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Comparison of indoor air and outdoor air contaminant concentrations

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DESCRIPTION

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Comparison of indoor air and outdoor air contaminant concentrations

Abstract

Since most people spend their time indoors, there has been increased interest in air pollution concentrations. Number of very small liquid and solid particles suspended in the air is depending on different factors. But how should be decreased particle number? The field of this work is particulate matter concentration in the indoor and outdoor air.

Measurements were carried out in number concentration. The Indoor-Outdoor correlation was determined in order to investigate normative particle number indoors. The aim of this Bachelor`s thesis was comparing results of indoor-outdoor ratio obtained in the measurements under different conditions and clarifying reasons impacted on indoor-outdoor correlation. This study aimed to investigate the impact of following factors: mechanical and natural ventilation systems, occupation of premise, presence of open window, presence of fan on the Indoor-Outdoor relationship.

A series of measurements were conducted in two locations. The investigated premises were kitchen in the apartment with natural ventilation system and classroom at the university with mechanical ventilation system. The study of outdoor air contamination was carried out immediately after measurements indoors under different scenarios.

The difference in results was achieved by different classes of filter, presence of indoor sources, air tightness of the building, the different levels of outdoor PN concentrations, various types of A/C system and the combination of the mentioned factors. The lowest I/O ratio according to the result in the apartment is with open window and switched on fan. When the best result in the classroom is with switched on mechanical ventilation system with filter and open window.

Subject headings, (keywords)

Inoor Climate, Particle Number Concentration, Particulate Matter, Indoor-Outdoor Ratio, Indoor Air Quality, Indoor Temperature, Indoor Humidity, Distribution of particles

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CONTENTS

ABBREVIATIONS

PM – Particulate Matter

PN – Particle Number

PM_{10} - Particles smaller than 10 microns in diameter

$PM_{2.5}$ - Particles smaller than 2.5 microns in diameter

I/O ratio – Indoor-Outdoor correlation

ACH – Air exchange rate

A/C – Air Conditioning System

MOAS - Mikkeli Student Housing Ltd

W.C. – Window Close

W.O. – Window Open

IAQ – Indoor Air Quality

UFPM - Particles smaller than 0.1 microns in diameter

1 INTRODUCTION

1.1 General overview

The issue of indoor environmental quality in premises has become more popular. Indoor environmental factors affect work performance, productivity and energy consumption in buildings. That is why concern all these factors attract more and more attention in design of buildings.

The main problem about air pollution is related to its effects on humans. Air pollution can lead to problems in the soil and water, such as eutrophication and acidification, as well as hazards in the air itself, such as the formation of ozone near ground level. Nascence of gaseous pollutants, such as ozone and nitrogen oxides, represent a direct health risk, as do fine particles that can get deep inside our lungs. Since most people spend their time indoors, there has been increased interest in air pollution concentrations indoors.

Outdoor levels of different air pollutants vary between cities, regions and countries. There are a lot of factors that cause pollution in the city (traffic, manufactures). In order to describe the air quality in each city Air quality index is used. In this study I want to consider a few places in Mikkeli which are situated in different districts, each having its own characteristics. We will try to analyze information acquired for our city from Helsinki Metropolitan Area Council and compare it with own result. Based on the results from our measurements it will be possible to achieve the interrelationship between outdoor and indoor pollutions.

The contamination of indoor air can be absolutely different in identical apartments situated in one area and considered in the same time. This issue depends on many factors. Good indoor climate can be achieved through the correct design of building construction and HVAC-systems. We should not ignore maintenance, management, considered interior. The factors affecting the quality of the Indoor Environment have been recognized such as: outdoor conditions, type of building, building services, human activities.

1.2 Aims

This thesis includes several aims. The first aim is the study of temporal variation of outside air concentration. We have to recognize outdoor particle number concentrations. This study comprises analysis of particle distribution during long period of time, the effect of external sources on the distribution of particles.

This study compares the effect of outdoor pollutant concentrations on the quality of indoor air. Hence the main goal is comparing results of indoor-outdoor ratio obtained in the measurements under different conditions and clarifying reasons impacted on indoor-outdoor correlation. This study aimed to investigate the impact of following factors: ventilation, occupation of premise, presence of open window, presence of fan on the I/O relationship. This goal implies a consideration of the impact on the I/O ratio different types of ventilation system: mechanical and natural ventilation systems.

The next aim is comparison of results with the guidelines. We check IAQ in classroom and in residential building under different conditions. Into account were taken temperature, humidity, CO_2 concentration and particle number concentration. Results of temperature, humidity and CO_2 concentration can be compared with guidelines. Particle matter is measured in number concentration. That is why it cannot be compared with any guidelines. Solely I/O ratio of particles can characterize the level of contamination indoors.

2 AIR POLLUTIONS

Outdoor air is composed of oxygen (O_2) – 20,9%, trace gases – 0,064%, argon (Ar) – 0,9%, carbon dioxide (CO_2) – 0,036% and nitrogen (N_2) – 78,1%.

Air consists of a solid, gas or a liquid pollutants. Air pollutants make harm to the health of people, animals and plants. It's the concentration of chemical pollutants in the air that makes the difference between "harmless" and "polluting" as in case with polluting of water. One of the examples is carbon dioxide (CO_2) that is present in the atmosphere in a typical concentration which is less than 0.05 %. Inhalation of carbon dioxide usually does not harm human health, but air with an extremely high concentration of carbon dioxide such as 5–10 % is toxic and could kill in a couple of minutes. Air pollution is distributed quite quickly because earth's atmosphere is very turbulent. Many years ago manufactory workers thought that if they built very high chimney, the wind would just blow smoke away, dispersing it so it wouldn't be a problem. Unfortunately pollution cannot disappear in such simple way because earth is not so huge as we think. /1, p.4-6./

Air pollutant is emitted to or produced in the atmosphere as a result of human activity in a significant amount to cause discomfort, disease, or death to humans, damage other living organisms such as food crops, or damage the natural environment or built environment. /1, p.4-6./

There are different harmful effects: direct and indirect. Direct harmful effects on human health, buildings and in direct mainly causes climate change.

2.1 Typical outdoor air contaminants, their sources and concentrations

Sources of outdoor air pollutions may be characterized in a number of different ways. The following paragraphs are based on David Pennise's studies about biomass pollution basics /2/.

First of all we can distinguish natural and anthropogenic sources. Anthropogenic sources consist of:

- Vehicles, traffic - pollutants generated during operation of road, rail , air, sea and river transport
- Manufacturing - pollutants produced during industrial processes, heating
- Domestic - pollutants due to combustion of fuel in the home and refining waste.

Anthropogenic sources of air pollution can also be divided into several groups:

- Mechanical pollutants - dust cement plants , dust from coal combustion in boilers , furnaces and kilns, soot from burning oil and fuel oil , abrade tires , etc.;
- Chemical pollutants - dust or gaseous substances that can enter into chemical reactions;
- Radioactive contaminants.

Second common classification is between stationary and moving sources. Stationary sources are power plants, incinerators, industrial operations, and space heating. Moving sources mean motor vehicles, ships, aircraft, and rockets. Second species of classification describes sources as point, line or area (city).

There are three kinds of pollutants according to the nature of air contaminant:

1. Physical - mechanical (dust, solids), radioactive (radioactive radiation and isotopes) and electromagnetic (different types of electromagnetic waves, including radio waves), noise (loud sounds and a variety of low-frequency oscillations), and thermal pollution (emissions of hot air and etc.)

2. Chemical - gaseous substances and pollution aerosols. The main chemical air pollutants are: carbon monoxide (IV), nitrogen oxides, sulfur dioxide , hydrocarbons , aldehydes , heavy metals (Pb, Cu, Zn, Cd, Cr), ammonia , dust, radioactive isotopes

3. Biological - mainly microbial contamination of nature. For example, air pollution vegetative forms and spores of bacteria and fungi, viruses, and their toxins and waste products.

Both anthropogenic and natural emissions are variable from year to year, depending on fuel usage, industrial development, and climate. World Health Organization referred to priority pollutants released into the air, particulate matter, especially fine particles less than 10 micrometers (PM10). /2./

2.2 Typical indoor air contaminants, their sources and concentrations

The following four paragraphs are based on Nilsson's studies about Air Pollutants /2/. A lot of internal sources affect the indoor air quality. Internal sources are divided into seven categories.

- Humans and Human activities
- Tobacco smoking
- Building products and furniture
- Radioactive ground and building materials
- Office equipment
- Pets and other sources of allergen

One of the main indoor sources is people. Humans can release different substations such as particles or gas. For example people release carbon dioxide, fragments of skin, hair, water vapour and different odours. Moreover clothes also release particulate substances (textile fibres). It is possible to recognize presence of indoor source like a human. On the one hand, if coarse particles inside exceed amount of coarse particles outside, indoor source presents indoors. On the other hand, the additional indoor sources cannot be distinguished by counting of fine particles. /3, p.142-144./

The chemicals that result from any form of tobacco smoking will stay in the air to be inhaled long after the cigar, cigarette, or pipe goes out. /3, p.147./

Environmental tobacco smoke carries risks akin to those brought on by direct smoking, and include lung cancer and other lung ailments, heart disease, and general irritation of the eyes, throat, nose, and lungs. It can also exacerbate asthma and cause other health problem. Second-hand smoke is tobacco smoke which affects other people other than the 'active' smoker. Second-hand tobacco smoke includes both a gaseous and a particulate phase, with particular hazards arising from levels of carbon monoxide (as indicated below) and very small particulates (at PM2.5 size) which get past the lung's natural defenses. This is one source of pollution that is very easy to control. /3, p.147./

2.3 Particulate matter

Particulate matter (PM) encompasses very small liquid and solid particles suspended in the air. There are dust, ashes, soot, smoke, sulfates, nitrates, and other solid components. Particulate matter produced by the combustion of fuels and in the production processes. Depending on the contents of emissions, they may be highly toxic, and almost harmless. They can be either man-made and natural origin. /4./

Particulate matter which are generated in the atmosphere as a result of gases interaction are known as secondary particles. Combustion of coal, oil and gasoline leading to producing large particles (coarse particles). Fine particles are created by condensation of materials due to vaporizing during combustion. Secondary particles are appeared because of atmospheric reactions which include sulfur and nitrogen. The major chemical components of particles are sulfates, nitrates, ammonia ions, organic aerosols, carbon, different metals and other substances. /4./

The particle size has important meaning in describing their behavior, origin, chemical composition, and distribution processes in time. Particles smaller than 10 µm in diameter belong to PM_{10} whereas particles smaller than 2.5 µm in diameter belong to $PM_{2.5}$. Ultra-fine particles (UFPM) include PM smaller than 0.1 µm in diameter. Coarse particles with size more than 10 microns are deposited quickly and trapped during the purification. Air contains the smallest particles in the bigger amount than coarse particles. Fine particles precede coarse particles in the quantity. Fine particles are the most harmful for human health because they easily penetrate into human`s body. Unfortunately there are no available standards for UFP. /4./

Ambient PM is composed of particles that are emitted directly, for example dust, soot and secondary particles that are produced in the atmosphere from reactions involving pollutants for example oxides of nitrogen, sulfur oxides, volatile organic compounds , ammonia. Secondary PM and combustion soot are fine particles (PM 2.5), whereas fugitive dust is mostly coarse particles. /4./

Directly-emitted particles come from different of sources such as vehicles, industry, building sites, unpaved roads, power plants, burning of wood.

Other particles are produced when gases are formed by fossil fuel combustion at power plants, and in other industrial processes. Many combustion source emit PM directly and emit precursor pollutants that form secondary PM. Ammonium nitrate and ammonium sulfate are the principal components of secondary PM.

2.4 CO_2 concentration

The concentration of carbon dioxide in the atmosphere is defined by contribution of the greenhouse effect and the rates of plant photosynthesis. The background concentration of CO_2 in the atmosphere is about 350 ppm as in usually declared in the literature. Different outdoor pollution sources can influence considerably the CO_2 concentration.

The following five paragraphs are based on Nilsson's studies about Indoor sources of Air Pollutants /3/.

CO_2 concentration is one of the IAQ indicators. Indoor air quality can be checked by CO_2 concentration indoors. CO_2 concentration indoors is a result of outdoor CO_2 level and CO_2 concentration from indoor sources (human metabolism produces CO_2 indoors). Although outdoor CO_2 level is not of importance from a health, it supplied to a building and affect IAQ. /3, p.140./

One person in a quiescent state consumes 20-30 liters of oxygen per hour with the release of 18-25 liters of carbon dioxide. The inhaled air contains 300 ppm of CO_2, during the breath - 36000 ppm. Gas stove for cooking intensively release carbon dioxide. A person begins to feel uncomfortable, headaches, nausea and sickness when concentration of CO_2 level above a certain value. Concentration of carbon dioxide varies with the concentration of other bio-effluents. Concentration of CO_2 level can be easily measured by affordable devices. /3, p.142./

The outdoor concentration of carbon dioxide can vary from 350-400 parts per million (ppm) or higher in areas with high traffic or industrial activity. /3, p.142./

The concentration of carbon dioxide indoors depends on:

1. the amount of people inside
2. time of occupation
3. the amount of outdoor air entering inside
4. the area of the room
5. contaminating the indoor air by combustion products (smoking, vehicles)
6. the outdoor CO_2 concentration

The level of CO_2 concentration indoors can vary from 100 ppm above the outdoor air concentration ppm up to 2000 ppm or even more in areas with many occupants present for an extended period of time and where outdoor air ventilation is limited. /3, p.143-144./

2.5 Health effects and symptoms

The following four chapters are based on Nilsson's studies about Human Health /3/.

Indoor air climate can affect human health. Besides it should be given attention to other factors such as light, noise, thermal climate and psychosocial factors. /3, p.38./

The size of particles is directly linked to their impact on human health. Particles that are 10 micrometers in diameter or smaller are hazardous because they generally pass through the throat, nose and enter the lungs. Once inhaled, these particles can harm the heart, lungs and can be cause of serious health problems. /3, p.38./

Numerous scientific studies have explored effect of particle pollution exposure on health problems. Affect of particulate matter on health expresses in a wide range of biological effects. For example increasing the frequency of cough and other problems with upper and lower respiratory tract, aggravation of asthma, bronchitis, respiratory and cardiovascular diseases. Primarily these diseases can affect children and older adults. /3, p.39./

According to statistics, demand for hospitalization due to respiratory diseases increase by 0.5% - 3.4% for every 10 mg/m^3 particulate matter which size is less than 10 microns.

2.6 Studies of the INDOOR/OUTDOOR relationship of air contaminant

It have been conducted a lot of studies that related to this issue. This problem is considered to be interesting because people spend highest percentage of their time inside. All people are susceptible to air pollutions however some groups even much more susceptible to it.

The correlation between indoor concentrations and outdoors concentrations differs between various places. Each city, region, country has own outdoor level, own climate. Furthermore building characteristics, human activity and HVAC systems can influence the indoor concentration. In terms of previous studies PN concentration indoors depends on following factors: the outdoor level, the air exchange rate, type of ventilation system, the penetration effect, and additional indoor sources. /6, p. 4356-4257./

Air exchange rate is index of air quality or ventilation system quality. ACH equal air flow rate divided by volume of the space and measures in 1/h. According to D2 air change rate should be less than 0.7 1/h. Air exchange rate indoors is needed for air purification from harmful substances such us harmful gases, vapors and dust. /7, p. 757-758./

In the previous studies was investigated that the Indoor/Outdoor correlation mainly depends on air change rate. Changing of indoor conditions leads to changing of ACH what implies on I/O relationship. Therefore ACH affect PN concentration indoors. The IAQ can be improved by increasing air change rate (opening the window, turning on fan) only if outdoor level of PN less than indoor. Otherwise if outdoor PN concentration higher than indoor concentration, good IAQ can be achieved by decreasing ACH (closing the window, switching off fan)./7, p. 757-758./

Furthermore the lack of air changes supports the higher daytime concentrations indoors while during the night the outdoor concentrations reduce. Accordingly there are many ways to change this characteristic and thereby decrease I/O ratio.

There are different ways to the ingress air inside. Outdoor air can enter and leave a room by infiltration, natural ventilation, and mechanical ventilation. Air movement associated with mechanical ventilation is caused by force of supply air. In this case the main role is playing filter in the mechanical ventilation system. Filter can remove up to 80 % of air pollutants. This value depends on the class of filter. In the case with natural ventilation air movement is caused by air temperature differences between indoors and outdoors and by the wind.

2.7 Air quality index (AQI), guidelines and regulations of contaminant concentrations

The AQI is connected to the new air quality guidelines in Finland. The AQI is based on the principles of acute health effects, long-term effects on nature and materials. Index indicates how clean or harmful our air is. Subindices are calculated hourly for all pollutants. The highest subindex for a given hour becomes the AQI. Values are calculated for the center of Helsinki and for suburban areas nowdays. /8./

Helsinki Region Environmental Services Authority observes air quality in the Helsinki Metropolitan Area. Air quality is monitored in eleven points in the Helsinki area and in two points in district of Uusimaa. The assessment of air quality is carried out by continuous and indicative measurements, dispersion modelling, and bioindicator monitoring. Updated information of air quality is available in the official website for all. /8./

The Air quality index is calculated by obtained data in the Helsinki Metropolitan area There are carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), particles (PM_{10}), fine particles ($PM_{2.5}$). The air quality index expresses the concentrations of different pollutants in five categories. The categories vary from good to poor. Description of situation is illustrated in real time, each hour. Mentioned index relies on health effects, limit values and guidelines for air quality. Threaten fall risk the main groups such as children, elderly and sensitive individually when air quality has poor class. The highest value for one of air pollutants determines the air quality index. If one of pollutant concentrations exceed limit value and guide line then the AQI reaches 100. /8./ In the following table the concentration behind the classes of the Finnish air quality index is shown.

Table 1. The concentrations behind the classes of the finnish air quality index since april 2007 /8./

Air quality (value)	**CO**	**NO_2**	**SO_2**	**O_3**	**PM_{10}**	**$PM_{2.5}$**	**TRS**
Good (<50)	<4	<40	<20	<60	<20	<10	<5
Satisfactory (50-75)	8	70	80	100	50	25	10
Fair (75-100)	20	150	250	140	100	50	20
Poor (100-150)	30	200	350	180	200	75	50
Very poor (>150)	>30	>200	>350	>180	>200	>75	>50

2.8 HVAC design

“The task of the heating, ventilation, air-conditioning and cooling systems, the HVAC systems, is to add or remove heat and sometimes humidity to the extent needed to obtain the thermal climate required, and to remove airborne pollutants to the extent needed to establish the desired air quality.” /3, p.292/

Important factors for the good supply air quality have to include:

1. Right air volume selection including required outdoor air flow rate for designed amount of people and substance loads
2. Correct outdoor air inlets location
3. Rightly designed, selected and located air-handling unit
4. Prevention of leakage
5. Proper equipment selection
6. Possibility for maintenance and cleaning items of air handling system

7. Correct supply-air flow pattern, avoidance of drafts
8. Avoidance of extra humidity behind outside of wet areas such as air humidifiers, coolers /9, p.10./

Materials for the air-handling unit of the ventilating and air-conditioning system should be chosen according to "Emission classified products". The products are to be tested with regard to the following characteristics: total volatile organic compounds (TVOC), formaldehyde (HCOH), ammonia (NH3), carcinogens and odours. Radon can be avoided by construction solution. The above list of requirements is needed to prevent the emissions of harmful substance in indoors. /9, p.10./

During manufacture and installation relevant factors should be met: after manufacture each air-handling component ought to be clean also air-handling ceilings, false floors and cavity floors ought to be clean. All components of ventilation system should be checked for cleanliness. The infiltration of dust and humidity in ventilation system should be achieved by protection of any openings or accessible surface. In addition to this all components should have access for inspection, cleaning, disinfection. /9, p.11./

All components of air conditioning system should be checked for cleanliness in terms of requirements (EN12097 for Europe, building code in Finland) and voluntary guidelines. Cleanliness criteria helps to design high IAQ. Operating of ventilation and air-conditioning systems should be in such way as to avoid microbial growth on surfaces of components of air-handling unit, especially air filters and on wet surfaces. /9, p.11./

2.8.1 Classification of filters

Air filter element is a filter unit that cleans air from particulate contamination. Filter comprises filter material including framing, gaskets and supporting parts. Accordingly filter elements are characterized and presented in EN 779:2002. /10./

Standard for ventilation filters was published in 2002 year by the European Committee for Standardization. The guideline consists of classes ventilation system, pressure drop, average arrestance of synthetic dust, average efficiency of 0,4 microns particles. The claseses are divided according their characteristic into grops G1-G4, F5-F9. Division of classes G is based on average arrestance of synthetic dust while segregation of classes F is based on average efficiency of 0,4 microns particles. Filters with efficiency less than 40% belong to class G. Mainly filters media based on electrostatic effects. It is used to increasing efficiency at low resistance to air flow rate. Efficiency of filter can decrease due to impact such substance as particles from combustion and oil drops. Important feature of current classification is making consumers sure that filters remove necessary quantity of contaminant. The main characteristic of filter`s classification is final pressure drop. For filters with class G (coarse filters) maximum final pressure drop is 250 Pa and for fine (F) filters maximum final pressure drop is 450 Pa./10./

In our case we have F7-Filter which has been one year in use. F-Filter class is class of fine air filters. In terms of EN779:2012 fine filter F7 has minimum efficiency (ME) equal 35%. It is estimated by conducting three different tests for 0,44μm particles. /10./ Filter characteristic is shown below in the figure 1.

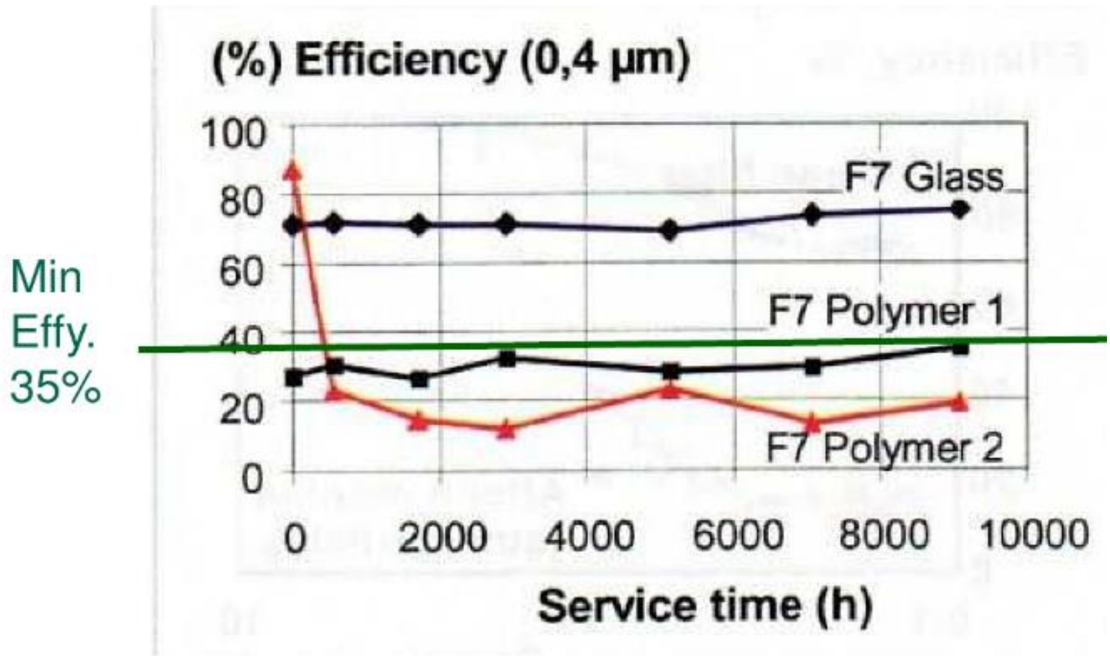

FIGURE 1. F7-Filter characteristic /10/

F7-Filter during all service time has to exceed minimum efficiency. The service time of filters is vary. This information is available from manual of given filter. Usually changing of filters are conducted twice per year. /10./

3 METHODS

3.1 Plan of measurements

In order to reach the main goal of this study the following methods are applied. A few measurements should be carried out, described and obtained conclusions. Measurements were made in an apartment and classroom under different conditions. For this goal measurement setup to study temporal variation of concentration was used. Practical work was divided in to three parts and each of them will have its own goal.

The first one is setting loggers outside to give us results of air temperature, humidity and particle number concentrations during three-four hours. This information helps to find out about outdoor air conditions and pollution. The next two parts will be related to indoor air conditions. The main difference between selecting places is availability of mechanical or natural ventilation system.

Second part of measuring will be conducted in classroom of Mikkeli University of Applied Sciences. We chose this place because there we can get precise results using different ways of measuring because there are mechanical ventilation system presents. That is why we can measure in different conditions using different combinations (open/ close window, switch on/switch off ventilation system).

The last part of measuring will consist of analyzing particle concentration in indoor air of apartment with natural ventilation. The apartment is situated on Raviradantie, Mikkeli. Measurements are carried out under different conditions. The plan of our measuring is shown in tables 2-4.

TABLE 2. The study of outside air concentration

Aim	Place	Date and duration	Object of measurement	Device
1.1 The study of outside air concentration in the apartment	Balcony next to the apartment(Raviradantie 17E, 22-50m from the road)	13/10/2013 3h	-temperature -humidity -CO_2 concentration -particle concentration	-Datalogger EBI 20 -AeroTrac Handheld Optical Particle Counter -TSI for CO_2
1.3 The study of outdoor air concentration immediately after measurements in the classroom	Yard next to the university laboratory (100m from the road)	10/10/2013 10min	-temperature -humidity -CO_2 concentration -particle concentration	-Datalogger EBI 20 -AeroTrac Handheld Optical Particle Counter -TSI for CO_2
1.4 The study of outdoor air concentration immediately after measurements in the apartment	Balcony next to the apartment(Raviradantie 17E, 22-50m from the road)	11/10/2013 10min	-temperature -humidity -CO_2 concentration -particle concentration	-Datalogger EBI 20 -AeroTrac Handheld Optical Particle Counter -TSI for CO_2

TABLE 3. The study of indoor concentration at the university

Aim	**Place**	**Date and duration**	**Object of measurement**	**Device**
2.1. The study of indoor air concentration with ventilation system switched on, windows closed, occupied	Classroom A 231	10/10/2013 40 min	-temperature -humidity -CO_2 concen-tration -particle con-centration -air flow	-Datalogger EBI 20 -AeroTrac Handheld Op-tical Particle Counter -TSI for CO_2 -
2.2. The study of indoor air concentration with ventilation system switched on, windows opened, occu-pied	Classroom A 231	10/10/2013 10 min	-temperature -humidity -CO_2 concen-tration -particle con-centration -air flow	-Datalogger EBI 20 -AeroTrac Handheld Op-tical Particle Counter -TSI for CO_2 -
2.5. The study of indoor air concentration with ventilation system switched on, windows closed, non-occupied	Classroom A 231	11/10/2013 40min	-temperature -humidity -CO_2 concen-tration -particle con-centration -air flow	-Datalogger EBI 20 -AeroTrac Handheld Op-tical Particle Counter -TSI for CO_2 -
2.6. The study of indoor air concentration	Classroom A 231	11/10/2013 10min	-temperature -humidity -CO_2 concen-	-Datalogger EBI 20 -AeroTrac

with ventilation system switched on, windows opened, non-occupied			tration -particle concentration -air flow	Handheld Optical Particle Counter -TSI for CO_2 -

Table 4. The study of indoor concentration at the apartment

Aim	Place	Date and duration	Object of measurement	Device
1. The study of indoor air concentration With windows opened, fan switched on	Apartment (Raviradantie 17E) Kitchen	13/10/2013 15min	-temperature -humidity -CO_2 concentration -particle concentration -air flow	-Datalogger EBI 20 -AeroTrac Handheld Optical Particle Counter -TSI for CO_2 -
2. The study of indoor air concentration with windows closed, fan switched on	Apartment (Raviradantie 17E) Kitchen	13/10/2013 40min	-temperature -humidity -CO_2 concentration -particle concentration -air flow	
3.The study of indoor air concentration with windows opened, fan switched off	Apartment (Raviradantie 17E) Kitchen	13/10/2013 15min	-temperature -humidity -CO_2 concentration -particle concentration -air flow	

3.4 The study of indoor air concentration with windows closed, fan switched off	Apartment (Raviradantie 17E) Kitchen	13/10/2013 40min	-temperature -humidity -CO_2 concentration -particle concentration -air flow	

3.2 Object of measurement

3.2.1 Measurements in the kitchen of the apartment

The first measuring point is situated on Raviradantie 17E. Apartment belongs to Mikkeli Student Housing Ltd (MOAS). The company rents the apartments it owns and administers to students studying in educational establishments following comprehensive school and other young people and other special groups. MOAS 7 was built in 1984. Studied apartment is situated on the first floor. It has been claimed that in the apartment is natural ventilation system. Measurements were conducted at a height of 1.1 m in the middle of the room. In the kitchen was one person. Prior to the experiment the window was closed for three hours, the fan was not switched on, nobody was cooking. The mean level of CO_2 concentration was 682ppm. The floor plan of the apartment is presented in figure 2.

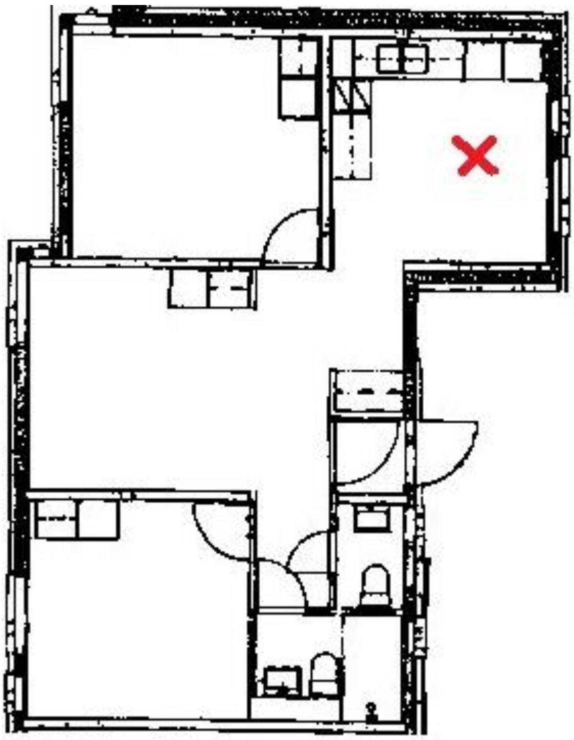

FIGURE 2. Floor plan of the apartment

In order to accelerate the air flow rate in this kind of measurements was included fan (220-240V 45 W black tower fan has power 45 W and frequency 50Hz-60Hz). It is presented on the figure 3 below.

FIGURE 3. 220-230 45W black tower fan (0.74m in height)

3.2.2 Measurements in the classroom at university

The second measuring point is located in the classroom at Mikkeli Applied Science University. Measurements were carried out in the classroom A231, second floor. The building is equipped with mechanical ventilation system. This system contains air filter F7 class. It was calculated that there are three supply air devices and three exhaust air devices. Supply air flow rate is 137 l/s and exhaust air flow rate is 235 l/s. The classroom is designed for 40 people. Indoors is located only one computer, projector and window which can be opened. Measurements were conducted under different scenarios. At the time of measuring 19 people attended in the room. The mean level of CO_2 concentration is 588 ppm. Devices were established at a 1.1 m height in the middle of the classroom. Before the measurement the window was closed for approximately 1 hour. In order to get reliable result for one serial of measurements we have opened window for 10 min. In figure 4 below classroom and point of measurements (red cross) are presented.

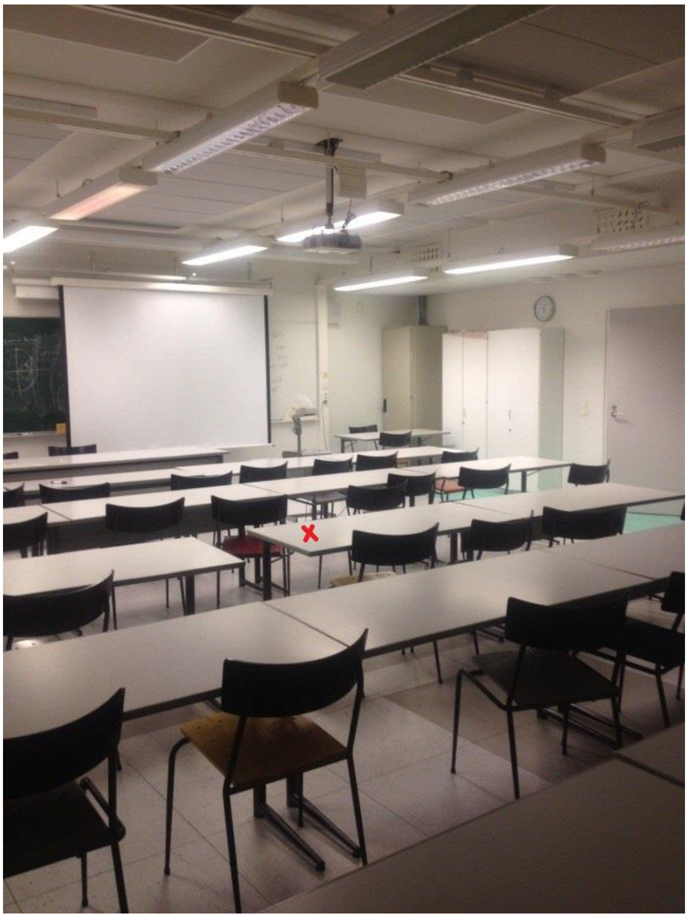

FIGURE 4. Classroom № 231

3.3 Measuring devices

EBI 20 Temperature/Humidity dataloggers (figure 4). For measuring of air temperature and humidity was chosen the datalogger because he can record data for long period of time and work independently. Firstly device was programmed by using PC according to requirement conditions. Possible sampling time is from one sec. to 24 hrs. In our case programmable sampling was three min. The main characteristics of the datalogger is quite big screen (LCD) and lithium battery. The device store 5000 data sets. Interface of following device is required Winlog basic software. The datalogger can be connected to PC by USB cable. /11./This equipment is presented in figure 5 below.

FIGURE 5. EBI 20 Temperature/Humidity Dataloggers /11/

The next device which was involved into measurements is AEROTRAK Optical Particle Counter. The sampling is based on the work of the isokinetic probe. The counter can be charged by lithium-ion battery or by electricity cable. Manual of AEROTRAK Optical Particle Counter advised users to perform zero check once per day. This equipment is used to verify filter, count PN and analyze size distribution. The unit has USB computer communication./12./ The model is required TRAKPRO™ Data Analysis Software. Device meets guidelines such as ISO 14644 and JIS standards. The equipment store around 100 000 data sets that can be extracted through USB cable. AEROTRAK Optical Particle Counter counts particles with size from 0.3 microns to 10 microns./12./ In figure 6 is shown one example of this equipment.

FIGURE 6. EBI 20 AEROTRAK Optical Particle Counter /12/

4 RESULTS AND ANALYSES OF RESULTS

4.1 Environmental conditions

4.1.1 Environmental conditions in the apartment

In the table below are presented results obtained of measurements in the apartment under different conditions. Measurements were carried out in the kitchen in the heating season at the centre of the room at the level 1.1 m. Apartment was occupied. Plate was switched off. Measurements were conducted consequently. Results of these measurements are presented in table 5 below.

TABLE 5. Indoor air conditions in the kitchen of the apartment

	W. closed		W. opened		W. closed+fan		W. opened+fan		outside	
	t, °C	ϕ	t, °C	ϕ	t, °C	Φ	t, °C	ϕ	t, °C	ϕ
Mean	31,6	23,7	21	29,4	23,4	29,1	21,9	28,2	4,5	46,3
Stdev	0,9	1,7	0,8	2,2	0,4	0,4	0,3	1		
Max	33,7	32,6	23,4	32,9	24,2	30	22,2	30		
Min	30,2	23,3	20,1	21,2	22,5	28,3	21,1	27		

Outside air conditions were almost steady during measuring.
The indoor temperature was 23.4 °C in the most typical case, when the window is closed and the fan is on. In the result we can see variation of temperature and humidity under different conditions. We have to take into account that measurements were conducted in occupied premises. The relative humidity of indoor air depends on the outdoor air conditions, air exchange rate and the production of humidity indoors. The indoor air humidity has to be below 60%. According to D2: Indoor Climate and Ventilation of Buildings design value for temperature is 21°C for the heating season. The maximum acceptable deviation to justify requirements is ±1 °C. In the case of occupancy the temperature should not exceed 25 °C whilst only one person was presented in the room.

We can make a conclusion that room temperature does not meet the standard. The maximum temperature during all measurements is 33.7 °C and the minimum is 20.1 °C. The worst case is scenario with window closed, fan switched on. The mean temperature reaches 31.6 °C. We get this temperature together with the lowest relative humidity. If humidity was higher, indoor air temperature was lower. In other cases air temperature almost meet a guideline. On the other hand relative humidity meets the standard. The measured values for indoor air relative humidity except the first case are even acceptable for category S1 in Finnish Indoor Air Classification 2008 because the value is more than 25% and less than 60%.

Open window in our case impacts on decreasing air temperature and rising up relative humidity. The presence of fan in conjunction with closed window helps to decrease air temperature and increase humidity. In the same time working fan with the opened window decrease both of indicator temperature and relative humidity.

4.1.2 Environmental conditions in the classroom at the university

Results of study environmental conditions in the classroom at university under various scenarios are presented in table 6 below. There are shown the descriptive statistics for indoor temperature and humidity. Outside air conditions did not change during measurements.

TABLE 6. Indoor air conditions in the classroom at the university

	W.close+occupaied		W.open+occupaied		W.close+nonoccupaied		W.open+nonoccupaied	
	t, °C	ϕ	t, °C	ϕ	t, °C	ϕ	t, °C	ϕ
Mean	22,9	46,1	21,0	48,6	23	30,4	20,5	33,4
Stdev	0,3	0,5	0,6	2,2	0,1	0,5	0,9	1,6
Max	23,3	47,8	22,1	50,6	23,1	32	22,2	35,4
Min	22,1	45,3	20,5	44,3	22,7	30	19,4	30,6

Outside air conditions did not change during measurements. The result of indoor air temperature is almost steady. The mean temperature during our study was 21.9. In the most typical case when window close and classroom is occupied temperature rises to 22,9 °C. The maximum temperature is 23,3 °C and the minimum is 19,4 °C. Standard deviation has low meaning what shows us that all values are very close to mean value.

The data set which describes us humidity has more variable values. In the scenario when window is closed and classroom is occupied level of humidity rises to 46%. All values are less than 60%, it means that in all scenarios indoor air conditions meet guideline. Mechanical ventilation system provides supply air according to regulations.

4.2 Temporal variation in outdoor air

In table 7 below are presented results of outdoor air concentration immediately after measuring at apartment. Temporal measurements of outdoor air concentration has important feature such as standard deviation. In this case standard deviation for all sizes of particles has a big value. It means that quite many samples are situated far from mean value. Because of that have been done descriptive analyze of PN concentration in different size range.

TABLE 7. Outside air concentrations for 3 hours in the kitchen

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**3 084 565**	**460 642**	**46 060**	**28 417**	**11 688**	**1 983**
Stdev	4 088 211	391 975	21 191	18 993	10 735	3 068
Max	29 366 722	3 087 885	140 733	149 591	98 415	25 587
Min	1 008 003	181 754	19 569	10 808	1 970	0

Figure 7 below illustrates the time series of particles which have size 0.3-0.5 µm for the duration of the sampling period 3 hours. The mean value for this sampling is 3 084 565 1/l. Values are varied from 1 008 003 1/l to 29 366 722 1/l. Deviation is approximately 132 % from the mean value. Peak occurs in the end of period. In spite of this peak almost during all measurement amount of particles was steady. Sharp peak was caused by external conditions. Arrival of car affected on the course of measurements.

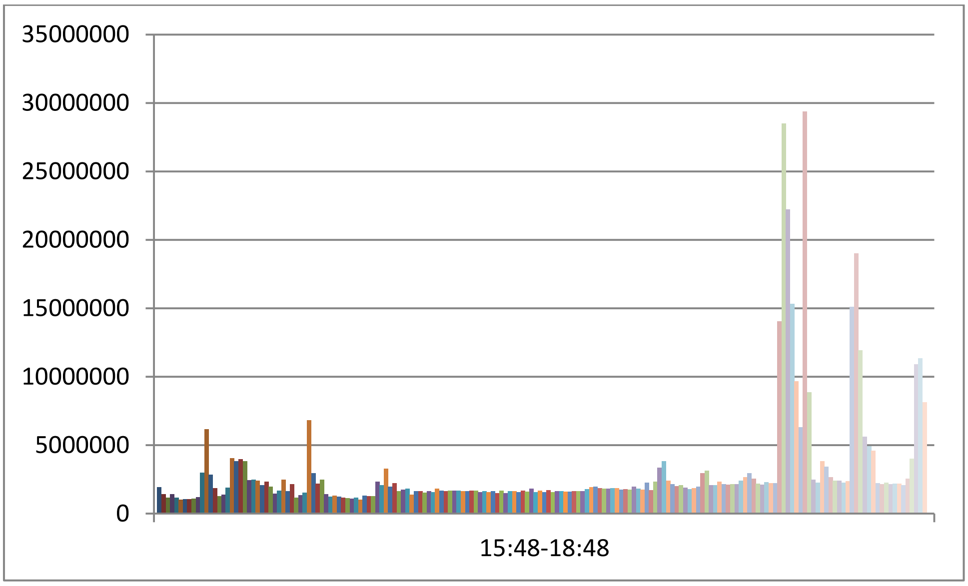

FIGURE 7. Distribution of outside air particles in the size 0.3 – 0.5 µm

In figure 8 is shown distribution of particles with size 0.5-1 µm. Mean value for amount of particles with size 0.5 – 1 µm is 460 642 1/l. The standard deviation is 391 975 1/l, it is about 85% from mean value. For this case relative standard deviation is in 1.5 times less than for previous case. It means that particles with size 0.5-1 µm has smaller deviation from the mean value than the smallest particles. Obvious that peak was at the end of period. In the figure below distribution of particles is illustrated.

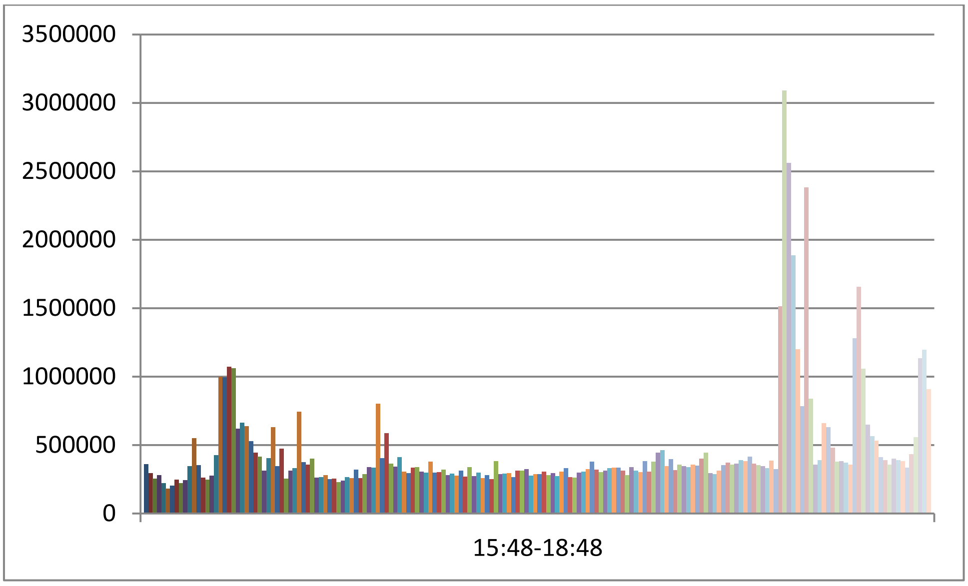

FIGURE 8. Distribution of outside air particles in the size 0.5 – 1 µm

Analysis of particle distribution with size 1-3 µm is illustrated in figure 9. The mean value for these amount of particles is 460 060 1/l. Relative deviation is 46% of average value. The peak is in the end of sampling. Amount of particles is less than in previous two cases.

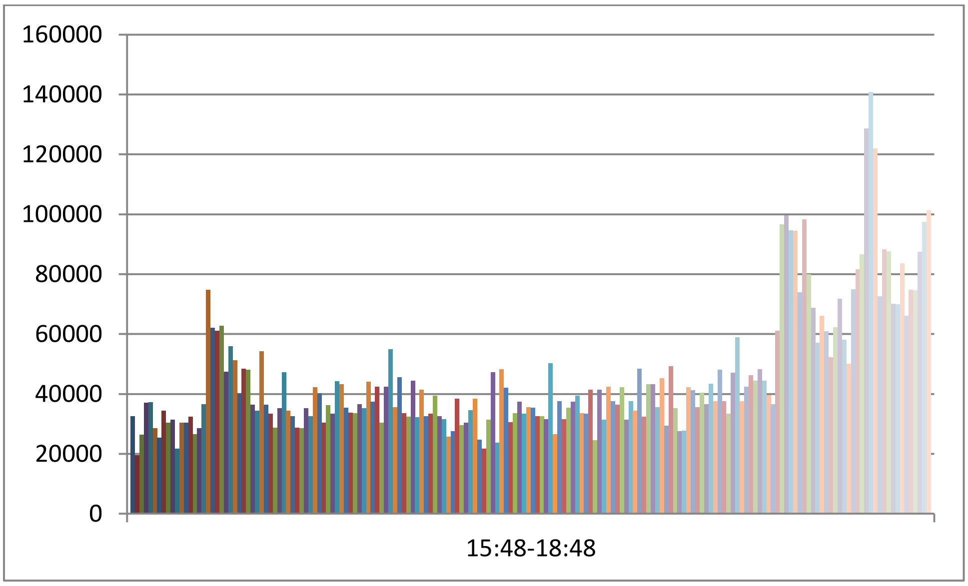

FIGURE 9. Distribution of outside air particles in the size 1 – 3 µm

In figure 10 below is presented distribution of particles with size 3-5 µm. The mean value for the particles with the size 3.0-5.0 µm equal to 28 417 1/l. Standard deviation is 66%. Peak is in the end of measurement due to impact from outdoor sources, which has been mentioned already. The number of particles is significantly reduced when their size increases.

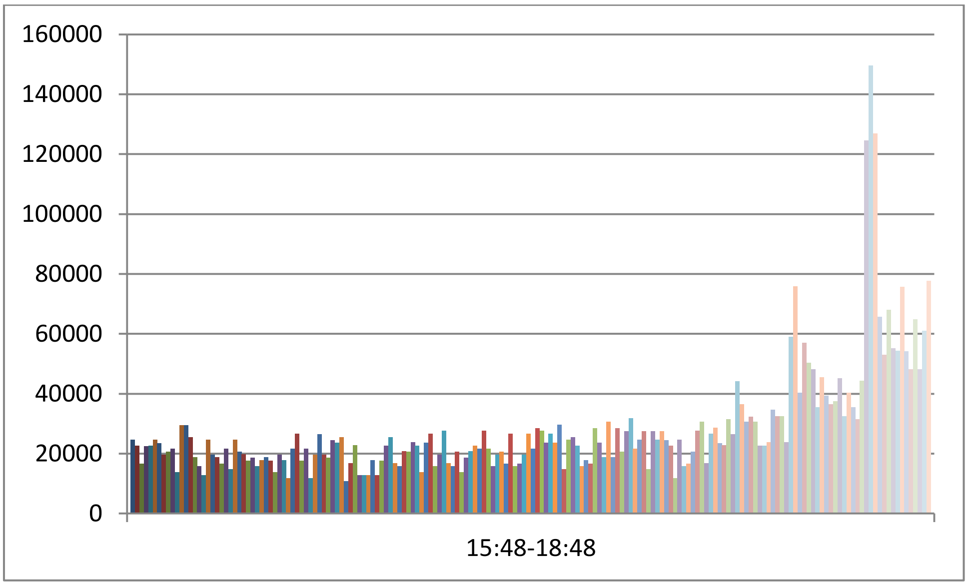

FIGURE 10. Distribution of outside air particles in the size 3 – 5 µm

In figure 11 is presented distribution of particles in size 5-10 µm. Amount of particles is decreasing with the increasing size of particles. In the main time variation of the number of particles is also very high. Peak is presented as in all previous cases. Level of relative standard deviation is almost 92%.

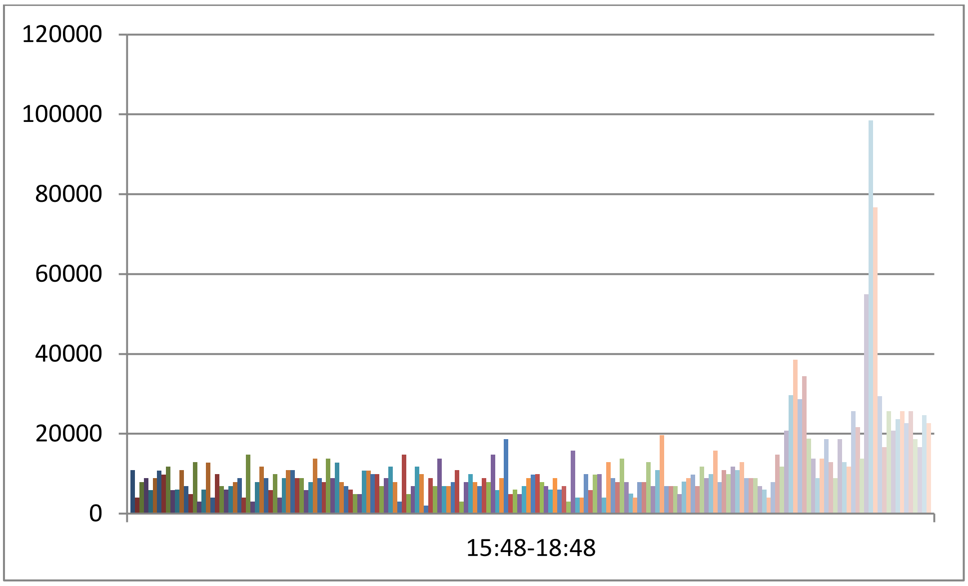

FIGURE 11. Distribution of outside air particles in the size 5 – 10 µm

In the last experiment when number of particles is the smallest was obtained the biggest standard deviation. Stdev equals 154%. This can be seen in figure 12. It is obvious that the largest particles respond to an external source significantly stronger than particles with small size. Moreover during all sampling time amount of fine particles is not steady. There is big value of standard deviation even during main time before peak. In some cases amount of particles reached zero.

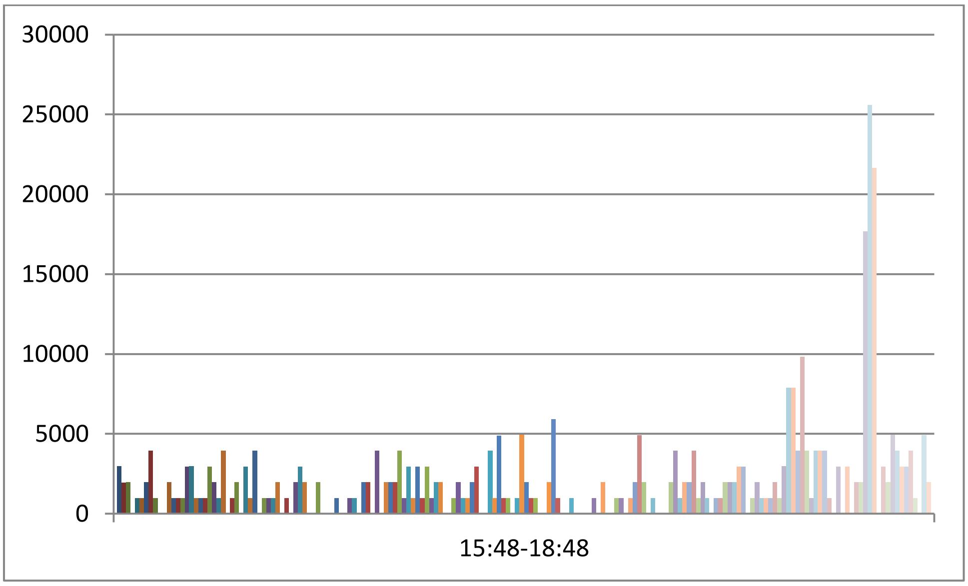

FIGURE 12. Distribution of outside air particles in the size 10 –25 µm

4.3 Particle concentration in the classroom

Our study concentrates on number concentration of particles. There are no guidelines for number concentration. We have various methods to change number concentration to mass concentration but these methods are not so reliable.

Table 8 presents descriptive statistical analysis of the data for PM concentration measured in the classroom with ventilation system switched on, windows closed, occupied. Ventilation system was switched on during the whole measurement, number of people was not changed.

TABLE 8. Indoor air concentrations with ventilation system switched on, windows closed, occupied

Statistics	Number Concentration 1/l					
	0,3-0,5µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**2 744 516**	**231 957**	**33 640**	**21 190**	**11 488**	**7 435**
Stdev	1 327 306	87 242	11 026	8 459	4 994	3 525
Max	5 976 254	446 033	56 623	43 709	22 726	17 796
Min	1 388 201	122 349	15 915	9 840	3 951	1 982

If we compare results with outdoor air concentration we can see difference in the results. There are no similar correlations between different sizes of particles. It is obvious that this difference was reached by filter in the air conditioning system. Filter traps different amount of particles in each size range. In this case filter more adjusted for particles of small sizes. According to results filter removes around 90% among the smallest particles in the range 0.3-1, around 50% in the middle size of particles and does not decrease amount of large particles. We can assume that we can see impact of indoor air sources because of increasing the amount of large particles. The main source in this scenario is people.

Table 9 shows analysis of the data for PM concentration measured in the same classroom with ventilation system switched on, windows opened, occupied. The main difference between this study and previous is the open window. Window was being open for 10 min during the measurement. It was closed for at least 5 hours before the start of measurement.

TABLE 9. Indoor air concentrations with ventilation system switched on, windows opened, occupied

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**2 436 824**	**289 971**	**40 145**	**26 332**	**11 249**	**6 419**
Stdev	400 095	57 317	8 740	6 045	3 979	3 078
Max	3 180 473	408 927	52 178	38 273	16 683	10 931
Min	1 555 743	180 923	25 635	16 893	3 933	1 969

According to data obtained in the second sampling we can notice that results are similar to study with ventilation system switched on, windows closed, occupied. The amount of particles is almost the same in both cases. Window does not play a huge role in number of particles. Filter removes the same percent of particles as in the previous scenario.

In order to get more accurate result we have measured particle number concentration in outdoor air. There was not raining outside what could lead to significant changes of particles number. Table 10 below presents us descriptive statistics of data set obtained from the yard of university. The study of outdoor air concentration was conducted immediately after measurements in the classroom.

TABLE 10. Outdoor air concentrations immediately after measurements in the classroom

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**41 625 387**	**2 602 950**	**76 074**	**28 104**	**6 117**	**1 379**
Stdev	57 505 059	3 371 593	61 259	12 975	2 808	1 245
Max	1,56E+08	9951314	247769	58992	12930	3934
Min	4383587	381483	39634	18725	2955	0

The measurements were conducted successive. The distribution of particles tends to be irregular. Such indicator as a standard deviation shows us that data points are spread out over a large range of values.

The data set is obtained from the classroom with ventilation system switched on, windows closed, non-occupied. The main reason of this measurement is absence of one type of indoor source - students in the classroom. Premise was empty for 1 hour before measurement was started. That is why we can claim that all fine particles did not have time to fall down during this time. We carried out the similar series of experiments but under non-occupation. The results got in the measurements are presented below in tables 11, 12.

TABLE 11. Indoor air concentrations with ventilation system switched on, windows closed, non-occupied

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**1 157 318**	**173 475**	**21 456**	**16 365**	**10 234**	**3 008**
Stdev	110 972	23 342	8 833	9 325	5 955	2 395
Max	1 409 979	225 599	38 198	35 400	23 237	7 900
Min	958 661	121 244	9 837	2 961	1 967	0

The number of particles is almost in the range as in scenario with ventilation system switched on, windows closed, occupied. In this study we got a little bit less amount of particles than in the study with occupation. We should take into account absence of one indoor source – people. That is why amount of large particles is two times less than in the previous measurement. Filter removes the same present of particles as in a previous case. The main difference is value of standard deviation. In the case with non-occupation we got smaller standard deviation that indicates tending to be very close to average value. In addition to this there have been changes in the filter performance. In this case filter removes only 50% of particles.

If we are comparing results got during this measurement with scenario of ventilation system switched on, windows closed, occupied we can conclude that the number of particles is bigger in two times than in second scenario. We should to take into account the different time of measuring and different outside PN concentration. All appearances these characteristics can lead to so big difference due to various results of PN in outdoor air in different time.

TABLE 12. Indoor air concentrations with ventilation system switched on, windows opened, non-occupied

Statistics	Height	Number Concentration 1/l					
		0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	1,1	**1 796 514**	**362 377**	**50 020**	**32 658**	**13 907**	**2 267**
Stdev	1,1	295 091	70 733	12 215	8 205	4 860	1 611
Max	1,1	2 275 437	475 405	67 069	46 428	18 751	4 931
Min	1,1	1 344 251	246 561	26 628	16 766	2 958	0

Considering the situations with the steady similar conditions except opening we can conclude that when window is closed amount of particles among all sizes is in the same range. Since outdoor air concentration is bigger than inside air concentration, number of particles with the window open is insignificantly increased. The main difference we can see in the size range between 1.0-5.0 1/l. Number of particles which belong to this category is two times bigger in the scenario with ventilation system switched on, windows opened, non-occupied than in the scenario without opening.

We can notice that the number of particles in this case is less than in case with ventilation system switched on, windows opened, occupied for 28 percentages. There are differences between these two scenarios: occupation and different time of measuring. Being sure in small difference of fine PN concentration in outdoor air in the time of both measurements we can detect the main factor which leads to difference is occupation.

TABLE 13. Outdoor air concentrations immediately after measurements in the first location

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**3 625 246**	**704 184**	**115 778**	**54 628**	**20 963**	**2 950**
Stdev	390 086	176 867	29 829	18 511	7 779	2 492
Max	4 346 178	1 013 770	152 875	83 297	33 467	6 867
Min	3 034 299	546 209	74 200	27 506	12 820	0

4.4 Particle concentration in the apartment

The following series of measurements were conducted in the kitchen of an apartment. In the apartment is natural ventilation system without any filter to remove the particles compared to the university with mechanical ventilation system with F7 class filter. It is obvious that we will get rather different results. Unfortunately as already mentioned we have not any guidelines for number concentration of particles. But we can check infiltration of endurance and analyze impact of main indoor sources of particle concentration. Results of these measurements are presented in tables 14, 15, 16.

TABLE 14. Indoor air concentrations with windows closed, fan switched off

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**8 055 667**	**1 648 305**	**123 815**	**41 304**	**12 965**	**8 095**
Stdev	565 818	122 909	32 117	18 031	9 094	8 960
Max	9 339 716	1 874 492	197 229	78 891	35 501	38 459
Min	7 433 785	1 419 796	82 861	17 813	1 979	0

If we compare results with outdoor air concentration we can see difference in results. Indoor air contains particles in size range 0.5-25 in an amount greater than outdoor air. Just the content of fine particles has been exceeded in outdoor air. Obvious that the cause of such variable distribution of particles absence of mechanical ventilation system with filter.

TABLE 15. Indoor air concentrations with windows opened, fan switched off

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**6 721 667**	**1 095 084**	**119 754**	**54 186**	**16 103**	**8 462**
Stdev	241 376	185 339	26 661	9 374	6 434	6 136
Max	7 226 261	1 499 966	208 656	68 080	31 564	23 621
Min	6 189 417	869 112	80 863	38 463	6 941	986

According to data set we can notice that results of measurements in the apartment are very close to each other. However results for small particles got in the case with windows opened, fan switched off are less than in the same case but with the window open. Amount of larger particles which size is more than 1.0 1/l leaves almost steady. We can see impact of indoor sources due to high level of fine particles. Outside PM concentration increases level of small particles, which size is less than 0.5 1/l.

We carried out two next measurements in the same conditions but with fan on.

TABLE 16. Indoor air concentrations with windows close, fan switched on

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**8 605 340**	**1 032 392**	**121 498**	**64 120**	**21 132**	**8 875**
Stdev	497 650	77495,75	22 171	18 036	9 992	7 027
Max	9 226 377	1203615	165 916	101 722	44 342	31 532
Min	7 269 142	826012	84 517	29 430	8 891	982

We should compare this case with similar scenario but fan switched off. The data set got in these measurements does not have any differences. The values are in the same range, standard deviation close to each other, maximum and minimum values are similar for both cases. Comparing results we can assume that the presence of fan in scenarios with closed window does not play a stronger role in the distribution of particles.

In previous two cases we measured situation with fan switched on/off, windows closed. In the following cases we are considering the situation with windows opened, fan switched on/switched off. The results are shown in table 17 below.

TABLE 17. Indoor air concentrations with windows opened, fan switched on

Statistics	Number Concentration 1/l					
	0,3-0,5 μm	0,5-1 μm	1,0-3,0 μm	3,0-5,0 μm	5,0-10 μm	10,0-25 μm
Mean	**6 801 807**	**856 811**	**67 485**	**30 303**	**8 329**	**5 274**
Stdev	194383,8	63716,04	11948,76	7741,045	3460,734	4437,219
Max	7239721	989910	96604	47169	13839	19653
Min	6526204	743551	50181	18840	2948	0

We can compare these results with the following scenario. Measurement when windows close, fan switch on. The measurements were carried out under different conditions. The main factor is opened window. Opened window affects amount of particles in all size ranges. The median level of particles increased towards scenario with the closed window. Obvious that number of particles which were generated indoors exceeds outdoor air concentration. Under conditions with opened window with natural ventilation seemed to infiltrate better than with window close.

Following measurements prove previous studying with windows closed, fan switched on/off. The amount of particles with fan switched on and windows open exceeds the number of particles with fan switched off. Moreover the situation with windows opened shows better result than in scenario with windows closed.

In table 18 below are presented results of outdoor air concentration immediately after measuring at apartment.

TABLE 18. Outdoor air concentrations immediately after measurements in the kitchen

Statistics	Number Concentration 1/l					
	0,3-0,5 µm	0,5-1 µm	1,0-3,0 µm	3,0-5,0 µm	5,0-10 µm	10,0-25 µm
Mean	**10 146 097**	**1 038 454**	**82 346**	**32 682**	**6 824**	**897**
Stdev	1 597 111	102 258	12 213	8 078	2 359	820
Max	12 514 961	1 207 540	99 483	43 429	9 922	1 976
Min	7 380 110	880 934	57 088	17 790	3 937	0

4.5 I/O ratios

All studies were conducted in order to investigate the relationship between indoor and outdoor PN concentrations and to characterize the infiltration behavior of PM. The I/O ratio reflects impact from indoor source, meteorological conditions, airtightness of the building envelope. The analysis of particle number provides Indoor/Outdoor ratios at different scenarios with natural ventilation system or with mechanical ventilation system. In the table 19 results are presented.

We have calculated the I/O ratios under different scenarios. Results show us distinction between measurements with different type of ventilation system (mechanical and natural ventilation systems). Including in fan could also play a role in improving ventilation system.

In the beginning we will consider scenario with A/C system in the classroom. The most typical case is A/C switched on, window close, occupied. In this case the I/O ratio exceeds 1 only in particle size 5-25 µm. It shows us the obvious influence the internal source –people on indoor air quality. In this study the I/O ratio of fine particles in some other cases is over 1 too. It means that the presence of indoor sources is considered to be significant.

In the first case we will analyze the influence of open window on PN concentration. We should take into account that window was opened only for 10 minutes. So it is possible that during this time particles have not enough time to penetrate indoors. Results of the I/O ratios for cases when A/C switch on, occupied and window open or close are similar. Values for all size of particles are in the same range. Difference is approximately 10%. If window open for a long period of time we will have a rather different result.

For the second case the difference in results is more obvious. The second case implies a comparison between scenarios with A/C switch on, window close, occupied and A/C switch on, window close, non-occupied. It is illustrative example of presence one of indoor source – people. The amount of fine particles in case with occupation is larger in 2-5 times than in case with empty premise. Although fine particles have relative relationship, small particles with size 0.3-1 got the opposite result. The amount of particles for the case with occupation is bigger in 3-5 times than in scenario without occupation. This fact can be explained that people at usually are carriers of fine particles. Moreover small particles are lighter than fine particles and because of this they need more time to fall down. This area was in non-occupied conditions only one hour before measurement and it is possible that it was not enough time to fall down.

The second study is in the apartment with natural ventilation. The most typical case in this research is window close, fan switched off. The I/O ratio exceeds 1 in particle size 0.5-25 μm. Overall the mean I/O ratio for the apartment is much higher than the mean I/O ratio for the classroom with A/C. In the first comparison main difference is presence of open or close window. Window was opened for 30 minutes. According to data set these two cases have very similar results. Probably 30 minutes is not enough to falling down particles. The next indicator which can impact on I/O ratio is fan. Fan accelerates the movement of particles what can lead to increase of air flow rate. In the scenario with window close involving of fan is increased the I/O ratio among fine particles. Fan gives opportunity to fallen particle to continue her movement.

Under conditions with open window impact of fan can be consider in different way. Fan can improve air change rate. Result shows us that the I/O ratio is decreased while fan is switched on and window is opened. Values have remained in the same range but considerably lower.

The penetration efficiency is assumed to equal to the I/O ratio. The low penetration efficiency protects the premises from the infiltration of polluted outdoor air. Thus the best IAQ can be reached by using mechanical ventilation system with filter in order to decrease penetration efficiency.

TABLE 19. Indoor/Outdoor ratios for different scenarios

Measurement	**Particle size, µm**					
	0,3-0,5	0,5-1	1,0-3,0	3,0-5,0	5,0-10	10,0-25
Classroom						
A/C switched on, W.C. occupied	**0,066**	**0,09**	**0,44**	**0,75**	**1,88**	**5,39**
A/C switched on, W.O. occupied	0,059	0,11	0,53	0,94	1,84	4,65
A/C switched on, W.C. non-occupied	0,319	0,25	0,19	0,30	0,49	1,02
A/C switched on, W.O. non-occupied	0,496	0,51	0,43	0,60	0,66	0,77
Kitchen						
W.C. fan switched off	**0,79**	**1,59**	**1,50**	**1,26**	**1,90**	**9,02**
W.O. fan switched off	0,66	1,05	1,45	1,66	2,36	9,43
W.C. fan switched on	0,85	0,99	1,48	1,96	3,10	9,89
W.O. fan switched on	0,67	0,83	0,82	0,93	1,22	5,88

A/C= Air Conditioning System; W.C.= Window Close; W.O.=Window Open

5 DISCUSSION

This study is comparable with some previous studies. One of the considered studies is "Impact of ventilation scenario on air exchange rates and on indoor particle number concentrations in an air-conditioned classroom, H.Guo, L,Morawska and Indoor / Outdoor air quality relationship in urban commercial buildings: Dublin case studies, Challoner, Gill are considered".

In the beginning should be taken into account that different way to measure PN concentrations inside was chosen in the previous studies. Temporal measurements were carrying out during two weeks. It could help to get more reliable result. The setting of the instrumentation was the same but equipment was different. Moreover initial characteristics of ventilation system in the previous study differ from characteristic in the study presented here. The outdoor air intake of the air conditioner in the study of H. Guo /7/ was 133 liters per second when the outdoor air intake of the air conditioner in the current study was 137 liters per second. In current case class of the filter was F7 while in the previous study it was F4.

The obtained results showed that the I/O ratio for PN concentration varies from 0.08 to 0.50 under mechanical ventilation and from 0.75 to 1.19 under natural ventilation system when indoor sources were absent. The results presented the I/O ratio for PN concentration in the previous studies ranged from 0.502 to 0.621 for submicrometer particles. The data set obtained in the present study is comparable with previous observations in the H. Guo`s /7/ study where the mean I/O ratio for particles was 0.52 (for particles with diameter less than 1 μm) at conditions when windows closed, A/C on and fans off. In the study presented here under a similar conditions (windows closed, A/C on and fans off) the mean I/O ratio for the tested particle size-range was 0.08. H.Guo /7/ also got that the I/O ratio was 0.53 when all windows were closed, A/C off and fans off. In comparison, in the measuring in the apartment under the same conditions (windows closed, fan off, A/C is absent) the I/O ratio equal to 1.19. These results are presented in table 20.

TABLE 20. Indoor/Outdoor ratios for different studies under similar conditions

Measurements	I/O ratio	
	Presented study	Previous study
A/C switched on, W.C. occupied	0.08	0.52
W.C. fan switched off	1.19	0.53

It can be assumed that if the ratio is below 1, indoor PN concentrations are below outdoor PN concentrations and if the ratio is above one then indoor concentrations exceed outdoor ones.

In previous studies related to this topic was observed size–dependent penetration efficiencies of particles. It has been analyzed in premises with natural ventilation system and mechanical ventilation system. The penetration efficiency equal I/O ratio when the deposition rate is less than ACH. It was announced that penetration efficiency depends on particle size in naturally ventilated venues. According to previous measurements the penetration efficiency is 0.79 when the particle size range 0.853 to 1.382µm as well as penetration efficiency is 0.48 in the size range 4.698 µm to 9. 647 µm. It was reported that penetration efficiency is 40-60% for particles 0.01-0.4./7 p.765./

In current study the mean I/O ratio considered for various conditions differs from results obtained in other studies. The supply air in the A/C system in Guo`s /7/ observation has mixture of outdoor and return air while A/C system at the University has only outdoor air as supply air. This is one of the reasons to have such difference in the results. In addition to this in previous studies unfortunately was not mentioned amount of people inside. Comparing these two cases it has been assumed that the difference in values was achieved by different classes of filter, presence of indoor sources, air tightness of the building, the different levels of outdoor PN concentrations, various types of A/C system and the combination of the above factors.

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