Evdokimova Ekaterina

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Air pollution and air cleaning equipment in buildings

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MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

DESCRIPTION

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Abstract

The subject of this thesis work is air pollution and air cleaners in building. Clean air has big significance for human health because different pollutions can cause allergy and disease. The quality of indoor air affects health and effective working.

The aim of this thesis is to present methods and devices for cleaning the air. To describe which air cleaner can arrest certain pollutant is another purpose of thesis. And a comparison of air cleaners of different manufactures and detection the best was made.

Air cleaning is discussed in every country. And each country has its own guidelines and standards like ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and EN (European norms). In Russia there is the National Standard of the Russian Federation that was made according to European Norms. All these standards were used in the thesis.

Information about problems of air pollutants in the buildings is described in this thesis. Conclusion is done at the end of thesis which said that there are three decisions of this problem. All sources of pollutants should be control or eliminate. The second solution to use duct air cleaners in ventilation systems. And household air cleaners can provide of indoor air impurities.

Subject headings, (keywords)
Indoor air, sources of air pollution, air cleaners, duct air filters.

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CONTENTS

1 INTRODUCTION

Nowadays, because of the developed industry, air of atmosphere contains a lot of pollutants and impurities. Most of them have a negative effect on almost all systems of human body and on human health in generally. Besides outdoor pollutants indoor air has its own pollutants. 90 % of the life people spend in premises breathing indoor air. So people are exposed to the hazard impact of indoor and outdoor air pollutants. To prevent this negative affect air should be pre cleaned or clean directly in premises.

Cleaning the air is the main subject of this thesis work. For this purpose the different types of air cleaning devices can be used. It can be household cleaners which are placed in a room and filter or devices which are part of air-handling systems of the whole building (duct filters). Classification and individual types of air cleaners will be told in this work, describe principals of operation and processes of arresting pollutants. Also manufactures information of some air cleaners, comparison of this information and conclusion will be shown.

This thesis work has three main parts. The first part has information about air pollutants that have negative effects on human health. Sources of indoor and outdoor air pollutants are written in the thesis. How they go into the buildings or how they are formed in the buildings. Also the common diseases which these air pollutants can cause and discomfort from this pollution are described.

The second part of the thesis work tells about the air cleaners and their classification. Household air cleaners and sorts of filters (mechanical, electrostatic, coal, HEPA, photocatalytic), which belong to this type, are told in the first section. Each filter has its own role and arrests a certain type of pollutants. After description of household air cleaners three filter types of common manufactors are presented, compared their characteristics and made a decision about which filter manufacture is the best. About duct air cleaners, and their classification according to ASHRAE standard is told in the second section. ASHRAE devides duct air cleaner into three groups: Fibrous media unit filters, renewable media filters, electronic air cleaners. In additition fibrous media filters have own classification according to the EN 779-93 and Russian standard is GOST P 51251-99. Comparison between three fibrous media unit filters (subclass dry-type extended surface filters) of common manufactures and chosen the best filter is made at the end of the second part of the thesis.

Last part of the thesis contains the description of the experiment that was done to find out the effectiveness of duct air filters. Also primary results of the experiment, graphics and conclusion are presented in the fourth part. The conclusion provides an answer to the question: what type of air cleaners is the most effective for air cleaning.

2 AIR IMPURITIES

Indoor air quality in the buildings depends on few factors. These factors include outdoor air quality, construction of the ventilation system and effects of indoor pollutants. Growing sources of harmful substances can be external and internal. External sources include air pollution from combustion processes, road traffics, factories, allocation pollution from soils such as radon, leakages from the tanks with fuel, pollution around intake ducts through which air flows to the building etc. Outdoor air always contains the pollution associated with various natural processes in our planet (soil erosion, volcanic pollution, etc.).

Internal sources include all pollutants associated with air handling systems. There are materials which are used in this systems such as air filters, ducts, fittings and air or fire dampers. Materials which are used during the building process or building occupants also can be sources. More specific substances are tobacco smoke, sources of laboratories, kitchens, cafeterias, bathrooms, offices, parking garages etc. All these places should be equipped with ventilation systems. /1/

2.1 Air impurities from outdoor sources

The areas where the soil is covered with grass, or near large space of water, the air does not contain harmful gaseous impurities. It is almost free from dust and microorganisms. But in populated areas, especially in industrial centers, the air can be contaminated. Consequences of human activity are more significant factors in air pollution. They appear especially in large cities with an increasing the number of cars (to increase exhaust gas emissions) and growing industrial emissions into the atmosphere caused by the higher production. Products of these processes are the air pollution by fine aerosol, and molecular (gaseous) contaminants. /2/ Also atmospheric air always contains a certain amount of dust (airborne solid particles of mineral or organic) and micro organisms (viability of microorganisms in the air provides the suspended particles of water, mucus, dust and fragments of the soil).

Dust particles are distributed in the air and stay in suspension. This is because the size of dust particles is small. Typically, the particle diameter is less than 100 microns (from 0.01 to 100 microns).

More powerful source of air pollution from dust is the smoke from the burning of coal, peat and other fuels. The wind carries the smoke over long distances, so around large power plants and other industrial air may be contaminated with a radius of 1-5 km. Also sources of pollution are industrial enterprises, which in the course of the process are a significant dust generation. The amount of dust, its characteristics and influence on the human body vary and depend on the location and source of dust, and on its composition./3/

With the dust in the air and in indoor air (homes and public buildings) there are different kinds of microorganisms. The more dust, the more microorganisms. In the air, microorganisms are on the dust particles. Amount of free airborne bacteria is very small. The number of microorganisms in the air as well as the amount of dust is variable and depends on conditions of air environment. In the summer, when the season is dry, the amount of microorganisms is bigger than in winter. In the air of large populated areas amount of micro-organisms is also bigger than on the outskirts of the city. In the certain season dust in the air is mixed with pollen from trees and grasses. Pollen because of a warm air flow is transported long distances and the same way as the dust disperses in the air. /3/

In the air of populated areas, especially near industrial plants, there are different kinds of harmful gases and vapors (sulfur dioxide, hydrogen sulfide, carbon disulfide, chlorine, nitrogen oxides, carbon monoxide, etc.). A certain amount of these may be harmful for people, animals and nature. Near the chemical industry the air may be polluted by different gases (chlorine, hydrogen sulfide, nitrogen oxides, etc.). It depends on the products or used materials.

Most often in the air of populated areas there is sulfur dioxide ($S0_2$). Air is polluted by this gas during burning of fuels which contain sulfur. Industrial boilers, power plants and heating plants which operate on solid fuel, especially more heavily pollute the air with this gas.

Near the steel plants the air is polluted with carbon monoxide. It is also found on the streets with a large traffic. Carbon monoxide is contained in the smoke and exhaust gases from cars as a product of incomplete combustion. Carbon monoxide is lighter than air. When this gas goes into the atmosphere it is rising up. In the villages sources of carbon monoxide are exhaust gases of tractors and combines. /3/

2.2 Air impurities from indoor sources

Many people think that outdoor air quality is most harmfull for human health. But air inside the building is not less pollutant. People spend inside the buildings 80-90% of the time (at shools, in offices, at homes). Hence indoor air quality is very important./4/

Indoor air is usually different to compared with outdoor air. But the consentration of pollution in indoor air depends on outdoor air, flow rates of ventilation, the characteristics of building, seasons, etc. In general, everything that interact with the air can pollute it. The more things in the room, the more they pollute the air. In the indoor air there are big amount of microorganisms, virious and all kinds of harmfull or sometimes poisonous impurities.

A large amount of dust particles, particles of wool, pollen and carpets are containing in the indoor air. People are breathing dust which contains dust mites, fungal spores and microscopic particles. Materials, which we use for repairs also can be sources of air pollution. For example, wallpapers on the walls, linoleum on the floor, paints, polystyrene ceiling panels. All these materials allocate gases and can be very dangerouse for health. They can emit phenol, formaldehyde and can cause some disease. Cleaning the room with too many household chemicals can also be a source of air pollutions. In some case it can allocate formaldehyde and cemical pollution. /4/

If in the building there are some air cleaners or air handling systems with filters they should be maintened well. Dirty filters can be a source of harmfull pollutions. Materials in air handling systems also can emite some pollutants. To evoid this in Finland there is the cleanliness classification of air – handling components (M1). The aim of this classification is the use of constraction materials with low emission.

Different pollutants are formed and emitted during the constraction (TVOC, formaldehyde, ammonia, etc). This classification is showing emission requirements for materials in relation to good indoor quality. Classification M1 means low emissions./5/

2.3 Health effects of different pollutants

Pollution of indoors can affect your body at home, at work and even when visiting friends. This is the common reason of respiratory diseases and asthma, allergy and lung cancer. For some people, there is a greater risk - as very young children and the elderly or those who already suffer respiratory illnesses as people with increased allergic sensitivity. Harmful substances of indoor air can cause a variety of effects for people. Various air pollutants, with different effects on human health, can be causing various diseases.

Nitrogen dioxide (NO2)

Gas cookers, which are poorly ventilated or used as a heater, may produce nitrogen dioxide. It is a very common indoor pollutant. This is a real problem in countries where are used of homes gas cookers. Gas NO2 is a product of fossil fuel combustion.

This gas cause more health effects for children with respiratory illness, which will increase susceptibility of infections. Also NO2 can be hazard for asthmatics, bronchitis and other people with respiratory problems. /6, p 102-104./

Formaldehyde and other Volatile Organic Compounds (VOCs)

The content of VOCs and formaldehyde in residential buildings depends on several factors such as building materials, paints, tobacco smoking, furniture, furnishings, adhesive, cleaning agents and occupants themselves. It can be industrial or natural.

Formaldehyde can cause illnesses from subtle neuropsychological changes, mucous membrane irritation of the eyes, nose and throat, and airway irritation to asthma and cancer. The more formaldehyde, the more serious is disease.

Other VOCs can cause irritancy, allergy and other transient effects. The influence of VOCs is hard to measure because it can be temporary for example the influence of painting during the repaint. /6, p105 -110/

Fungi and bacteria

Fungi and bacteria can be produced by the surface coating of the walls, wool, fabrics and foodstuffs. They appear if there is excess of moisture on the surfaces and or if ventilation is poor.

These substances can cause health effects other than illnesses attributed to saprotrophic bacteria and fungal flora in building. There is also relation between respiratory morbidity and dampness. According to some investigations mould houses have influence on children respiratory illnesses. But it is not proved well and requires further investigations. /6, p 110-112/

Dust and house dust mites

Temperature and humidity affects on the content of dust and house dust mites in buildings. Dust can be held on carpets or other surfaces. Their presence can cause allergy or asthma. But they have their influence only on those who have predisposition to this type of illness, mainly children. /6, p 112-116/

Carbon monoxide (CO)

CO can appear from unlocked leakages in flue or gas heating appliances. Danger also comes if the house is situated close to main roads or to the garage. One more source is tobacco smoke.

Health hazards: when CO comes to the blood it replaces oxygen, which blocks the income of oxygen to the body. It has a role in promoting atherosclerosis. Accidental exposures can cause lethal effects. The most susceptible are pregnant mothers, old people, children and people suffering from anemia. /6, p 116-118/

Particles (PM 10)

Particles PM 10 mean particles less than 10 micrometers in diameter. It can usually come from environmental tobacco smoking, wood-burning stoves and kerosene heaters. Cooking, sweeping, vacuuming can increase the number of particles. They can come from outdoors for example from traffic and from indoors from peoples activities.

There is a link between mortality and morbidity and particle concentration. Effects on cardiopulmonary impairment and may cause cancer. It is also known the influence on lung function and bronchial reactivity because particles can easily pass into lungs and stay there. /6, p 118-121/

Other pollutants

Other pollutants such as radon, tobacco smoke, organ chlorine compounds, other biological allergens, fibers etc. Radon can cause cancer. Tobacco smoke contains a number of chemicals which irritates the eyes, nose and throat. They can cause lung cancer, nasal sinus cancer, heart disease. In children – low birth weight, sudden infant death syndrome, asthma induction, exacerbation, middle ear disease and lower respiratory disease.

All the impurities mentioned above demand special approach. The number of their effects is called sick building syndrome. They are also dangerous for people who have multiple chemical sensitivity. /6, p 121-124/

3 AIR CLEANERS

Air inside and outside building is not very clean. Our health and the people lifetime depends from the quality of air. Nowadays some technology can help us to breathe clean air. Air cleaners are the equipments which purify and make air free from particles, gases and different compounds. There are two types of air cleaners which are used in buildings:

- Household air cleaners (purifiers). There are small devices which are set directly in the room
- Dust air cleaners. There are air cleaners in air handling systems.

3.1 Household air cleaners

Household air cleaners are devices for people who do not want to live in the polluted indoor air, and prefer to breathe clean and healthy air. Also air cleaners are good for people who suffer from allergies and chronic respiratory diseases.

Air cleaners are intended for cleaning indoor air pollutions such as: dust, fungal spores, odors (cigarette smoke, smoke city), allergens (pollen, animal dander). Air purifiers are designed to operate in one closed room. Air purifiers are used in residential and office premises for the removal of air contaminants. They are mobile and do not need installation. And their work should be noiseless.

The type of these air cleaners usually depends on air pollutants in the buildings and preference of people. People who suffer from allergies know what symptoms dirty indoor air can cause.

The operation principle of most air cleaners is the filtering mechanism (i.e detention of pollutants (particles), which are present in the air, on special filters). Some air cleaners (with special filters) can oxidize and degrade contaminants into harmless components.

Typical air cleaner consists of a fan and a filter set (sometimes air cleaner include several types of filters for better cleaning of air) collected in a single equipment.

Nowadays the following filters are used in air cleaners:

- Mechanical filters
- Electrostatic (ionizing) filters
- Coal (adsorption) filters
- HEPA filters (filters for better mechanical cleaning)
- Photocatalytic filter

3.1.1 Mechanical filters

This type of filters is the most common used in air cleaners. Mechanical filters arrest large particles of dust, fabric fibers and animal dander. They consist of the usual fine grid used as a pre-filter. Such filters are installed in almost all equipment and protect from dust, not only people but also the inside of equipment. Particles go through this grid and settle on it. But the minus of this type of filters is that it can become a source of air pollution. That is why filters should be cleaned in time. This process needed removing dust or washing./7/

3.1.2 Electrostatic filters

This type of filter arrests much smaller particles than mechanical (until 0,01 micron). The air goes through an ionization chamber. In this chamber particles become positively charged. Then air goes over two negative charged plates, on which positively charged particles are deposited.

But electrostatic filters can’t arrest molecules of gases. And on the other hand, this filter can produce ozone and nitrogen oxides in the process. The reason of generation of ozone is voltage of several thousand volts used in the ionization chamber. Such filters cannot completely clean the air from dust particles./7/

3.1.3 Coal filters

The main purpose of coal filters it is adsorption of gas molecules. Coal filters are good deleting organic compounds. This type of filter destroys odors and harmful gas impurities: tobacco smoke, carbon monoxide, nitrogen oxides and sulfur, phenol, formaldehyde and esters (which we feel like unpleasant odors). The operating principle is based on absorption on activated carbon. The amount of filter media is one of the most important determinants of efficiency. The more micro pores contained in the filter, the more gas and odor can be arrest and the longer the time of the work of filter. That coal filters should be equipped also with mechanical filters.

Carbon filters should be replaced by new one, according to pollution. Positive characteristic of this filter is that it captures almost all the toxic impurity with a molecular weight of more than 40 atomic and good capture of dust. But if filters are not changed in time air cleaners become a source of harmful substances./7/

3.1.4 HEPA filters

This type of filters is the main filter element in many air cleaners. The principle of the HEPA filter is simple: air goes through the filter element and becomes free from dust particles. These filters are made of special porous material based on glass fiber. They capture dust and odors. Filters manufactured according to new HEPA technology and arrest more than 99% of all particles less than 0.3 microns. Most allergens (pollen, fungal spores, animal dander, dust mite allergens) are more than 1 micron, so this type of filters is recommended for people with allergic or respiration disease. But the disadvantages of these filters are high cost and inability of regeneration./7/

3.1.5 Photocatalytic filters

Filters of this type are nowadays new in the field of air cleaning and one of the best. This type of filters in contrast with other filters does not arrest pollutants. Photocatalytic filters fully destroy them. The method of air purification is the decomposition and oxidation of toxic contaminants under ultraviolet light. The size of particles is less than 0,001 micron. In this case, filters are not contaminated and cannot cause air pollution as other filters. This type of filters makes the air almost sterile. But it is not necessary if you don't have asthma or allergies. The immunity of the healthy humans may reduce because of sterile air. At the moment this type of cleaners is under investigation./7/

3.2 Comparison of household air cleaners

The main characteristics of air cleaners:

Efficiency of cleaning by filters depends on quality of air which required. It is depends on the problems which you are trying to solve. When we deal with allergic, the problem is more serious and the air must be cleaner. People without or with light forms of allergy can feel comfortable when using air cleaner with one type of filtration, while for another person with more serious allergy, such air cleaning system seems quite inefficient. The most high-quality filtering produce air cleaners which have HEPA filter or a photocatalytic filter. These air purifiers are recommended for asthmatics and allergy sufferers.

Air flow rate of air cleaner and the size of the room is an important factor in choosing the air cleaner. Recommended to selection of the air cleaner air flow rate (m^3 / h) so that the air cleaner at one hour could pass through itself all volume of air in the room at a maximum speed three times.

Sound level – the air cleaner must work all the time while the person is in the room. Especially at night, noise of air cleaner becomes one of the main factors influencing on the choice of model. Noise of use depends on filter area and working of the fan. The more filter area, the less device noise.

In the following paragraphs there are three models of air cleaners from different manufacture. They are compared according to efficiency of cleaning, air flow rate and sound level characteristics and also such characteristics as power demand and working room area. These air cleaners were selected with similar air flow rate (130-150 m^3/h). All this information was taken from the technical specifications of the each model of air cleaners.

3.2.1 Bionaire BAP830

Bionaire promises that their aie cleaners effective for preventing many diseases. Bionaire air purifiers can be used in homes and offices. This type of air cleaners effectively removes 99% of airborne particles because of HEPA filter. HEPA filter can remove 99% of airbone particles with size more than 0.3 microns (pollen, dust, etc.). Bionaire BAP830 is equipped with a filter status indicator. The lamp is switched on if it is time to replace filter. Air cleaner operates with low noise level. Bionaire air cleaners have an additional independent ionizer - which means you can turn off or turn on the ionizer. /8/ Main elements are shown in the figure 1 below.

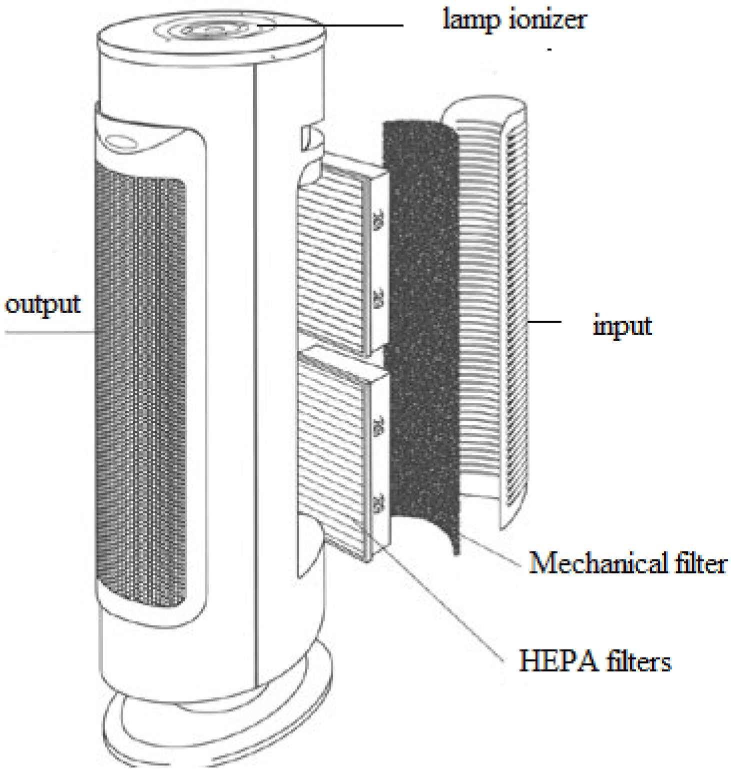

Figure1. Bionaire BAP830 air cleaner. /8/

3.2.2 Boneco P2261

The Swiss manufacturer “Plaston” has developed a model Boneco P2261 (figure 2). This air cleaner combines high efficiency, functionality and traditional European quality. System of filtering elements includes pre-filter, filter class «HEPA» and coal filter. Passing through coal filter air is completely purified of bacteria. Air cleaner Boneco P2261 is economical, silent and has three levels of power. It can be used both in homes or offices. /9/

The principle of operation is following: after mechanical filters air is supplied to allergies HEPA filter. Air is cleaned from dust, pollen, pet dander, dust mites and other micro particles. Cleaned air goes to the coal filter, which reduce the gaseous substance, including tobacco smoke and unpleasant odors. One of the functions of Boneco P2261 is air ionization. /9/

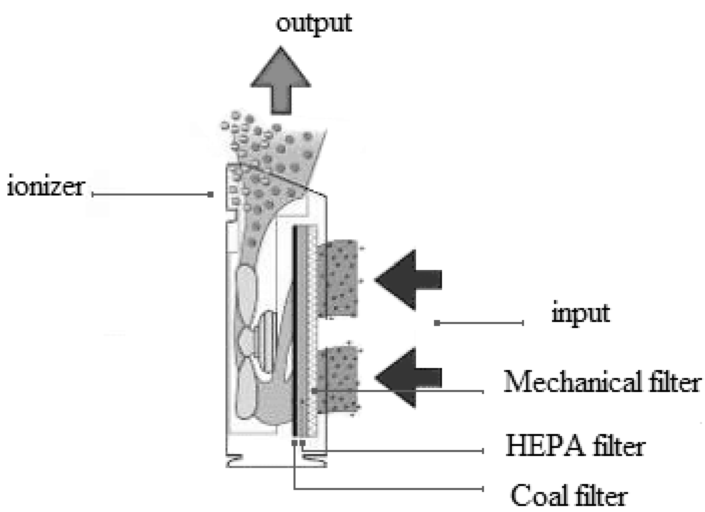

Figure2. Boneco P2261 air cleaner. /9/

3.2.3 Ballu AP250

The Chinese company Ballu industrial group has developed a model Ballu AP250 (figure3) which is efficient air cleaner with five air-filter system (HEPA filter, coal filterphotocatalytic filter, ultraviolet lamps and ionizer). The air is purified and so prevented the risk of respiratory diseases. The air cleaner is often installed in bedrooms, children rooms and offices. Air goes through 5 degrees of purification and is achieved high efficiency. As a result, micro organisms are killed; the dust is arrested, pollens and other allergens, tobacco smoke and other odors are removed. The air cleaner has three modes of power and operates with low noise level./10/

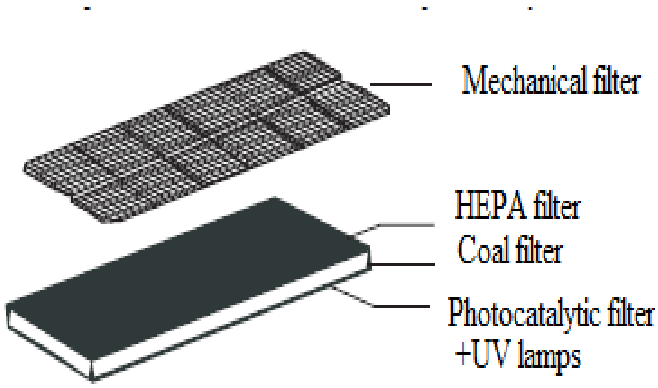

Figure3. Ballu AP250 air cleaner./11/

3.2.4 Comparison

In the table1 characteristics of three air cleaners are shown. In the comparison of this three types we can see that at almost similar performance power of “Boneco P2261” is 150W. It is more than in other air cleaners. And it is meaning that energy consumption of “Boneco P2261” is more than in another two types. Sound level 25 dB is low and this device is working quietly. Quality of air purification is good because there are tree filters inside. Pre filter arrest large particles and protects next Hepa filter.

Table1. Comparisons of characteristics Bionaire BAP830, Boneco P2261 and Ballu AP250 air cleaners.

Characteristics/models	Bionaire BAP830	Boneco P2261	Ballu AP250
Air flow rate, m^3/h	153	130	150
Power, W	70	150	45
Room space m^2	32	Up to 60	Up to40
Room volume m^3	96	150	120
Sound level dB	30	25	low
Filters	Mechanical filter HEPA filters Ionizer	Mechanical filter HEPA filter Coal filter Ionizer	Mechanical filter HEPA filter Coal filter Photocatalytic filter + UV lamps Ionizer

Hepa filter arrests small particles. It is the main element of air cleaner. The last step is a coal filter. It removes gas molecules and organic compounds. Also “Boneco P2261” air cleaners have large effective area. So, we can see that "Boneco P2261" has satisfactory parameters and just one minus is high power demand.

"Bionaire BAP830" has bigger performance 153 m^3/h and smaller power 70 W. Noise level is also low 30 dB. There are two filters. Pre filter which arrest large particles and Hepa filter for small particles. Negative properties of this air cleaner is that there no filters for removing gases and odors. But in some case it is not necessary. And effective area is small too.

Third air cleaner is Ballu AP250. This air cleaner has the best parameters because the small power demand 45W and performance is 150 m^3/h. Noise level is not written in the technical data but it is said that "Ballu AP250" works at low sound level. There are five steps of cleaning. Hepa filter arrests all particles, coal filter remove all gases and photocatalytic filter with ultrafiolet lamps make air absolutly sterile. Also this type of air cleaners have large effective area.

The conclusion is that all air cleaners have good parameters. Ballu AP250 seems to be the best. It is because this air cleaner has low noise level, low energy consumption, high performance and high quality of air purification. All air cleaners have Ionizer function. It is saturated the space of room with negative oxygen ions. The air with ions effect on the body and even has antibacterial action. Microorganisms, viruses and fungi are died in negative ionizing air.

Household air purifiers are used to remove harmful impurities such as dust, smoke, gas emissions from building materials, dust mites, pollen, etc. But the main pollution source of air can be outdoor source. And we cannot say that even the best and most expensive equipment can delete carbon dioxide or saturate the air with oxygen. Only air handling system can perform those functions. In the air handling system air goes through filters and system prevents entry of particles and gases in the room. So both air handling system and air cleaners are necessary to prevent air pollution in the buildings. That is why in my thesis work I am going to pay more attention to air cleaning equipment in the system of ventilation.

3.3 Duct air cleaners (air cleaners in air handling system)

The quality of outdoor air it is one of the factors which affect indoor air quality.But according to the fact that outdoor air have pollutions the quality of indoor air is linked with ventilation. Ventilation air is supplied in to the building throught air handling system. It is a part of engeneering systems of the building. These systems provide intake, cleaning and delivery of oudoor air to the premises.

If you find that the outside air or circulating air is polluted, the recommended control measures are filtration and purification. In ventilation systems some forms of air filters for removing the amount of particles from the air are used. The most effective method for removing particles from the air is the use of electrostatic and mechanical filters. Nowadays, they are the most effective, because of size of removing particles.

The reasons of using this kind of air cleaners are: the protection of ventilation system from dust particles and other impurities; the protection of rooms from the contamination; the maintenance of the necessary parameters the air in according with requirements of clean air (medical operational, etc.); the protection of human health.

According to ASHRAE handbook, duct air cleaners are divided to the following groups:

- Fibrous media unit filters
- Renewable media filters
- Electronic air cleaners

3.3.1 Fibrous media unit filters (Panel filters)

There are two types of filters in Fibrous media unit filters category:

- Viscous Impingement filters
- Dry - type extended surface filters

Viscous Impingement filters.

This is a filter which is made of the porous fibers. Filter media is coated by adhesive. Adhesive is arresting particles which go through this media. The property named this type of filters « viscous ».

Consider the air flow with particles before filter. The particles move with flow, and because of the mass and inertia try to continue moving. But it collides with the filter media and separates from the air flow. Molecular force is not enough for adherence particles to media. The adhesive is used to avoid the return of particles to flow. This method is applied for heavy particles which have large inertias. /12, p 10.6/

"A number of different materials have been used as the filter medium, including coarse (15 or 60 microns diameter) glass filter, animal, hair, vegetable fibers, synthetic fibers, metallic wools, expanded metals and foils, crimped screens, random matted wire and synthetic open-cell foams". /12, p 10.6/

To ensure maximum efficiency, speed should be from 1,5 to 3 m/s to decrease implement with viscous media. Speed depends on the concentration of particles and types of filter. For indication the time when filter needs service, pressure drop should be measured by draft gauges and manometers. This type of filters can be removable or permanent. Removable filters are made of not expensive materials such as combination of metal stiffeners and cardboard. Permanent filters are usually made from robust metal.
Cleaning of these filters can be recommended by design. But usually it is used steam or water washing. After it the filter should be inflicted by the amount of adhesive using spraying or dipping. Except arresting particles, adhesive performs following functions:

"A low percentage of volatiles to prevent excessive evaporation; 2 A viscosity that varies only slightly within service temperature range; 3 The ability to inhibit growth of bacteria and mold spores; 4 A high capillarity or the ability to wet and retain the dust particles; 5 A high flash point and fire point; and 6 freedom from odor". /12, p 10.6/

Viscous impingement filters have low cost, low pressure drop and high efficiency. These types of filters are designed to remove dust particles in the size range about 3 to 30 microns.

Dry-type extended surface filters

Media of dry air filters is fiber. They are made up from synthetics (polyester fiber), cellulose fiber, glass fiber, asbestos, wool felt and other materials. The fibers are randomly intertwined in different directions. Media is easy to handle, high strength and durability.

The media of dry-type filters looks like pockets form or V-shaped pleats. This form is usually supported by the wire frame. But design can be various. Media of dry-type filters provide a high relation between area of medium and area through the filter. And because of this pressure drop is normal.

Resistance of this kind of filters depends on media and design form of filters. The air velocity before filter and the air velocity through the filter are different. It is because of area of filter media is much more than face area. The access velocities are 3 - 8 m/s and the velocity through the filters media is from 0,03 to 0,46 m/s. /12, p 10.6-10.7./

Dry type air filters are more efficiency than Panel filters. It is because of variety of media which is available to achieve desired degree of cleaning. Another option of the dry extended surface media is HEPA filter (High Efficiency Particle Air). When the dust velocity inside it is near 1,3 m/s, this type of filter can work.

3.3.1.1 Classification of dry-type extended surface filters in Europe and in Russia.

Classification of air cleaners in Europe and in Russia is similar. Air filters are used for cleaning incoming air, and in some cases for cleaning emissions from air pollution (exhaust). In Europe there are standards: EN 779-93 “Particulate air filters for general ventilation. Requirements, testing, marking” and EN 1822-98 "High efficiency particulate air filters (HEPA and ULPA)". Russian standard (GOST P 51251-99 “Air

cleaning filters. Classification. Marking") was based on these European standards. Those standards make the classification of these filters. They are divided on classes according to efficiency of passage through the filter media: fine filters classes (from F5 to F9) and coarse filter classes (from G1 to G4). Those types of filters are used as general purpose filters. Filters for special requirement such as HEPA – High efficiency particulate air filters (H) and ULPA – Ultra low penetration air (U). Comparing the filters from this standards and ASHRAE classification, we can say that filters from EN and GOST to ASHRAE which are named Dry-type are the extended surface filters.
At the coarse filtration the arrested particle size is from 10 microns, with a fine filtering from 1 micron or upwards and in high efficiency particulate air filters - the particles up to 0.1 microns.

The efficiency of filters and the ability to arrest particles are classified according to the following test condition:

"The air flow shall be 0,944 m3/s (3 400 m3/h) if the manufacturer does not specify any rated air flow rate; 250 Pa maximum final pressure drop for Coarse (G) filters; 450 Pa maximum final pressure drop for Fine (F) filters"./13, p 11/

"600 Pa maximum final pressure drop for High efficiency particulate air filters (H and U)"/15/

There are several types of filters depending on the effectiveness of the treatment in each class of filters. According to these conditions the classification of filters is presented on the next tables:

Table2. Classification of air filters according to EN 779. /13, p12/

Class	Final pressure drop Pa	Average arrestance (Am) of synthetic dust %	Average efficiency (Em) of 0,4 μm particles %
G1	250	50 ≤ Am < 65	
G2	250	65 ≤ Am < 80	
G3	250	80 ≤ Am < 90	
G4	250	90 ≤ Am	
F5	450		40 ≤ Em < 60
F6	450		60 ≤ Em < 80
F7	450		80 ≤ Em < 90
F8	450		90 ≤ Em < 95
F9	450		95 ≤ Em
NOTE The characteristics of atmospheric dust vary widely in comparison with those of the synthetic loading dust used in the tests. Because of this the test results do not provide a basis for predicting either operational performance or life. Loss of media charge or shedding of particles or fibers can also adversely affect efficiency (see annexes A and B).			

Table3. Classification of EPA, HEPA and ULPA filters according to EN 1822-1. /14, p 8/

Class	Integral value		Local value	
	Efficiency, %		Coefficient overshoot,%	
H10	85	15	-	-
H11	95	5	-	-
H12	99,5	0,5	-	-
H13	99,95	0,05	97,75	0,25
H14	99,995	0,005	97,975	0,025
U15	99,9995	0,0005	97,9975	0,0025
U16	99,99995	0,00005	99,99975	0,00025
U17	99,999995	0,000005	99,9999	0,0001

Coarse filters

Coarse filters are used if the requirements for clean air are low for cleaning the supply air without special requirements. This type is installed in a single-stage air cleaning system or as a pre-filter in multistage systems. Using coarse filters as first stage helps to solve one more problem. Because of the fact this type is usually set on the air intake, filter protects devices of system from contamination. Filters material is consist of a metallic grid or synthetic fibers. In this class Panel filters, Pocket type filters or Pleated filters are used.

Fine filters

These filters are used as a secondary treatment and at general purpose remove high concentration of dust. These filters must perform stricter requirements for cleaning air and are installed to areas with more high requirements (offices, museums). To increase using time of fine filters they are used as second stage after coarse filters. Filters material is a fiberglass and activated charcoal.

High efficiency particulate air filters.

HEPA and ULPA filters are intended for final cleaning. They are used for areas where are the strictest requirements for clean air (hospitals, laboratories) and places where is needed complete removal of bacteria and dust. These filters are installed as the third purification stage. High efficiency particulate air filters are set directly before supply air device to the room. Filters materials are bonded fiberglass or paper.

3.3.2 Renewable material filters

Moving Curtain Viscous Impingement Filters

There are two types. In the first case the filter material is packed in a roll form. Fresh and dirty material is changed the following way: while dirty part of the filter is removed automatically, fresh one is served. On the bottom there is a roll which moves this dirty material and after it is thrown away. The roller works automatically and depends on a pressure switch control or timer. The pressure control defines pressure through the media and according to these measurements switches on or switches off the roller. The service of this type includes utilization of the dirty roll and involving clean roll at the top. The cover of this media is the same as in viscous impingement filters. The accumulated dirt should be deleted from adhesive reservoir. It can be done by scraping. The operating period of this type of filter is made by time control. /12, p 10.7-10.8/

Figure 4. The renewable material filter. /16/

Moving Curtain dry-media filters

The media of this type of filters are as on previous dry-media filters made from random fiber and also like in moving-curtain viscous filters are presented from a roll. /12, p 10.8/

3.3.3 Electronic air filters

Electrostatic air cleaners are collecting particles by principles of electrostatic precipitation. These air filters are mainly used in industrial plants. There are three types of work at low voltage

- Ionizing plate-type Electronic air cleaners
- Charged Media No ionizing Electronic air cleaners
- Charged Media Ionizing Electronic air cleaners

Ionizing plate-type Electronic air cleaners

Operation of this type is basing on charged particles. Air flow goes through the ionizer wire with high potential voltage. It gives particles positive ions. After this flow streams through to the opposite locating charged plates and particles are caught by them. These plates are coated with adhesive or air. If there are prefilters or afterfilters in this type, resistance of air flow is higher. Sometimes it is used for uniform distribution. For this purpose perforated plates are also used. This type of filter works with low pressure drops and removes particles of dust and tobacco smoke. For better operation suitable screens are set before cleaner. They protect filters from shits of paper, insects and pollutions like this.

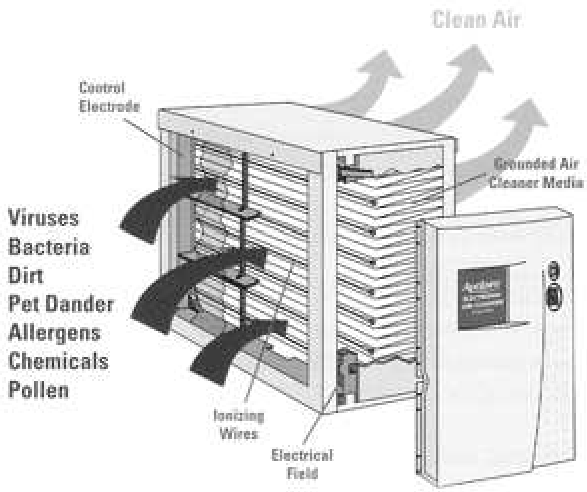

Figure 5. The electronic air filters. /17/

“The efficiency of electronic air cleaner is sensitive to air velocity, and the device itself has much less tendencies to rectify air steam velocity differences than do filters which have higher resistances”. /12, p 10.8,10.9/

Charged Media Nonionizing Electronic air cleaners

This type of air cleaners includes both: dry type filters characteristics and electronic air cleaner characteristics. The material looks like in dry-type: intertwined fiber, in pleats form. Material is glass fiber, cellulose fiber or another similar material. This media is dielectric and it makes nonuniform and intense electrostatic field. Particles go through this media, polarize and stay in it. But charged media can be a cause of air flow resistance, because of dust amount. It is one of the problems with this type of cleaners: changing the filter media. The other problem is that dielectric media does not work well when humidity more than 70%. /12, p 10.8-10.9/

Charged Media Ionizing Electronic air cleaners

As in two previous types of filters dust accumulates on the filter media charged on a corona-discharge ionizer before. Ionizer makes this filter more efficient but this type should be designed carefully.

3.3.4 Comparison of dry-type extended surface filters.

As was written before according to standards EN 779-93, EN 1822-98 and GOST 51251-99, dry-type extended surface filters are divided on coarse, fine, HEPA and ULPA filters.

In this section of my thesis there is a comparison of coarse bag filters of three common manufacturers: “General filter”, “Jack filter” and “Halton filter”. The aim is to identify the most effective filter. From the value of efficiency would follow ease of operation, good dimensions, low pressure drop and high efficiency.

General filter

Activities of Italian company General Filter Company have placed in the production and sale of components, systems and accessories for filtration in industrial, civil and hospital building. This company operates in various markets, as in Italy and abroad./18/

Jack filter

Company Jack is a leading manufacturer of filters for air-conditioning equipment. Company produces the highest quality products at a reasonable price, the products of this company has a good ratio price / performance. Most filters are made specifically to the needs of customers. This company is operated in many countries but the main offices are in Austria and Hungary. /19/

Halton filter

Halton Company specializes in the indoor climate and production of goods, services and solutions. Halton is goal is to create a comfortable and safe rooms.

This company solves the problems of public, commercial and industrial buildings, kitchens and restaurants. Halton is operating in 23 countries. The maine part of the company are in Finland, USA and Malaysia. /20/

In table 4 was shown technical and functional characteristics of three coarse bag filters. In this section a comparison of these parameters is concluded – to find out the most effective filter.

Table4. Comparison of technical and functional data General filter ABA 40, Jack Inofil Basic filter and Halton mesh filter coarse bag filters.

Technical and functional data	General filter ABA 40	Jack Inofil Basic filter	Halton coarse mesh filter
Nominal air flow m^3/h	2880	2850	2880
Filtretion surface m^2	1,78	1,9	-
Max working Temperature ℃	90	100	75
Max working humidity resistance	90%	100%	100%
Initial efficiency	90%	High economic efficiency	85%
Final pressure drop Pa	250	250	-
Dimensions mm	287×592×500	300×592×490	standard-sized+ manufacture filter with needed dimensions
Material	Polyester	Polyester	Polyester

Air filters made by “Jack filter” can work with high working temperature 100℃ and high working humidity resistance 100%. This type of filter have the same pressure drop but bigger filtration surfaise 1,9 m^2.This is paramets worse than filter made by ”Halton filter” because hence velosity is lower. The dimensions are almost the same as another coarse bag filters. Efficiency is not written in the technical data, but is said to be high and economic.

Filters made by “General filter” have smaller working temperature 90℃ and smaller working humidity resistance 90%. Filtration surfase of this type is 1,78 m^2 it is less than in the previous filter but the pressure drop is the same and it is plus of this. Effisiency is 90%. Dimensionse about the same.

Filter made by ”Halton filter” have smaller working tempereture 75℃ and high maximal working humidity resistance 100%. Effitiency of this type is 85%. It is less than others. Dimentionis are not written in the thachnical data because the manufacturer produces it with customer requirements. Filtration surface is not written too.

Material of all this filters is polyester. In conclusion we can say that all coarse bag filters of these manufactures have good parameters and they are approximately the same. Hence choosing depends from requirements of the customer.

4 EXPERIMENT

In this section of the thesis experiment will be described. This experiment was conducted in the air conditioning laboratory in campus A of Mikkeli University of Applied Sciences . The subject of the experiment was to study cleaning possibilities of duct Dry-type extended surface filters which are related to a Fibrous media unit type of filters and are according to EN standard named fine filters. There were two filters: one absolutely new, the other has worked for some time (little dirty). Later it will be named just “dirty” in the text. The purpose of the experiment is to establish the effectiveness of filters. In other words, which amount of existing content of contaminated particles in the air the filter can arrest? The experiment is divided into two parts: in the first part filter cleaned air flow which wasn’t additionally contaminated. In the second part we had an additional source of pollution – matches smoke. The smoke increased the initial number of contaminated particles in the air.

Figure 6. The new dry-type extended surface filter.

Number of contaminated particles was determined by AEROTRAK Handheld Optical Particle Counter (TSI model 8222). The device determined number of particles in one cubic meter of existing air and the values of number were given for six size categories: 0,3 μm and 0,5, 1,0, 3,0, 5,0, 10,0 μm.

4.1 The first part of experiment.

The cleaning possibility of filters was determined in the first part of the experiment when existing air doesn't have any additional source of pollution. Initially was measured the content of contaminated particles related to the six size categories (0,3 μm and 0,5, 1,0, 3,0, 5,0, 10,0 μm). Then was determined their content in the air flow after clean new filter. After all that the clean filter was replaced and the dirty filter's installed. Again, the number of particles was measured after the filter. The values of content of contaminated particles in the existing air before filter were measurement at the same time.

The Particle Counter is designed with new technologies and allows not only to measure easily, but provides facilities to get results of measurement also easily. The values obtained using the device can be translated into table form of Excel-program. All tables with the values obtained during the experiment are presented in Appendix 1 in the end of the thesis. On the basis of the measured values the following figures were created. They are visually reflecting the content of particles of various sizes before and after cleaning of the air flow in the filter.

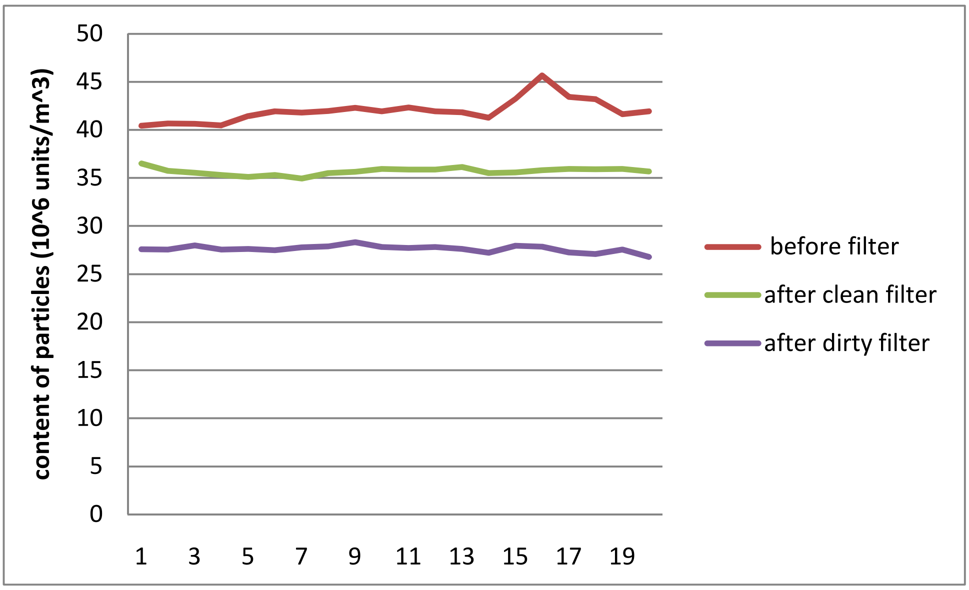

Figure 7. Extraction capability of filters. Particles sizes 0,3 µm.

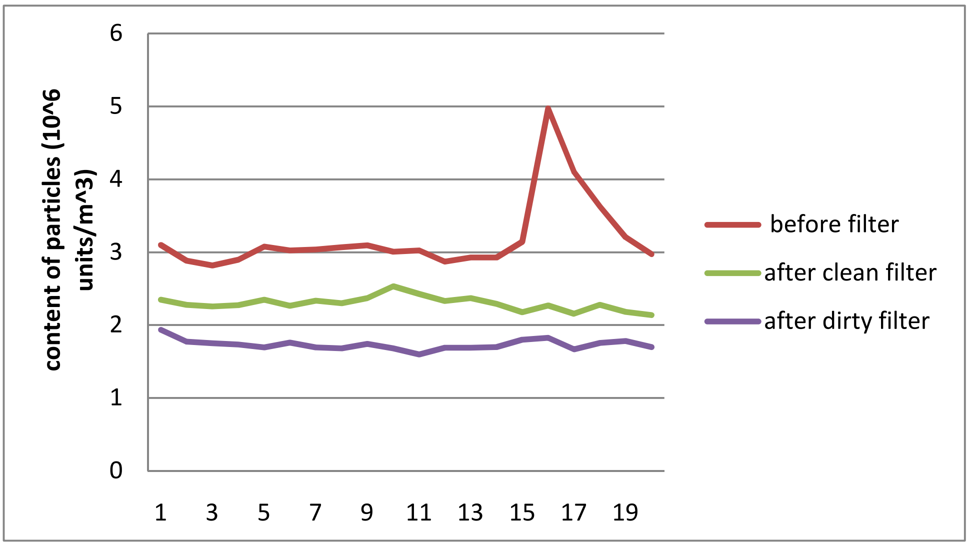

Figure 8. Extraction capability of filters. Particles sizes 0,5 µm.

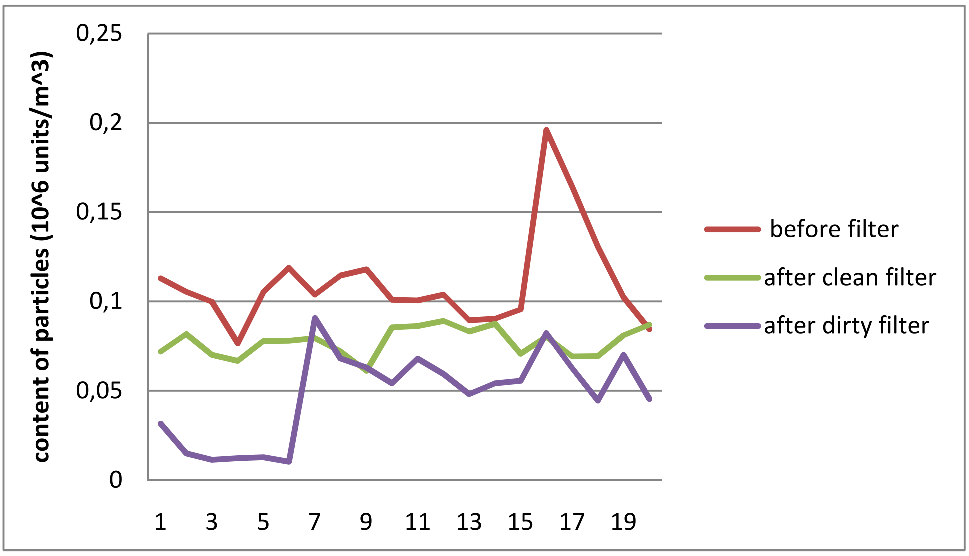

Figure 9. Extraction capability of filters. Particles sizes 1,0 µm.

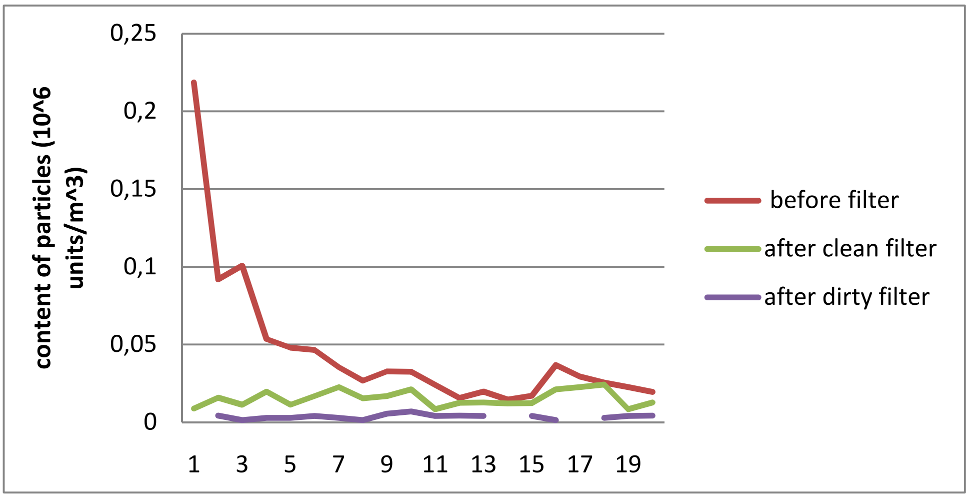

Figure 10. Extraction capability of filters. Particles sizes 3,0 µm.

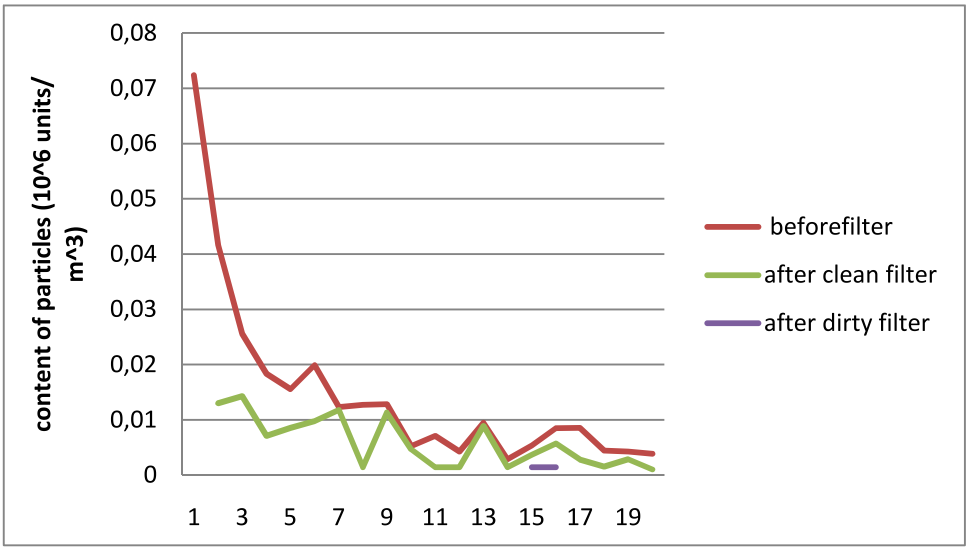

Figure 11. Extraction capability of filters. Particles sizes 5,0 µm.

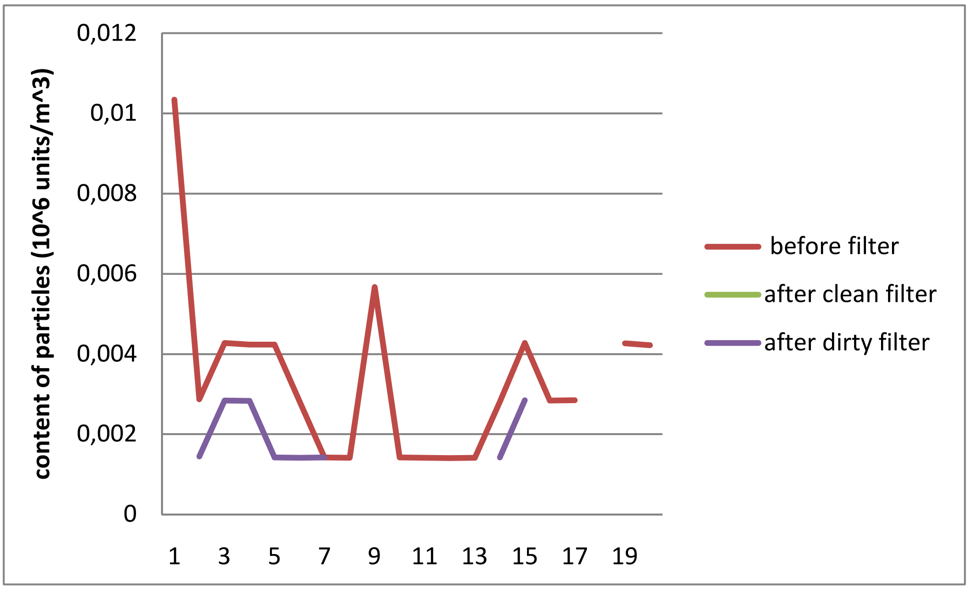

Figure 12. Extraction capability of filters. Particles sizes 10,0 µm.

The content of contaminated particles of any of the six categories has the biggest values before the filter, in the other words before cleaning. Therefore, the curve of the values in the figures is locating above the others. Further, in all six figures it can be seen that the curve of values of particle contents after cleaning on dirty filter is lower than a similar curve for the clean filter. So, when air flows through the dirty filter the values of particle contents are much lower. In other words, a dirty filter has a higher cleaning efficiency compared with a new one. This can be explained as follows. Particles, which were detained during the passage of air flow, began to accumulate in the filter during the process of the filter usage. Therefore, the sizes of holes begin to decrease, which creates additional resistance to the passage of contaminated particles. This circumstance improves the effectiveness of the filter. But when the particles stuck in the filter, load will become too much. They will begin to detach from the filter, getting into the flow of treated air. This increases the contaminated particle content in the air flow after the filter. This means that the filter should have been replaced.

4.2 The second part of experiment (with additional source of pollution - smoke)

In the second part of the experience the existing air has been further polluted with smoking. This consequently increased the content of particles of all sizes in the air. Experiments were carried out in the same way as previously. In the beginning, the content of particles before the filter was measured, then after passing through a new filter. After that, the new filter has been replaced by a dirty filter and the content of particles passed the dirty filter was measured. The obtained values are also presented in Appendix 1 in table form. Figures, built on the basis of these values, are listed below.

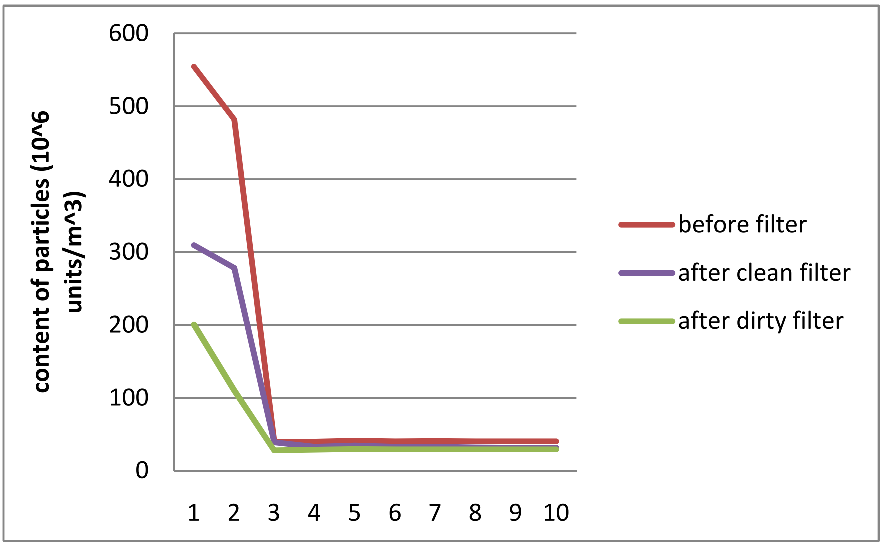

Figure 13. Extraction capability of filters. Particles sizes 0,3 µm.

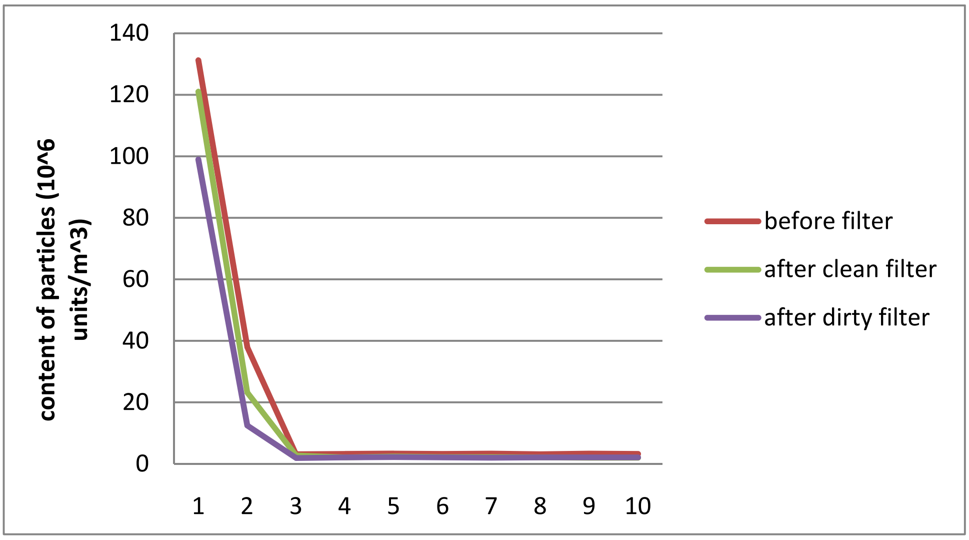

Figure 14. Extraction capability of filters. Particles sizes 0,5 µm.

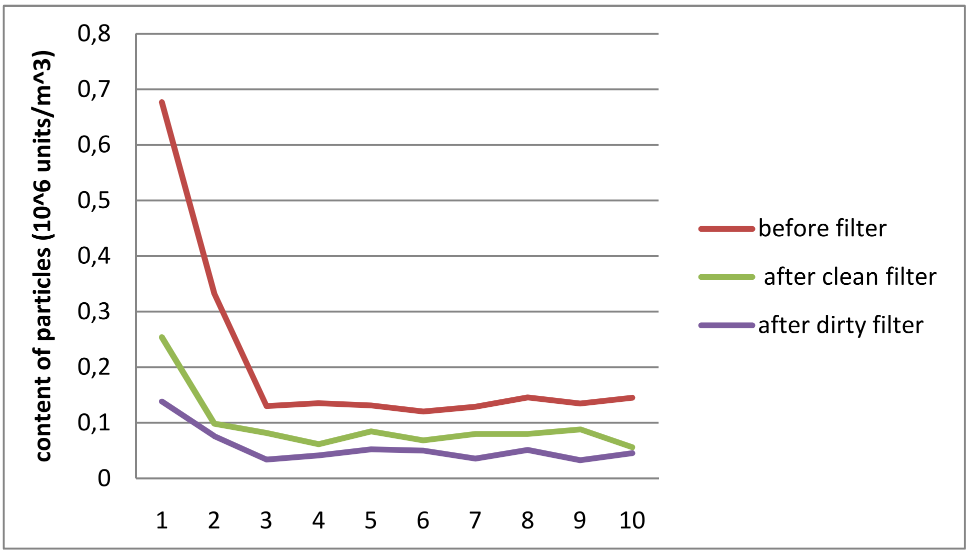

Figure 15. Extraction capability of filters. Particles sizes 1,0 µm.

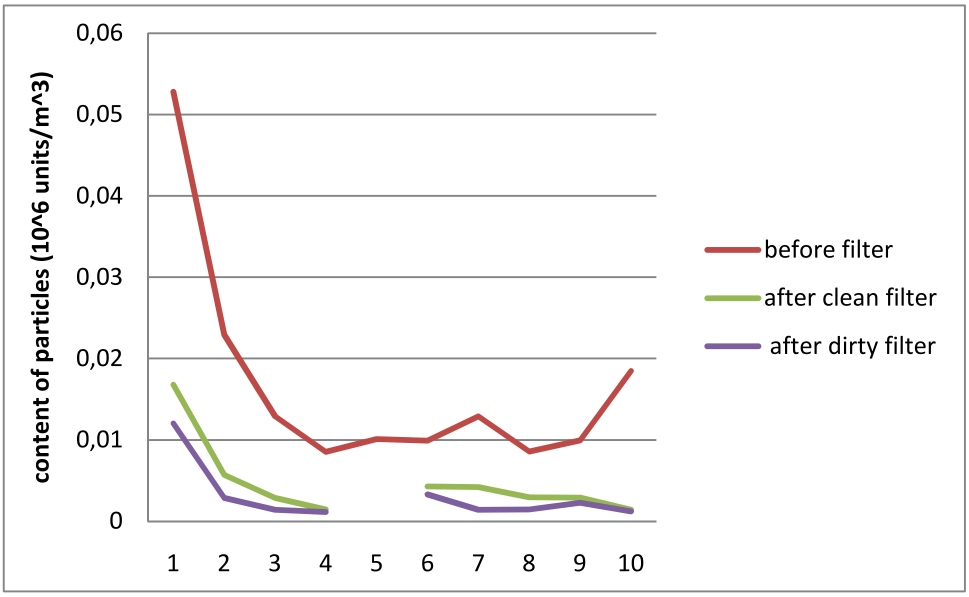

Figure 16. Extraction capability of filters. Particles sizes 3,0 µm.

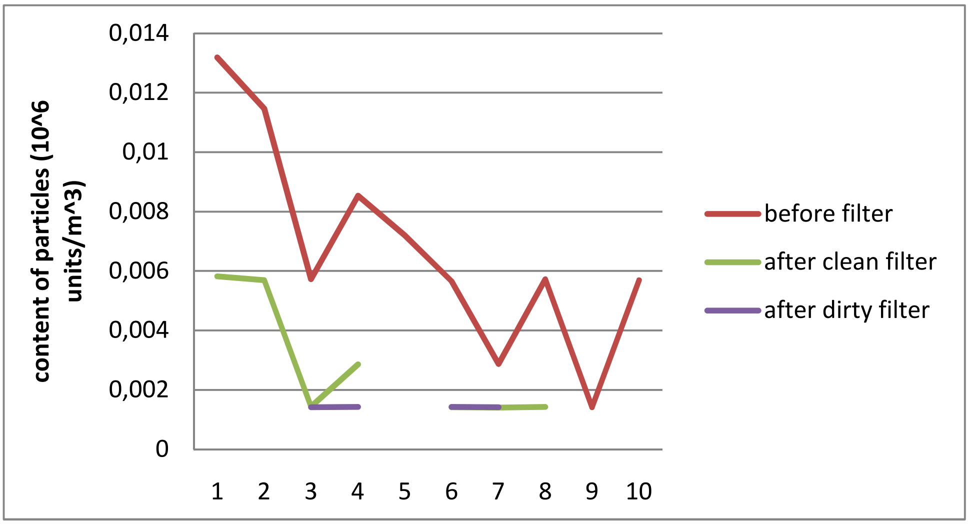

Figure 17. Extraction capability of filters. Particles sizes 5,0 µm.

As a result of the second part of the experiment, when the air had an additional source of pollution - smoke, we obtained results similar as in the first part. The cleaning efficiency of the dirty filter is better than the new one. This can be explained by an additional resistance of particles linked to the loading, which the contaminated particles passing through the filter.

5 CONCLUSION

In indoor air there are lots of different pollutants which make air dirty. But the air, should be clean, because of avoid the risk for human disease. As it was written in my thesis there are three main methods to make air clearer: The best way to prevent this problem is to control of sources of pollutants. The second method is pre cleaning. It is using duct air cleaners which are set in ventilation system. This method is used, when we have outdoor sources of air pollutants. But sometimes this method is not enough or there are some internal sources of impurities in the room and in that case we have to clean the air by using household air cleaners. Household air cleaners, in contrast to dust air cleaners in ventilation system, are operating in separately in single spaces. This method removes impurities from indoor air. Especially household air cleaners are useful for people with allergies or children.

Besides the description of air pollutants and air cleaners there is the comparison of duct air cleaners in my thesis. Then according to results of comparison conclusion was made. On the grounds of this comparison the best household air cleaner is Ballu AP250. The best coarse bag filter manufactures was not defined, because technical characteristics of these filters are almost similar and choice of needed cleaner depends on preferences of customer.

At the end of my thesis an experiment is described. The experiment was made with duct dry-type extended surface filters and a devise for measurement of particles AEROTRAK Handheld Optical Particle Counter (TSI model 8222). As a conclusion of this experiment it can be written, that filters really make the air cleaner. In our case little dirty filter arrest more particles, because an additional resistance of particles. But too dirty filter can be also a reason of an additional amount of air pollutants.

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Appendix 1.

Table 1. Content of particles with size 0,3 µm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)				Part 2 of experiment (with smoke - source of pollutant)			
Number of measurment	Before filter	After clean filter	After dirty filter	Number of measurement	Before filter	After clean filter	After dirty filter
	10^6 units/m^3	10^6 units/m^3	10^6 units/m^3		10^6 units/m^3	10^6 units/m^3	10^6 units/m^3
1	40,44576	36,49628	27,577412	1	554,502272	309,283328	200,560576
2	40,67764	35,7462	27,538944	2	482,241808	278,2184	109,957088
3	40,642076	35,536092	27,983474	3	39,684272	39,005492	27,86033
4	40,478804	35,324556	27,55715	4	39,981136	32,983704	28,891546
5	41,428596	35,101628	27,632262	5	41,218224	34,560716	29,67963
6	41,931076	35,295956	27,497108	6	40,473236	32,963406	29,10329
7	41,79052	34,957824	27,792354	7	40,728644	32,802136	29,254768
8	41,96786	35,51074	27,873016	8	40,288248	31,731222	29,434106
9	42,298084	35,656076	28,311966	9	40,431272	31,547708	29,208406
10	41,947356	35,949768	27,811436	10	40,14804	31,704722	29,30542
11	42,341684	35,8899	27,723788				
12	41,927736	35,861988	27,830804				
13	41,818036	36,129528	27,612732				
14	41,277468	35,493592	27,206				
15	43,231288	35,577372	27,965362				
16	45,657848	35,808384	27,851008				
17	43,415712	35,943436	27,262912				
18	43,201296	35,914264	27,077422				
19	41,646492	35,9317	27,55984				
20	41,925496	35,681972	26,801926				

Table 2. Content of particles with size 0,5 μm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)				Part 2 of experiment (with smoke - source of pollutant)			
Number of measur-ment	Before filter	After clean filter	After dirty filter	Number of measur-ment	Before filter	After clean filter	After dirty filter
1	3,097898	2,347748	1,937305	1	131,220064	120,976584	98,986824
2	2,883292	2,276736	1,77439	2	37,941578	23,167208	12,474586
3	2,818526	2,255081	1,752781	3	3,205884	2,71569	1,92444
4	2,897105	2,273699	1,734761	4	3,328087	2,175268	2,093176
5	3,078624	2,348218	1,694537	5	3,338202	2,437787	2,226501
6	3,022327	2,262579	1,76142	6	3,275912	2,253774	2,150982
7	3,037089	2,335158	1,693359	7	3,340623	2,189244	2,068619
8	3,066235	2,299662	1,678688	8	3,150468	2,183531	2,163043
9	3,092906	2,370727	1,744054	9	3,394331	2,00149	2,088345
10	3,005272	2,530369	1,681363	10	3,302779	2,074793	2,17522
11	3,024203	2,426653	1,599095				
12	2,872185	2,330713	1,689964				
13	2,927587	2,369311	1,688355				
14	2,929514	2,292321	1,696641				
15	3,142152	2,17596	1,799058				
16	4,972932	2,269354	1,825156				
17	4,101355	2,156493	1,668722				
18	3,626386	2,278834	1,756768				
19	3,202264	2,179701	1,78372				
20	2,970677	2,136934	1,696109				

Table 3. Content of particles with size 1,0 µm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)				Part 2 of experiment (with smoke - source of pollutant)			
Number of measurment	Before filter	After clean filter	After dirty filter	Number of measurment	Before filter	After clean filter	After dirty filter
1	0,112944	0,071765	0,031456	1	0,677214	0,254145	0,138341
2	0,105292	0,081642	0,014901	2	0,332516	0,09824	0,075898
3	0,099745	0,069945	0,01134	3	0,130239	0,082031	0,034111
4	0,076425	0,066623	0,012202	4	0,135114	0,061496	0,041434
5	0,10513	0,077802	0,012781	5	0,131107	0,084645	0,052205
6	0,118688	0,077922	0,010173	6	0,120333	0,068253	0,050022
7	0,103698	0,079431	0,09069	7	0,129092	0,080094	0,035518
8	0,114453	0,071952	0,067882	8	0,145868	0,080024	0,050995
9	0,117923	0,061079	0,062848	9	0,134752	0,088279	0,032697
10	0,100939	0,085512	0,054008	10	0,14502	0,055574	0,045563
11	0,100485	0,086161	0,067926				
12	0,103729	0,089026	0,059247				
13	0,089322	0,083114	0,048036				
14	0,090285	0,08746	0,054042				
15	0,095389	0,070556	0,055518				
16	0,195907	0,079977	0,082252				
17	0,164166	0,069154	0,062594				
18	0,13068	0,069269	0,044384				
19	0,102336	0,08094	0,069977				
20	0,084354	0,086786	0,045342				

Table 4. Content of particles with size 3,0 µm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)				Part 2 of experiment (with smoke - source of pollutant)			
Number of measurment	Before filter	After clean filter	After dirty filter	Number of measurment	Before filter	After clean filter	After dirty filter
1	0,218704	0,0088		1	0,052769	0,016806	0,012018
2	0,091877	0,015866	0,004295	2	0,022932	0,005695	0,002864
3	0,100767	0,011399	0,001427	3	0,01288	0,002878	0,001421
4	0,053637	0,019814	0,002835	4	0,008533	0,00143	0,001128
5	0,048011	0,011365	0,002829	5	0,010085		
6	0,04665	0,016955	0,00425	6	0,009909	0,004265	0,003287
7	0,035425	0,022728	0,002839	7	0,012909	0,004215	0,00142
8	0,02687	0,015543	0,00141	8	0,00858	0,002933	0,001439
9	0,032852	0,017017	0,005681	9	0,009929	0,002894	0,002264
10	0,032689	0,021313	0,007127	10	0,018483	0,001424	0,001205
11	0,024057	0,008483	0,004237				
12	0,015615	0,012517	0,004305				
13	0,019771	0,012779	0,004243				
14	0,014651	0,012221					
15	0,017084	0,012335	0,004233				
16	0,03691	0,021272	0,001428				
17	0,029465	0,022761					
18	0,025567	0,024339	0,002827				
19	0,022741	0,008568	0,00426				
20	0,019682	0,012752	0,004268				

Table 5. Content of particles with size 5,0 µm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)				Part 2 of experiment (with smoke - source of pollutant)			
Number of measur-ment	Before filter	After clean filter	After dirty filter	Number of measur-ment	Before filter	After clean filter	After dirty filter
1	0,072408			1	0,013192	0,005818	0,003824
2	0,041632	0,012981		2	0,011466	0,005695	
3	0,025546	0,014249	0,001427	3	0,005724	0,001439	0,001421
4	0,018349	0,007076		4	0,008533	0,00286	0,001428
5	0,015533	0,008524		5	0,007203		
6	0,019895	0,009781		6	0,005662	0,001421	0,001429
7	0,012336	0,011784	0,001419	7	0,002868	0,001405	0,00142
8	0,012728	0,001413		8	0,00572	0,001429	
9	0,012855	0,011344		9	0,001418		
10	0,005263	0,004683		10	0,005687		0,001408
11	0,007075	0,001413					
12	0,004231	0,001401					
13	0,009477	0,008885					
14	0,002844	0,001434					
15	0,005333	0,003694	0,001411				
16	0,008508	0,005678	0,001428				
17	0,008535	0,002806					
18	0,004431	0,001522					
19	0,004284	0,002842					
20	0,003833	0,001029					

Table 6. Content of particles with size 10,0 µm before and after dry-type filter (Fine filter)

Part 1 of experiment (without additional sources of pollutant)			
Number of measurment	Before filter	After clean filter	After dirty filter
1	0,010344		
2	0,002871	0,001431	0,001442
3	0,004274		0,002838
4	0,004234		0,00283
5	0,004236		0,00142
6	0,002825		0,001413
7	0,00142		0,001417
8	0,001414		
9	0,005672		
10	0,00142	0,001425	
11	0,001415		
12	0,001401		
13	0,001412		
14	0,002811		0,001422
15	0,004272		0,002847
16	0,002839		
17	0,002845		0,002806
18			
19	0,004264		
20	0,004217		