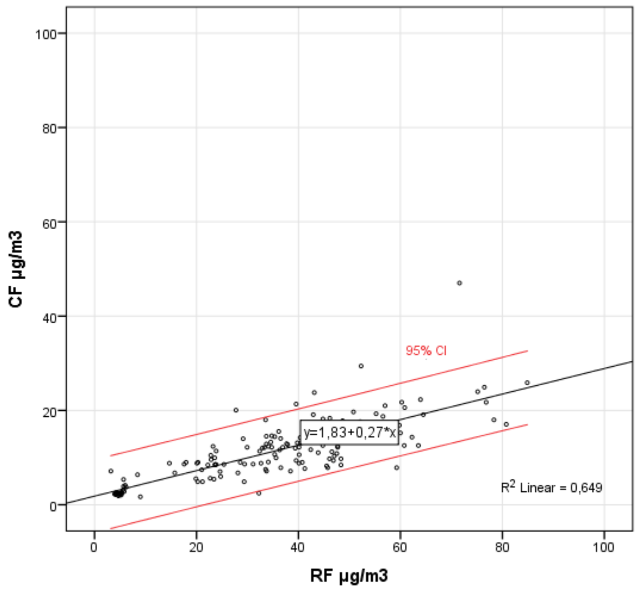


*Figure 31. Scatter plot illustrates the relationship between Regular-Filter (RF) and Combination-Filter (CF) through a regression line, regression equation and a 95% CI. The plot is based on Monday to Friday 1-hour mean Nitrogen Dioxide ($NO_2$) concentrations values between 07:00-17:00.*

When the RF-CF regression line is compared with a 1:1 RF relationship it indicates that that the difference between CF and RF increases with higher RI concentrations (Figure 32).

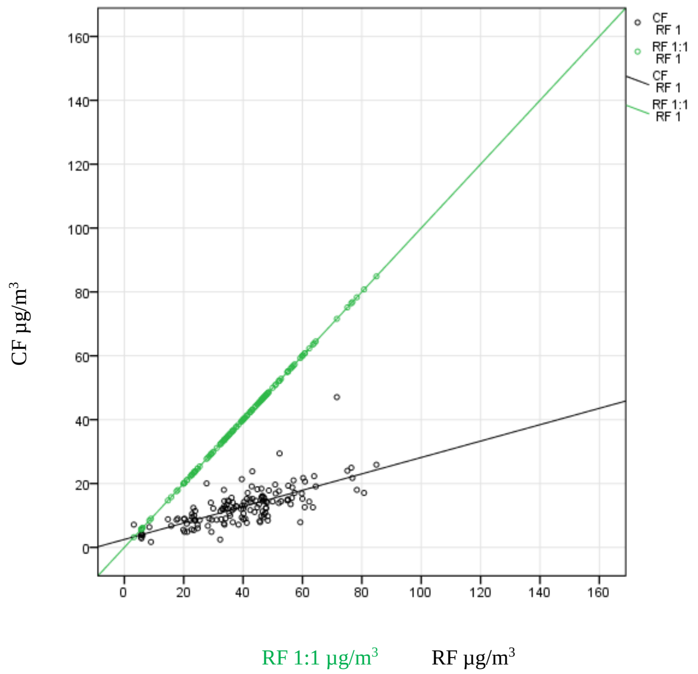


*Figure 32. Scatter plot illustrating the relationship between a Regular-Filter (RF) and a Combination-Filter (CF) regression line and a line representing a 1:1 slope. The plot is based on Monday to Friday 1-hour mean Nitrogen Dioxide ($NO_2$) concentrations values between 07:00-17:00.*

# 8 Discussion

**General**

The results show that the $NO_2$ concentration at the Municipality Instrument is influenced by vehicle frequency, wind speed and temperature. The average $NO_2$ concentration is approximately 30% lower at the Roof Instrument than at the Municipality Instrument.

A multiple linear regression model shows that wind speed, temperatures and $NO_2$-concentrations at the Municipality Instrument is significantly associated with the $NO_2$-concentrations at the Roof Instrument, and explain approximately 83% of the variance in the $NO_2$-concentrations at the Roof Instrument.

The relationship between the Roof Instrument and Regular-Filter area shows that the Regular-Filter does not reduce $NO_2$. While a Combination-Filter reduces the $NO_2$ concentration by 72%.

Simultaneous comparison between the Regular-Filter and the Combination-Filter shows that the Combination-Filter reduces $NO_2$-concentrations by approximately 68% compared to a Regular-Filter.

## 8.1 $NO_2$-concentrations at the Municipality Instrument

In the present study vehicle frequency was identified as a factor that affected the local $NO_2$-concentrations, this is in agreement with a Dutch study (Rijnders, et al., 2001). The NIPH also relates traffic to be the most important source to $NO_2$ pollution (NIPH, 2013). In the same report it is mentioned that the $NO_2$-concentrations are dependent on local meteorological circumstances.

*… on cold days with little wind, the concentrations are particularly high (NIPH, 2013, p.67).*

The mentioned associations are visualized in the results, which indicates that MI $NO_2$-concentrations vary in phase with frequency of vehicles passing through Danmarksplass intersection. The highest frequency of vehicles and the highest $NO_2$-concentrations at MI occurs at the same time. However, even if the daily vehicle frequency seems to be stable from day to day, that is not the case for the $NO_2$-concentration at MI. The concentration level at MI appears to be influenced by wind speed and outdoor temperatures as well. The trends indicate that MI $NO_2$-concentration rise when temperature and wind speed decreases. This argument is also in line with the report *air quality standards – health effects of air pollution* (NIPH, 2013).

The results show that vehicle frequency, wind speed and temperature were identified as significant determinants of the MI $NO_2$-concentrations even when the parameters were adjusted for each other.

### 8.2 Relationship between the Municipality Instrument and Roof Instrument

This study showed that the mean $NO_2$-concentration at RI are on average approximately 30% lower than MI, but highly correlated. This means that the concentrations at RI are different from MI, which rejects my $H_{01}$ hypothesis suggesting that there is no difference between MI and RI.

There might be several reasons for the lower $NO_2$-concentrations at RI compared to MI. One reason could be that MI is located in direct proximity to the most trafficked road in Bergen, while RI is situated approximately 100m away from the same road. In addition, the OB is located in an area with less surrounding buildings and closer to the fjord (approximately 250m), this can lead greater air movement at RI than at MI. Another reason could be that the measurements at the OB were taken at the roof. The building is higher or at least at the same height as surrounding buildings. This may lead to more wind than at MI and this could reduce the $NO_2$ levels.

According to a previous study (McAdam, et al., 2010) the location of the API at the roof of the building should not significantly affect the results. In the mentioned study two instruments were deployed, one at ground level and one at 9-meters height. There was no significant concentration difference between the two sampling points.

Thus, in the present study the lower concentrations are probably mainly due to the distance from the main road and that there are less surrounding buildings higher than the OB. However, it is difficult to draw a conclusion because the traffic pattern at Danmarksplass intersection will also leads to more queuing of vehicles close to the OB compared MI.

**Correlation analysis**

The present study indicates that temperatures, wind speed and vehicle frequency were associated with the $NO_2$-concentrations at MI. Available data like air humidity and wind direction could have been possibly have been included into the model, but to limit the study it was chosen not to.

The correlation analysis for $NO_2$-concentrations at RI shows that air temperature, wind speed, vehicle frequency and $NO_2$-concentrations at MI were independently significantly associated with the $NO_2$-concentrations at RI. When the mentioned variables were adjusted to each other in a multiple linear regression model, vehicle frequency was excluded due to a significance level >0.05, while wind speed, MI $NO_2$-concentrations and temperatures explained approximately 83% of the $NO_2$-concentrations at RI.

The given example on predicted values provided by the multiple linear regression equation indicates that the estimated values stays within 95% CI of the regression line for the actual measured values. Thus, the equation can give an indication on what the RI levels are at defined circumstances within a margin of ±25µg/$m^3$.

The multiple linear regression model indicates that it is possible to give an indication of the expected $NO_2$-concentrations at a specific location with the help of MI data. With a more targeted work it may be possible to estimate more specifically the local concentrations and minimize the uncertainly level. This would require more data analysis, literature research, testing of different prediction models in addition to model validation.

## 8.3 Office Building outdoor to indoor concentration comparison

The propagation trends of $NO_2$-concentration from outdoor to indoor environment changes almost directly in phase. The reason is presumably that the mechanical ventilation system forces 40$m^3$/sec air into the building.

### 8.3.1 Regular-Filter area

The concentrations at RF is not significantly different from RI. This means that my $H_{03}$ hypothesis, suggesting that there is no concentration difference between the OB outdoor and indoor RF concentrations is not rejected.

According to NIPH (NIPH, 2015) the indoor $NO_2$-concentrations are normally reduced between 20%-60% compared to outdoors. The NIPH report suggests that the reason is that $NO_2$ will rapidly react with active surfaces. Similar reduction (50%-60%) is also described in an article review (J.T. Milner, 2004). However, these numbers are not in line with the results from the present study when using regular filters. It is important to specify all relevant information, for instance filters, ventilation, capacity applicable to the facility.

The indoor $NO_2$-concentrations found at the RF-area in the present study are slightly higher (8%) than outdoor at RI, especially at low concentrations. The higher indoor concentrations are also in line with the 8.7% higher indoor concentrations than outdoors from a previous study (Parti-Pellinen, et al., 2000). Other similar studies of facilities where mechanical ventilation systems have been installed shows a 2%, (Challonger, 2011) and 11% (Stranger, et al., 2007) reduction between outdoor and indoor measurements.

There might be several reasons that could explain the slightly higher indoor concentrations. Maybe it is because the reaction of $NO_2$ with active surfaces is not as efficient as described in NIPH report (NIPH, 2015). Another possible reason could be that the remaining indoor NO-concentrations from vehicle combustion reacts with background $O_3$ (J.T. Milner, 2004).

### 8.3.2 Combination-Filter area

The results show that the mean $NO_2$-concentrations at CF are on average 72% lower than RI, which means that my $H_{02}$ hypothesis suggesting that there is no concentration difference between RI and CF is rejected.

In case the CF results are linear, extrapolation to higher $NO_2$ levels indicates that the CF might reduce the $NO_2$-concentrations down to a justifiable level even when outdoor $NO_2$-concentrations reach worst-case values up to 400µg/m$^3$.

Using the prediction model for 400µg/m$^3$ as a worst-case level at MI will give 240-270µg/m$^3$ at RI. With an average reduction of 70% with a combination-filter, indoor $NO_2$-concentration at the CF-area at given conditions corresponds to approximately 70-80µg/m$^3$.

A Finnish study (Parti-Pellinen, et al., 2000) was designed to compare mechanical and chemical filters. Their results indicate an average $NO_2$ reduction of approximately 47% (average outdoor 23.7µg/m$^3$ and indoor 12.5µg/m$^3$). It is important when comparing filter reductions to take into consideration that the filter efficiency may increase with higher outdoor levels. In the present study the mean outdoor $NO_2$-concentrations was more than double compared to the Finnish study (Parti-Pellinen, et al., 2000).

## 8.4 Methodological discussion

The API-instruments are used in national and international $NO_x$ quantification studies, because of their reliability. The instruments used in present study were scaled with a zero-gas and a span-gas approximately every 7-10 days. The scaling indicated a small (±2.5%) but constant $NO_2$ concentration variation over time. When the direct comparison of the instruments was performed in present study, the difference between both API was very small (<0.01%). This indicates a high reliability, even when the concentrations approach zero. In addition, MI and RI data was extracted from identical instruments, which strengthens the results.

This quantitative study is based on a large set of data (625 1-hour mean values) ranging from 2.5-174.0µg/$m^3$ which strengthens the results and makes the study highly reliable. During the present study the filters had been used for around 9 months. This means that the average 72% $NO_2$ reduction when using the CF might not be representative for the whole lifetime of the filters which is normally 2 years for the present OB.

It was of great benefit for the study to have access to the MI data. By having access to historical data from MI, it was possible to compare and evaluate the presently studied MI $NO_2$-concentrations with previous years. However, during the study period the outdoor concentrations at MI did not exceed 200µg/$m^3$, which is not representative for potential worst-case scenarios at Danmarksplass, Bergen. For example, during the winter 2009-2010 outdoor $NO_2$-concentrations exceeding 400µg/$m^3$ was measured. This means that the measured reduction in $NO_2$ across the filters may not be valid for a worst-case scenario.

The analysis between $RI_2$ and $RF_2$ shows no significant correlation, a reason can be the low number (43) of 1-hour mean values included in the analysis. Yet the result indication that there is no reduction between outdoor and indoor concentrations is considered reliable. The argument is indirectly showed in the similarities between the 68% difference between RF and CF and the 72% reduction between RI and CF. In fact, these similar concentrations strengthen also that the combination-filter average reduction is around 70%.

The purpose of placing the inlet air hose from the API between the main corridors was to achieve a homogeneous air mixture. Placement of the inlet hose was as far as possible from both the ventilation systems outlets in the corridors. The placement is not considered as a major issue because gasses normally spread very fast and will always work towards a homogeneous mixture. However, this issue is important to mention and the arguments needs to be tested and validated.

# 9 Conclusions and recommendations

The results show that the outdoor concentrations at RI are strongly related to $NO_2$-concentrations at MI, wind speed and temperature. Thus, it is possible to estimate the RI $NO_2$-concentrations when MI $NO_2$-concentrations, outdoor temperature and wind speed are known.

The results also show that a regular-filter has no reduction effect on $NO_2$. However, the combination-filter reduced the outdoor to indoor $NO_2$-concentrations with an average of 70%, which indicate that it is possible to reduce the outdoor to indoor concentrations below the NIPH recommendations even when outdoor $NO_2$-concentrations reach worst case scenarios.

Thus, for areas where local historical data show that the outdoor $NO_2$ concentration may reach levels close to or above the NIPH recommendations, the present study indicates that it is advisable to install combination-filter in the ventilation system.

# 10 Future studies

**General**

To improve knowledge on the efficiency of different types of ventilation filters at reducing $NO_2$-concentration it is recommended to continue research on this topic. In the present study, the focus has been on $NO_2$ as a pollutant. In the future other gaseous pollutants might be the focus. These types of studies will help society to understand how gaseous pollutants propagates both locally between different locations and from outdoor to indoor environments.

The present study has unused data that can be utilized in future analysis. For example, NO-concentrations can be used to analyse the total mass balance between $NO_2$ and NO and possibly reveal why indoor measurements from time to time are higher than simultaneous outdoor measurements.

## 10.1 Location propagation

### 10.1.1 Analytical models

The MI data is available for the public at any time. One aim for the present study was to make a regression model to estimate the OB $NO_2$-concentrations from MI data.

This study reveals that it is possible to estimate $NO_2$-concentrations at a specific location using data collected at a different location. More measurements, dedicated work and a validation period is needed to improve the understanding of local dispersion. The benefit of such studies is the possibility for the population and stakeholders to be prepared for peaks in air pollution. Knowledge of local outdoor $NO_2$-concentrations combined with knowledge on ventilation systems and filter efficiencies might make it possible to predict the indoor $NO_2$-concentration.

### 10.1.2 Additional data analysis

The municipality of Bergen has collected monthly outdoor mean $NO_2$-concentration samples at different locations in Bergen. This data has been used to show how pollution disperses from road with heavy traffic into neighbouring areas. It might be possible to use this dispersion data to expand a single point prediction model into an area prediction model.

## 10.2 Outdoor to indoor propagation

### 10.2.1 Ventilation system

As shown in the present study there are several other studies where outdoor to indoor $NO_2$-concentration reduction have been measured. The challenging part is to classify different facilities and their ventilation systems to give an evaluation of potential $NO_2$ reduction in different scenarios. This area needs more research.

### 10.2.2 Filters

Furthermore, it would also be of interest to perform studies comparing the filtering efficiency of different chemically treated filters. Full scale studies might be challenging, but it might be possible find representative results might be found in lab tests by using pilot units. Parameters of interest might filter saturation based on time of exposure and filter effectiveness at a wide range of concentrations.

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# 12 Appendix

## 12.1 Detailed timeline description

Table 13. Detailed timeline description, describing objectives in relation to the comparing objectives and dates for data scaling.

| Objective | Date | Week | Comparing | Notes | Location (calibration doc. nr.) * | Period | Scaled inst./dedicated logger: 2050 (INV NR 6912) / 2608 (NDL3-0081) | Scaled inst./dedicated logger: 2608 (Instr. Snr. 30062) / 2050 (ND3L3-0022) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | DD. MM. YYYY; HH:MM | |
| A & B | 3/1-24/1 | 1-4 | RI (inst.2050), CF (inst.2608) and MI | Inst 2050 got locked for approximately 190h, between the 5-13 of January. | RI (1) | 3/1-17/1 | 03.01.2014; 13:00-15:00 | |
| | | | | | | | 13.01.2014; 15:00-15:30 | |
| | | | | | | | 17.01.2014; 12:00-13:00 | |
| | | | | | CF (3) | 3/1-17/1 | | 03.01.2014 15:00-16:00 |
| | | | | | | | | 10.01.2014 16:00-17:00 |
| | | | | | CF (8) | 17/1-24/1 | | 17.01.2014 09:30-11:00 |
| | 24/1-31/1 | 4-5 | RI(inst.2050), RF(inst.2608) and MI | Transports CF inst. to RF area between 13:00-14:00. It was shutting down twice a day. Powering was following personnel working hours. | RI (2) | 24/1-30/1 | 24.01.2014 14:30-15:30 | |
| | | | | | | | 30.01.2014 11:30-12:15 | |
| | | | | | RF (5) | 24/1-31/1 | | 24.01.2014 14:00-14:30 |
| | | | | | | | | 31.01.2014 13:00-13:40 |
| C | 31/1-14/2 | 5-7 | CF (inst.2050), RF (inst.2608) | Moves the RI instrument to RF. Instrument was sent for maintenance the 14/2 because sensor failure. | CF (4) | 31/1-14/2 | 31.01.2014 13:50-14:50 | |
| | | | | | | | 10.02.2014 09:50-12:00 | |
| | | | | | | | 14.02.2014 11:40-12:15 | |
| | | | | | RF (5) | 31/1-10/2 | | 31.01.2014 13:00-13:40 |
| | | | | | | | | 10.02.2014 12:45-13:15 |
| | 14/2-24/2 | 7-9 | RF (2608) | CF (Inst. 2050) shut down for maintenance. Instrument parameters started to | RF (7) | 14/1-24/4 | | 14.02.2014 10:20-11:00 |
| | | | | | | | | 24.02.2014 13:40-14:10 |
| | 24/2-28/2 | 9 | CF (2050), RF (2608) | Instrument 2050 was setup after maintenance | CF (6) | 24/2-28/2 | 24.02.2014 14:20-14:45 | |
| | | | | | | | 28.02.2014 14:20-15:10 | |
| | | | | | RF (7) | 24/1-28/2 | | 24.02.2014 13:40-14:10 |
| | | | | | | | | 28.02.2014 15:40-16:10 |
| IC | 28/2-10/3 | 9-10 | RF (2050), RF (2608) | Simultaneous measurements inside RF-area | $RF_1$ (9) | 28/2-10/3 | 10.03.2014 09:30-10:10 | |
| | | | | | $RF_2$ (9) | 28/2-10/3 | | 10.03.2014 10:20-11:00 |

*Investigator have access to specific calibration documents

## 12.2 Example sheet for obtaining scaling data

The example sheet is filled in for three scaling times 3.1.2014, 13.1.2014 and 17.1.2014.

1

**Rutinemessig drift og vedlikehold. API200A/E NOx-monitor.** 2050

| Stasjonsnavn | Stasjons-Id | Driftsansv | Instr. snr. | Spangass Snr. | Produsent | Kons. NO | Kons. NOx |
|---|---|---|---|---|---|---|---|
| GC Rieber tak | | | INV NR6912 | 0171 | | 802 ppb | |
| | | | | Nulluft Snr. 110 | | Produsent | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tid | Dato | | 3.1.2014 | | 13.1.2014 | | 17.1.2014 | |
| | Starttid / Stopptid | | 13⁰⁰ → $13^{00}$ | $15^{00}$ | $15^{00}$ | $15^{30}$ | ~~12~~ $09^{15}$ | |
| Utcluft | Monitor | | NO | NOx | NO | NOx | NO | NOx |
| | | | 2.8 | 14.9 | 13.3 | 40.9 | 12.4 | 22.1 |
| Driftsmodus | | | SAMPLE | | SAMPLE | | | |
| Status-lamper | | Grønn på | OK | | OK | | OK | |
| | | Gul av | OK | | OK | | OK | |
| | | Rød av | OK | | OK | | OK | |
| Flow | Samp Fl | (500 ± 50) cc/min | 529 | | 522 | | ~~530~~ 535 | |
| | Ozone Fl | (80 ± 15) cc/min | 78 | | 78 | | 78 | |
| Detektor | HVPS | 420-900 V | 709 | | 709 | | 709 | |
| Temp | Rcell Temp | (50 ± 1) °C | 50.0 | | 50 | | 50 | |
| | Box Temp | ambient + (3-7) °C | 34.8 | | 38.5 | | 36.7 | |
| | PMT Temp | (7 ± 2) °C | 6.2 | | 6.2 | | 6.2 | |
| | Moly Temp | (315 ± 5) °C | 314.5 | | 314.9 | | 314.9 | |
| Pressure | Rcel | 2-10 in Hg A | 5.4 | | 5.4 | | 5.4 | |
| | Samp | ambient -1 | 27.0 | | 27.4 | | 28 | |
| Gain | NOx Slope | 1.000 ± 0.300 | 1.009 | | 1.009 | | 1.009 | |
| | NOx Offs | (-20 - 150) mV | -0.4 mV | | 0.4 mV | | 0.4 mV | |
| | NO Slope | 1.000 ± 0.300 | 1.009 | | 1.009 | | 1.009 | |
| | NO Offs | (-20 - 150 mV) | -1.3 mV | | -1.3 | | -1.3 | |
| Vedlikehold | | Inntaksfilter | Nei | | Nei | | Nei | |
| | | Innvendig | Nei | Nei | Nei | Nei | Nei | Nei |
| | | Aktivt kull | Nei | | Nei | | Nei | |
| Spangass | | Flasketrykk | 100 bar | | 92 bar | | 91 bar | |
| Instrument | | | NO | NOx | NO | NOx | NO | NOx |
| | Nulluft | NO/NOx | -0.3 | -0.5 | 0.1 | -0.2 | 0.5 | 0.1 |
| | | Min | -0.2 | -0.4 | 0.1 | -0.2 | 0.5 | 0.1 |
| | | Max | -0.3 | -0.5 | 0.1 | -0.2 | 0.6 | 0.1 |
| | Spangass | NO/NOx | 841.4 | 842.8 | 843 | 842.6 | 836.8 | 836.7 |
| | | Min | 841.2 | 842.6 | 842.8 | 842.4 | 836.2 | 836.5 |
| | | Max | 841.6 | 843.1 | 843.3 | 842.9 | 837.1 | 837.2 |
| Innenfor ytelseskrit. | | | NO | NOx | NO | NOx | NO | NOx |
| | Nulluft | NO/NOx ±5ppb | OK | OK | OK | OK | OK | OK |
| | Spangass | NO/NOx ±25% | OK | OK | OK | OK | OK | OK |
| Husk! | Inntaksslange på plass | | OK | | OK | | OK | |
| | Gassflaske stengt | | OK | | OK | | OK | |
| | Nulluft avslått | | OK | | OK | | OK | |
| Merknader | | | | | ~~Maskin~~ Instrument står på, men ingen respons | | | |
| Signatur | | | D. Reyes | | | | | |

Startet om 13:08

temp ~~[illegible]~~ 29-30°C

MonMaint.xls NOx-API Versjon 002 06.11.13

## 12.3 Example $NO_x$ – Scaling calculation

### Scaling-data

The scaling of data has the purpose to adjust the $NO_x$ RAW-data. This is performed weekly because the instrumentations sensors sensitivity changes over time. The scaling process includes three main steps:

1. Before starting the scaling process instruments parameters shall be checked out according to example sheet presented in chapter 12.2.
2. Scaling data is obtained by letting a zero-gas and a span-gas run through the instrument, during normal operation.
    - The span-gas (in present study 802ppbV) is delivered by an external supplier, and it works as a reference gas. The gas is composed of a carefully analysed $NO_2$, concentration and is used to determine how far from the specific concentration the instrument actually is measuring.
    - The zero gas, is a gas where all $NO_x$ is removed. The zero gas is used as a marker to determine how far from the theoretical zero the instruments reads.
3. The instrument changes continuously between NO, $NO_x$ and $NO_2$ readings. NO and $NO_x$ was written down ten times when the instrument was stable (normally after 10min). Out of ten values the mean was calculated and written in the sheet.

### 12.3.1 Data treatment

The $NO_x$ RAW-data is extracted and exported to an Excel sheet where all preparatory treatment was performed. Corrected data value was calculated according to an adjustment formula:

$$C_s = \frac{C_c}{S - Z} * (C_z - Z)$$

Where:

$C_s$= Scaled raw-data value

$C_c$= Reference value (concentration at the span-gas bottle)

S= Read value on the display of API 200E when span-gas is running thru the instrument

Z= Read value on the display of API 200E when cero-gas is running thru the instrument

$C_z$= RAW data extracted from logger

### 12.3.2 Example based on real measurements

Table 14. Raw-data preparation

| Data preparation | | | | | | |
|---|---|---|---|---|---|---|
| RAW-data outcome from Microsoft Note | 2014/01/14 11:00 38.0 69.6 31.7 100<br>2014/01/14 12:00 103.5 141.0 37.4 100<br>2014/01/14 13:00 94.3 130.1 36.0 100 | | | | | |
| Data was exported to an Excel-sheet | A<br>2014/01/14 11:00 38.0 69.6 31.7 100<br>2014/01/14 12:00 103.5 141.0 37.4 100<br>2014/01/14 13:00 94.3 130.1 36.0 100 | | | | | |
| Data was separated ito different columns | | A | B | C | D | E |
| | | Date/Time | NO | NOx | NO2 | Valid percentage of mean values |
| | | 14.01.2014 11:00 | 38.0 | 69.6 | 31.7 | 100.00 |
| | | 14.01.2014 12:00 | 103.5 | 141.0 | 37.4 | 100.00 |
| | | 14.01.2014 13:00 | 94.3 | 130.1 | 36.0 | 100.00 |

Table 15. Scaling of raw-data

| Scaling of data | |
|---|---|
| Example calculation based on data 14.01.2014. 11:00 [ppbV] | |
| $C_c$ | 802 |
| $S_{NO}$ | 836.8 |
| $S_{NOx}$ | 836.7 |
| $Z_{NO}$ | 0.5 |
| $Z_{NOx}$ | 0.1 |
| $C_z$ | measured values on 14.01.2014 11:00: 38.0(NO); 69.6(NOx); 31.7(NO2); 100% |
| Calculation | |
| $C_s$ for NO | $C_s = \frac{802}{836.8-0.5} * (38.0 - 0.5) \Rightarrow C_s = 36.0$ |
| $C_s$ for $NO_x$ | $C_s = \frac{802}{836.7-0.1} * (69.6 - 0.1) \Rightarrow C_s = 66.6$ |
| **Subtract NO from $NO_x$ to get $NO_2$** | |
| $NO_2$ | 66.6-36.0= 30.7 |
| **Convert ppb to µg/m3** | Conversion to match NIPH recommendations |
| **µg/m3** $NO_2$ | 30.7*1.912= 58.7ug/m$^3$ |

(NEA, 2014)

Table 16. Factors for converting $NO_x$ from ppb to µg/m$^3$

| Component | Factor | From | To |
|---|---|---|---|
| NO | 1.25 | ppb | µg/m$^3$ |
| $NO_x$ | 1.912 | ppb | µg/m$^3$ |
| $NO_2$ | 1.912 | ppb | µg/m$^3$ |

(NEA, 2014)

## 12.4 Filter specifications

# Superpleat Duo

Spesialfilter

**Superpleat Duo** er et kompakt kull/F7-filter som kombinerer gass- og F7 partikkelfiltrering i ett og samme filter.

Superpleat Duo stopper både de mest skadelige partiklene i lufta, og et bredt spekter av skadelige gasser. Derfor er filteret blant annet svært godt egnet til bruk i ventilasjonsanlegg i byer og tettsteder med dårlig luftkvalitet.

Filtermediet består av et syntetisk medie med aktivt kull. Mediet inneholder langt mer kull enn mange konkurrerende "billigfilter" på markedet. Dette, sammen med den store filteroverflaten, bidrar til at levetiden også er svært lang i forhold til andre kombinasjonsfiltre.

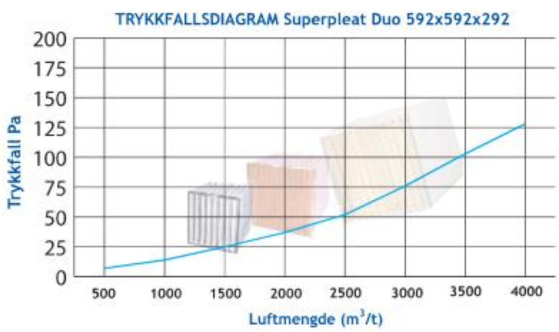
Superpleat Duo er også et godt valg i andre anlegg der en ønsker å fjerne både skadelige partikler og forurensende gasser.

Rammematerialet i Superpleat Duo er laget av forbrennbar plast.

**TEKNISKE DATA SUPERPLEAT DUO**

| | |
|---|---|
| **Filterklasse** | F7/Kull |
| **Filtermedie** | syntet/aktivt kull |
| **Ramme** | Polystyrene |
| **Kullmengde** | min. 500 g/m² |
| **Nom.luftmengde** | 3400 m³/t |
| **Areal** | 9,5 m² |
| **Starttrykkfall** | 120 Pa |
| **Temperaturgrense** | 70° C |
| **Størrelser** | 592x592x292*<br>490x592x292*<br>287x592x292* |
| **Bruksområde** | - Hovedfilter i ventilasjonsanlegg i byer, tettsteder og andre områder med dårlig luftkvalitet<br>- Sykehus<br>- Trykkerier<br>- Museum<br>- Næringsmiddelindustri<br>- Elektronikkindustri |

* *Andre dimensjoner på forespørsel*




INTERFIL AS 12.02.2010


Interfil AS
Bismo Industripark
2690 Skjåk

INTERFIL ventilasjonsfilter

Tlf.61 21 36 00 Fax 61 21 36 01
e-post: post@interfil.no
www.interfil.no