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FILTER MONITORING AND REPLACEMENT STRATEGIES

Why do we filter air in an Air Handling Unit? How are the new international ISO 16890 standards different from the old European EN 779 standard? What are some of todays filter replacment strategies and how could these be improved? These are some of the questions answered in this project, while monitoring and investigating the effects of relative humidity and pressure drop on used filters, collected by a Danish ventilation manufacturing company called, Airmaster.

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1. Table of Contents

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Introduction

This master thesis is conducted with a collaboration of Aalborg University (AAU) and Airmaster, a company that specializes in assembling and selling its own Air Handling Units, (AHU). AHU is consisted of several important components that come together to provide the desired, indoor air quality (IAQ).

The research and development department of Airmaster is working continuously to upgrade and optimise the performance of their AHU's. Airmaster not only produces their own AHU but is also involved in monitoring and servicing the AHU that is sold to their clients.

It is this unique position that allows Airmaster to obtain the first-hand knowledge and work with a chosen AHU's used components (collected by the existing clients during maintenance visits) to focus, study, improve and enhance the productivity and performance of a system, as a whole.

For this master's thesis the focus of investigation was, filter changing strategies and monitoring the used AHU filters, collected by Airmaster over several months. The reason for collecting the used filters, was to test and monitor filters under controlled environment. The aim of monitoring was to observe and propose possible filter replacement strategies, as the existing methods being used followed traditional rules of thumb.

When the project started, during the first initial meetings, one of the main aims in terms of 'experiment campaign' was to determine the best course of action to utilize the opportunity of best *monitoring used filters and recommend filter replacement strategies.*

Many options were discussed but one option brought up by Erik Bjørn, the head of Research and Development Department at Airmaster seemed to be very interested in investigating, 'the effects of relative humidity on filters. The bases of this interest was that a team at Airmaster that collects and observes data about the functionality of the sold AHU units realized occasional and 'unexplained' pressure drop peaks in the monitoring software programme. Erik suspected these 'unexplained and momentary peaks' to be a cause of high relative humidity (RH). Therefore, a decision was made to study and observe the effects of RH on filters, in an environment replicating close to real-life situations.

Problem statement

At present, AHU filter changing strategies follow certain 'rules of thumb'. How could this be improved?

Aims and objective

- To briefly analyse hazardous air-bourne contaminants, in form of micro particles (indoor and outdoor climate) to see if the contaminants are rising e.g. in Denmark or the opposite. The aim is to realize why do we use filters and what filters are supposed to filter.

- To analyse the new common American/European filter standard ISO 16890 ; to see how the new standard are different from the old EN 779 .

- Looking at the present filter changing techniques and investigating if there are any new state of the art filter changing indicators available on the market?

-One of the main objectives of this project is to *monitor* used filters collected by Airmaster and determine, if RH has a profound effect on filters. Therefore, in a climatic chamber, the used filters will be subjected to various levels of RH. The aim would be to determine, if there is a substantial weight variation in the used filters. Furthermore, in the same climatic chamber, tests would be conducted, using a custom-made test rig, to investigate the impact of different RH levels on pressure drop.

- Conducting, Vapour Sorption Analysis, at AAU, on selective used filters (dust samples taken from used filter). (VSA) is a technique in which a sample is subjected to varying conditions of humidity and temperature, and the response of the sample is measured gravimetrically: the VSA detects the sorption/desorption of water vapor by the means of the increase or decrease in mass of a given material (in this case dirt from the filter) as the RH varies.

- Cross analysis of the experiments conducted in the climatic chamber and the VSA analysis.

-Finally, proposals for further filter *monitoring* and *replacement* strategies and drafting a future experiment protocol.

Case Description

Filters play an integral part in providing the desired and healthy indoor environment and as one of the leading AHU companies in the north Jylland, Denmark, AIRMASTER took the initiative of monitoring used filters and investigating possible alternative filter replacement strategies than the traditional, 'rules of thumb' based strategies. These was done in collaboration with Alborg University.

Airmaster offer a range of decentralised ventilation units. Among some of their present AHU series is AM 150, AM 300, AM 500, AM 800, AM 900, AM 1000, etc. AM represents, the name of the company 'Airmaster', and the number represents the nominal air flow rate in m^3/h. The AHU AM 150 should be able to cater a flow rate of up to or close to $150m^3h$ and AM $300m^3h$ a flow rate of $300m^3h$ and AM 1000 a flow rate of 1000 m^3/h. Each unit can either be mounted vertically or horizontally and has its own unique size and dimensions.

Since one of the main aims of the project is to assist a process or processes that can accommodate alternative filter replacement strategies as present filter changing strategies are considered "notoriously primitive" and mostly follow "the rules of thumb": as one of the 'rules of thumb' strategies was monitoring the pressure drop to assist the filter replacement, it was only natural to speculate what else affects or might affect the pressure drop in a filter, apart from the dirt factor (cloggyness in a filter) .

In a meeting, where the head of Airmasters Research and Development Department and two supervisors from AAH were present, RH appeared to be a very appealing and a likely contributor, therefore it was decided to investigate the effects of different levels of RH on filter weight and the respective affects, on the pressure drop. For this project the AM 300-unit filter type was chosen as it is one of AIRMASTER's most selling units (which also meant that there were plenty of AM 300 AHU used filters available).

There was an additional follow up 'experiment 3', conducted on three filters (2 old filter sets and a new filter). The aim was to calculate, a filters pressure drop for a flow outside of the data points and to see the characteristics of a clogged filter (inlet and outlet) vs the new filter.

There were more than 140 filters that Airmaster collected, over a period of many months. Firstly, all the filter bags were labelled, the filter data was recorded and then shelved. The next step was to make a climatic chamber, in order to control temperature and RH. Secondly, to weigh all the filters at 10%, 40% and 90% RH, to analyse respective weight variation and pressure drop, in a custom-made test rig.

At the same time VSA experiment were done and a cross analysis was made.

Delimitations

In the initial stages of the project it was one of the aims of this thesis to conduct an experiment to determine if a clogged/used filter, filters more or less? But due to the lack of time this experiment never took place.

Another experiment that was not conducted, due to the lack of time was, to determine as to what extent does filters exposed to test dust (artificial dust) replicate the conditions of the real-life used filter? It would be considered a delimitation of the thesis, as the results from these experiments could have further added to the proposals for filter replacement strategies.

A chance to work with electro filter, due to time constraints.

Experiments adding water to clogged filters and analysing the pressure drop in the custom based test rig. The aim was to see how the system reacts (after experiment 1 and 2 an issue regarding the unexplained peaks in pressure drop that Airmaster staff witnessed remained. Therefore, following up on a hunch one filter was chosen, water was sprayed on it and the filter was placed in a test rig. Instantly the fan speed was high, and the flow rate increased. But after a while the system normalized, settling down to the chosen air flow rate.

Due to the lack of time this experiment was not repeated on more filters). But the hunch turned into a very strong suspicion that the unexplained peaks are due to rainwater. Please note, Airmaster specializes in AHU that are decentralized and avoid duct work which means that the filters are located very close to the external wall/grill. This means that the inlet filter is also placed close to the external wall and are very exposed to the weather conditions. It must also be mentioned that Airmaster is already working on a specialized grill and the main purpose of the grill is to sit just before the inlet opening on the external wall to try and deflect the rainwater).

Indoor Air Quality

According to the European Union's Public Health Department, a few indoor air pollutants come from the outside air, but most are released inside the indoor environment, for example through cleaning products, air fresheners, pesticides and in some cases fuel for cooking and heating. Emissions from construction materials and furniture are an additional common source of indoor air pollution. Micro-organisms, such as fungi that release spores, may also contaminate indoor air and can be a cause of allergies and asthma [38].

The European Union's Public Health Department states that, evaluating and managing the health risks of indoor air pollution in Europe is complex as not only the pollutants, the exposure levels and possible health effects must be considered but the differences in cultural habits, lifestyles and climate should also be taken into account [38].

Regarding indoor air quality, (IAQ) in Denmark and according to EN 15251, there are different categories to be achieved (for example 1, 2 and 3) for private buildings, offices, schools and public places like museums. See Table 1. for limit values. Please note that the limit values can vary according to BR 20 or 'Arbejdstilsynet', applicable to offices and working places.

Furthermore, attention must also be given to Volatile Organic Compounds (VOCs), while designing a healthy indoor environment. VOCs are organic chemicals that have a high vapor pressure at ordinary room temperature. High vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate and enter the surrounding air. A distinct process known as 'volatility'[20]. VOCs are numerous and in various sizes. They include both human-made and naturally occurring chemical compounds. Most scents or odours are of VOCs. To see more on VOCS please see appendix 2 and See Table 1. for limit values for buildings that have to qualify for Green Building Council Denmark, (DGNB) score for IAQ.

A special attention should also be given to a type of VOC called, formaldehyde. Formaldehyde is found in manufactured wood products used as building materials such as plywood or OSB etc. These manufactured wood products are also found in furniture like desks, beds, bookshelves, kitchen cabinets. See Table 1. for limit values if a building has to qualify for DGNB score for (IAQ).

RH is another important factor when designing a healthy indoor climate. Normally, this process is more meticulously followed in "special buildings like museums, some health care facilities, process control, paper industry" as stated in Danish Standard 15251 [37]. See Table 1 for limit values according to the Danish standard 15251.

Relative humidity in relation to indoor air quality

RH can have considerable impact on occupant's health; if it is too low or too high, is important. The "ideal" humidity conditions for humans can be considered between 40 - 60%, which also depends on indoor temperature. Nine epidemiological studies analiysed the relationship between the number of respiratory infections or absenteeism and the RH of the office, residence and school. Absenteeism due respiratory infections was found to be lower in people working or living in environments with medium versus low or high RH. The indoor size of allergenic mite and fungal populations is directly associated with the RH. According to the research, mite populations is minimized when the RH is below 50% and reach a maximum size at 80% RH. Most species of fungi cannot grow unless the relative humidity exceeds 60% [20].

Briefly, if indoor air has a low humidity or "too dry", it could affect human mucous system negatively. Moreover, having too high humidity can result in a risk of mold in the indoor environment. Furthermore, low humidity causes eye irritation, dryness of the skin and the nose, and rashes, while high humidity fosters the growth of moulds and dust mites [20]. For more on RH please see appendix 6.

Above were some of the parameters within a building. How about the air pollutants that are entering the building by the means of mechanical ventilation? In order to analyse that, the most fundamental parameters that has to be taken into account is the location of a building.

Air pollution

According to the World Health Organization (WHO), air pollution is the greatest environmental risk to human health. WHO estimates that around 7 million people die every year from exposure to fine particles in polluted air that penetrate deep into the lungs and cardiovascular system, causing diseases which includes, stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases and respiratory infections [30].

Ambient air pollution alone caused some 4.2 million deaths in 2016, while household air pollution from cooking with polluting fuels and technologies caused an estimated 3.8 million deaths in the same period [30]. Pollutants with the strongest evidence for public health concern, include particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) [22].

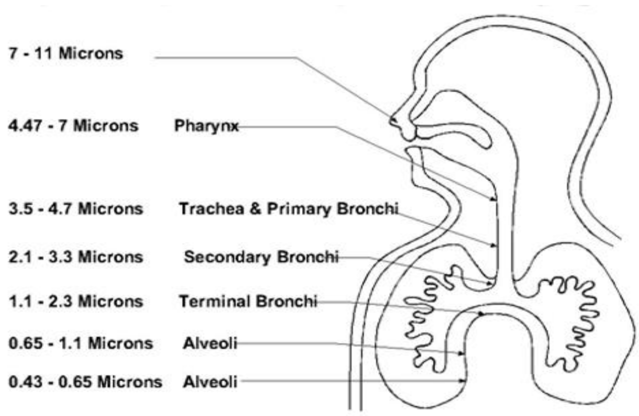


Figure 1. Micron description [2]

Description of PM_1, $PM_{2.5}$ and PM_{10}

According to the European Health Commission, (EHC) our bodies have a built-in defence system to protect against PM larger than 10 µm. In order to be protected against air pollutants below 10 µm, human body is dependent on filters: PM bigger than 10 µm, are causing visible contamination, whereas the PM smaller than 10 µm are primarily considered to be a health hazard because those particles, if inhaled, travel to the lungs which can result in serious repercussions [30][22]. The health risks associated with PM of less than 10 and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$) are especially well documented. EHC states the same concerns on its official website as WHO that PM is capable of penetrating deep into lung passageways and entering the bloodstream causing cardiovascular, cerebrovascular and respiratory impacts. In 2013, PM was classified as a major cause of lung cancer by WHO's International Agency for Research on Cancer (IARC). It is also the most widely used indicator to assess the health effects from exposure to ambient air pollution[30] [22].

More than 4300 cities in 108 countries are included in WHO's, 'ambient air quality database', making this the world's most comprehensive database on ambient air pollution. Since 2016, more than 1000 additional cities have become part of WHO's database which shows that more countries are measuring and taking action to reduce air pollution than ever before [22]. The database collects annual mean concentrations of fine PM (PM_{10} and $PM_{2.5}$). $PM_{2.5}$ includes pollutants, such as sulphate, nitrates and black carbon, which pose the greatest risks to human health. WHO air quality recommendations urge countries to reduce their air pollution to annual mean values of 20 $\mu m/m^3$ (for PM_{10}) and 10 $\mu m/m_3$ (for $PM_{2.5}$) [22]. Please view Table 2. for a more detailed guidelines regarding four common air pollutants. For air pollutants not considered in the present document the conclusions presented in the "WHO Air quality guidelines for Europe, 2nd Copenhagen,2000", remain in effect. [29]

Parameter type For Indoor climate	Range	Standards
CO_2 Category 1	350 PPM above outdoor	DS/EN 15251
CO_2 Category 2	500 PPM above outdoor	DS/EN 15251
Relative Humidity	50-30 %	DS/EN 15251
Relative Humidity	60-25 %	DS/EN 15251
Formaldehyde concentration	120 μg/m^3 max	EN 16000
TVOC concentration	3000 μg/m^3 max	EN 16000
Threshold for Particulate Matter size & air pollutants Outdoor	Guidelines set by WHO	
$PM_{2.5}$	10 μg/m^3 annual mean; 25 μg/m^3 24-hour mean	
PM_{10}	20 μg/m^3 annual mean; 50 μg/m^3 24-hour mean	
O_3 (Ozone)	100 μg/m3 8-hour mean	
NO_2 (Nitrogen dioxide)	40 μg/m^3 annual mean 200 μg/m^3 1-hour mean	
SO_2 (Sulphur dioxide)	20 μg/m^3 24-hour mean 500 μg/m^3 10-minute mean	

Table 1. Important parameters to consider for a healthy indoor environment, based on DS/EN 15251 (please note that PPM stands for parts per million). Additionally, threshold for PM_{10} and $PM_{2.5}$ & 3 most hazoudous air pollutants outdoors, according to WHO. [29]

Description of the Air pollutants

NO_2 stands for nitrogen dioxide. It primarily gets in the air from the burning of fuel. NO^2 forms from emissions from cars, trucks and buses, power plants, and off-road equipment [30].

Breathing air with a high concentration of NO^2 can irritate airways in the human respiratory system. Such exposures over short periods can instigate respiratory diseases, specially asthma, leading to respiratory symptoms (such as coughing, or difficulty in breathing). Longer exposures to concentrations of NO_2 may contribute to the causing asthma and potentially increase exposure to respiratory infections. Moreover, people already with asthma, children and the elderly are generally at greater risk for the health effects of NO_2 [30].

O_3 stands for Ozone. Because of stratospheric Ozone depletion (relating to the layer of the earth's atmosphere above the troposphere, extending to about 50 km above the earth's surface ozone) a hole is appearing in the ozone layer thus causing increased Ultraviolet (UV) radiation. On the other hand, due to tropospheric ozone formation (the troposphere is the lowest layer of Earth's atmosphere and is also where nearly all-weather conditions take place. It contains approximately 75% of the atmosphere's mass and 99% of the total mass of water vapor and aerosols) there is smog formation in cities affecting human [30].

The concentration of 160 μg/m^3 has an impact on lung function. Lung inflammation has also been recorded in a controlled chamber tests following WHO air quality guidelines, in healthy young adults undertaking intermittent exercise (high-intensive training). Studies showed health effects in children as well (based on various summer camp studies in which children were exposed to ambient ozone levels). Furthermore, estimated 3–5% increase in daily mortality [30].

At concentrations exceeding 240 µg/m^3 significant health effects are considered, moreover likely physiological and inflammatory lung effects. In healthy exercising young adults exposed for periods of 6.6 hours; studies showed significant health effects. [30]

SO_2 stands for sulphur dioxide and is a major consequence for the drop-in ph. value (in water and soil) with impact on flora and fauna (plants and animals). This has been linked to substantial reductions in health effects (e.g. childhood respiratory disease and all-age mortality). Intermediate goal is based on controlling either motor vehicle emissions, industrial emissions and/or emissions from power production [30].

Please note that the above-mentioned pollutants do not only have a profound effect on human beings and animals but also on the whole planet. Furthermore, health effects remains even if the guideline value are achieved. It should also be noted that countries might decide to adopt lower concentrations than the WHO guideline values, as their national air quality standards [30].

The European standards for selective air pollutants in air

The European Union's (EU) air quality directives set pollutant concentrations thresholds that shall not be exceeded in a given period of time [39]. In case of exceedances, authorities must develop and implement air quality management plans. These plans should aim to bring concentrations of air pollutants to levels below the limit and target values [33].

Selected EU standards and the (WHO) guidelines are summarised in Table 2. These apply over different periods of time because the observed health impacts associated with the various pollutants occur over different exposure times [33].

The WHO guideline values are set for the protection of health and are generally stricter than the comparable, politically agreed EU standards [33].

EU Air Quality Directive				WHO Guidelines	
Pollutant	Averaging Period	Objective and legal nature and concentration	Comments	Concentration	Comments
$PM_{2.5}$	Hourly			25 µg/m^3	99th percentile (3 days/year)
$PM_{2.5}$	Annual	Limit value, 25 µg/m^3		10 µg/m^3	
PM_{10}	Hourly	Limit value, 50 µg/m^3	Not to be exceeded on more than 35 days per year	50 µg/m^3	99th percentile (3 days/year)
PM_{10}	Annual	Limit value, 40 µg/m^3		20 µg/m^3	
O_3	Maximum daily 8-hour mean	Target value, 120 µg/m^3	Not to be exceeded on more than 25 days per year, averaged over three years	100 µg/m^3	
NO_2	Hourly	Limit value, 200 µg/m^3	Not to be exceeded on more than 18 times a calendar year	200 µg/m^3	
NO_2	Annual	Limit value, 40 µg/m^3		40 µg/m^3	

Table 2. Air quality threshold directive of European countries[33].

Air quality in Denmark

According to Environmental Performance Index (EPI) 2018 Denmark is in top ten (ranking at no 3) countries in the world, when it comes to countries with cleanest air, following Switzerland and France respectively [27].

The air quality is measured in Denmark by a 'monitoring programme', carried out by the DCE - Danish Centre for Environment and Energy (DCE) at Aarhus University. The primary part of this programme consists of continuous measurements at eleven monitoring stations; nine stations situated in the four largest cities (Copenhagen, Aarhus, Odense and Aalborg), two stations located in background areas and a minor station in a suburban area. [12].

The aim of the program is to monitor air pollutants relevant to human health in accordance with the EU air quality directives. The programme includes, among other measurements, measurements of 4 primary atmospheric pollutants, namely suspended particulates smaller than 10 µm in aerodynamic diameter (PM_{10}) along with, suspended particulates smaller than 2.5 µm in aerodynamic diameter ($PM_{2.5}$), Ozone (O_3), Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2). The programme also monitors a number of VOCs, which are not only injurious to human health but also contributing to the formation of Ozone [12].

The measurements and model calculations are used to evaluate the air quality in relation to limit values as well as to follow trends. Furthermore, the program serves as basis for determination of sources of the air pollutants and future projects [12].

		2012	2013	2014	2015	2016
O3	percentile 93.15	0.0	0.0	0.0	0.0	0.0
PM2.5	annual mean	0.0	0.0	0.0	0.0	0.0
NO2	annual mean	2.1	2.1	2.1	2.1	2.1
PM10	percentile 90.41	0.0	0.0	0.0	0.0	0.0

Table 3. Denmark's percentage of urban population exposed to concentrations above EU standards[33]

Table 3. shows the percentage of urban population exposed to concentrations above EU standards for selected air pollutants such as PM_{10}, $PM_{2.5}$,O_3, for the years 2012-2016 [32].

Yearly average 2016-EU limit value for air quality of NO_2 was not met. Meanwhile, all EU air quality limit values for O_3, $PM_{2.5}$, PM_{10} were met. In a detailed report for other air pollutants, including SO_2, CO, ozone, benzene, polycyclic aromatic hydrocarbons (PAHs) and heavy metals (Pb, As, CD and Ni) the EU air quality criteria are met [32]. For more on the outdoor air quality in Denmark please see appendix 1.

The conclusion that can be drawn from looking at Table 2. And Table 3. is that, in terms of tackling an overall pollution problem apart from nitrogen dioxide, Denmark is at a winning front. It must be noticed that Denmark is successful at meeting the European union's threshold guidelines and not WHO's.

Filter standards and filter types

As far as the EU guideline are concerned, Denmark is doing a good job in maintaining the limit values for PM and selective gases (apart from one, NO_2). What if a person is located in a highly polluted city like shanghai? Or, what if a certain school in Denmark wants to abide by the WHO rules regarding ambient pollution, because they are not being held in that particular area. This was realized during a project called 'Indoor Air Quality and Thermal Environment in Classrooms with Different Ventilation Systems' [45], where the during the project it was found that a school located in a Danish suburb did not meet the WHO guidelines for clean air.

That is where ventilation, filtration could be implanted (or other devices like air purifiers). In Europe a standard called EN 779 had been the most widely used method of classifying air filters for over 20 years (in the mid-2018, a new filter standard has been introduced).There are/were 17 different filter types. From G1 to F 17; higher the number the better the filtration (For details please look at appendix 5, under the section, 'Filter types and classes') [6].

On the other hand, 'American Society of Heating, Refrigerating, and Air-conditioning Engineers', (ASHRAE) was promoting the adoption of 'Standard for Minimum Efficiency Reporting Value', (MERV) both in the United States of America [USA] and Canada. These filters are rated on how small of a particle they can filter, out of the air. The numbers range is from 1 to 16, higher the number, the better the filtration. A low ranking filter is rated 1-4 MERV, and medium filter falls into the 5-13 MERV range, and high-efficiency filter will range from 13 to 16 MERV [6].

There are different types of filters to be chosen from in the market, 'Basic Filters' are among the common ones in Denmark. Basic filters are made of synthetic fibers, polyolefin fibers carrying electrical charges, fiberglass or specially impregnated cotton (For details please look at appendix 5, under the section, 'Filter types and classes') [6].

It has to be noted that the focus of this report is filters classified under the old European standard EN 779. More specifically, a filter type called 'M5'.

EN 779 the European filter standard and common *filters choosing strategies*: inlet and outlet

In Europe filters are/were available in degrees of fineness classified from 1 to 17, with the highest number filtering most; for example, the filter type F17, was a filter where even the smallest of the dirt particles are difficult to squeeze through [3].

Generally, it is recommended using the F7 filter class as inlet filters. Pollen, traffic smoke, combustion particles, bacteria are then reasonably filtered (more than 60% filtered off), while the fan, at the same time, can easily provide very fresh air to the room [3].

Moreover, it is recommend using at least F5 filter class for the extraction. This also helps to keep the equipment clean. However, if an AHU has a heat recovery system, e.g. rotary heat exchanger and the priority is to safeguard it: thus, increase its life span, ideally, the F7 (M7) filter is preferred and using the same filter class, both in supply and extraction [3].

It is recommended that the filter be replaced once a year (justified in DS13779) from a hygienic point of view. Although, it would be argued later in the report that filters should be change not only on the bases of time but also on the bases of the location of a building and the type of an AHU (centralized or decentralized). Furthermore, to keep the system balanced, the exhaust filter should be replaced at the same time as the supply air filter [3].

According to a paper, 'The Long-Term Performance of Electrically Charged Filters in a Ventilation System' [35], the efficiency and pressure drop of filters made from polyolefin fibers carrying electrical charges were compared with efficiency and pressure drop for filters made from uncharged glass fibers to determine if the efficiency of the charged filters changed with use. Thirty glass fibre filters and thirty polyolefin fibre filters were placed in various but almost identical, AHU that supplied external air to a large building. Using two kinds of real-time aerosol counting and sizing instruments, the efficiency of both sets of filters was measured repeatedly for more than nineteen weeks while the AHU operated almost continuously. Pressure drop was recorded by the ventilation system's computer control. Measurements showed that the efficiency of the glass fibre filters remained almost constant with time. However, the charged polyolefin fibre filters exhibited large efficiency reductions. Almost twice as much pressure drops were recorded for the glass fibre filters [35].

As all the new filter are mostly made of glass fibre it only further improves the efficiency of the filters, yet the setback in terms of higher-pressure drop is already been overcome by suppliers of filter companies like in the case of filter supplying company of Airmaster, as it was mentioned by Erik Bjørn in one of the early meetings of the project.

Thumb rules for filter replacement

As it was mentioned in 'the project brief' (the introduction outline to this master's thesis) and 'the problem statement', that much of today's filter replacement strategies are old and follow ' rules of thumb'. These rules of thumb are certain guidelines in the ventilation industry based on past experiences and common professional knowledge. Before reporting on the analysis of the old filters collected by the company Airmaster, it might be a good idea to see what some of these strategies are [3],

- Normal filters should be changed approx. once per year.
- Use (pre) filter before fine expensive filters
- Filters on supply and exhaust should be changed together (to keep

balance in the system)

• If the fan was working at full speed all the time even to supply the minimum design flow (sound)

•Looking at the pressure drop

Some of the additional rules of thumb in terms of precautions are [3]:

• Make sure air distributes evenly over entire filter

• Change of filters should be easy (one-man job)

• No leakage around filter should be possible.

What could be the future of filter replacement techniques?

The future of air filtration is going to be very different than today. The past couple of years has seen the mobile phone technologies and nano technologies to flourish. Following this, it was in 2017 when a US based company called Breezi, in a science forum introduced a small button like object that might go a long way in assisting with filter replacement strategies. This little piece of technology is called 'AirPulse' and can be seen in figure 2.

Figure 2. A button/pin like object called 'Air pulse' from Breezi

According to the supplier, installing the 'Air Pulse' is simple in a sense that one simply pushes the small triangular button/pin into the filter.

According to the supplier's home page 'Air pulse' operates , "With an array of sensors to detect HVAC health and environmental conditions, along with onboard algorithms to transform the data into information. Its differential pressure sensors track the filter condition, while readings from the temperature and humidity sensors help determine conditions that could promote mold growth. It even monitors indoor air quality and warns when volatile organic compounds (VOCs) such as acetone and carbon monoxide are present" [19].

It must come as an unclear explanation to the reader as to how exactly this new piece of technology works therefor an email has been written to the company acquiring further details, as to how 'Air Pulse' works. The price of this product is 30 US dollars [19].

Maintenance of Air Handling Units

Filters also protect AHU from dust. Dust massively reduces the heating/cooling performance of heat exchangers. It can burn onto the surface, resulting in awful smell in the supply air; the lifetime of heat exchangers bearings, belts and engines are reduced, if they run dust polluted. Protecting air ducts and their accessories from dust should also be a priority as greasy air ducts are very dangerous: not only are they unhealthy and decreasing the efficiency of the system but they easily catch fire [1].

Precautions when using filters

Generally, when filters are delivered by the factory they are without defects. Nevertheless, after a short period of time, it is seen that the filters are leaking. Generally, this happens because the manufacturer's regulations have not been followed during assembly or assembly has been done irresponsibly. Another reason may be that the operation of the AHU occurs with high and forcing pressure conditions, which can often lead to leakage around the frame [3].

As far as fire is concerned, in addition to the provisions of DS 428, "Standard for Fire Protection Measures in Ventilation Systems", it should be remembered that filters should not contribute to fire development in the event of fire, as well as to develop toxic gases [3].

The neighbouring buildings

As mentioned in the introduction, it is not only the intake of the air by the ventilation system that is important, but also the air that is released out to the atmosphere; for the extraction air it is important to know how much the air is contaminated; the level of the dust, fibre, gasses, damp, and smell. Moreover, what are the neighbouring conditions, at what height the extraction is taking place, the wind conditions, the local municipality demands. But the most of above-mentioned demands play a major role when sizing a ventilation system for an industrial scale [5].

Merger of the MERV (USA) and EN 779 (European) standards: new ISO 16890 standard

As mentioned earlier, since the mid 2018 instead of a separate European and the US filter standard there is one common filter standard for both USA and EU. The new standard provides the first opportunity for global harmonization as it sets off to replace the two existing standards [10].

The ISO 16890 comes in four parts and it has been published in December 2016. It was expected that it will last 18 months before EN 779: 2012 will be withdrawn. This was to allow the manufacturers to adapt their current catalogues and was also considered as a transition period [34] [10].

The new international standard ISO 16890 consists of the following parts [10] [34] [44]

- — Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)
- — Part 2: Measurement of fractional efficiency and air flow resistance
- — Part 3: Determination of the gravimetric efficiency and the air flow resistance versus the mass of test dust captured
- — Part 4: Conditioning method to determine the minimum fractional test efficiency

In Table 4. It can be seen how different chapters from EN 779 could be aligned to ISO 16890.

Object	ISO 16890	EN 779:2012
Technical specifications, requirements and classification	Part 1	Chapters 5 - 6
Efficiency measurements	Part 2	Chapters 7, 8 and 9
Definition of the gravimetric efficiency	Part 3	Chapter 10.4
Packaging method to determine the minimum spectral efficiency of the test	Part 4	Chapter 11

Table 4. ISO 16890 parts 1,2,3,4 when alligned with EN 779:2012 chapters [36]

The new ISO 16890 standard does a far better job of accounting for real-world scenarios and places more focus on a number of particles than just one. As far as the testing conditions are concerned, a filter is challenged with a variety of different sized particulate, just as it would be if it was installed in an air AHU. PM size stretches from 0.3 µm all the way up to 10 µm in a series of 12 tests [11] [41] [34].

The scale looks at the percentage of particulate removed at various particulate sizes and provides a final classification by combining the scores. Filter ratings will be shown as a percentage of particulate matter removed from the air for each particle size group [40] [11] [34]

On the other hand, EN 779 is based entirely on a filter's ability to capture one size of particulate, which is 0.4 µm, as can be seen in Table 5. It doesn't take into account all the different particle sizes that are present in outside air. And that's why the testing procedure has been criticised for not reflecting the conditions in which a filter will be expected to operate. It would not be wrong to say that the results from the lab are not demonstrating the real-world scenarios. [8] [36] [34].

En 779-	Test Particle size	ISO 16890	Test Particle size in µm
Test	0,4 µm	Test	0.30 - 0.40
		2	0.40 - 0.55
		3	0.55 - 0.70
		4	0.70 -1.00
		5	1.00 - 1.30
		6	1.30 - 1.60
		7	1.60 - 2.20
		8	2.20 - 3.00
		9	3.00 - 4.00
		10	4.00 - 5.50
		11	5.50 - 7.00
		12	7.00 – 10.00

Table 5. PM test comparison for EN 779 and ISO 16890 [8] [10] [34]

It must be noted that a direct conversion from the old filter standard to a new one is not directly possible. But a company called 'EMW filtertechnik' that has been working in the filter industry for more than 60 years has made an attempt, as seen in Table 6.

In regard to table 6, if the filter M5 is chosen as an example, what it reflects is, in the case of filtering efficiency, ePM_1 filter type M5 would be only 5%-35% efficient. Whereas, in terms of $ePM_{2,5}$ the filter type M5 would be 10%-45% efficient and finally, the filter type M5 would be up to 40%-70% efficient as far as, ePM_{10} is concerned.

Filter Classes	ePM1	ePM2,5	ePM10
M5	5%-35%	10%-45%	40%-70%
M6	10%-40%	20%-50%	60%-80%
F7	40%-65%	65%-75%	80%-90%
F8	65%-90%	75%-95%	90%-100%
F9	80%-90%	85%-95%	90%-100%

Table 6. Table to help convert old filter type to new filter type according to the new standard [8]

Filter classes, ISO 16890 classifies according to filter groups, evaluating a filter's performance by its arrestance of particles from 0.3 to 10 µm in size. Filter group PM $_1$ comprises particulate sizes ≤1 µm, PM $_{2.5}$ includes particulates sizes ≤2.5 µm and PM $_{10}$ covers particulate sizes ≤10 µm [8] [34]. As it can be seen in Table 7.

Filter Group	Particulate Size (µm)	Classification Criterium
ISO ePM_1	$0.3 \leq x \leq 1$	Minimum efficiency ≥ 50 %
ISO $ePM_{2,5}$	$0.3 \leq x \leq 2,5$	Minimum efficiency ≥ 50 %
ISO ePM_{10}	$0.3 \leq x \leq 10$	Average efficiency ≥ 50 %
ISO Coarse	$0.3 \leq x \leq 10$	Average efficiency < 50 %

Table 7. The new filter standard classification method [8][23] [10] [34] [40]

According to the new standards, if a filter achieves a minimum efficiency of 45% in the PM_1 size range and 56% in the $PM_{2.5}$ size range, it does not qualify for the ISO ePM_1 filter group, having missed out by 5 %, but does qualify for the ISO $ePM_{2,5}$ filter group. Moreover, assuming that the average efficiency achieved by a particular filter for $ePM_{2,5}$ is 54%, the percentage is rounded down to the nearest 5% (i.e. rounded down to 50%) and the filter's ISO 16890 classification would be ISO $ePM_{2,5}$ 50% [8] [40]

To be classified in filter group ISO ePM_{10} a filter must achieve an average efficiency of $ePM_{10} \geq 50$ %. Filters with an average efficiency less than 50% are classified under the filter group, ISO coarse [8] [40].

The used filters collected by Airmaster: the filter monitoring process

Why monitor the condition of filters and replace them as soon as necessary? That is because clogged filters can lead to an undersupply of air, substantial loss of energy as well as efficiency, fan noise, reduced filter performance.

The aim to monitoring and when to replace the filters is what led AIRMASTER collect 140 filters, over a period of many months. The filters are, for the most, collected from Airmasters AHU clients, which is mostly consisted of offices, schools as well as private business owners such as, the local ferry operators, local gyms, etc.

There are normally 2-3 filter packed in a sealed plastic bag with a desiccant and a slip of paper containing the below mentioned information.

1. Last filter change date

2. Filter collection date
3. the amount of running hours,
4. how much air flow m^3/h it has sustained,
5. Inlet/outlet type (with exceptions), room type and surrounding conditions
6. Serial number
7. Filter type
8. AHU type
9. Building type
10. Land zone
11. If the filters, when collected were wet or dry
12. The address of the location.

The process undergone to organise and collect data is described in detail through pictures and small description in appendix 2.

The purpose of the was to task of sort and organize both filters and the associated data in a manner that a filter or a filter set along with the associated data would be readily available for the research purposes.

Items used for the task were:

1. Mask
2. Gloves
3. Shelves
4. Manila tages (Manila paper is a relatively inexpensive type of paper, commonly used for tags)

As a result, each filter set in a transparent plastic bag is now labeled with a manila tag, caring a homogenous number that is associated with the filter number and the unit type. For example, a label carrying a number 1.300.a, b would represent, 1 = filter number 1; 300 = AHU, AM 300; a and b = inlet and outlet filter, respectively. The last part is still open to further evaluation: the filters were initially given a label 'a' for inlet and 'b' for outlet. This was done on the bases of the fact (as the filters were not initially marked as inlet or outlet filters) that there were different sizes filters for inlet and outlet for most of the AHUs and based on the side a filter could be differentiated as inlet or outlet. But the AHU type AM 300 used same size filters and type, for both inlet and outlet. Therefore, based on a calculated guess, the filters chosen for the experiment 1 and 2 where examined again with professional help. As a result, the title of the filter has remained the same, but the filters chosen for experiment 1 and 2 are now additionally marked as inlet and outlet.

The Filter number was recorded in an excel template followed by the associated data, mentioned above. In total there were filters from 12 different AHU. Some AHU's were no longer being produced but filters were still decided to be preserved for experimental purposes.

The total number of filters added up to be 264 (for inlet and outlet =132 x2). For details, please look at the excel template called organised filter data, in the appendix 3.

Impact of relative humidity on filters

Experiment 1 : Filters tested in a custom made test rig, at 10%, 40% and 90% realtive humidity

The purpose of the experiment 1 was to see if filters gain weight when exposed to different level of RH.

The location was at the AIRMASTER, climatic chamber; details of which are mentioned in appendix 3 and 4.

The equipment used for this experiment was a scale type, ‘Entris’ by ‘Sartorius’, used for laboratory solutions and able to way up to 0,01 gram.

Moreover, the filters selected were, 1.300.a, 1.300.b, 4.300.a, 4.300.b, 8.300.a, 8.300.b, 14.300.a, 14.300.b, 15.300.a, 15.300.b, 17.300.a, 17.300.b, 29.300.a, 29.300.b, 30.300.a, 30.300.b, 37.300.a, 37.300.b, 12500.a, 12.500.b, 12.500.c. Please note that the AHU type for all the experiments was AM 300 and the filter type was M5.

Process was to weigh the chosen used filters in a climatic chamber at 10%, 40% and 90% RH to see if there was a variation in weight. The temperature chosen was room temperature at 22-23 degrees.

Please note that before the experiment began, the used filters were left at 10%, 40% and 90% RH over-night, respectively; firstly, all the filters were left in the climatic chamber over night at 10% and the weight was measured the next day and recorded. The same step was repeated the next day. It was realized that there is no substantial weight increase. The same step was repeated for 40% and 90% RH and it was realized that there was weight increase over the first day but not the second.

Note. Upon choosing a new filter, the reference weight of a new filter was chosen to be 103.17.

Figure 3. On the left, the test room (climatic chamber, to test filters at different levels of RH. On the right, the cold room for dehumidification.

Results from Experiment 1

For this experiment, the results were very clear. All the filters exposed to the different levels of humidity gained weight. This can also be seen looking at Tabel 8 and Figure 5.

It was also aparent viewing the filter physically and looking at the dirt content that more clogged a filter is (more dirt trapped in a filter) the more it is affected by RH% (the weight gain is higher).

Although it must be mentioned that the weight gain is not as much as it was anticipated (as mentioned earlier, one of the background basis of the experiment 1 was involving RH % affecting the filter/weight as a staff members at Airmaster, responsible for observing the AHU functionality and similar data, for research and development purposes, realized that on some occasions the pressure drop in a system would increase and decrease without any plausible explanation and it was presumed that it could be because of RH. But after the first experiment, RH affecting pressure drop theory was already looking weak). (Note, it should be added that while conducting the experiments, in the case of one filter which was very clogged, some dirt sample seemed to get parted from the filter. The results from that particular filter were NOT used in the experiments).

Filter nr	Type	10% RH	40% RH	90% RH	40%	90%
1	*New*	*103.17g*	*103.27g*	*103.69g*	*.10g*	*.42g*
2	1.300.a.i	98.37	98.65	102.66	.28	4.01
3	1.300.b.o.	134.20	134.60	137.05	0.40	2.45
4	4.300.a.i	104.40	104.32	108.96	-0.80	4.64
5	4.300.b.o	121.10	121.39	123.04	0.29	1.65
6	8.300.a.o	103.15	103.24	111.15	0.09	7.91
7	8.300.b.i	103.26	111.18	115.12	7.92	3.94
8	14.300.a.o	93.89	94.08	94.54	0.19	0.44
9	14.300.b.i	97.05	97.30	99.93	0.25	2.23
10	15.300.a.o	95.75	95.83	97.58	0.08	1.75
11	15.300.b.i	102.21	103.50	103.77	1.29	0.27
12	17.300.a.i	145.79	149.15	159.44	3.36	10.29
13	17.300.b.o	145.25	145.60	147.50	0.35	1.90
14	29.300.a.o	128.49	128.52	136.81	0.03	8.29
15	29.300.b.i	134.55	134.79	136.95	0.24	2.16
16	30.300.a.0	112.50	112.91	118.20	0.41	5.29
17	30.300.b.i	122.70	122.95	124.17	0.25	1.22
18	37.300.b.i	107.95	108.26	109.76	0.31	1.50
19	37.300.a.o	124.67	125.23	131.70	0.56	6.47
20	12.500.a.o	190.30	190.73	194.22	0.43	3.49
21	12.500.b.i	98.37	98.65	102.66	0.28	4.01
22	12.500.c.i	134.20	134.60	137.05	0.40	2.45

Table 8. Weight change at 10%, 40% and 90% RH

Looking at Tabel 8 and Figure 5, it can be seen that in the case of filter number 1 which is a new filter there is only a slight weight increase from 10% RH to 40% RH but more form 40% RH to 90% RH. This seems to follow the same trend in the case of all the other used filters as well.

Impact of relative humidity on a filters pressure drop

Experiment 2 : Filters tested in a custom made test rig. at 10 %, 40% and 90 % realtive humidity

The purpose of the experiment 2 was to see the affects of RH on pressure drop and other parameters affected by pressure drop, such as the RPM of a fan and the airflow.

The Location for the second set of experiments, the set up details of which have been describle in appendix 4, the location was also Airmaster. In a climatic chamber, please see figure 3.

The equipment test rig aparatus, of which presice dimensions and pictures are given in the appendix 4.

The process there were a total of 14 differenent used filters from the unit AM 300 that could be fitted in the test rig (there were some odd sizes aswell, which could obviously not tested). All the filters would be placed in a test rig for a duration of 3-5 min. Firstly at 10% realtive humidity, than 40% and finally at 90%.

The test rig also consited of two airllink controlers and monitering units called airlink controller '0' and '1' , the dark blue rectangular boxes, as it can be seen in fig 4, in the bottom left and top right corner. The Airlink Controllers are equipped with sensors to meaure air pressure difference (Digital Differential Pressure Sensor) and detect and transfer the data (there were additional sensors to detect flow rate in m^3/h , pressure drop, Volt, RPM) to a laptop.

The inlet was from the right, also demonstrated by an aero on the far right, pointing left. The out let is under the fan.

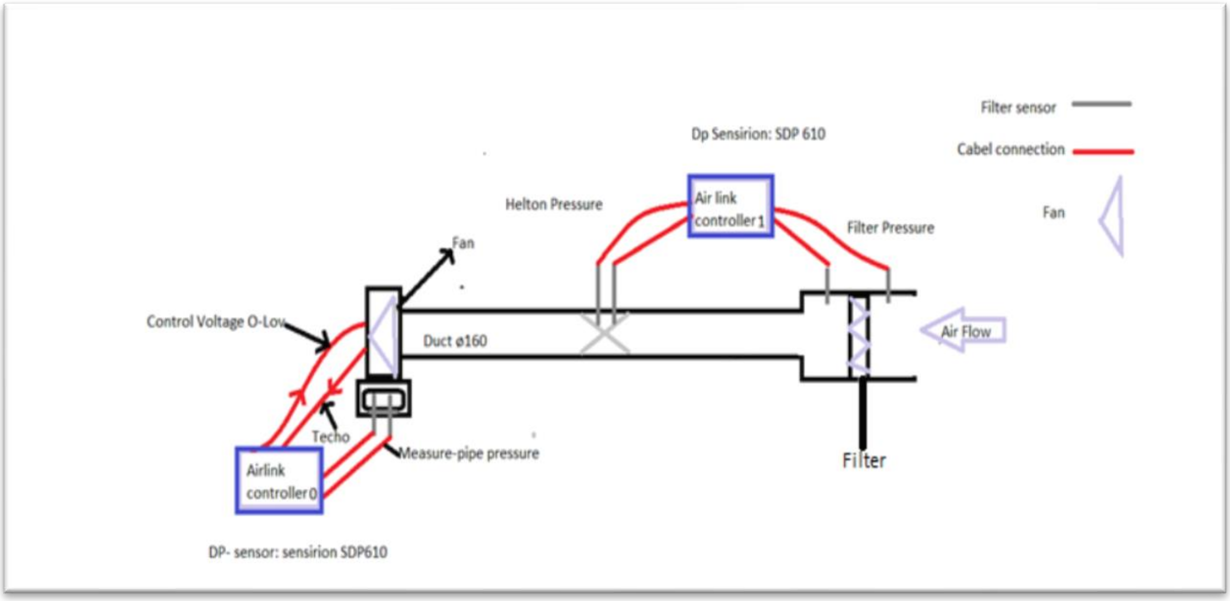


Figure 4. Drawing of the test rig setup

Using an airlink software program (used by Airmaster) , the information was further recordeded and assessed. Please note that the flow used for all the experiments was 250m^3/h as AM 300 AHU is equipped to supply flow of up to 250-300 m^3/h. Please look at Figure 3. for a brief overview and appendix 4, for a detailed description of the process with pictures.

The results of experiment 2

It was the finding of the experiment 2 that RH even at 90% did not have a substantial impact on the pressure drop. (For a detail analysis please look at figure 5).

It was visible that the more clogged a filter is, higher the pressure loss for example in the case of filter number 17.300.a pressure loss due to RH (even from 10% to 90%) was only 30[pa]. Please note this is the worst-case scenario (17.300.a from the right, filter marked with a black outline). And that is one example out of 10 filters, seen in figure .

It has to be mentioned that, having a high pressure drop because of a clogged filter is one aspect of the problem but not reaching the desired air flow rate (in the cases of 17.300.a for the inlet and 37.300.b for the outlet) to accommodate the desired air change rate (ACR) is another. This simply means that the performance of the AHU is being compromised and the 'high pressure drop', becomes a secondary problem. As can be seen in figure 8.

The data retrived through the experiment 2 supported the expected theory based on experiment 1.

Experiment 1 and 2 with graphs and description

In this chapter the graphs from both experiment 1 and 2 are included. With detailed description for some graphs and brief for the other graphs.

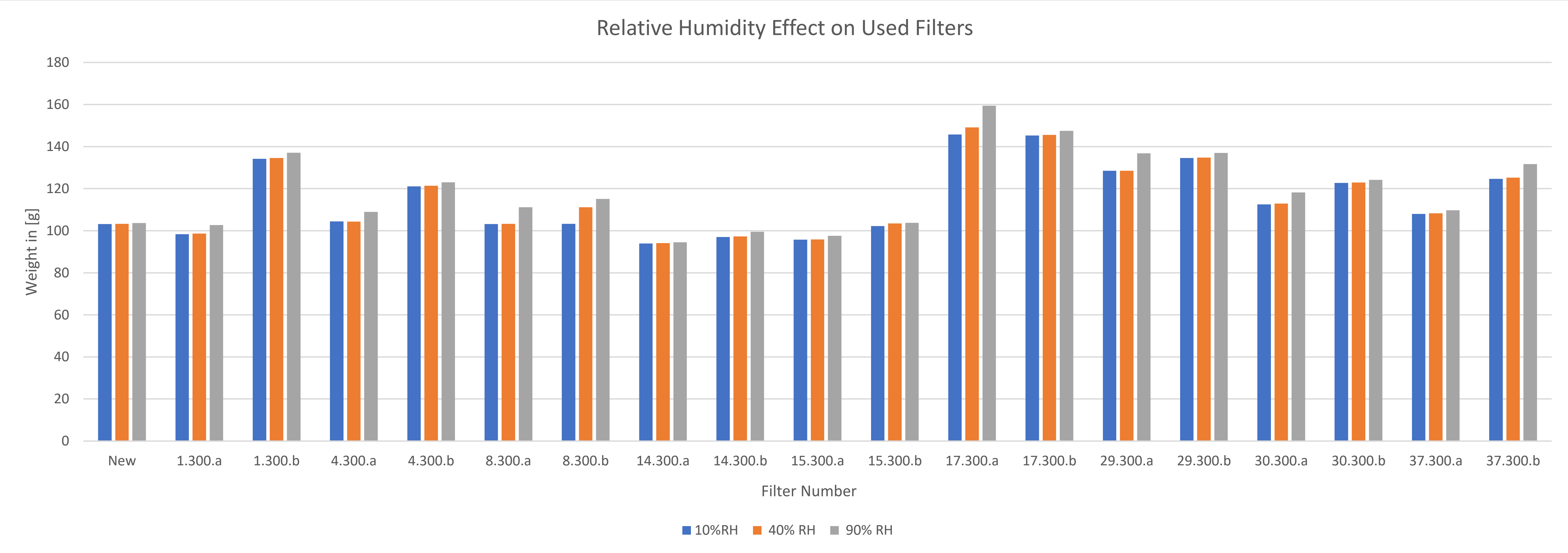


Figure 5. weight change in grams due to 10%, 40% and 90% RH

Basically, obvios variation in weight but not substantial, due to RH%. A detailed discission has already taken place under the chapter, 'results from experiment 1'.

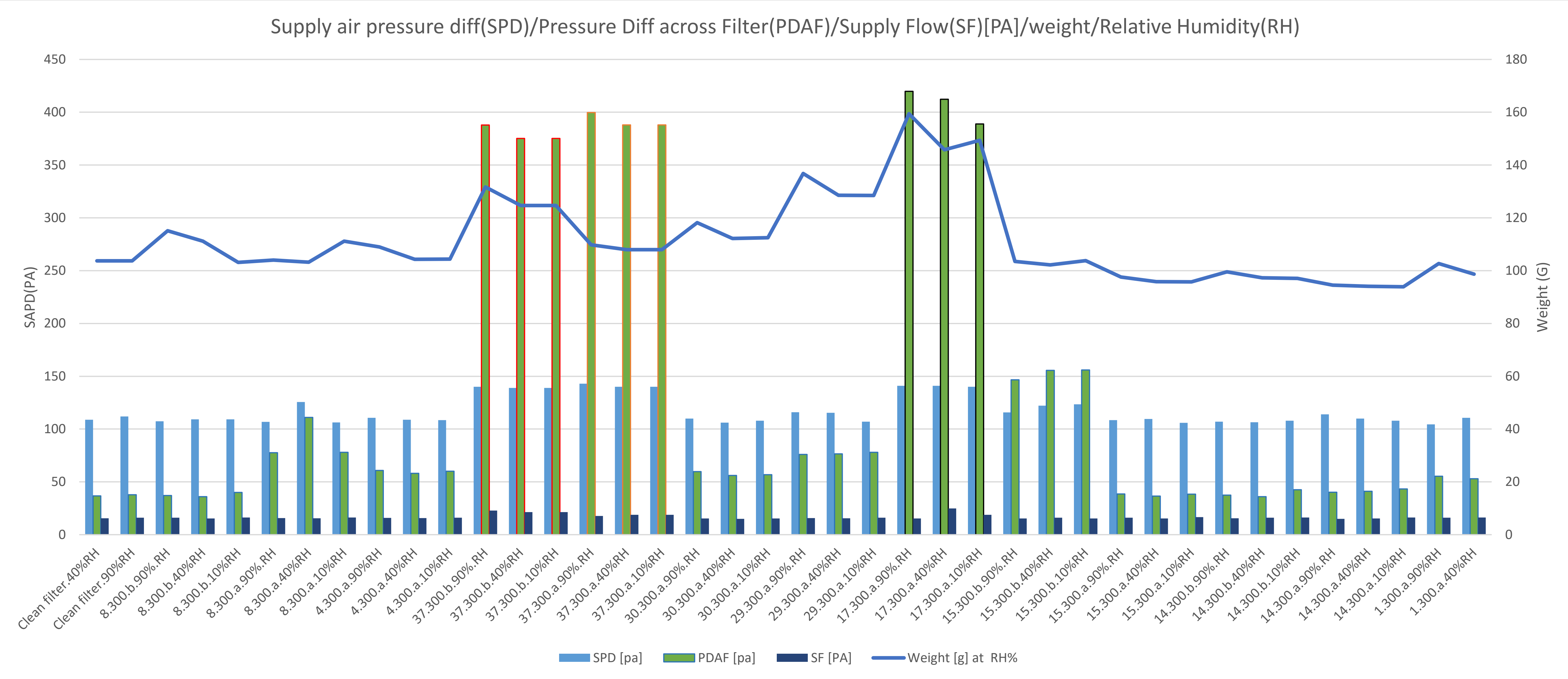


Figure 6. Pressure difference across filter as a function of weight of filters

There is a clear relationship between weight change and pressure drop. In terms of change in PD across the filter it also reaches high peaks. Ones to notice are and 17.300.a inlet and 37.300.a,b. inlet

- For filter 17.300. a (inlet) the difference in RH from 10% to 90% is 30 Pascals. From the right, with a black outline.
- For filter 37.300.b (inlet)10 pascal.
- For 8.300.a outlet filter highest PD is seen at 40% RH 25 pascals (Molstien)
- Pressure drop across filter is noticeable, but the effects are negligible

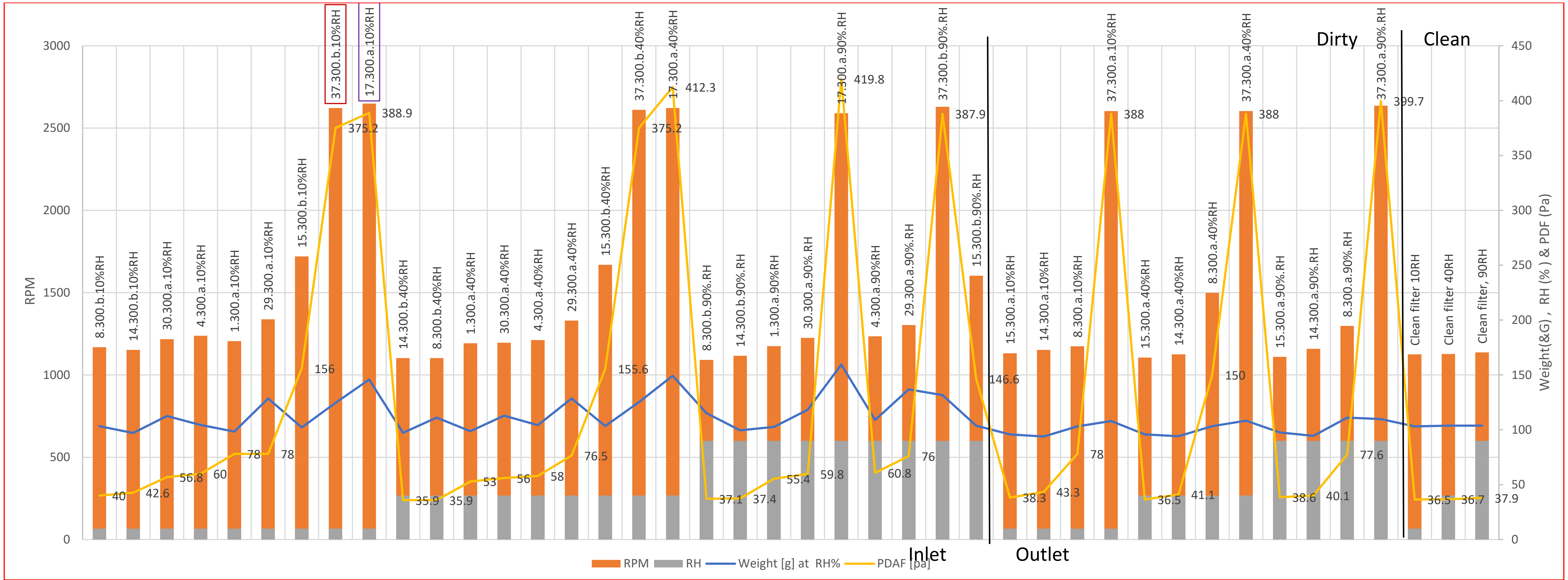


Figure 7. Pressure diff across filter, RH as a function of weight

The graph above exhibits the fact that it might be more frequent for the RPM to reach higher values, when the experiment is treated as an inlet, than outlet, compared to the no. of samples taken in each scenario 15/27.

Some of the samples show a trend between the RPM of the fan and the weight of the filter. When the weight decreases, the RPM increases. This phenomenon can be seen in filter number 15.300, seventh filter from the left. A further close analysis of the filter (as to where it was placed; seminarievej 31, 9681, determination of the dirt type etc. might reveal as to why this phenomenon is occurring). Composition of dirt could be an answer.

However, there are also, more plausible opposite scenarios. It can be noticed that the RPM increases concomitantly with the weight. In theory, the RPM should increase when the weight increases, as the fan needs to

Output more work to fulfill the task. As in the case of 37.300.b inlet and 17.300 inlet, filters from left, marked red and purple rectangular boxes

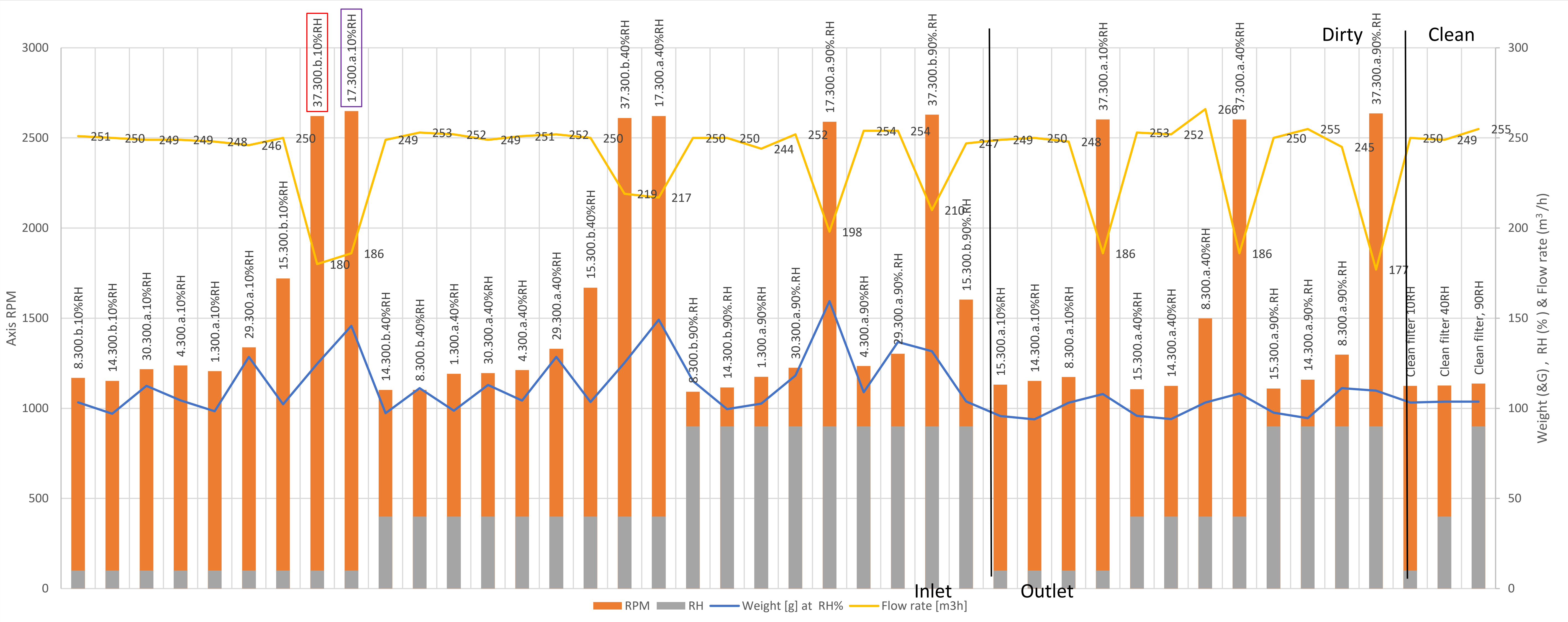


Figure 8. Flow rate and weight as a function of weight and RH

Comparing the flow rate with the RPM of the fan can indicate the performance of the system. The graph above exhibits the time when the highest RPM is achieved, desired flow rate is not achieved in some of the filters e.g. from the left of the graph, filters nr 37.300.a,b and 17.300.a.inlet, marked in red and purple rectangular boxes. It must also be stated that the energy consumption is at the maximum, but the wished set point is not achieved. This situation could be predicted in theory, considering that a clogged filter highly decreases the air flow through it; while achieving the high rpm, close to 2600 the max V of 10 V was attained. And since the system would not exceed the limitation of 10V the desired flow could not be achieved.

When observing the RH factor and the flow rate for the "inlet" cases, it can be noticed that flow rate at RH 10 % is more stable than at 90%.

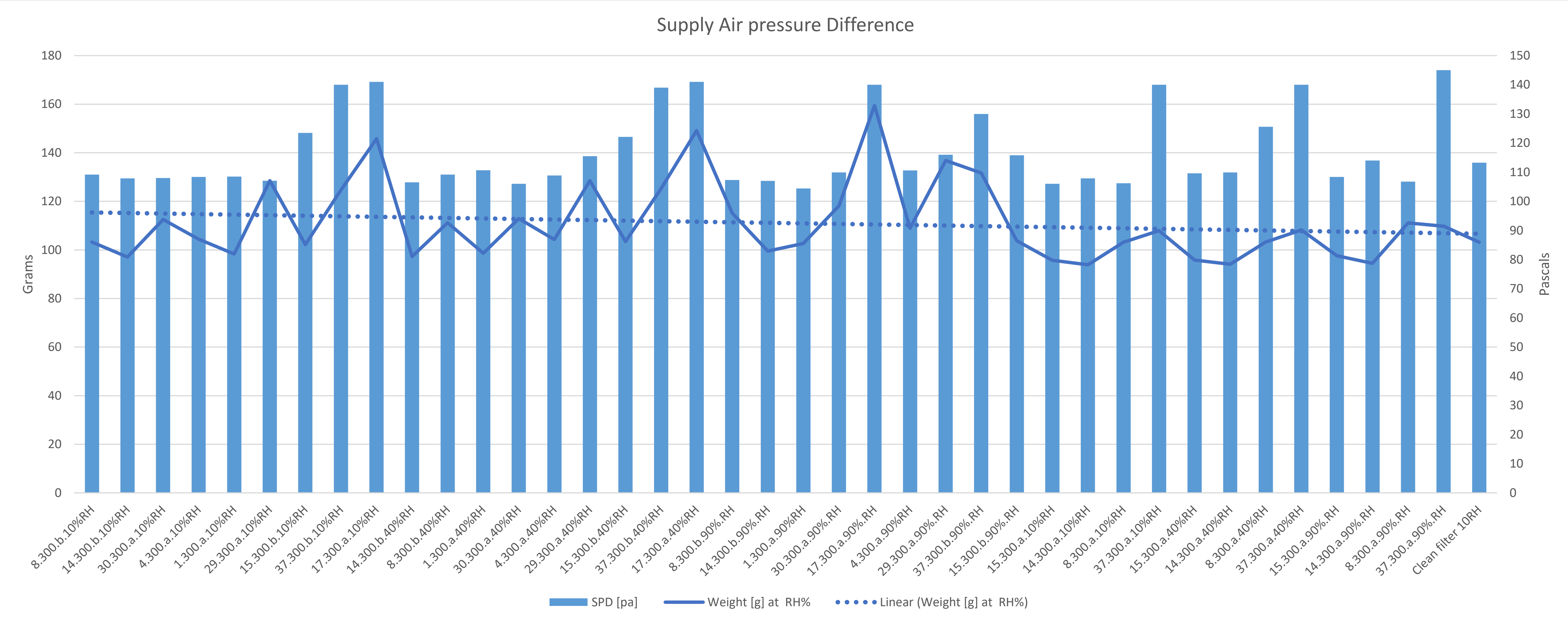


Figure 9. Flow rate and weight as a function of weight and RH

It is observed that SPD (SPAD, Supply air pressure digference) increases when the weight increases but at the same time it also increases on occasions when the weight is not increasing. Supply air pressure difference as a function of weight.

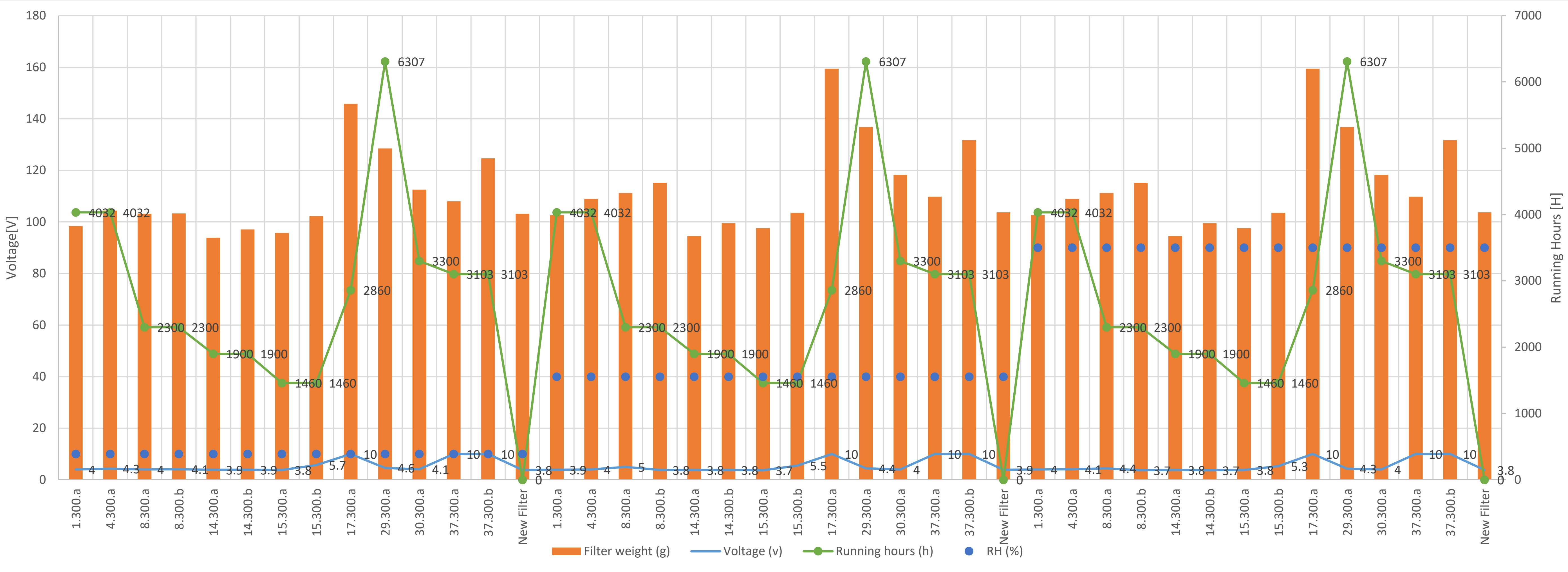


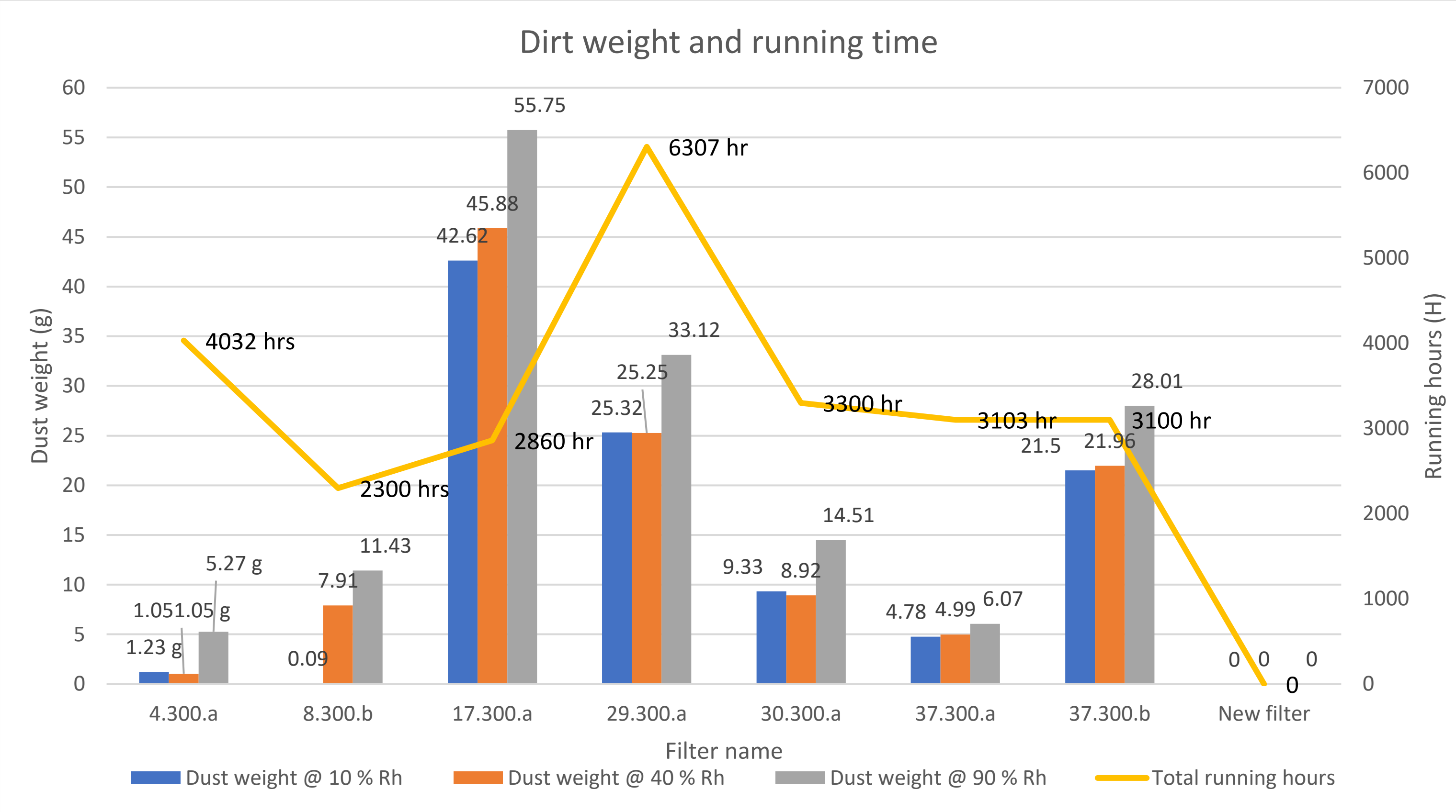
Figure 11. filter weight in relation to viltage and running hours

Please note, the voltage at 10V is the max: this is the max power a fan can provide. Please also note that filter number 17.300 a inlet , along with 37.300.a, b are one of the most clogged filters and yet compared to a lot of other filters they have not been running as many hours. 17.300 a inlet is a filter taken from Industrivej 59, 9600, which is AIRMASTER. 37.300.a, b on the other hand is a day-care center for kids in copenhagen in a very heavy trafic area. Scandiagade 100, 2450. One is an office another a school, both have working hours of 0700 -1600.

The process of sorting.

Must note that, the weight of a clean filter cannot be used as a reference because each filter has a unique weight and this could be due to the construction process(perhaps one filter was made using less glue, or less layers of fabric than the other filter). A possible solution is that each new filter should be weighted before placed in a ventilation system, and the system should monitor the weight, during the off-usage time.)

Further more the dimensions of the filters taken for the experiment might be too small for noticeable change. The solution might be to use bigger filters where the load-intake will be significantly higher.



Filter Number	Setting	location	Dry or Not	Filter Type	Filters Placed	Filters Removed	Address
4.300.a	Other	Small City	Dry	Inlet	17/08/2017	13/09/2018	Åkandevej 6, 8920
8.300.b	Office	City Center	?	Inlet	?	19/04/2018	Molslinien Aarhus
17.300.a	Other	?	?	Inlet	24/04/2016	30/08/2018	Industrivej 59, 9600
29.300.a	Office	City Center	Dry	Inlet	?	24/09/2018	Industrivej 59, 9600
30.300.a	Other	?	?	Inlet		20/09/2018	Tjele
37.300.a	Other	City Center	Dry	Outlet	20/09/2017	17/09/2018	Scandigade 100, 2450
37.300.b	Other	City Center	Dry	Inlet	20/09/2017	17/09/2018	Scandigade 100, 2450

Figure 10. Filter dirt (separated and the running hours)

While make this graph, the reference weight of a filter was chosen to be 103.17. All the filters were subtracted from the reference filter. The focus was the dirt of the filter. Note: Filters weighing less than the reference filter were excluded.

Again, it is apparent that, even though the filter 17.300.a. inlet is running comparatively less hours, but still very clogged. 37.300 a. which is an outlet filter is performing ok, but the 37.300. b. inlet filter compared to 29.300.a inlet in terms of hours, is performing far less. One explanation could be that filter 29.300.a. which is from Airmaster is based on a small city, away from the heavy traffic but 37.300.a. outlet on the other hand is based in the biggest city of Denmark, in an industrial hub, en-rout to the airport and other major motorways.

When comparing 37.300.b. inlet and 29.300.a. inlet, if it is presumed that both filters have almost the same dust level (there is a difference of 3-4 grams), filter 37.300.b.inlet has done half has many hours (close to 3000hrs) than filter number 29.300.a inlet (close to 6000hrs). The explanation could be that 1st filter is from a heavy traffic area (ring road, cph) and the other is from a comparatively smaller city (AM, Aars)

As for filter 17.300.a. inlet, marked in red in the table on the right. When compared to above analysis (bearing in mind that just like filter nr 29.300.a. inlet it comes from Airmaster and contrary to 29.300.a. inlet has done less than half as many hours), a plausible explanation could be that even though the location of the filter was a small city, close to open fields but, this particular filter was not changed for almost two years and perhaps a filter that is not changed on time, especially in the case of a decentralized unit, is simply getting clogged as it is consuming dust and dirt over time: in some of the inlet filters traces of organic compounds was found (insects and furs).

Maybe filters close to heavy traffic area be changed twice a year instead of one.
Furthermore, perhaps filters in a decentrailized AHU based on the location should be change at least once a year, regardless of the fact that they have done less hour. Certainly not over 20 months

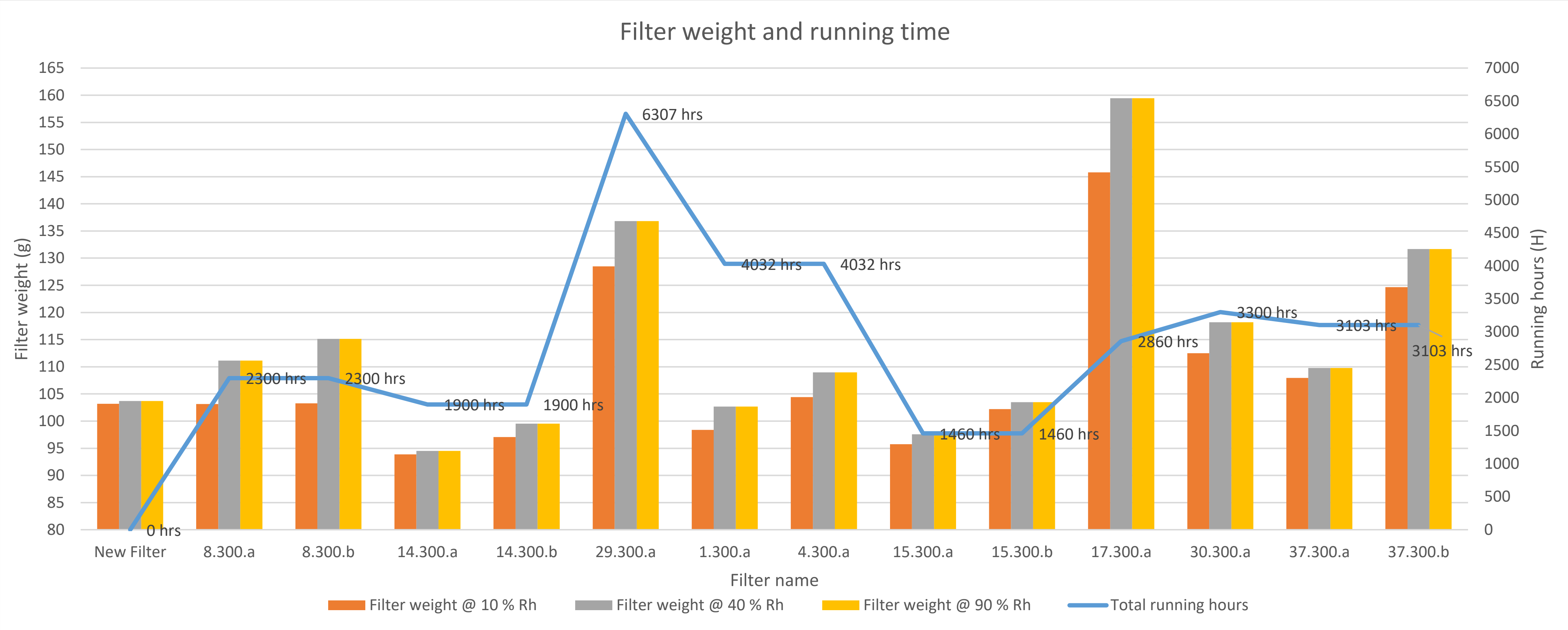


Figure 7. Filters in relation to total running hours

Filter Number	Filter Type
4.300.a	Inlet
8.300.b	Inlet
17.300.a	Inlet
29.300.a	Inlet
30.300.a	Inlet
37.300.a	Outlet
37.300.b	Inlet

All the filters are included. Sorted by *offices* and *others*. Separation of offices starts from 1.300.a.

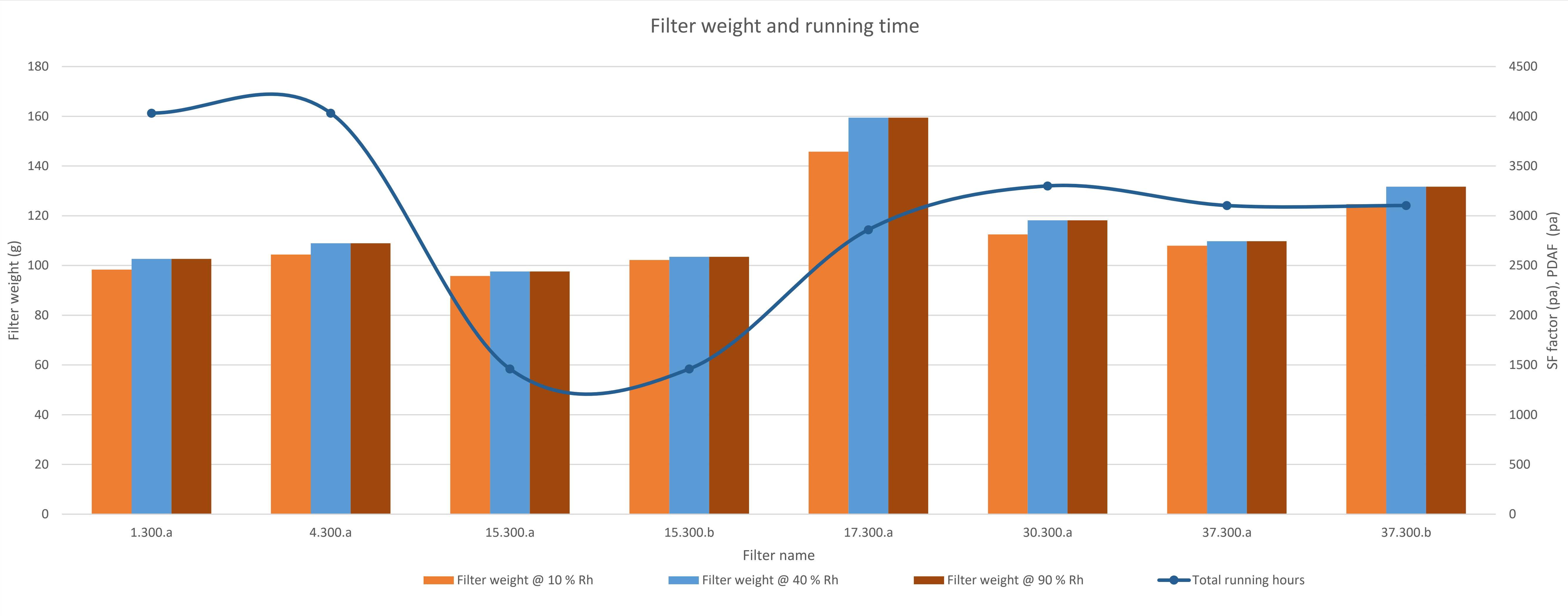


Figure 11. Filters running hours in others Apart from the fact that others are doing less hours in total no other analogy has been establish as of this point.

Filter Number	Filter Type
4.300.a	Inlet
8.300.b	Inlet
17.300.a	Inlet
29.300.a	Inlet
30.300.a	Inlet
37.300.a	Outlet
37.300.b	Inlet

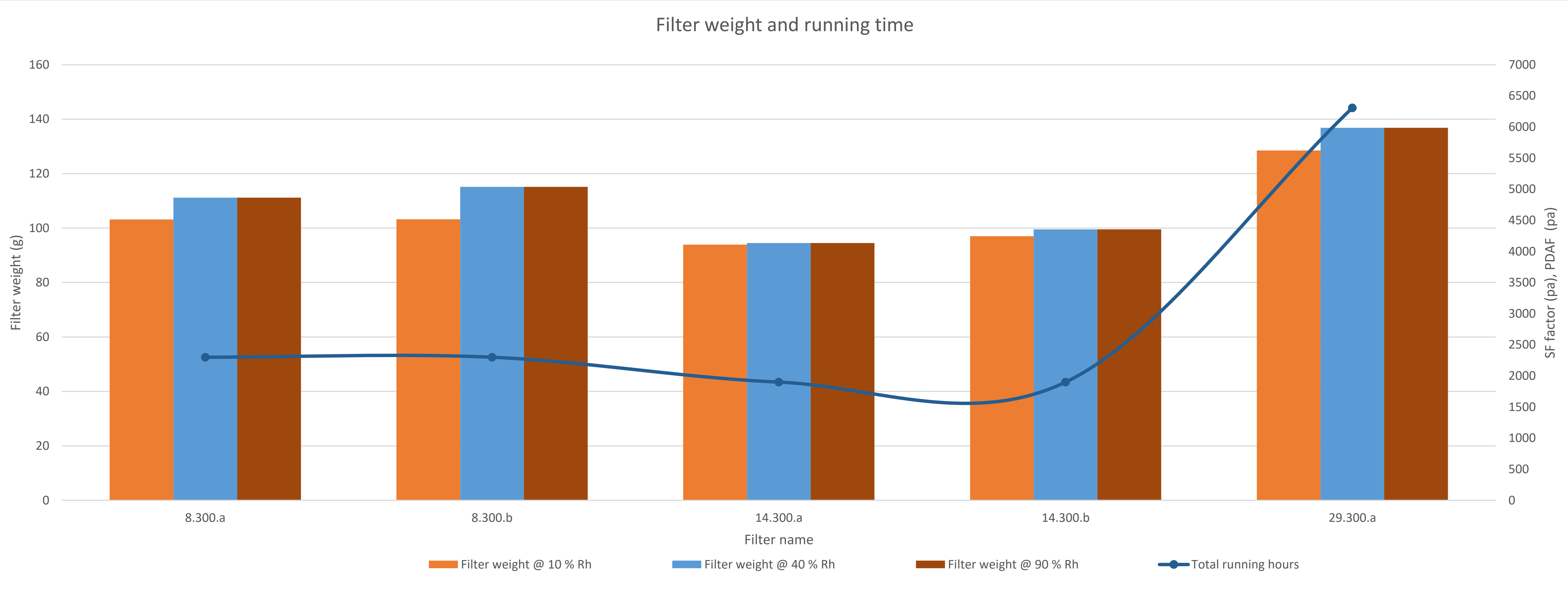


Figure 12. filters running hours in offices

Apart from the fact that offices are doing more hours in total no other analogy has been establish as of this point

Filter Number	Filter Type
4.300.a	Inlet
8.300.b	Inlet
17.300.a	Inlet
29.300.a	Inlet
30.300.a	Inlet
37.300.a	Outlet
37.300.b	Inlet

Pressure drop characteristics of an inlet filter vs the outlet and a new filter Vs the old

The aim of this experiment was,

a. To see the pressure drop characteristics of an inlet filter vs the outlet filter

b. to see if a clogged filter and a fresh filter have the same or different pressure characteristics

c. to calculate a pressure drop for a flow outside of the data points

The Location was Airmaster, in a climatic chamber.
The process two used filters were selected and a new filter. was the filters were run with three different flows of 100, 150 and 200 m^3/h. Data was collected and the graphs were made.

Experiment no 3a. and results: to see the pressure drop characteristics of an inlet filter vs the outlet filter

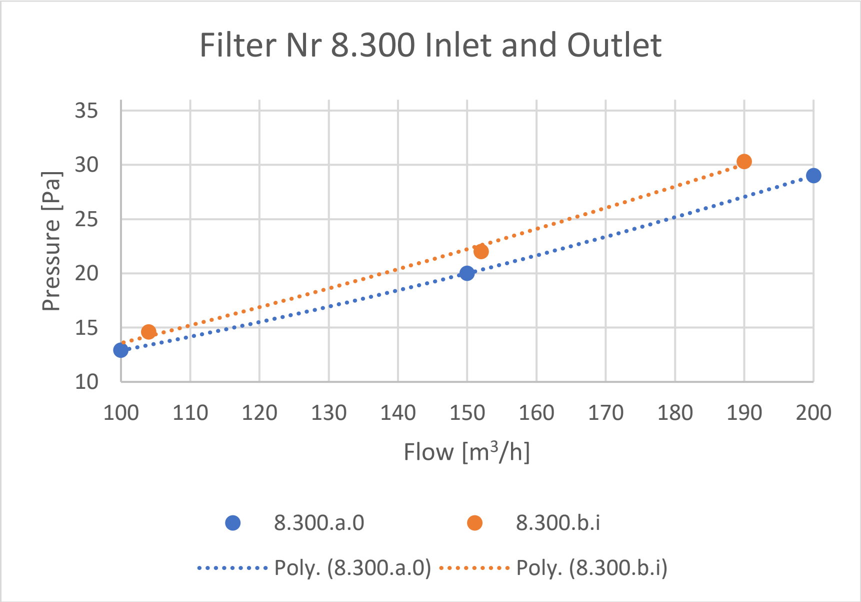


Figure. 13 Experiment 3a part 1

In terms of experiment nr 3, regarding the inlet filter vs the outlet filter, with filter nr 8.300a.o and filter number 8.300.b.i it was seen that the inlet filter (8.300.b.i) had a higher pressure drop than the outlet filter. As seen in Fig 12.

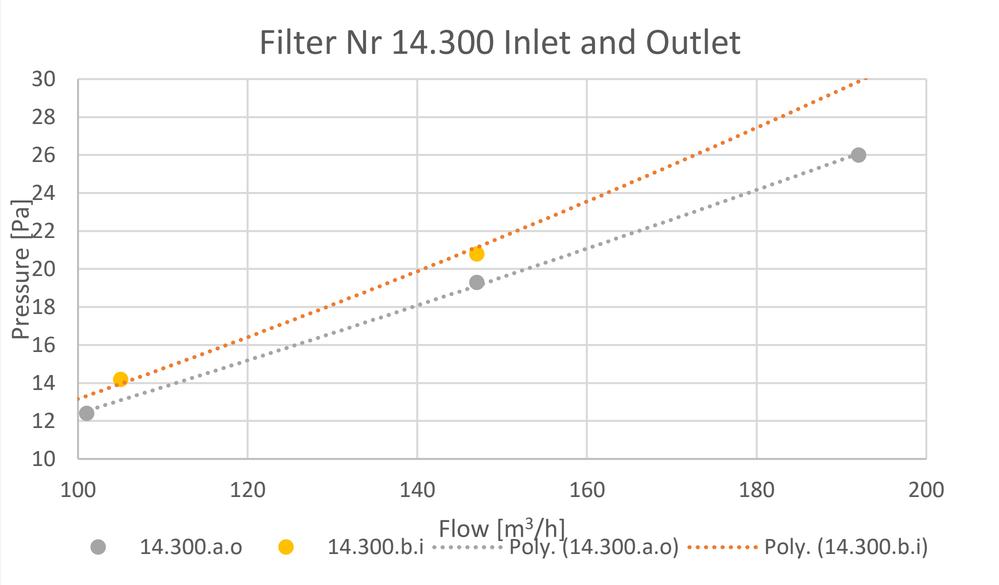


Figure 14. Experiment 3a part 2

In terms of experiment nr 3, regarding the inlet filter vs the outlet filter, with filter nr 14.300, it was seen for the second time that inlet filter had a higher pressure drop than the outlet filter. As seen in Fig 14.

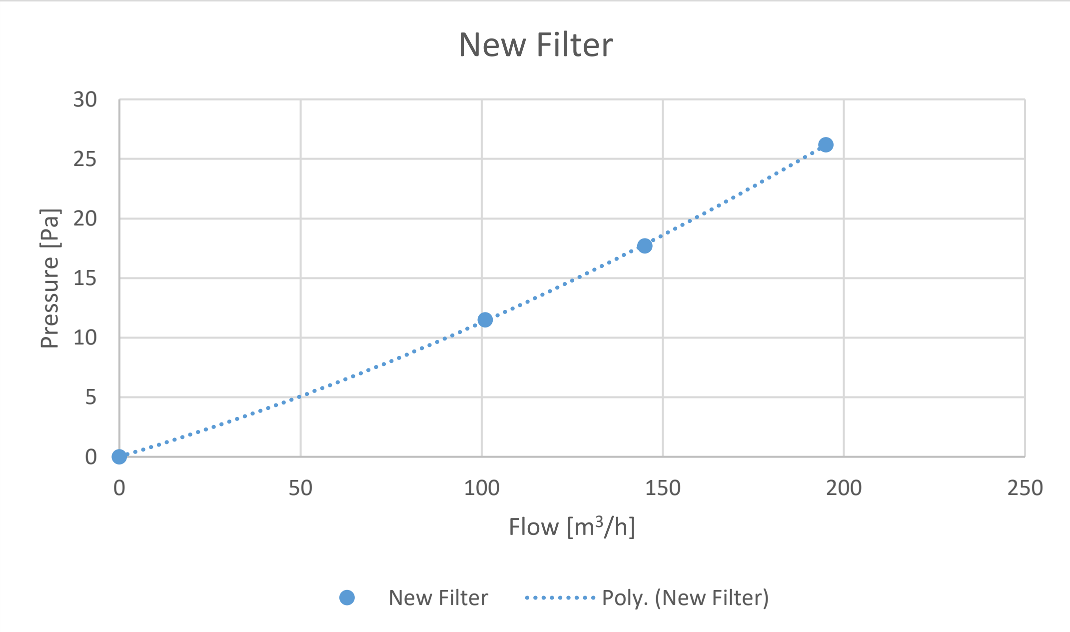


Figure 15. Experiment 3a part 3

In terms of experiment nr 3a it was seen that the new filter had the least pressure drop than the used filters**.**

Experiment 3b. and results: to see if a clogged filter and a fresh filter have the same or different pressure characteristics

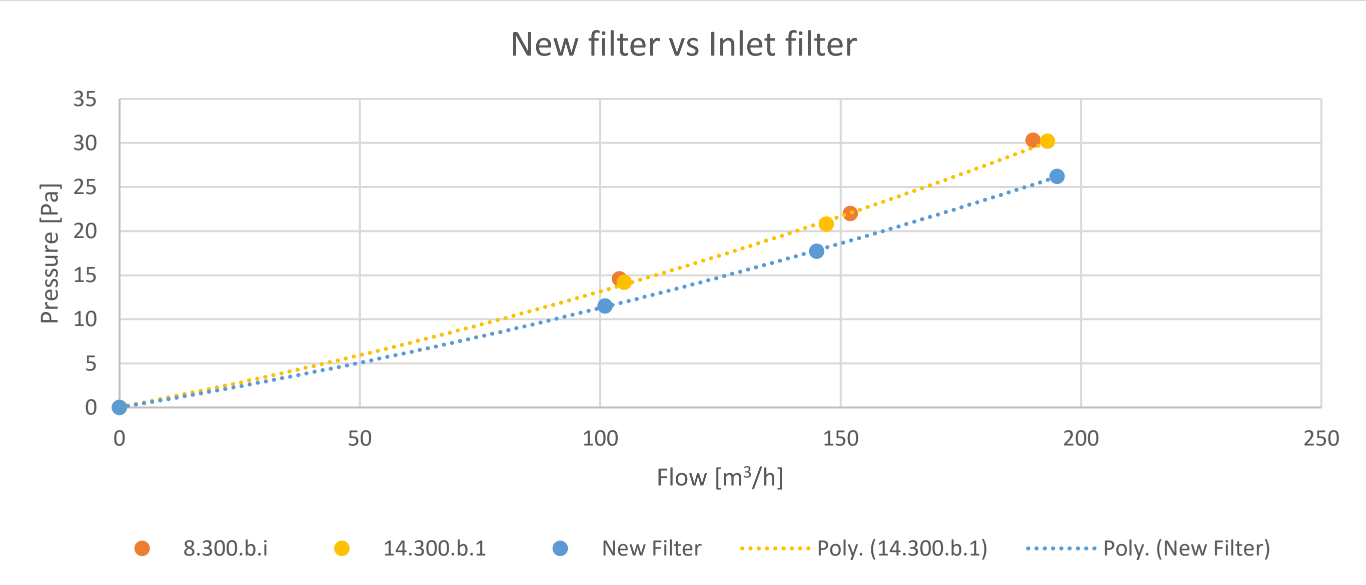


Figure 16. Experiment 3b used vs new comparisen

In terms of experiment nr 3, new filter and the used filter it was observed that the used filters had a higher-pressure drop-in comparison to the new filter, as anticipated.

Experiment 3c. and results: to calculate a pressure drop for a flow outside of the data points

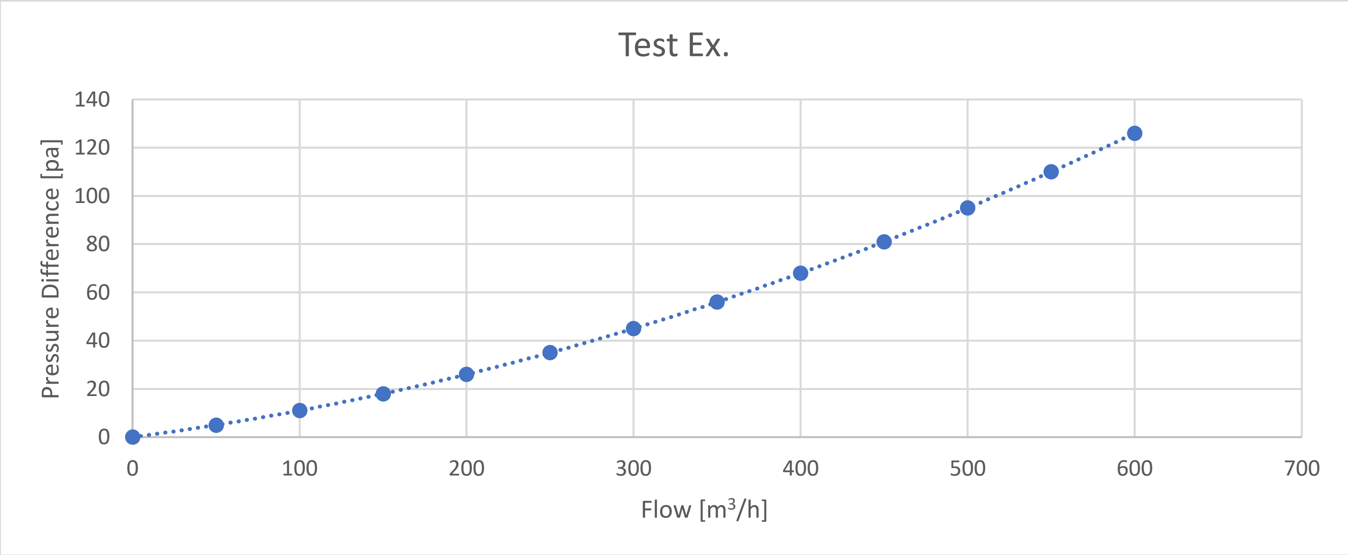


Figure 17. Experiment 3c test experiment

This Experiment was conducted, in order to calculate a pressure drop for a flow outside of the data points. Please note this test was done using the new filter

VSA (Vapour Sorption and Analyser)

Experiment 4.

Description Vapor Sorption Analysis is a technique in which a sample is subjected to varying conditions of humidity and temperature and the response of the sample is measured gravimetrically: detects the sorption/desorption of water vapor by the means of the increase or decrease in mass of a given material (in this case dirt from the filter) as the RH varies. A picture of a Vapour Sorption and Analyser (VSA) can be seen in Figure 18.

Figure 18 Vapour Sorption Analyser [46]

The aim of conducting Vapour Sorption Analysis on selective used filters (dust samples taken from used filter) was to observe and detects the sorption/desorption of water vapor by the means of the increase or decrease in mass of a given material (in this case dirt from the filter) as the RH varies under controlled conditions.

The location at AAU

The process the RH is firstly increased to log water adsorption, and then again decreased to log water desorption, in a VSA analyser and the results are recorded. This experiment should be considered as a follow up of experiment 1, where filters were left in a climatic chamber overnight and weighed the next day. The difference is that one experiment was carried out in a climatic chamber at Airmaster and the other in a lab at AAU. Moreover, VSA analyser can only process small amounts of material 500 to 5000 mg.

The water soprtion Isothers

The water sorption isotherms were achieved by testing samples in the VSA by Meter Group. The VSA alters the RH in the environment surrounding the sample, while at a relatively constant temperature

of 23 C. The water isotherm has been calculated in accordance with DS/EN ISO 12571 ('Hygrothermal performance of building material and product; determination of hygroscopic sorption properties') [7].
.

In the case of filter nr 21.300 inlet RH is firstly increased to log water adsorption, and then again decreased to log water desorption. As can also be observed in fig 19. This, of course, causes the moisture content of the sample to increase and decrease, respectively. The VSA constantly measures the weight and logs it along with the RH [7].

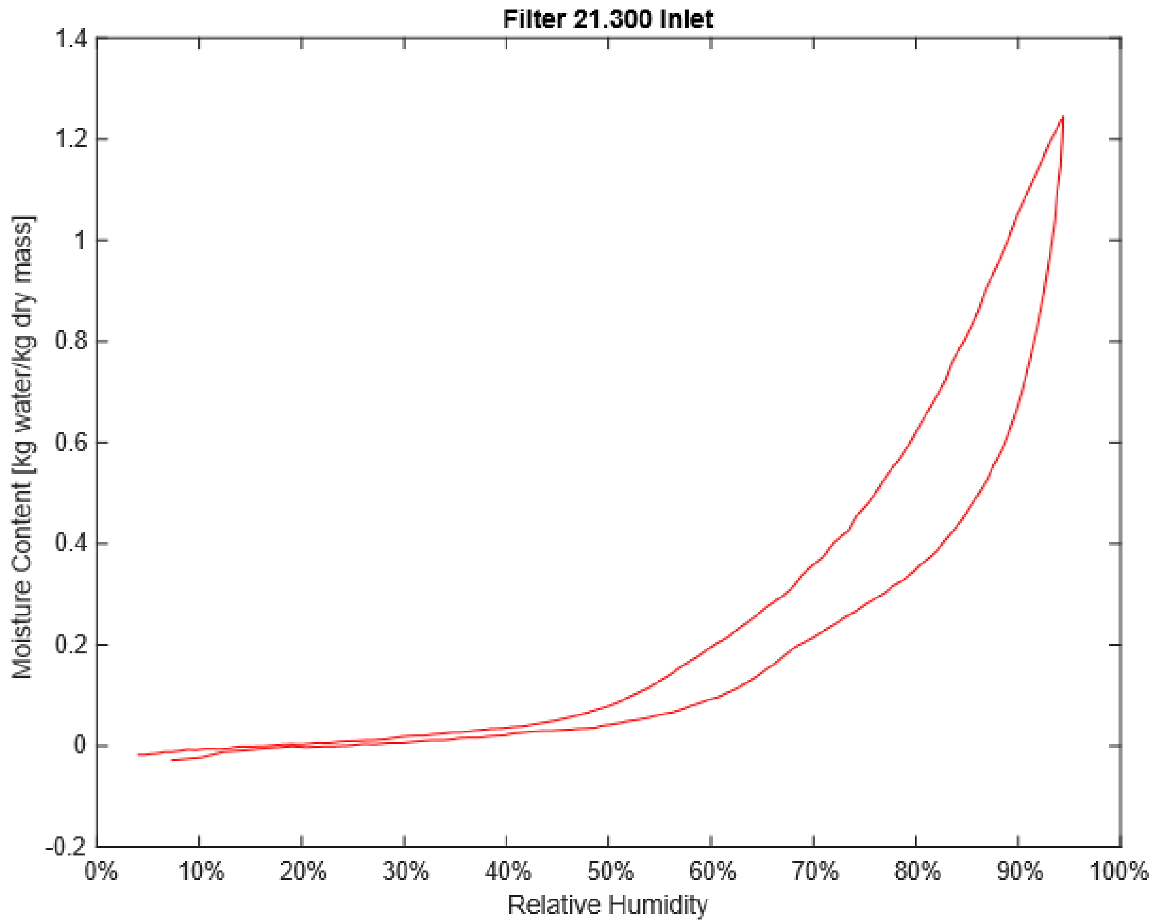


Figure 19. Sorption and desorption curves for 21.300 inlet

As it can be seen in the graphs the test sample was run from RH of 7% to 95% and then back down to 3%. The dry weight of each sample was measured after it had been tested in the VSA. The dry weight is achieved by drying the sample in an oven at 80C for several days, where after the sample weight is measured. For some of the graphs, it can be seen that the dry weight is slightly higher than the initial weight (e.g. 25. 300.intake). This could be due to a number of reasons: [7

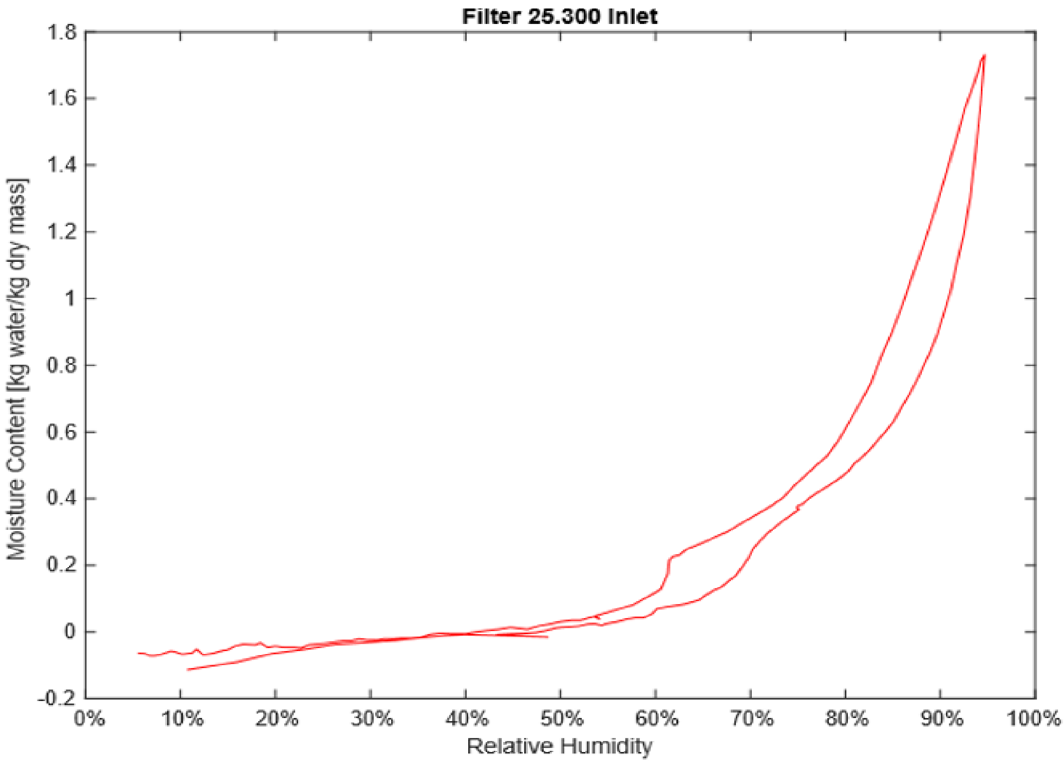


Figure 20. VSA results filter number 25.300 intake

1) The sample isn't completely dry. [7]

2) There is a difference between the scale in the VSA and the scale used to measure the dry weight. [7]

3) The process of drying the sample has affected the composition of the sample (this is unlikely at the given temperature) [7].

One of the hurdles with the measurements was also the sample weight and sizes. The VSA prefers to use samples between 500 to 5000mg. However, it was difficult to extract this big a sample from the filters, presumably due to the low density of the dust. Most of the samples only just reached 50mg (the bare minimum necessary to run a sample test) [7].

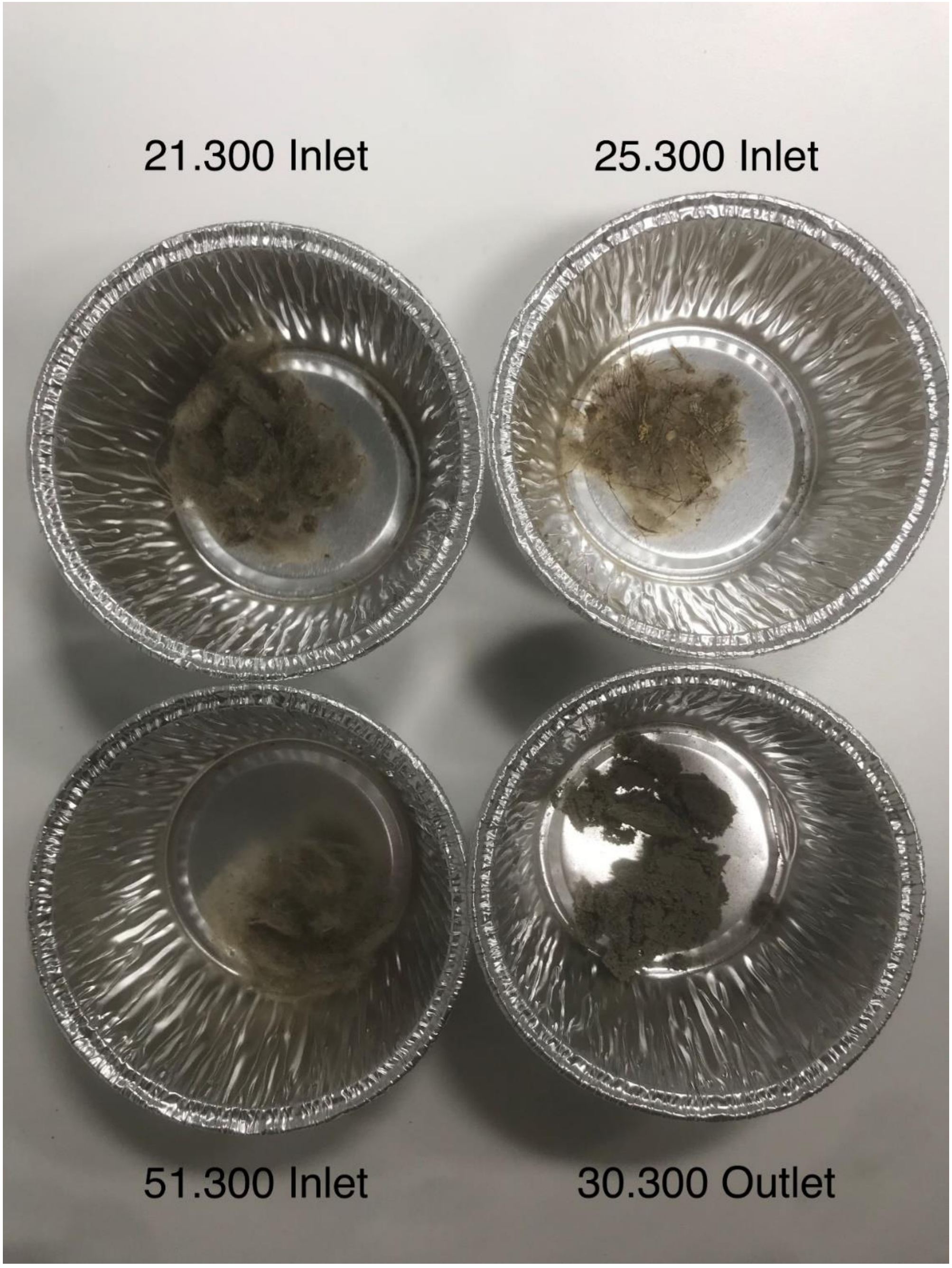


Figure 21 VSA sample pictures from 4 different filters

As it can be seen from the graphs in figure 19 and 20, there is a relatively high moisture content uptake of dust samples. When the moisture content is 1 kg water/kg dry mass, this means that the water in the sample weighs just as much as the sample itself. Or in other words, the sample has doubled in weight due to moisture content. Filter sample moisture content results range from 0.9 to 1.7 kg/kg at 95% RH. FYI - that's a lot. The moisture content usually recorded is from 0.02 to 0.4 kg/kg [7].

Figure 22. A filter dirt sample with organíc material

On the other hand, the dust texture seemed different for the different filters, despite showing similar results. Some (from the inlet filters) in particular showed organic material (e.g. insects) [7].

Cross analysis of the Climatic chamber experiments and the VSA experiments

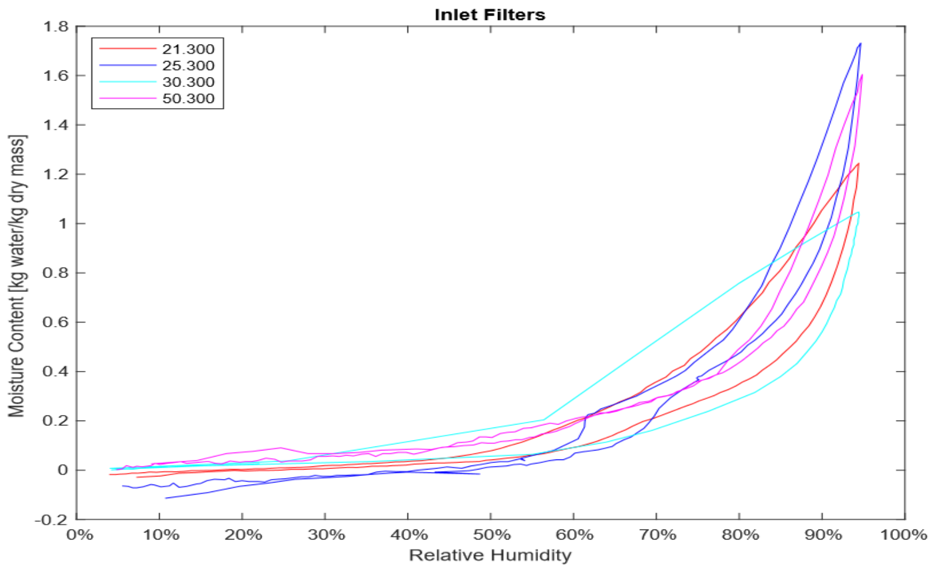
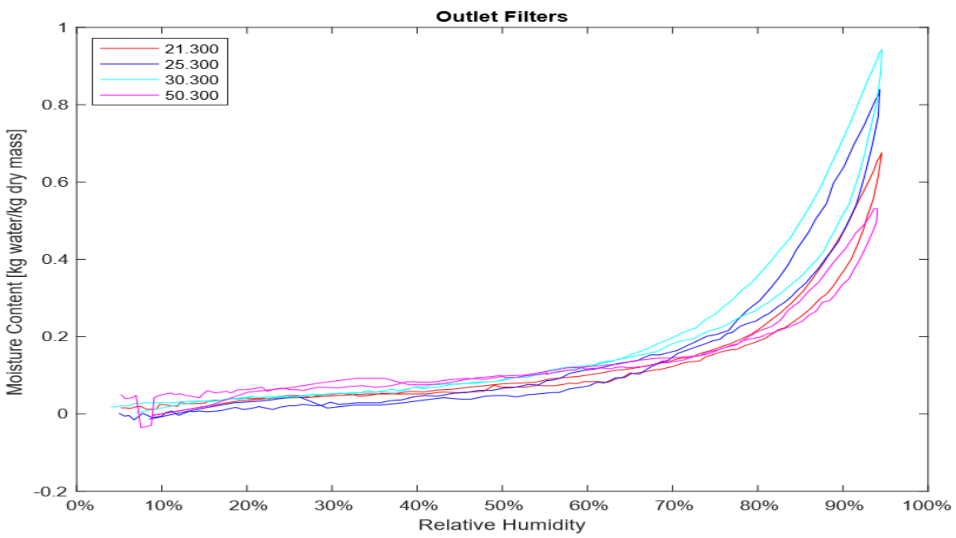


Figure 23 inlet filters on the left and outlet on the right in a VSA lab test

Inlet filters reach moisture content: from 100% up to 180 %, this is a lot. Note: Filter 30.300, the sorption isotherm is a product of 3 step RH% (1%-100% in 3 steps, contra the rest; which are achieved at 3% RH steps (almost 33 steps).



Outlet filters reach moisture content: from 50%, up to 100 %. The mass increase from 3% to 60% is 20%. The mass increase from RH 60% to RH 95% is highly noticeable. Supports Climatic chamber experiments. This relates to the composition of the samples - that is, the pore structure. we are dealing with an isotherm type III.

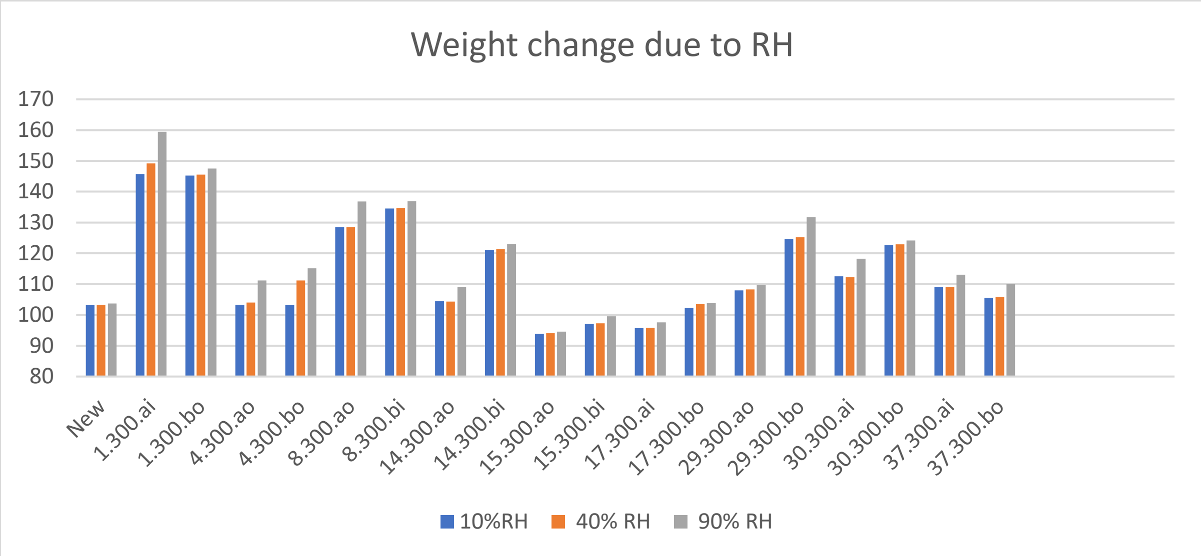


Figure 24. Experiment 1, where used filter in a climatic chamber were subjected to varing RH. Please note that the weight on the y axis is starting from 80 grams.

A clear observation in the climatic chamber experiment with regard to the changing RH is that the weight increase from 10% to 40% is apparent but the weight increase from 40% to 90% is highly noticeable. The similar pattern is observed in the VSA. (The pore structure and thereby the surface area of the sample influences how much moisture can be adsorbed/desorbed).

Recommendations for filter replacment strategies

As a filter becomes clogged, its resistance to airflow increases. In a system in which airflow is kept constant, this leads to a rise in differential pressure across the filter bank. Because fans often propel less air as a filter becomes impeded, airflow changes as a filter progresses from a clean state to an obstructed one [47].

One of the main focus of this thesis was to recommend proposals that can help facilitate when to change filters. Although, when to change a filter is not as easy as one solution fit all scenarios: In general, filter replacement could perhaps follow some pre-set guidelines but for the most filter replacement recommendations should be part of a manufacturers AHU selling custom guidelines, as factors such as the season, homeowner behavior, and the location of each filter determine, how frequently they need to be changed.

During the research for this thesis it was realized that one off the problems with filter replacment was the fact that it is simply, forgotten. According to the US Department of Energy (DOE) fewer than 30% of Americans change their filters on schedule. Even homeowners who changed their filters regularly are not changing them at the right time [9]. This could be avioded by:

Subscribing a service contract with the company, that is installing the AHU. This is in particular recommended for private home owners (as they don’t have a janitor coming over ocassionaly for service and maintanance). The AHU companies with the incentive of, keeping a customer happy and making money, should make sure that the filter is changed on time, spend well planned service letters to their clients suggesting a filter change.

A janitor, among other things, should also be appointed to monitering air filters at municiple and company homes, schools or offices. This could be done on a monthly basis until a trend has been established. As the usage can differ depending on the season, usage and location.

While above mentioned solutions could take care of the ‘forgetting’ part of the problem, below mentioned sloutions might help in determining when to replace the filters.

Pressure switches which indicate when a certain predefined pressure value is exceeded [47].

Differential-pressure sensors for example sensors type SDP610 Series used in experiment 2 seen in figure 4 could be used to trigger a predetermined off-set value. When the value is breached an alarm or a display light could turn on, indicating time for a filter change. An example of high pressure drop can be seen in Figure 7. in the cases of 37.300.b. inlet and 17.300 inlet filters, from left marked in red and purple rectangular boxes. The same method is also recommended in an article called, ‘State-of the-Art Filter Monitoring’, by Andries Bosma and Manuel Eckstein [47].

Flow sensors for example the sensors used in experiment 2 (or a sensirion SFM3000 digital flow meter), could be used to measure flow. If a required flow is not achieved an alarm could be set off or a display light turned on. The same method is also recommended in an article called, 'State-of the-Art Filter Monitoring', by Andries Bosma and Manuel Eckstein

The example of flow rate not being reached could also be seen in Figure 8. e.g. from the left of the graph, filters nr 37. 300.a,b and 17. 300.a.inlet, marked in red and purple rectangular boxes where even with the highest RPM, desired flow rate is not achieved.

According to the article 'State-of the-Art Filter Monitoring', the most accurate filter monitoring is accomplished when both pressure drop, and flow are measured to determine changes in pressure across a filter in relation to airflow. A few other methods, called, optical systems, through which the discoloration of a filter is measured, and dust-load sensors, which measure dust concentration based on the triboelectric effect also in use. But the article states that these are complex and costly and not suitable for high-volume applications[47].

Fan characteristics it was mentioned in a meeting that a Airmaster team looks at the fans charateristics, to recommend next filter change (it was further added that more cannot be said as it is a trade secret). Perhaps that fan reading can be used to set off a light indicating a filter change.

Set number of hours an alert on a set number of hours could be another option (specially interms of a location in a polluted climate), as mentioned on page 35 regarding Figure 10. That location plays an integral role in changing the filter. It was further recommended that filters in high trafic area be changed twice a year rather than one.

Decentrailzed AHU filters in a decentrailized AHU, should be change at least once a year, regardless of the fact that they have done less hour.

Particulate Matter sensor using for example SPS30 particulate matter (PM) sensor by sensirion Which simply tells if the inside air in the room is too contaminated could be another option to know as to when to change a filter.

Findings

1.Both climatic chamber and VSA results showed that there was a clear correlation of RH and used filters. Although, according to experiment 1, overall effect in the weight of filters, even at 90% RH did not increase as anticipated.

2. A clear observation in the climatic chamber experiment with regard to the changing RH is that the weight increase from 10% to 40% is apparent but the weight increase from 40% to 90% is highly noticeable. The similar pattern is observed in the VSA. (The pore structure and thereby the surface area of the sample influences how much moisture can be adsorbed/desorbed).

3. The results of experiment 1 were also reflected in experiment 2, where it was further observed that the pressure difference due to the low to high RH (10%-90%) is negligible.

4. The inlet filter weighs more than the outlet filter, the physical observation was also supported during the VSA tests and experiment 3a.

5. Filters in densely populated areas and/or highly traffic areas, and perhaps schools, should be changed at least twice a year (in DS13779, it only justified to be one year).

6. It is suggested to use a bigger size filter e.g. from a unit AM 500 or AM 800 as the proportion of dirt would be higher to a new filter of the same unit. This could also further facilitate the process of VSA experiments; VSA prefers to use samples between 500 to 5000mg (It was difficult to extract this quantity of sample from the filter).

7. Although not fully tested but the only experiments adding water to a clogged filter and analysing the pressure drop in the custom-made test rig pointed in the direction that indicate that the 'unexplained peaks' in the pressure drop witnessed by the Airmaster team might be due to rainwater.

Future recommendations:

Conducting an experiment at Airmaster, in a chosen room, with e.g. AM 300 unit installed. First running a test with a new filter over a certain period of time and then with clogged filter and finally with a very clogged filter. Recording the results using a professional Particulate Meter. The aim of this experiment would be to determine if a clogged filter filter's more or less.

Conclusion

Acoording to DOE, clogged air filters force AHU systems to use up to 15% more energy to maintain a comfortable temperature. Clogged filters also increase the strain on the AHU system itself, which is why 9 out of 10 AHU equipment failures are related to dirt buildup, according to the Cooperative Extension Service, which is is an extension agency of an executive branch of the federal government. [9]

It does raise a question as to how come something that is associated with some of the very important factors of life, namely, health and money can be neglected for such a long time. New technological breakthroughs like, 'Airpulse' from companys like breezi are certainly a step in the right direction.

RH has an effect on objects and humans and could have a profound effect on machines; depending on the climate but as far as this project was concerned and contrary to a highly anticipated speculation, RH did have an effect on the weight of the filter and the pressure drop but not to an extent that would have a profound effect on energy bills.

Overall, it was a very interesting, practical and ambitious project. Ambitious in a sense that several tasks associated with 3-4 experiments were planned to be executed in a very short span of time which is also understandable given that a similar experiment had not been conducted in the past.

Lastly and ideally, instead of the focus on pressure drop so much, because it effects the power consumption, the focus should rather be on changing a filter due to the health implications. Imagine being in an environment where clogged filter is not only providing polluted air, but at the same time it is not providing the required air flowrate, as it has been the in the two cases of the experiment (17.300.a and 37.300.b both inlet filter). To make matter worse, what if this environment happens to be your own office and a day-care for children? As it is in both the cases.

Future Experiment Protocol

While organising the filter stock and running the experiment there were a lot of things it was realized that there were a lot of steps that can be improved both in terms of filter collecting process and the experiments.

A. One of the very first recommendation towards future filter collection strategy would be that all the filter when put in the AHU, should be weighed. As it was realized, while conducting the experiments that a used filter e.g. 14.300.a, b regardless of doing 1900 hrs with a flow rate up to 250m^3/h weighed less than a new filter. This was also seen in some other examples. This means that filters do not have a standard weight, which is a big obstacle in evaluating precisely how much dirt the used filter have consumed.

B. Moreover, it is also crucial to weigh the filters as soon as they are taken out of a unit and placed in a plastic bag because some of dirt and pollutant material are going to be separated from the filter.

C. Another important note that has to be made is that all the inlet and the outlet filters should be clearly marked. Specially, if they are the same size. In one of the meetings with the supervisors it was brought up that normally filters weighing more is considered to be the outlet filter as it is getting rid of a lot of moistures in terms of latent heat. But to contradict this theory during the experiments and observations of the filters it was realized that the presumably (outlet) 'weighing more' filter had normally bugged, insects and sometimes even furs trapped inside them, so it has to be inlet filter.

D. This brings the focus on a very crucial aspect regarding any future study with the used filter and that is the health aspect of the student or a person who is conducting the experiment.
   1. Glasses and mask don't go hand in hand in conducting the experiment, as every time you are breathing out you are clouding the glasses.
   2. Gloves do not work when you have to lift up the bag with the filter, spot the slip that is in the bag, carrying all the filter data and move the data on to the laptop. wearing gloves.
   3. After a while, both the mask and gloves, are not part of the health precaution as it was delaying the work process.
   4. More than 300 hundred used filters in a room with carpet, some filter bags are caring live bugs. Some bags are not even sealed and even the ones that are sealed have to be opened sometimes to retrieve the filter data slip. All of this does not add up to be an ideal working environment. A specialized AHU with the focus on extraction, properly sealed bags and a room without carpet could be a possibility to tackle this issue.
   5. The situation worsens when the filters are moved to the climatic chamber. The heavily polluted filters are out of the bags in the open, fully exposed to the changing RH from 10% to 90%. To ensure a uniform humidification process across the 2m x 7m room the duct design is distributing the less humid and humid air very efficiently. There is a small damper that opens up to the cold room that is facilitating the dehumidification process but apart from that, one is pretty much trapped in the above mention environment, for hours.

6. The sound from the test rig fan, the humidification process (the fan used to blow the air and extraction fan for the dehumidification), the water pump, create a very distracting environment. Specially if point number d5 and d6 are added together. Some ear plugs were provided for the experiment, but they do not even come close to providing the desired comfort and focus level, to perform the experiments. Professional sound blockers should be considered to counter the sound problem.
7. Since it has been established that RH has a very little effect on filter performance (in terms of pressure drop) it is suggested to have a room with very good extraction possibilities to conduct any further experiment of similar manner.

E. One of the goals of this experiment was to conduct experiments evaluating the effect of artificial dust on the filter. It is a recommendation to incorporate the new filter type (glass fibre) into the experiments as well for a more realistic comparison.

F. It is recommended to conduct experiment adding water to filter to see how the system reacts especially considering the fact that Airmaster specializes in AHU that are decentralized and avoid duct work which means that the filters are located very close to the external grill used to intake fresh air thus also close to the filter.

G. It is recommended not to use airlink alpha software as it does not allow to store the logged data.

H. There was another ambitious goal for this project. And that was to clarify a theory which has opposing opinions in the intellectual or the professionals related to ventilation and air filters and that is if a used filter, filters more or less. An experiment with a test rig in a van in a traffic orientated area along with a particulate counter was suggested to pursue an answer to the above-mentioned speculation. Although another option could be to use a room at AIRMASTER, with for example and AM 300 or AM 500. First run the unit with a new filter and then replacing the filter with a very clogged filter (from the used filter collection), detecting and logging the results over a certain period of time with a professional particulate counter, and seeing the outcome.

I. For practical reasons mentioned above, it is recommended that this or similar project be conducted by at least two people.

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https://www.hpac.com/iaq-ventilation/state-art-filter-monitoring

Appendix 1

Detailed report by the Danish Environmental Center

"The sodium content in PM10 on street stations was about 1.6 µg/m3 corresponding to an estimated annual salt content (NaCl) of about 4.0 µg/m3 . High diurnal values of salt were observed during periods with winter salting of roads. The annual limit value for NO2 (40 µg/m3) was exceeded at one street station in Copenhagen (H.C. Andersen's Boulevard), whereas no exceedances were observed in Odense, Aalborg and Aarhus. The NO2 concentrations have decreased from 2014 to 2015 for most of the stations. At H.C. Andersen's Boulevard (HCAB/1103) there were still elevated concentrations of NO2 compared to the situation before 2010 due to a permanent change in the traffic lanes at the street segment in front of the measurement station. Additionally, there has been a gradually decrease in the concentrations during the last years in parallel to the decrease observed at Jagtvej. 6 Model calculations at selected streets in Copenhagen and Aalborg indicate that the limit value was exceeded at 9 out of 98 calculated streets in Copenhagen but not at any streets in Aalborg in 2015. The number of street segments with model calculated exceedances has decreased to one third of the value in 2010.' [11]

'The ozone levels in 2015 were on the same level as in 2014. No clear trend is observed for the average ozone concentration. The information threshold of 180 µg/m3 was not exceeded in 2015. The target value for the maximum daily 8 hours mean ozone concentration of 120 µg/m3 was not exceeded, but the long-term objective for this parameter was exceeded at all Danish stations. The læong term objective has not entered into force. Measurements of volatile organic compounds (VOCs) at the urban background in Copenhagen showed concentration levels between 0.01 µg/m3 and 0.75 µg/m3 for the selected 17 different compounds. VOCs can act as ozone precursors, and the aim of these measurements is to improve the general understanding of the ozone formation on a European level. The formation of ozone in Denmark is in general small due to moderate solar radiation. The ozone pollution in Denmark is to a large extent the result of long-distance transport of pollutants from other European countries south of Denmark. The levels of SO2 and heavy metals have decreased for more than two decades and are now far below the limit values. The limit values for benzene and CO are not exceeded and the levels have decreased for the last decade. Measurements of concentrations of particle bound PAH were performed at H.C. Andersen's Boulevard, Copenhagen and at the suburban measurement station at Hvidovre. The average concentration of benzo[a]pyrene was 0.29 ng/m3 and 0.25 ng/m3 at H.C. Andersen's Boulevard and Hvidovre, respectively. The target value for benzo[a] pyrene (1 ng/m3) was not exceeded in 2015. Measurements of the chemical content in PM2.5 showed that the annual average concentrations of NH4 +, Na+, K+, Mg2+, Cl- , NO3 - , SO4 2- are very similar at the street station at H.C. Andersen's Boulevard and at the rural station at Risø. The main difference between the two stations are for elemental carbon (EC), organic matter (OM) and Ca2+ where the concentrations are higher at the street station compared to the rural background station. This is mainly due to emissions of these compounds from the traffic in Copenhagen." [11]

Further explanation

"Pollutants measured in the network NO and partly NO2 are formed by combustion at high temperatures. The main sources are power plants and traffic. At the street stations the traffic is the main source. The application of catalytic converter in the exhaust reduces the emission considerably. NO is relatively harmless, but NO2 can cause respiratory problems. Most of the NO2 in the urban atmosphere is produced by oxidation of nitrogen monoxide (NO) by ozone (O3). The reaction will take place immediately, if sufficient O3 is present. O3 is often the limiting component for a complete oxidation in the street canyons, but practically all NO is oxidised at the urban background and rural stations". [11]

Within a few hours the NO2 is further oxidised to nitrate and/or nitric acid, which may cause acid precipitation and eutrophication. NO2 is a toxic gas, which may cause respiratory problems. There are limit values for the allowed concentration of NO2 in the atmosphere. O3 is formed by photochemical reactions (i.e. by the influence of sunlight) between nitrogen oxides and volatile organic compounds (VOC's). The VOC's can be of natural and anthropogenic origin. The major part of the O3 measured in Denmark originates from sources outside the country. [11]

Usually the highest concentrations are found at rural and urban background sites. O3 is removed by NO at street level. O3 is a toxic gas, which may cause respiratory problems and damage on crops and forests. There are so-called target values for the concentration of O3 in the atmosphere. The main source of CO in urban air is petrol-fuelled cars. The CO is formed due to incomplete combustion. The application of catalytic converter in the exhaust reduces the emission considerably. CO is only slowly removed from the atmosphere. CO is a toxic gas that may prevent the uptake of oxygen in the blood. There are limit values for the allowed concentration of CO in the atmosphere. Benzene is present in petrol. It may also be formed in engines due to incomplete combustion. [11]

Since 1994 the benzene content in petrol has been reduced by up to a factor of 5. The concentration in the atmosphere has been reduced correspondingly. Benzene is a carcinogenic gas. There is a limit value for the average content in the atmosphere. Many different VOC's are present in the air. Several of these are emitted by incomplete combustion in e.g. engines and wood burning stoves. Several of the VOC's are carcinogenic. A "target value" is implemented through an EU Council Directive in 2004 for Benzo[a]-pyrene as indicator for PAH (Polycyclic Aromatic Hydrocarbones). 65 The main sources for PM10 and PM2.5 are combustion and resuspended dust. PM are also produced by chemical reactions in the atmosphere e.g. oxidation of nitrogen dioxide, sulphur dioxide and VOC. The submicron particles, which are formed by combustion and chemical reactions in the atmosphere, are suspected to be the most harmful for the health. There are still a lack of knowledge about the connection between health effects and particle size. Limit values for the PM10 concentration in the atmosphere are implemented at present. PM10 and PM2.5 is measured using three different methods in the monitoriong program: [11]

- The Beta method: The particles are collected on filters for 24 hours intervals. The mass on the filters is automatic determined by measurements in the instrument of β-absorption in the filter with sampled dust. This method is considered to be equivalent to the reference method (EN 12341:1999 and EN14907:2005). [11]

• The LVS method: The particles are collected on filters for 24 hour intervals by a low volume sampler (LVS). The mass on the filters is subsequently determined in the laboratory by gravimetric measurements of the dust. This method is the current reference method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter in ambient air (EN 12341: 2014, into which the previous standards for PM10, EN 12341: 1998, and for PM2.5, EN 14907:2005, have been merged). [11]

• The TEOM method: The particles are continuously collected on a "tapered oscillating microbalance" (TEOM) and heated to 50°C. During heating volatile compounds may evaporate. The loss will be most pronounced for "secondary aerosols" containing ammonium nitrate. PM results are given with a time resolution as ½-hourly averages. [11]

There are a number of different heavy metals (HM) in the atmosphere. They are emitted from e.g. coal and oil fired power plants, waste incinerators and industries. HM's may also be emitted from traffic due to wear on engines, tires and brake pads. Several HM's are toxic even in low concentrations and a few also carcinogenic. A limit value is implemented for lead. Target values are values are implemented for arsenic, cadmium, nickel and mercury. WHO has proposed guideline values for the toxic non-carcinogenic and estimated life time risks for the carcinogenic HM's. Sulphur dioxide (SO2) is formed by burning of fossil fuel and biomass. The SO2 is oxidised in the atmosphere to particulate sulphuric acid and sulphate. The conversion time depends strongly on the temperature and humidity in the air. It is typically of the order of one day. Sulphuric acid contributes to "acid rain" and the deposition of sulphate causes damage to sensitive ecosystems. Since the beginning of the 1980'thies the reduction of sulphur in fossil fuel and improved flue gas cleaning has reduced the concentration of SO2 with one order of magnitude. SO2 may cause respiratory problems. There are limit values for the allowed concentration of SO2 in the atmosphere." [11]

Appendix 2

Air filters for removing Volatile Organic Compounds

VOCs, or volatile organic compounds, are a specific type of organic compound that can lead to mild or severe health problems in humans. VOCs are very common indoors, in workplaces, houses, and schools. Many industries, such as photography, chemical manufacturing, dry cleaning, copying or printing, and work with petroleum-based products, have regular high exposure to VOCs. [13]

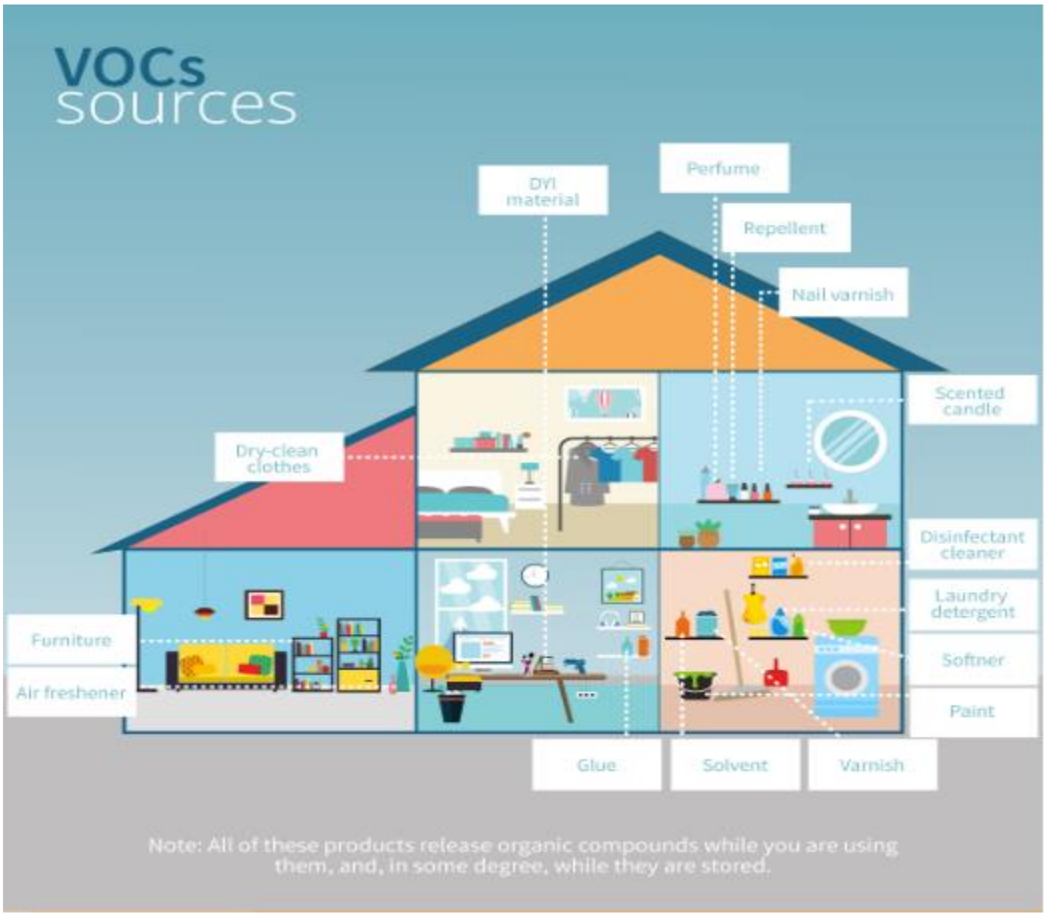


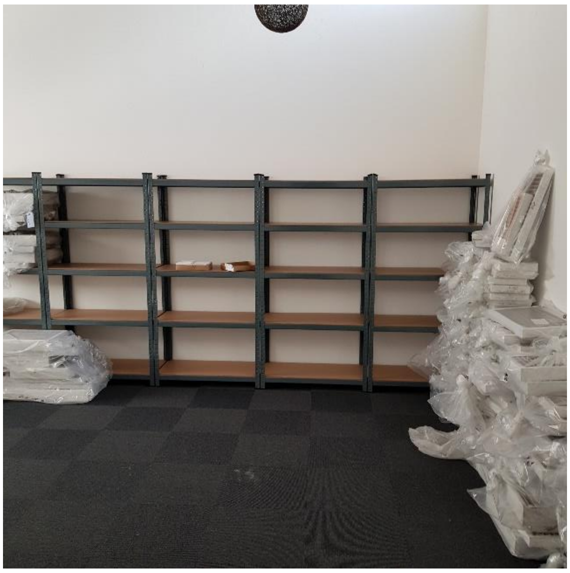
Table 9 VOC 13

Filter organizing process.

1. The first day at the Airmaster, to observe the used filter stock.

2. Some of the filter bages had abundance of alive bugs.

3. Shelves were ordered and put together in an adjoing room.

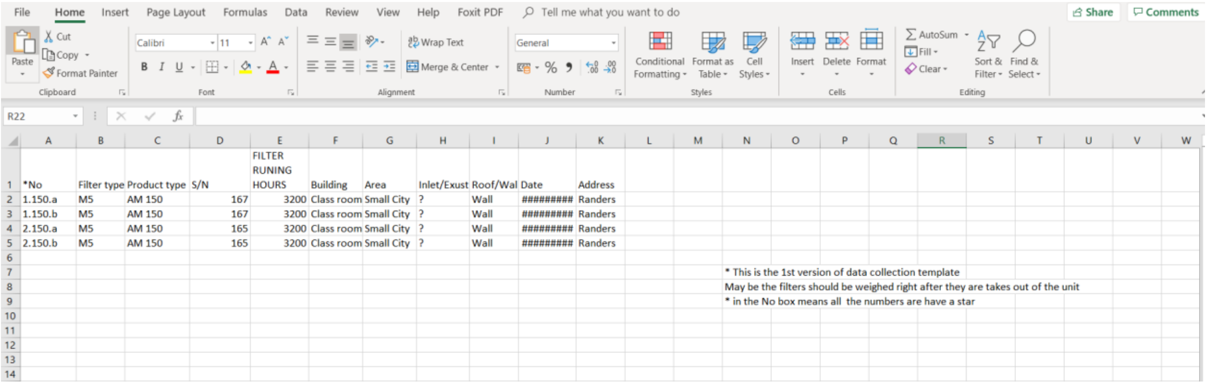
4. Filters labeled


5. Filters finaly stocked. It was a very time consuming process because as there was only one person doing the job, it was physically challenging. Forexample, picking up the filter bag with the info slip reading, reading data and typing it in the excel with the mask on (glasses getting moisty) and the gloves. Along the way the gloves and mask were simply droped as they were

lagging the process. On the other hand after finishing the organising part of the stocked filter collection (on the 1st of NOV) the next step was to see how far the work on climatic chamber is at and work on making a test rig for the experiment 1 (as discused, at , with the supervisors).

Excel print screens for The Filter data

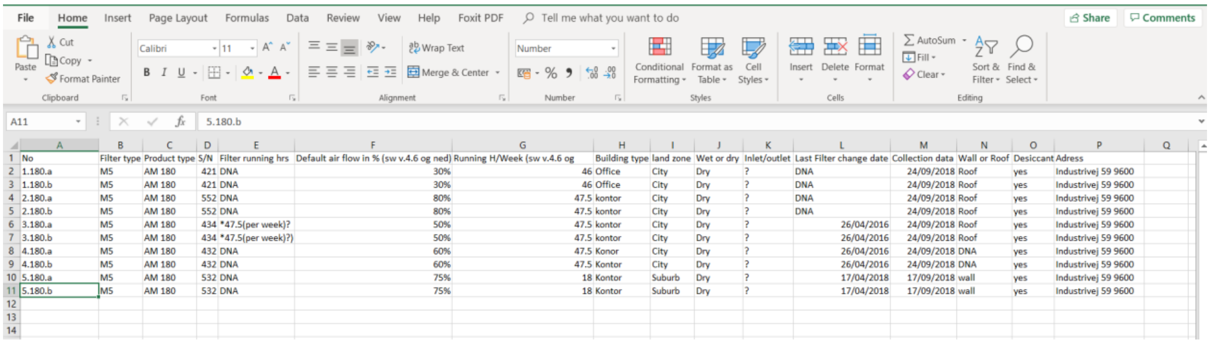
Sheet 1



*No	Filter type	Product type	S/N	FILTER RUNING HOURS	Building	Area	Inlet/Exust	Roof/Wal	Date	Address
1.150.a	M5	AM 150	167	3200	Class room	Small City	?	Wall	#########	Randers
1.150.b	M5	AM 150	167	3200	Class room	Small City	?	Wall	#########	Randers
2.150.a	M5	AM 150	165	3200	Class room	Small City	?	Wall	#########	Randers
2.150.b	M5	AM 150	165	3200	Class room	Small City	?	Wall	#########	Randers

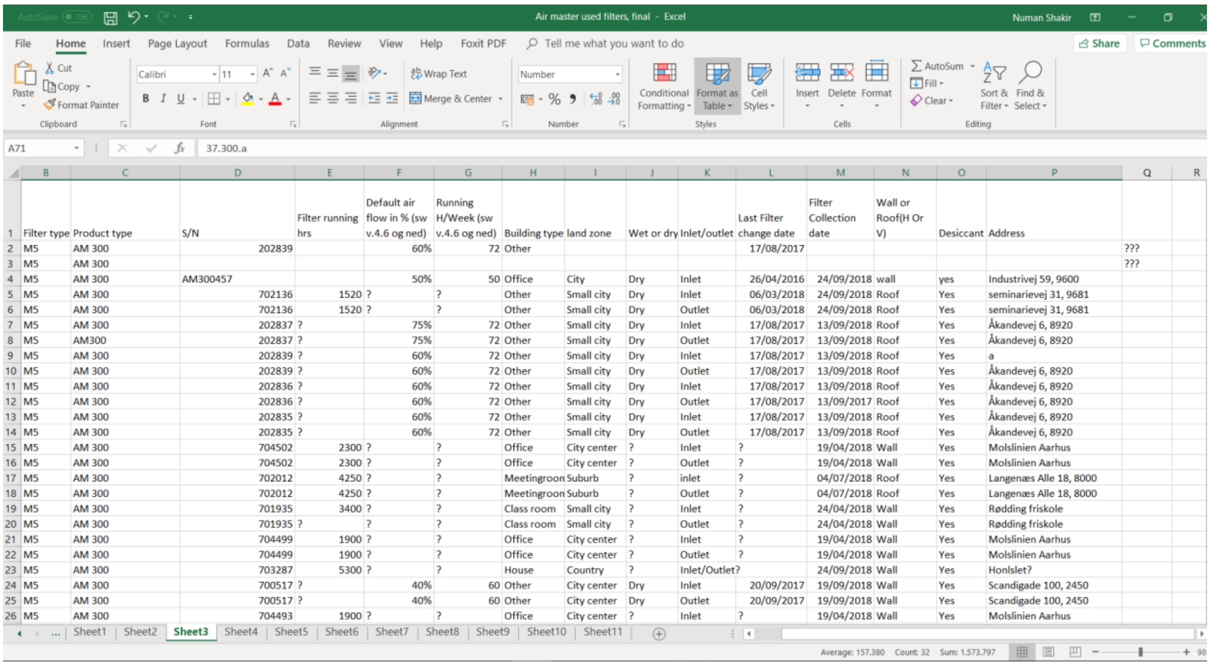
* This is the 1st version of data collection template
May be the filters should be weighed right after they are takes out of the unit
* in the No box means all the numbers are have a star

Sheet 2



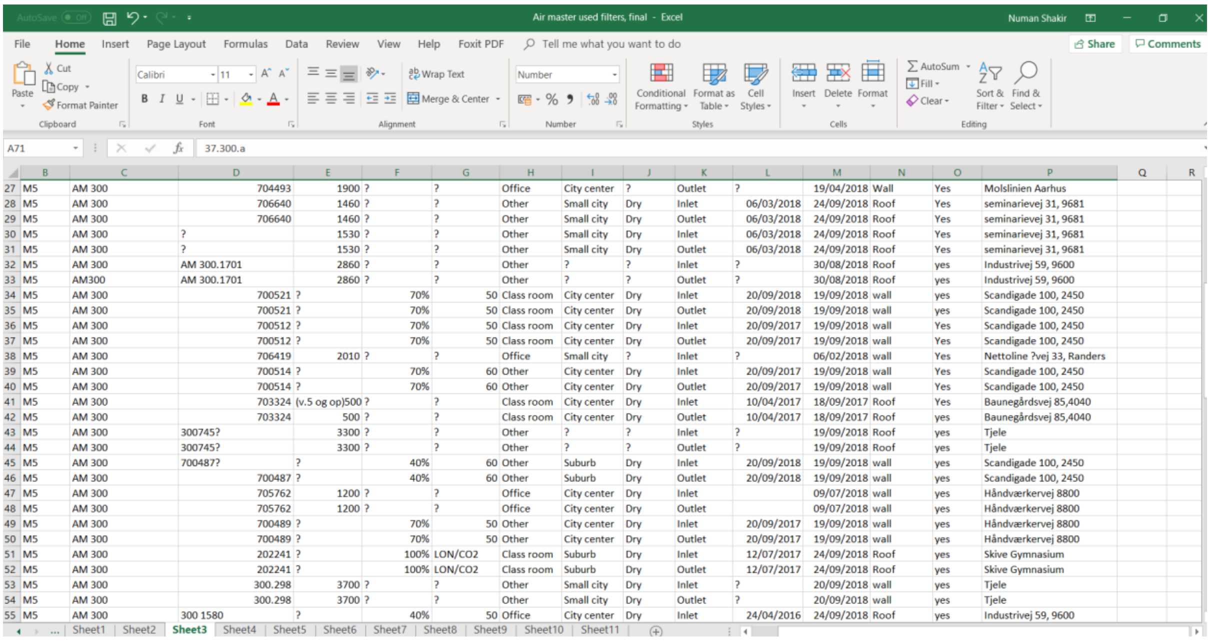
No	Filter type	Product type	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Collection data	Wall or Roof	Desiccant	Adress
1.180.a	M5	AM 180	421	DNA	30%	46	Office	City	Dry	?	DNA	24/09/2018	Roof	yes	Industrivej 59 9600
1.180.b	M5	AM 180	421	DNA	30%	46	Office	City	Dry	?	DNA	24/09/2018	Roof	yes	Industrivej 59 9600
2.180.a	M5	AM 180	552	DNA	80%	47.5	kontor	City	Dry	?	DNA	24/09/2018	Roof	yes	Industrivej 59 9600
2.180.b	M5	AM 180	552	DNA	80%	47.5	kontor	City	Dry	?	DNA	24/09/2018	Roof	yes	Industrivej 59 9600
3.180.a	M5	AM 180	434	*47.5(per week)?	50%	47.5	kontor	City	Dry	?	26/04/2016	24/09/2018	Roof	yes	Industrivej 59 9600
3.180.b	M5	AM 180	434	*47.5(per week)?)	50%	47.5	kontor	City	Dry	?	26/04/2016	24/09/2018	Roof	yes	Industrivej 59 9600
4.180.a	M5	AM 180	432	DNA	60%	47.5	Konor	City	Dry	?	26/04/2016	24/09/2018	DNA	yes	Industrivej 59 9600
4.180.b	M5	AM 180	432	DNA	60%	47.5	Kontor	City	Dry	?	26/04/2016	24/09/2018	DNA	yes	Industrivej 59 9600
5.180.a	M5	AM 180	532	DNA	75%	18	Kontor	Suburb	Dry	?	17/04/2018	17/09/2018	wall	yes	Industrivej 59 9600
5.180.b	M5	AM 180	532	DNA	75%	18	Kontor	Suburb	Dry	?	17/04/2018	17/09/2018	wall	yes	Industrivej 59 9600

Sheet 3



	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Filter type	Product type	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address	
2	M5	AM 300	202839		60%	72	Other				17/08/2017					???
3	M5	AM 300														???
4	M5	AM 300	AM300457		50%	50	Office	City	Dry	Inlet	26/04/2016	24/09/2018	wall	yes	Industrivej 59, 9600	
5	M5	AM 300	702136	1520	?	?	Other	Small city	Dry	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
6	M5	AM 300	702136	1520	?	?	Other	Small city	Dry	Outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
7	M5	AM 300	202837	?	75%	72	Other	Small city	Dry	Inlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
8	M5	AM300	202837	?	75%	72	Other	Small city	Dry	Outlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
9	M5	AM 300	202839	?	60%	72	Other	Small city	Dry	Inlet	17/08/2017	13/09/2018	Roof	Yes	a	
10	M5	AM 300	202839	?	60%	72	Other	Small city	Dry	Outlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
11	M5	AM 300	202836	?	60%	72	Other	Small city	Dry	Inlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
12	M5	AM 300	202836	?	60%	72	Other	Small city	Dry	Outlet	17/08/2017	13/09/2017	Roof	Yes	Åkandevej 6, 8920	
13	M5	AM 300	202835	?	60%	72	Other	Small city	Dry	Inlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
14	M5	AM 300	202835	?	60%	72	Other	Small city	Dry	Outlet	17/08/2017	13/09/2018	Roof	Yes	Åkandevej 6, 8920	
15	M5	AM 300	704502	2300	?	?	Office	City center	?	Inlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	
16	M5	AM 300	704502	2300	?	?	Office	City center	?	Outlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	
17	M5	AM 300	702012	4250	?	?	Meetingroon	Suburb	?	inlet	?	04/07/2018	Roof	Yes	Langenæs Alle 18, 8000	
18	M5	AM 300	702012	4250	?	?	Meetingroon	Suburb	?	Outlet	?	04/07/2018	Roof	Yes	Langenæs Alle 18, 8000	
19	M5	AM 300	701935	3400	?	?	Class room	Small city	?	Inlet	?	24/04/2018	Wall	Yes	Rødding friskole	
20	M5	AM 300	701935	?	?	?	Class room	Small city	?	Outlet	?	24/04/2018	Wall	Yes	Rødding friskole	
21	M5	AM 300	704499	1900	?	?	Office	City center	?	Inlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	
22	M5	AM 300	704499	1900	?	?	Office	City center	?	Outlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	
23	M5	AM 300	703287	5300	?	?	House	Country	?	Inlet/Outlet?		24/09/2018	Wall	Yes	Honlslet?	
24	M5	AM 300	700517	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	Wall	Yes	Scandigade 100, 2450	
25	M5	AM 300	700517	?	40%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	Wall	Yes	Scandigade 100, 2450	
26	M5	AM 300	704493	1900	?	?	Office	City center	?	Inlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	

Sheet1 Sheet2 Sheet3 Sheet4 Sheet5 Sheet6 Sheet7 Sheet8 Sheet9 Sheet10 Sheet11



	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
27	M5	AM 300	704493	1900	?	?	Office	City center	?	Outlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	
28	M5	AM 300	706640	1460	?	?	Other	Small city	Dry	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
29	M5	AM 300	706640	1460	?	?	Other	Small city	Dry	Outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
30	M5	AM 300	?	1530	?	?	Other	Small city	Dry	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
31	M5	AM 300	?	1530	?	?	Other	Small city	Dry	Outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	
32	M5	AM 300	AM 300.1701	2860	?	?	Other	?	?	Inlet	?	30/08/2018	Roof	yes	Industrivej 59, 9600	
33	M5	AM300	AM 300.1701	2860	?	?	Other	?	?	Outlet	?	30/08/2018	Roof	yes	Industrivej 59, 9600	
34	M5	AM 300	700521	?	70%	50	Class room	City center	Dry	Inlet	20/09/2018	19/09/2018	wall	yes	Scandigade 100, 2450	
35	M5	AM 300	700521	?	70%	50	Class room	City center	Dry	Outlet	20/09/2018	19/09/2018	wall	yes	Scandigade 100, 2450	
36	M5	AM 300	700512	?	70%	50	Class room	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	Yes	Scandigade 100, 2450	
37	M5	AM 300	700512	?	70%	50	Class room	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	Yes	Scandigade 100, 2450	
38	M5	AM 300	706419	2010	?	?	Office	Small city	?	Inlet	?	06/02/2018	wall	Yes	Nettoline ?vej 33, Randers	
39	M5	AM 300	700514	?	70%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	Yes	Scandigade 100, 2450	
40	M5	AM 300	700514	?	70%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	Yes	Scandigade 100, 2450	
41	M5	AM 300	703324	(v.5 og op)500	?	?	Class room	City center	Dry	Inlet	10/04/2017	18/09/2017	Roof	Yes	Baunegårdsvej 85,4040	
42	M5	AM 300	703324	500	?	?	Class room	City center	Dry	Outlet	10/04/2017	18/09/2017	Roof	yes	Baunegårdsvej 85,4040	
43	M5	AM 300	300745?	3300	?	?	Other	?	?	Inlet	?	19/09/2018	Roof	yes	Tjele	
44	M5	AM 300	300745?	3300	?	?	Other	?	?	Outlet	?	19/09/2018	Roof	yes	Tjele	
45	M5	AM 300	700487?	?	40%	60	Other	Suburb	Dry	Inlet	20/09/2018	19/09/2018	wall	yes	Scandigade 100, 2450	
46	M5	AM 300	700487	?	40%	60	Other	Suburb	Dry	Outlet	20/09/2018	19/09/2018	wall	yes	Scandigade 100, 2450	
47	M5	AM 300	705762	1200	?	?	Office	City center	Dry	Inlet		09/07/2018	wall	yes	Håndværkervej 8800	
48	M5	AM 300	705762	1200	?	?	Office	City center	Dry	Outlet		09/07/2018	wall	yes	Håndværkervej 8800	
49	M5	AM 300	700489	?	70%	50	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Håndværkervej 8800	
50	M5	AM 300	700489	?	70%	50	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Håndværkervej 8800	
51	M5	AM 300	202241	?	100%	LON/CO2	Class room	Suburb	Dry	Inlet	12/07/2017	24/09/2018	Roof	yes	Skive Gymnasium	
52	M5	AM 300	202241	?	100%	LON/CO2	Class room	Suburb	Dry	Outlet	12/07/2017	24/09/2018	Roof	yes	Skive Gymnasium	
53	M5	AM 300	300.298	3700	?	?	Other	Small city	Dry	Inlet	?	20/09/2018	wall	yes	Tjele	
54	M5	AM 300	300.298	3700	?	?	Other	Small city	Dry	Outlet	?	20/09/2018	wall	yes	Tjele	
55	M5	AM 300	300 1580	?	40%	50	Office	City center	Dry	Inlet	24/04/2016	24/09/2018	Roof	yes	Industrivej 59, 9600	

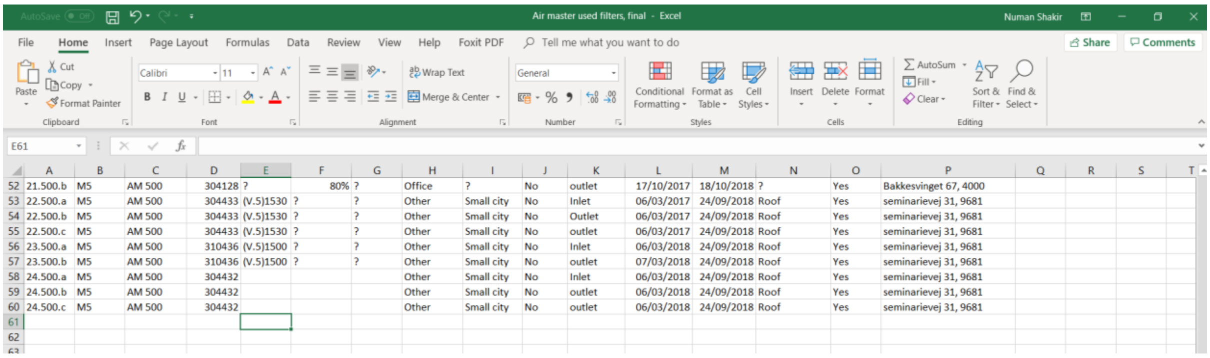
Sheet1 Sheet2 Sheet3 Sheet4 Sheet5 Sheet6 Sheet7 Sheet8 Sheet9 Sheet10 Sheet11

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
54	M5	AM 300	300.298	3700	?	?	Other	Small city	Dry	Outlet	?	20/09/2018	wall	yes	Tjele
55	M5	AM 300	300 1580	?	40%	50	Office	City center	Dry	Inlet	24/04/2016	24/09/2018	Roof	yes	Industrivej 59, 9600
56	M5	AM 300	300 1580	?	40%	50	Office	City center	Dry	Outlet	24/04/2016	24/09/2018	Roof	yes	Industrivej 59, 9600
57	M5	AM 300	300.319	3300	?	?	Other	?	?	Inlet	?	20/09/2018	Roof	yes	Tjele
58	M5	AM 300	300.319	3300	?	?	Other	?	?	Outlet	?	20/09/2018	Roof	yes	Tjele
59	M5	AM 300	700.516	?	70%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	Wall	yes	Scandigade 100, 2450
60	M5	AM 300	700.516	?	70%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
61	M5	AM 300	700.515	?	70%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
62	M5	AM 300	700.515	?	70%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
63	M5	AM 300	Am 300.394	?	?	?	Office	City center	Dry	Inlet	26/09/2016	24/09/2018	wall	yes	Industrivej 59, 9600
64	M5	AM 300	Am 300.394	?	?	?	Office	City center	Dry	Outlet	26/09/2019	24/09/2018	wall	yes	Industrivej 59, 9600
65	M5	AM 300	Mødelokale, Produktion	?	40% CO2	50	Office	Suburb	Dry	Inlet	18/02/2016	27/09/2018	Roof	yes	Industrivej 59, 9600
66	M5	AM 300	Mødelokale, Produktion	?	40% CO2	50	Office	Suburb	Dry	Outlet	18/02/2016	27/09/2018	Roof	yes	Industrivej 59, 9600
67	M5	AM 300	300.298	?	80%	50	Other	Small city	Dry	Inlet	12/04/2018	17/09/2018	wall	yes	Nordmarksvej 62, 4040
68	M5	AM 300	300.298	?	80%	50	Other	Small city	Dry	Outlet	12/04/2018	17/09/2018	wall	yes	Nordmarksvej 62, 4040
69	M5	AM 300	700519	?	70%	60	Other	City center	Dry	Inlet	20/04/2018	17/09/2018	wall	yes	Scandigade 100, 2450
70	M5	AM 300	700519	?	70%	60	Other	City center	Dry	Outlet	20/04/2018	17/09/2018	wall	yes	Scandigade 100, 2450
71	M5	AM 300	700480	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	17/09/2018	wall	yes	Scandigade 100, 2450
72	M5	AM 300	700480	?	40%	60	Other	City center	Dry	Outlet	20/09/2017	17/09/2018	wall	yes	Scandigade 100, 2450
73	M5	AM 300	700492	?	70%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
74	M5	AM 300	700492	?	70%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
75	M5	AM 300		?	70%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
76	M5	AM 300	700511	?	70%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
77	M5	AM 300	?												
78	M5	AM 300	?												
79	M5	AM 300	700510	?	40%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
80	M5	AM 300	700510	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
81	M5	AM 300	700481	?	40%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
82	M5	AM 300	700481	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
80	M5	AM 300	700510	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
81	M5	AM 300	700481	?	40%	60	Other	City center	Dry	Outlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
82	M5	AM 300	700481	?	40%	60	Other	City center	Dry	Inlet	20/09/2017	19/09/2018	wall	yes	Scandigade 100, 2450
83	M5	AM 300	AM 300 1706	2860	?	?	Other	Small city	Dry	Inlet	?	30/08/2018	Roof	yes	Industrivej 59, 9600
84	M5	AM 300	AM 300 1706	2860	?	?	Other	Small city	Dry	Outlet	?	30/08/2018	Roof	yes	Industrivej 59, 9600
85	M5	Am 300	300 288	3200	?	?	Other	Small city	Dry	Inlet	?	20/09/2018	Roof	yes	Tjele
86	M5	Am 300	300 288	3200	?	?	Other	Small city	Dry	Outlet	?	20/09/2018	Roof	yes	Tjele
87	M5	AM 300	703222	5000	?	?	Office	City center	Dry	Inlet	?	?	wall	yes	Hykenstræde 6, 1207
88	M5	Am 300	703222	5000	?	?	Office	City center	Dry	Outlet	?	?	wall	yes	Hykenstræde 6, 1207
89	M5	Am 300	702515	(V.5)2100	?	?	Office	Suburb	Dry	Inlet	?	27/09/2018	wall	yes	Industrivej 29, 9600
90	M5	Am 300 KØL	7002515	(V.5)2100	?	?	Office	Suburb	Dry	Outlet	?	27/09/2018	wall	yes	Industrivej 29, 9600
91	M5	AM 300	???????	(V.5)1530	?	?	Office	landzone	Dry	inlet	?	19/09/2018	wall	yes	seminarievej 31, 9681
92	M5	AM 300		(V.5)1530	?	?	Office	landzone	Dry	Outlet	?	19/09/2018	wall	yes	seminarievej 31, 9681
93	M5	AM 300	703225	(V.5)5000	?	?	Office	landzone	Dry	inlet	?	24/09/2018	Roof	yes	Hyskenstræde 6, 1207
94	M5	AM 300	702532	(V.5)5000	?	?	Office	landzone	Dry	Outlet	?	24/09/2018	Roof	yes	Hykenstræde 6, 1207
95	M5	AM 300	701971	4680	?	?	Office	landzone	?	inlet	?	02/07/2018	Roof	yes	Skyttevej 5, 7180
96	M5	AM 300	701971	4680	?	?	Office	landzone	?	Outlet	?	02/07/2018	Roof	yes	Skyttevej 5, 7180
97	M5	Am300	300.928	?	80%	?	Andet	Small city	Dry	Inlet	?	12/04/2018	?	yes	Nordmarksvej 62, 4040
98	M5	AM300	300.928		80%	?	other	Small city	Dry	Outlet	?	12/04/2018	?	yes	Nordmarksvej 62, 4040
99	M5	AM300	300.319	3300	?	?	Other	?	Dry	Inlet	?	20/09/2018	wall	yes	Tjele
100	M5	AM300	300.319	3300	?	?	Other	?	Dry	Outlet	?	20/09/2018	wall	yes	Tjele
101	M5	Am300	300.288	3700	?	?	Other	Small city	Dry	inlet	?	?	Roof	yes	Tjele
102	M5	AM300	300.288	3700	?	?	Other	Small city	Dry	Outlet	?	?	Roof	yes	Tjele
103	M5	AM300	202.241	?	100%	LON/CO2	Other	Suburb	Dry	inlet	12/07/2017	21/09/2018	Roof	yes	Skive Gymnasium
104	M5	AM300	202.441	?	100%	LON/CO2	other	Suburb	Dry	Outlet	12/07/2017	21/09/2018	Roof	yes	Skive Gymnasium
105	M5	Am300	300.315	3300	?	?	other	Suburb	Dry	inlet	?	26/09/2018	wall	yes	Tjele
106	M5	Am300	300.315	3300	?	?	Other	Suburb	Dry	Outlet	?	26/09/2018	Wall	yes	Tjele
107	M5	Am300	300.394	?	?	?	Office	City center	Dry	inlet	26/09/2016	24/09/2018	Wall	yes	Industrivej 59, 9600
108	M5	Am300	300.394	?	?	?	Office	City center	Dry	Outlet	26/09/2016	24/06/2018	Wall	yes	Industrivej 59, 9600

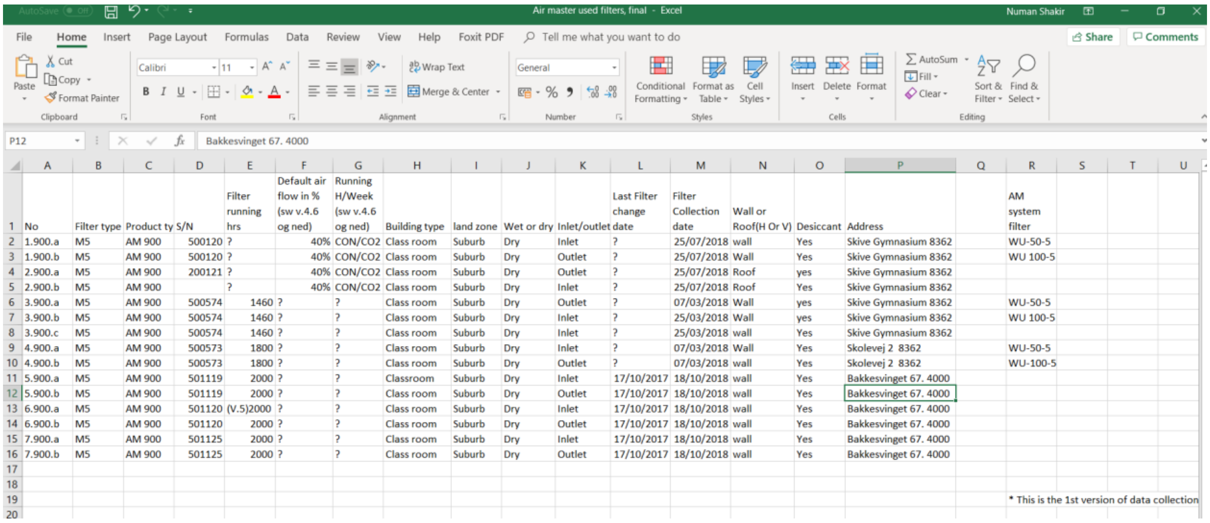
Sheet 4

	No	Filter type	Product type	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry (RH)	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof (H Or V)	Desiccant	Address	Size	R	S
2	1.a.500	M5	AM 500	500.077	?	?	PiR	Other	Small city	No	Inlet	17-Aug	20/08/2018	Wall	Yes	Gl trangelundvej 9, 8881	?		
3	1.b.500	M5	AM 500	500.077	?	?	PiR	Other	Small city	No	Outlet	17-Aug	20/08/2018	Wall	Yes	Gl trangelundvej 9, 8881	?		
4	2.a.500	M5	AM 500	310237	1800	?	?	Class room	City center	No	Inlet	?	19/09/2018	Roof	yes	Baunegårdsvej 85, 4040	?		
5	2.b.500	M5	AM 500	310237	1800	?	?	Class room	City center	No	Outlet	?	19/09/2018	Roof	Yes	Baunegårdsvej 85, 4040	?		
6	2.c.500	M5	AM 500	310237	1800	?	?	Class room	City center	No	Outlet	?	19/09/2018	Roof	Yes	Baunegårdsvej 85, 4040	?		
7	3.a.500	M5	AM 500	300978	?	40%	LON/CO2	Class room	Suburb	No	Inlet	?	24/07/2018	Roof	yes	Skive Gym	?		
8	3.b.500	M5	AM 500	300978	?	40%	LON/CO2	Class room	Suburb	No	Outlet	?	24/07/2018	Roof	Yes	Skive Gym	?		
9	3.c.500	M5	AM 500	300978	?	40%	LON/CO2	Class room	Suburb	No	Outlet	?	24/07/2018	Roof	Yes	Skive Gym	?		
10	4.a.500	M5	AM 500 K	702515	2100	?	?	Office	Suburb	No	Inlet	?	27/07/2018	Wall	yes	Indistrivej 29, 9600	?		**?** Means the inf
11	4.b.500	M5	AM 500 K	702515	2100	?	?	Office	Suburb	No	Outlet	?	27/07/2018	Wall	Yes	Indistrivej 29, 9600	?		K= Køl
12	5.a.500	M5	AM 500 M	500609	?	100%	80	Other	Small city	No	Inlet	?	20/05/2018	?	yes	Gl trangelundvej 9, 8881	?		M = Motions Ce
13	5.b.500	M5	AM 500 M	500609	?	100%	80	other	Small city	No	Outlet	?	20/08/2018	?	yes	Gl trangelundvej 9, 8881	?		Drift timer sider
14	6.a.500	M5	AM 500	3110237	1800	?	?	Class room	Suburb	No	Inlet	?	19/09/2018	Roof	Yes	Baunegårdsvej 85, 4040	?		
15	6.b.500	M5	AM 500	3110237	1800	?	?	Class room	Suburb	No	Outlet	?	19/09/2018	Roof	Yes	Baunegårdsvej 85, 4040	?		
16	6.c.500	M5	AM 500	3110237	1800	?	?	Class room	Suburb	No	Outlet	?	19/09/2018	Roof	Yes	Baunegårdsvej 85, 4040	?		
17	7.a.500	M5	AM 500 K	301895	?	80%	55	Office	Suburb	No	Inlet	?	18/02/2016	Wall	Yes	Baunegårdsvej 85, 4040	?		
18	7.b.500	M5	AM 500 K	301895	?	80%	55	Office	Suburb	No	Outlet	?	18/02/2016	Wall	Yes	Baunegårdsvej 85, 4040			
19	8.a.500	M5	AM 500	304779	1590	?	?	Office	Suburb	No	Outlet	?	24/09/2018	Wall	Yes	Indistrivej 59, 9600			
20	8.b.500	M5	AM 500	304779	1590	?	?	Office	Suburb	No	Outlet	?	24/09/2018	Wall	yes	Industrivej 59, 9600			
21	*9.a.500	M5	AM 500	305914	1800	?	?	Office	Suburb	No	Inlet	?	11/07/2018	Wall	yes	Vinklevej 8800			
22	*9.b.500	M5	AM 500	3005914	1800	?	?	Office	Suburb	No	Outlet	?	11/07/2018	Wall	yes	Vinklevej 8800			
23	10.a.500	M5	AM 500	301716	?	100%	50	Other	Small city	No	Inlet	?	28/08/2018	wall	yes	Bjertparken , 7830			
24	10.b.500	M5	AM 500	301716	?	100%	50	Other	Small city	No	Outlet	?	28//08/2018	wall	yes	Bjertparken , 7830			
25	11.a.500	M5	AM 500	310462	1300	?	?	Class room	Suburb	No	Outlet	?	13/09/2018	Roof	Yes	Vejlevej, Horsens, learnmark			
26	11.b.500	M5	AM500	310462	1300	?	?	Class room	Suburb	No	Outlet	?	13/09/2018	Roof	Yes	Vejlevej, Horsens, learnmark			
27	11.500.c																		
28	12.a.500	M5	AM 500	310346	1500	?	?	Other	Suburb	No	Outlet	?	24/09/2018	Roof	Yes	seminarievej 31, 9681			
29	12.b.500	M5	AM 500	310346	1500	?	?	Other	Suburb	No	Outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681			
30	*12.a.500	M5	AM 500	306923	3700	?	?	Class room	Small city	?	Outlet	?	12/04/2018	Roof	Yes	Odden Skole	Is it a only one filter		yes
31	12.500.b										Inlet								
32	*12.c.500										InletF								
33	13.a.500	M5	AM 500	307401	1050	?	?	Office	City center	?	Inlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	?		
34	13.b.500	M5	AM 500	307401	1005	?	?	Office	City center	?	Outlet	?	19/04/2018	Wall	Yes	Molslinien Aarhus	?		
35	14.a.500	M5	AM 500	306963	3700	?	?	Class room	Small city	?	Outlet	?	12/04/2018	Roof	yes	Odden Skole	?		
36	15.a.500	M5	AM 500	306926	3900	?	?	Class room	Small city	?	Outlet	?	12/04/2018	Roof	yes	Odden Skole	?		
37	15.b.500	M5	AM 500	306926	3900	?	?	Class room	Small city	?	Outlet	?	12/04/2018	Roof	Yes	Odden Skole			
38	15.500.c	M5	AM 500	306926	3900	?	?	Class room	Small city	?	Inlet	?	12/04/2018	Roof	Yes	Odden Skole			
39	16.a.500	M5	AM 500	304431	1530	?	?	Other	Small city	No	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681	?		
40	16.b.500	M5	AM 500	304431	1530	?	?	Other	Small city	No	Outlet	06/03/2018	24/09/2018	Roof	yes	seminarievej 31, 9681	?		
41	16.c.500	M5	AM 500	304431	1530	?	?	Other	Small city	No	Outlet	06/03/2018	24/09/2018	Roof	yes	seminarievej 31, 9681			
42	17.a.500	M5	AM 500	8000215	1200	40%	LON/CO2	Class room	Suburb	No	?	12/07/2017	24/02/2018	Roof	Yes	Skive Gym	?		
43	18.500.a	M5	AM 500	304127	?	80%	50	Office	Suburb	No	Inlet	17/10/2017	18/10/2018	Wall	Yes	Bakkesvinget 67, 4000			
44	18.500.b	M5	AM 500	304127	?	80%	50	Office	Suburb	No	Outlet	17/10/2017	18/10/2018	Wall	Yes	Bakkesvinget 67, 4000			
45	19.500.a	M5	AM 500	304470	?	80%	50	Office	Suburb	No	Inlet	17/10/2017	18/10/2018	Roof	Yes	Ålborgvej 775, 9320			
46	19.500.b	M5	AM 500	304470	?	80%	50	Office	Suburb	No	outlet	17/10/2017	18/10/2018	Roof	Yes	Ålborgvej 775, 9320			
47	19.500.c	M5	AM 500	304470	?	80%	50	Office	Suburb	No	outlet	17/10/2017	18/10/2018	Roof	Yes	Ålborgvej 775, 9320			
48	20.500.a	M5	AM 500	304471	1580	?	?	Other	land zone	No	Inlet	17/10/2017	18/10/2018	Roof	Yes	Ålborgvej 775, 9320			
49	20.500.b	M5	AM 500	304471	1580	?	?	Other	land zone	No	outlet	17/10/2017	18/10/2018	Roof	Yes	Ålborgvej 775, 9320			
50	20.500.c	M5	AM 500	304471	1580	?	?	Other	land zone	No	outlet	17/10/2017	18/01/1900	Roof	Yes	Ålborgvej 775, 9320			
51	21.500.a	M5	AM 500	304128	?	80%	?	Office	?	No	Inlet	17/10/2017	18/10/2018	?	Yes	Bakkesvinget 67, 4000			
52	21.500.b	M5	AM 500	304128	?	80%	?	Office	?	No	outlet	17/10/2017	18/10/2018	?	Yes	Bakkesvinget 67, 4000			
53	22.500.a	M5	AM 500	304433	(V.5)1530	?	?	Other	Small city	No	Inlet	06/03/2017	24/09/2018	Roof	Yes	seminarievej 31, 9681			



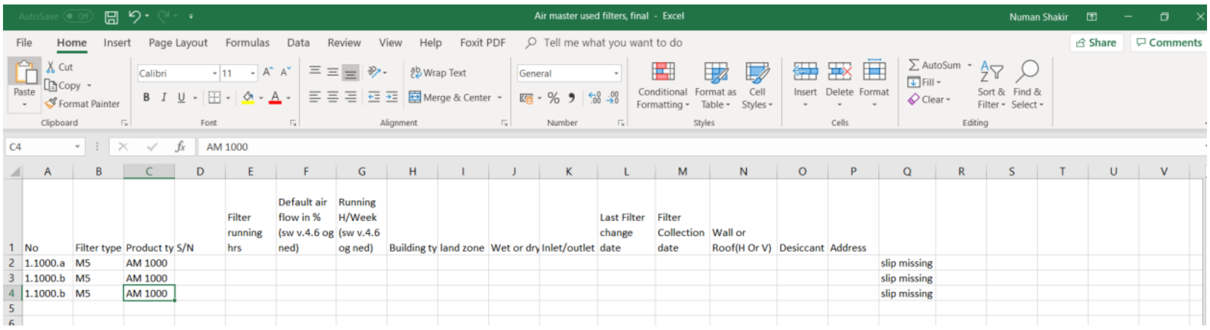
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
52	21.500.b	M5	AM 500	304128	?	80%	?	Office	?	No	outlet	17/10/2017	18/10/2018	?	Yes	Bakkesvinget 67, 4000
53	22.500.a	M5	AM 500	304433	(V.5)1530	?	?	Other	Small city	No	Inlet	06/03/2017	24/09/2018	Roof	Yes	seminarievej 31, 9681
54	22.500.b	M5	AM 500	304433	(V.5)1530	?	?	Other	Small city	No	Outlet	06/03/2017	24/09/2018	Roof	Yes	seminarievej 31, 9681
55	22.500.c	M5	AM 500	304433	(V.5)1530	?	?	Other	Small city	No	outlet	06/03/2017	24/09/2018	Roof	Yes	seminarievej 31, 9681
56	23.500.a	M5	AM 500	310436	(V.5)1500	?	?	Other	Small city	No	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681
57	23.500.b	M5	AM 500	310436	(V.5)1500	?	?	Other	Small city	No	outlet	07/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681
58	24.500.a	M5	AM 500	304432				Other	Small city	No	Inlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681
59	24.500.b	M5	AM 500	304432				Other	Small city	No	outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681
60	24.500.c	M5	AM 500	304432				Other	Small city	No	outlet	06/03/2018	24/09/2018	Roof	Yes	seminarievej 31, 9681

Sheet 6



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	No	Filter type	Product ty	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address		AM system filter
2	1.900.a	M5	AM 900	500120	?	40%	CON/CO2	Class room	Suburb	Dry	Inlet	?	25/07/2018	wall	Yes	Skive Gymnasium 8362		WU-50-5
3	1.900.b	M5	AM 900	500120	?	40%	CON/CO2	Class room	Suburb	Dry	Outlet	?	25/07/2018	Wall	Yes	Skive Gymnasium 8362		WU 100-5
4	2.900.a	M5	AM 900	200121	?	40%	CON/CO2	Class room	Suburb	Dry	Outlet	?	25/07/2018	Roof	yes	Skive Gymnasium 8362		
5	2.900.b	M5	AM 900		?	40%	CON/CO2	Class room	Suburb	Dry	Inlet	?	25/07/2018	Roof	Yes	Skive Gymnasium 8362		
6	3.900.a	M5	AM 900	500574	1460	?	?	Class room	Suburb	Dry	Outlet	?	07/03/2018	Wall	yes	Skive Gymnasium 8362		WU-50-5
7	3.900.b	M5	AM 900	500574	1460	?	?	Class room	Suburb	Dry	Inlet	?	25/03/2018	Wall	yes	Skive Gymnasium 8362		WU 100-5
8	3.900.c	M5	AM 900	500574	1460	?	?	Class room	Suburb	Dry	Inlet	?	25/03/2018	wall	Yes	Skive Gymnasium 8362		
9	4.900.a	M5	AM 900	500573	1800	?	?	Class room	Suburb	Dry	Inlet	?	07/03/2018	Wall	Yes	Skolevej 2 8362		WU-50-5
10	4.900.b	M5	AM 900	500573	1800	?	?	Class room	Suburb	Dry	Outlet	?	07/03/2018	wall	Yes	Skolevej 2 8362		WU-100-5
11	5.900.a	M5	AM 900	501119	2000	?	?	Classroom	Suburb	Dry	Inlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
12	5.900.b	M5	AM 900	501119	2000	?	?	Class room	Suburb	Dry	Outlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
13	6.900.a	M5	AM 900	501120	(V.5)2000	?	?	Class room	Suburb	Dry	Inlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
14	6.900.b	M5	AM 900	501120	2000	?	?	Class room	Suburb	Dry	Outlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
15	7.900.a	M5	AM 900	501125	2000	?	?	Class room	Suburb	Dry	Inlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
16	7.900.b	M5	AM 900	501125	2000	?	?	Class room	Suburb	Dry	Outlet	17/10/2017	18/10/2018	wall	Yes	Bakkesvinget 67. 4000		
19																		* This is the 1st version of data collection

Sheet 7



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	No	Filter type	Product ty	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building ty	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address	
2	1.1000.a	M5	AM 1000														slip missing
3	1.1000.b	M5	AM 1000														slip missing
4	1.1000.b	M5	AM 1000														slip missing

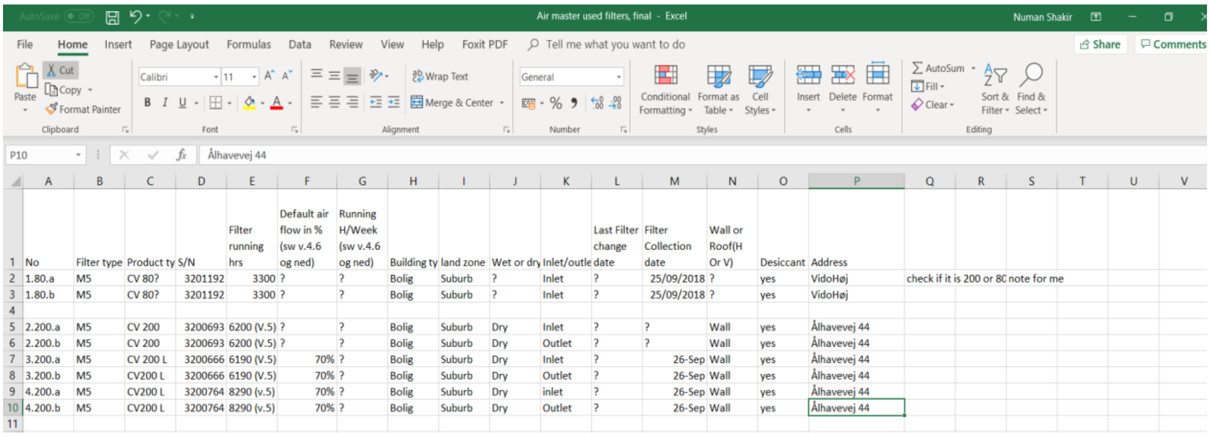
Sheet 8

No	Filter type	Product ty	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof (H Or V)	Desiccant	Address	Air master System filter
1.1200.a	M5	AM 1200	800045	?	40%		Class room	Suburb	Dry		?	24/07/2018	Roof	Yes	Skive Gymnasium	WUX-100-5
1.1200.b	M5	AM 1200	800045	?	40%		Class room	Suburb	Dry		?	24/07/2018	Roof			WU-50--5
1.1200.c	M5	AM 1200	800045	?	40%		Class room	Suburb	Dry		?	24/07/2018	Roof			WU-50--5

Sheet 9

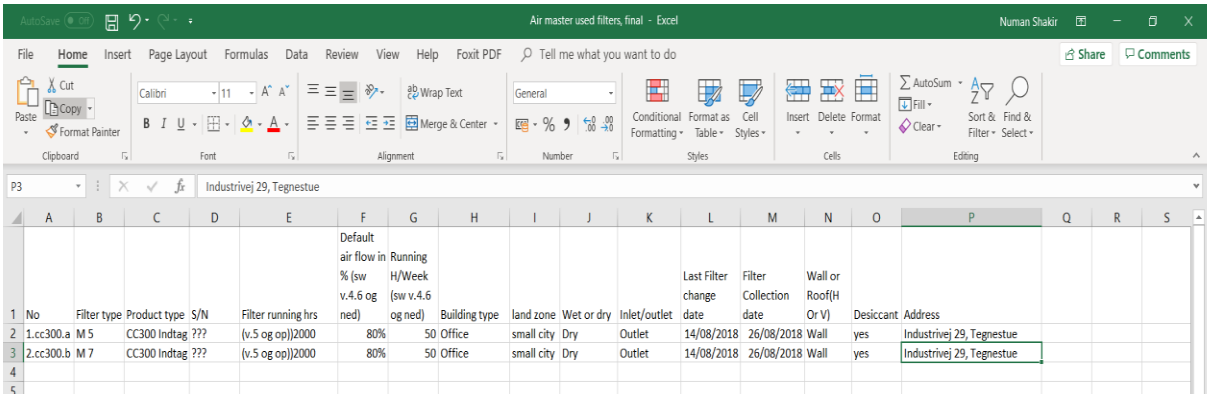
No	Filter type	Product ty	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address
1.80.a	M5	CV 80	3102632	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
1.80.b	M5	CV 80	3202632	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	Yes	Vidohøj
2.80.a	M5	CV 80	3201192	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
2.80.b	M5	CV 80	3201192	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
3.80.a	M5	CV 80	3102627	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
3.80.b	M5	CV 80	3102627	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
4.80.a	M5	CV 80	3102634	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
4.80.b	M5	CV 80	3102634	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
5.80.a	M5	CV 80	3102624	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
5.80.b	M5	CV 80	3102624	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
6.80.a	M5	CV 80	3102626	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
6.80.b	M5	CV 80	3102626	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
7.80.a	M5	CV 80	?	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
7.80.b	M5	CV 80	?	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
8.80.a	M5	CV 80	3102629	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
8.80.b	M5	CV 80	3102629	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
9.80.a	M5	CV 80	3102625	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
9.80.b	M5	CV 80	3102625	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
10.80.a	M5	CV 80	3102630	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
10.80.b	M5	CV 80	3102630	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
11.80.a	M5	CV 80	3102623	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
11.80.b	M5	CV 80	3102623	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
12.80.a	M5	CV 80	3102631	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
12.80.b	M5	CV 80	3102631	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj
13.80.a	M5	CV 80	3102633	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj

Sheet 10



No	Filter type	Product ty	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building ty	land zone	Wet or dry	Inlet/outle	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address	
1.80.a	M5	CV 80?	3201192	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj	check if it is 200 or 80 note for me
1.80.b	M5	CV 80?	3201192	3300	?	?	Bolig	Suburb	?	Inlet	?	25/09/2018	?	yes	VidoHøj	
2.200.a	M5	CV 200	3200693	6200 (V.5)	?	?	Bolig	Suburb	Dry	Inlet	?	?	Wall	yes	Ålhavevej 44	
2.200.b	M5	CV 200	3200693	6200 (V.5)	?	?	Bolig	Suburb	Dry	Outlet	?	?	Wall	yes	Ålhavevej 44	
3.200.a	M5	CV 200 L	3200666	6190 (V.5)	70%	?	Bolig	Suburb	Dry	Inlet	?	26-Sep	Wall	yes	Ålhavevej 44	
3.200.b	M5	CV200 L	3200666	6190 (V.5)	70%	?	Bolig	Suburb	Dry	Outlet	?	26-Sep	Wall	yes	Ålhavevej 44	
4.200.a	M5	CV200 L	3200764	8290 (v.5)	70%	?	Bolig	Suburb	Dry	inlet	?	26-Sep	Wall	yes	Ålhavevej 44	
4.200.b	M5	CV200 L	3200764	8290 (v.5)	70%	?	Bolig	Suburb	Dry	Outlet	?	26-Sep	Wall	yes	Ålhavevej 44	

Sheet 11

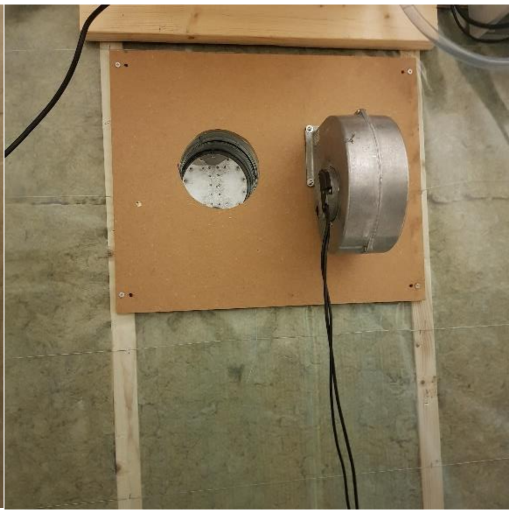


No	Filter type	Product type	S/N	Filter running hrs	Default air flow in % (sw v.4.6 og ned)	Running H/Week (sw v.4.6 og ned)	Building type	land zone	Wet or dry	Inlet/outlet	Last Filter change date	Filter Collection date	Wall or Roof(H Or V)	Desiccant	Address
1.cc300.a	M 5	CC300 Indtag	???	(v.5 og op))2000	80%	50	Office	small city	Dry	Outlet	14/08/2018	26/08/2018	Wall	yes	Industrivej 29, Tegnestue
2.cc300.b	M 7	CC300 Indtag	???	(v.5 og op))2000	80%	50	Office	small city	Dry	Outlet	14/08/2018	26/08/2018	Wall	yes	Industrivej 29, Tegnestue

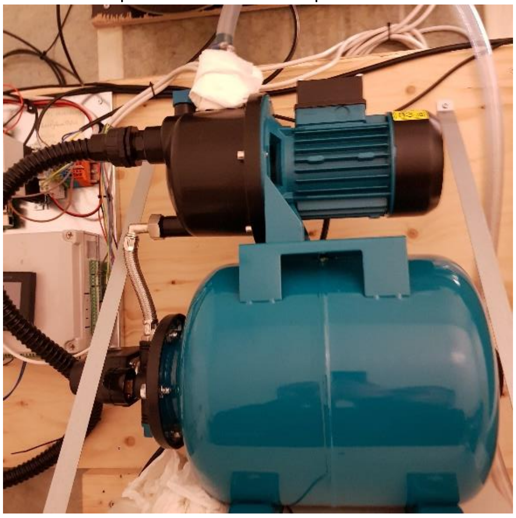
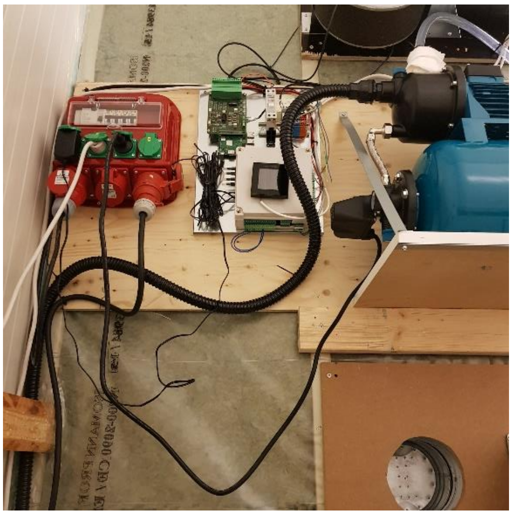
Appendix 3

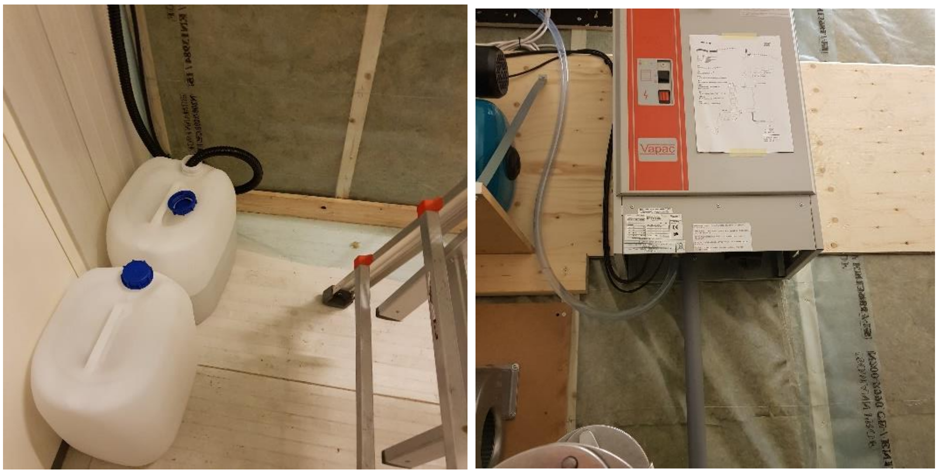
The experiment 1 and the climatic chamber

1. The below picture was taken inside the test facility on nov 8.
2. Here we can see a fan that circulate humid air, on the right and left picture (replacement air through the damper, as seen in the left picture is cold and dry/ facilitating the dehumidification process) the fan is activated when the temperature or humidity is too high inside the test faciliy.

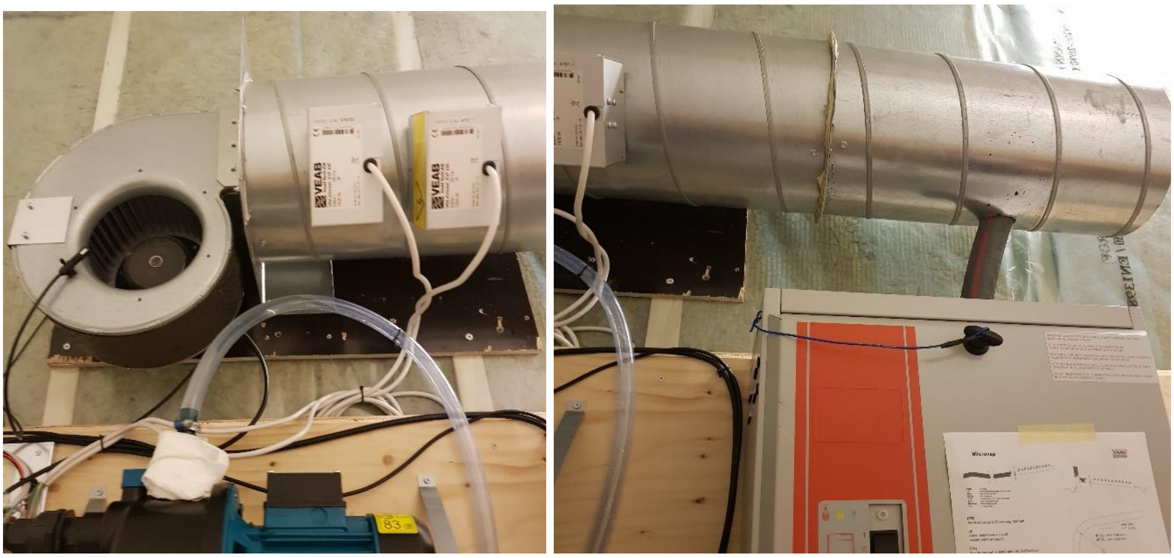



3. Below on the left is the water pump (vandværk) that is suppose to suck water from the water deposit below and provide to the humidifier



4. The humidifier along the water depot.



5. Fan used to blow air into the duct, where the steam is added and then circulated into the room. On the left picture there is located a sensor at the inlet of the fan, measuring relative humidity and tempereature for the room. At the output of the fan, an electric heating surface is mounted. At the right image shows pipe entering the duct – this is where the steam is added.

6. The experimental room (left) and the cold and dry room (right). Cold room is there to facilitate the dehumidification process.

It was also at this stage Rasmus Lund, one of the supervisor, aquired about the dehumidification process and Erik Bjørn, the head of the Research and development at AIRMASTER replied in a mail that goes at follows;

'Hello Numan

The dehumidification process is necessary and fully thought into the layout of the climatic chamber.

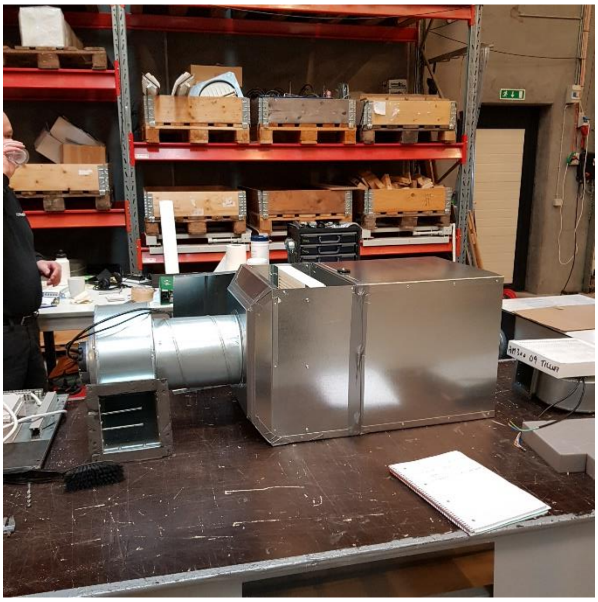
The idea is that we, if necessary, circulate air between your filter chamber and the surrounding climatic chamber, which will be cooled to whatever temperature appropriate.

The air from the climatic chamber will be very dry, when it is heated in the filter chamber.
We humidify it to which level we choose.
When conditions are good, we shut off the circulation and the heater/humidifier.
The chamber is insulated and quite airtight, it should not be necessary to climatize all the time'

Simultaneously, to the climatic chamber, the work on making a test rig to test pressure drop was being conducted.

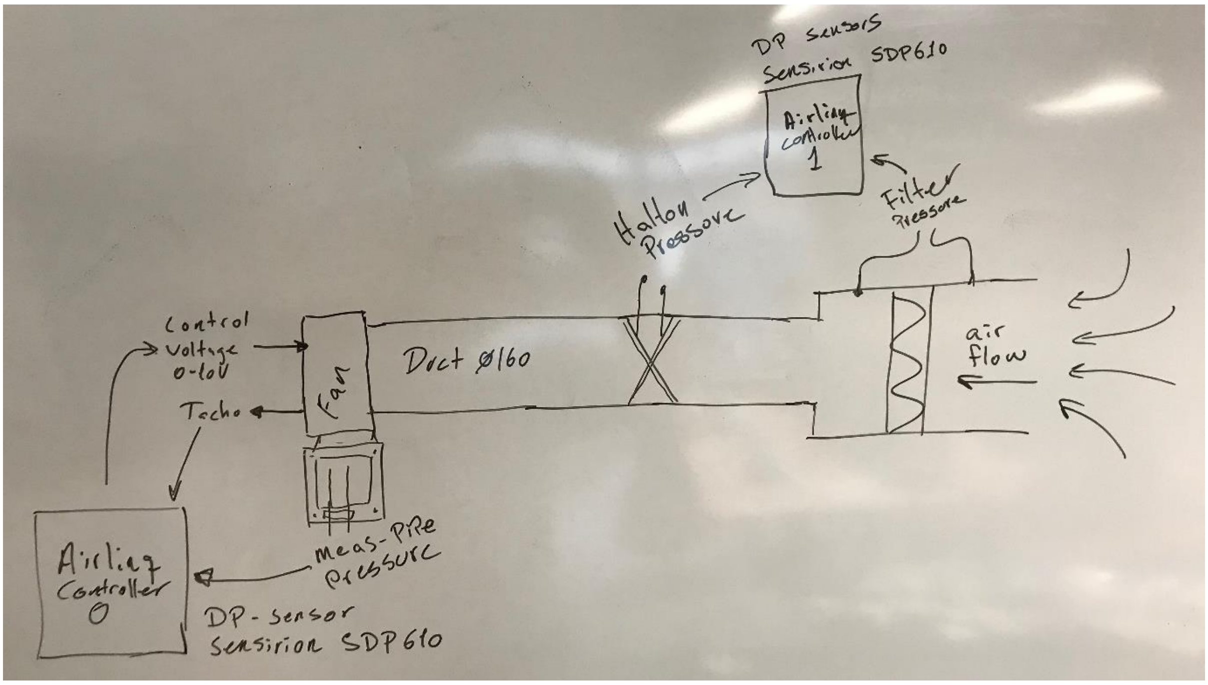
The following pictures were also taken on the 8th NOV.

Initially, the pressure difference measurements were going to be recorded by a 'testo' equipment, but this idea was dropped when Rasmus Lund recommended in a meeting that we showed use an equipment that can also log the data. The specifications of which are mentioned in the appendix 3.



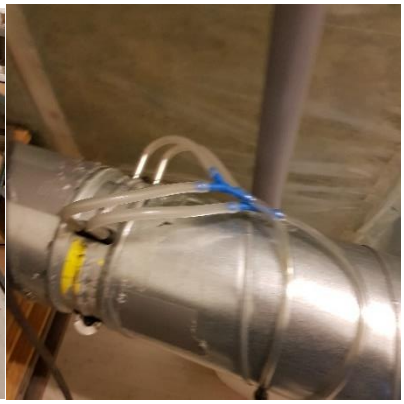
Appendix 4

The experiment 2

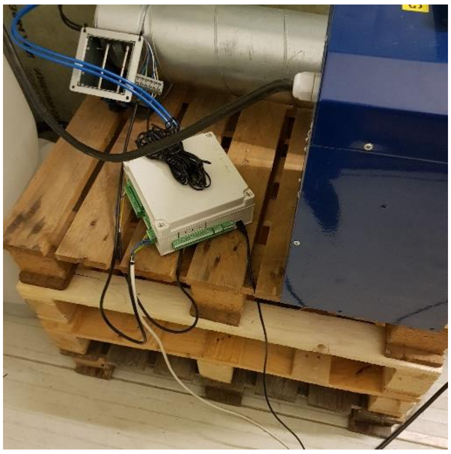


The following pictures were taken on the 22 november when the test rig, to measure the air flowrate and the pressure drop was finally completed (Duct size 340 cm long with an internal diameter of 160mm; filter casing metal box 29cm x 73cm).

1. ‘Airlink 1’ (grey control box), to measure pressure drop across filter (left picture) and flow rate at the Halton (right picture), the Halton is located in the middle of the duct.

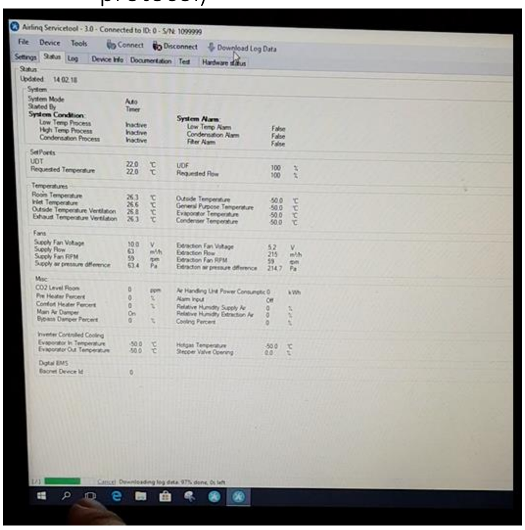
  

2. ‘Air link, Nr 0’ to measure Flow rate via , Volt, RPM, supply air pressure difference from across the Halton.

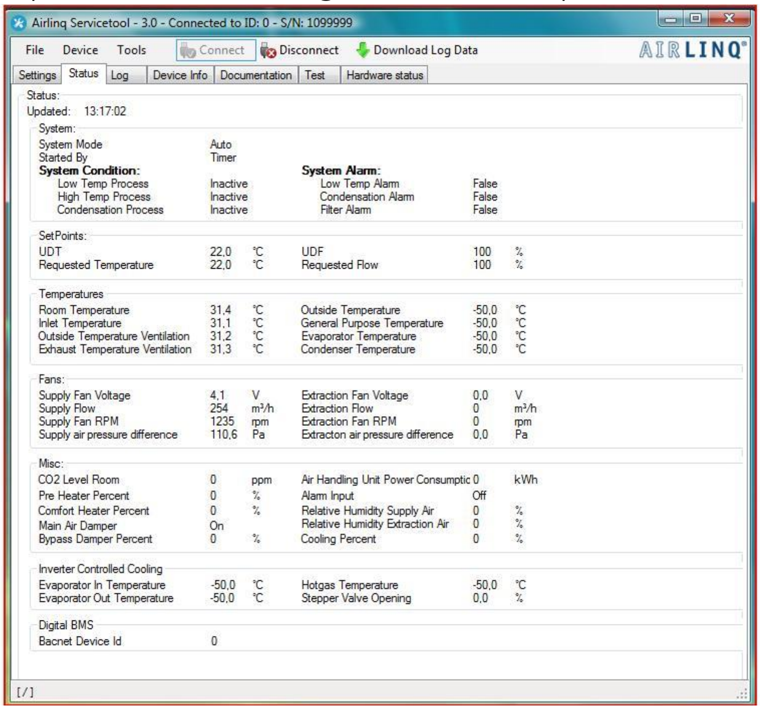


3. The 2 airlinq controllers were connected to the laptop that read and stored all the data. Once a filter was loaded into the setup, the experiment was run for 4-5 mins, whilst a printscreen was taken for both the airlink ‘nr 0’ and airlink ‘nr 1’.
4. It must be mentioned that taking print screens of all the filter experiments, both of airlink ‘0’ and ‘1’ turned out to be a really good idea as it turned out that the data taken for the filter experiment done at 10%RH, and 40%RH and part of 90% was not able to be recovered due to a glitch with the airlink software used initially and finally; First the whole test rig aparatus was run by using airlinq alpha edition software, which is used by AIRMASTER R and D workshop and it is not able to store data. Once this was realized the rest of the tests at 90% RH were conducted using another software which is just called airlinq (AM).

   For all the filter experiments process (10%, 40% and 90%RH) only the print screen data was used. As it was same for all. (Note. this should also be mentioned in the future experiment protocol)

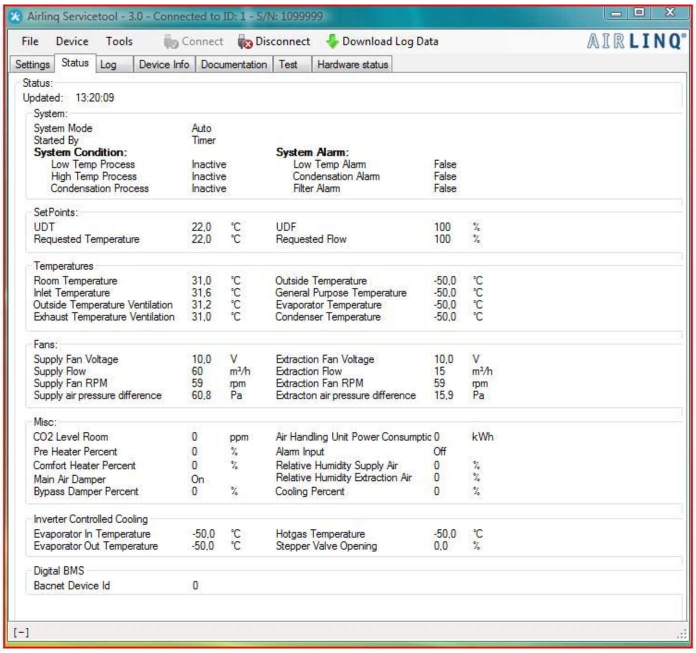


5. The process of collecting data from the print screens.

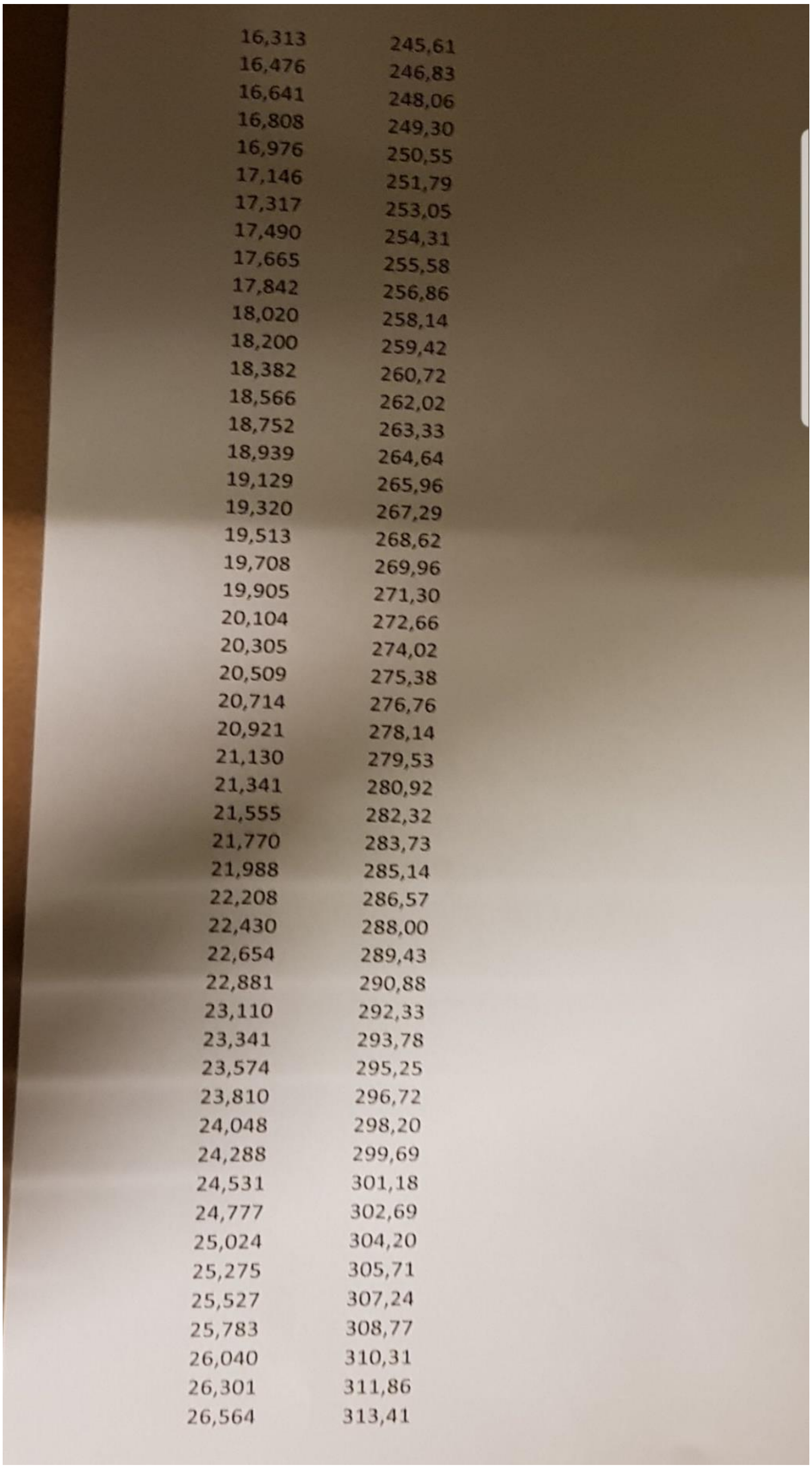


Above is a printsrcreen of Airlink '0'. The only recorded data was from the parameters mentioned under the 'Fan section'. 'Supply fan voltage', 'supply flow', 'Supply flow RPM', and 'Supply air pressure difference'.

6. Below is a print screen of airlink '1'. Just like air link '0' the focus was at only two parameters under the heading supply air pressure difference (across the filter) and Extraction air pressure difference which represented pressure in pascals that had to be converted to Flow in m^3/h by using a convertion table.

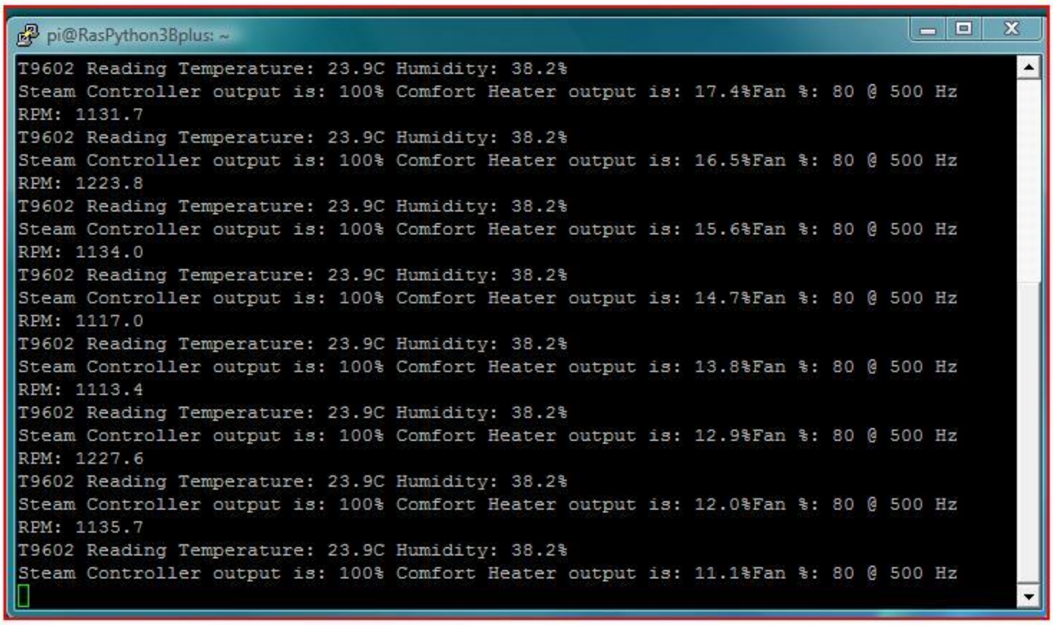


6. Convertion table. For flow that are not mentioned in this table a complete excel spreadsheet was also handed in at a later point.



16,313	245,61
16,476	246,83
16,641	248,06
16,808	249,30
16,976	250,55
17,146	251,79
17,317	253,05
17,490	254,31
17,665	255,58
17,842	256,86
18,020	258,14
18,200	259,42
18,382	260,72
18,566	262,02
18,752	263,33
18,939	264,64
19,129	265,96
19,320	267,29
19,513	268,62
19,708	269,96
19,905	271,30
20,104	272,66
20,305	274,02
20,509	275,38
20,714	276,76
20,921	278,14
21,130	279,53
21,341	280,92
21,555	282,32
21,770	283,73
21,988	285,14
22,208	286,57
22,430	288,00
22,654	289,43
22,881	290,88
23,110	292,33
23,341	293,78
23,574	295,25
23,810	296,72
24,048	298,20
24,288	299,69
24,531	301,18
24,777	302,69
25,024	304,20
25,275	305,71
25,527	307,24
25,783	308,77
26,040	310,31
26,301	311,86
26,564	313,41

7. The Relative humidity and temperature of the climatic chamber was controled by a software program called Raspberry PI 'putty'. Once the desired temperature and RH was set it would normally take 20-30 min for the climatic chamber to achieve desired settings.



Appendix 5

Particle/viruses/bacterias and sizes

An example of how clean air/Particle content in air is can be seen in the example below.

Clean room	1 Particle/Liter
Arctic air	10.000 Particle/Liter
Country side	10 millions Particle/Liter
Large city	50 millions Particle/Liter
Motor way	10 billions Particle/Liter
Cigarette smoke	billions Particle/Liter

Figure 25 different location / particle size [2]

Particles < 1 micro e.g

Examples of particles would be oil smoker, Tabaco smoke, Metal dust , Coil dust , Bacteria Viruses.

Examples of viruses would be, Fungus (yeasts and molds), 2- 30 µm, Candida, Aspergillus Penicillium. Norwalk virus 0.02 - 0.3 µm

Bacteria Examples of bacteria would be 0.3 - 2 µm, Salmonella bacteria (see table below)

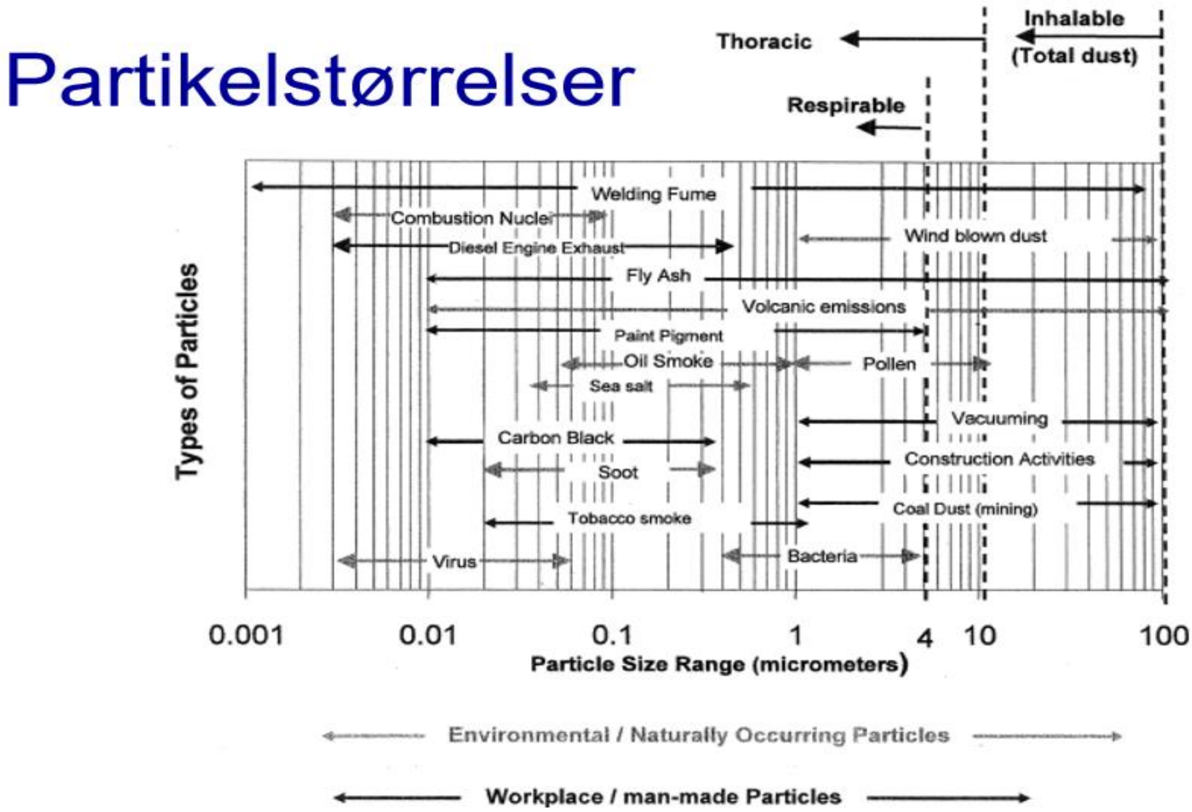


Figure 26 Particle size described [2]

Filter types and classes

Filtertyper & Filterklasser

Tabellerne nedenfor viser filter klasserne:

Filterklasse DS 779:2003	Arrestance A [%]	Eksempel på partikler	Diameter
G1	A < 65	Hår, tøj fnuller	20-200 µm
G2	65 < A < 80	vådmaling, sand, blade, fedt, dråber	10-100 µm
G3	80 < A < 90	dråber, flyvende jord, synligt støv	10-100µm
G4	90 < A	synligt støv	10-100µm

Filterklasse DS 779:2012	Effektivitet E [%]	eksempel på partikler	Diameter
M5	40 < E < 60	Pollen(hele), synligt støv	10-100 µm
M6	60 < E < 80	Sporer	10-25 µm
F7	80 < E < 9	Tonerpartikler, forbrændingspartikler, lungeskadende partikler, allergener	5-20 µm
F8	90 < E < 95	bakterier, skimmel, svampesporer	0,1µm -
F9	95 < E	bakterier, skimmel, svampesporer	0,1µm -

Filterklasse DS1822	Effiktivitet MPPS	eksempel på partikler	Diameter
E10	85 < h	Tonerpartikler	5-20 µm
E11	95 < h	Oilerøg	0,3-5 µm
E12	99,5 < h	Bakterie	0,2-25 µm
H13	99,95 < h	Tobaksrøg, aspest, skimmel	0,01-1 µm
H14	99,995 < h	Vira, mest brugte filterklasse	0,01-1 µm

Filterklasse EN 1822	Effektivitet MPPS	eksempel på partikler	Diameter
U15	99,9995 < h	Farlig levende vira, ekstreme krav	0,01-1 µm
U16	99,99995 < h	Virus	0,002-0,05 µm
U17	99,999995 < h	Ekstreme krav til filtrering, renhed	

Figure 27. Filter types and classes [3]

Suggestions to use filter depending on the location

Forslag til anvendelsesområder med filtertyper: (tryk på de blå felter, så kommer du diekte til produktet)

Udskiftning af filtre i meget gamle anlæg +30 år.	G2	PA, måtter, ruller
Olietågefiltrering 1. trin til dråber, Køkkenemfang, fedtfilter, CNC drejemaskiner, olietågeudskiller.	G2	PA, Metalfilter
Forfilter for store støvkoncentrationer, luftindtag til kølemaskiner for store maskiner, filtre for specifikke støvtyper.	G2 G3	Måttefilter, Panelfilter, Posefilter G3, PA
Som grov filter alene, eller som forfilter foran finfiltre, til offshore og tørre områder, filter for maskinrumsventilation, filter til beskyttelse af varmeflader, forfilter til luftbehandlings aggregater.	G3 G4	PA,Panelfilter,posefilter Måttefilter, Posefilter, panelfilter, G4 Z-line
Super fin støvudskilning til høj grad af renhed, filter til luftforsyning til relæudstyr eller spray malings kabiner, som afkast filter i næsten alle ventilationsanlæg og indtag til visse ventilationsanlæg.	M5/F5	Måttefilter, posefilter, panelfilter
Super fin støvudskilning i eletrisk og fotografiske industrier, airconditions anlæg, laboratorier, indtag til gas turbiner.	M6/F6	Glasmåtte C,posefilter, panelfilter, kompaktfilter,ECO-pak
Super fin støv udskilning i ventilations og airconditions anlæg, meget ren luft forsyning til krævende lokaler hvor der opholder sig mennesker, effektivt pollenfilter, effektiv mod trafik partikler, forbrændings partikler.	F7	Posefilter syntet / Glasfiber, panelfilter, kompaktfilter, kompaktfilterm/HF ramme
Følsomme relæanlæg, fødevareproduktion, forfilter til renrum, f.eks farmaceutisk, areosolfiltrering, luftindtag for gasturbiner, pollenfiltrering		
Super fin støvudskilning, for meget krævende opgaver, slutfilter til lettere operationsrum, filter til allergivenlige rum, slutfilter til klasse D (100.000) rum, forfilter til HEPA filtre,	F9	Posefilter, kompaktfilter, panelfilter

Figure 28. Filter types and classes [3]

Appendix 6

Humidity

In order to understand relative humidity, it is helpful to first understand absolute humidity. Absolute humidity is the water content of air. In other words, the mass of water vapor divided by the mass of dry air in a volume of air. It does not take temperature into consideration. Absolute humidity in the atmosphere ranges from near zero to roughly 30 grams per cubic meter when the air is saturated at 30 °C. The hotter the air is, the more water it can contain. Absolute humidity is measured in g/kg. For example, taking an average summer day at 22°C and 55% RH there would be an absolute humidity of 9 g/kg [15].

Relative Humidity

Relative humidity is expressed as a percentage. It measures the current absolute humidity relative to the maximum for that temperature; depending on the current air temperature. A reading of 100 percent relative humidity means that the air is totally saturated with water vapor creating the possibility of rain in the atmosphere and condensation [15].

• at 10°C, 10g water is the maximum amount the air can hold, so the RH is 100%

• at 30°C, 10g is about one-third of the maximum amount, therefore the RH is approximately 33%

This means that a change in temperature causes a change in relative humidity. If the temperature fluctuates between daytime and night-time, the RH will also fluctuate. This principle is an important factor in the control of the relative humidity [16].

The effects of relative humidity on objects

‘Plants and animals contain a high proportion of water, and it is therefore not surprising that their products - organic materials, such as wood, paper, cotton, linen, wool, silk, parchment, leather, fur, feathers, ivory, bone and horn - also retain moisture. These materials are hygroscopic. They can and will absorb or give off moisture until they reach a state of equilibrium with the air that surrounds them’ [16].

‘When the surrounding air is very dry, organic materials will give off some of their moisture: they become brittle and may shrink, warp, split or crack. When the surrounding air is damp, the materials will absorb some of the moisture from the air: they may swell, cockle, warp, change shape and/or lose strength. Dampness can also cause mould and fungal growth on organic materials’ [16].

‘Inorganic materials (glass, ceramics, metals and minerals) are also affected by high or low humidity. Materials that have a natural salt content may suffer from efflorescence when the air is dry. The salts in deteriorated glass, porous ceramics and some geological material are carried to the surface by moisture (which may have entered the pores during a period of higher humidity). The moisture evaporates and the salts crystallise on the surface. Other inorganic materials are affected by high humidity: metals (particularly iron and copper alloys) corrode; dyes and pigments fade more readily; and geological material can suffer from decay’ [18].

‘Physical Damage If the humidity of the air changes frequently, hygroscopic materials will swell and shrink repeatedly. This causes internal stress and damage and can particularly be a problem in composite objects where the different materials have different rates of shrinkage. The expansion of one material may force changes in the dimensions of another, causing considerable tension and eventually damage e.g. skins on drums, paintings on wooden panels [18].

VSA results

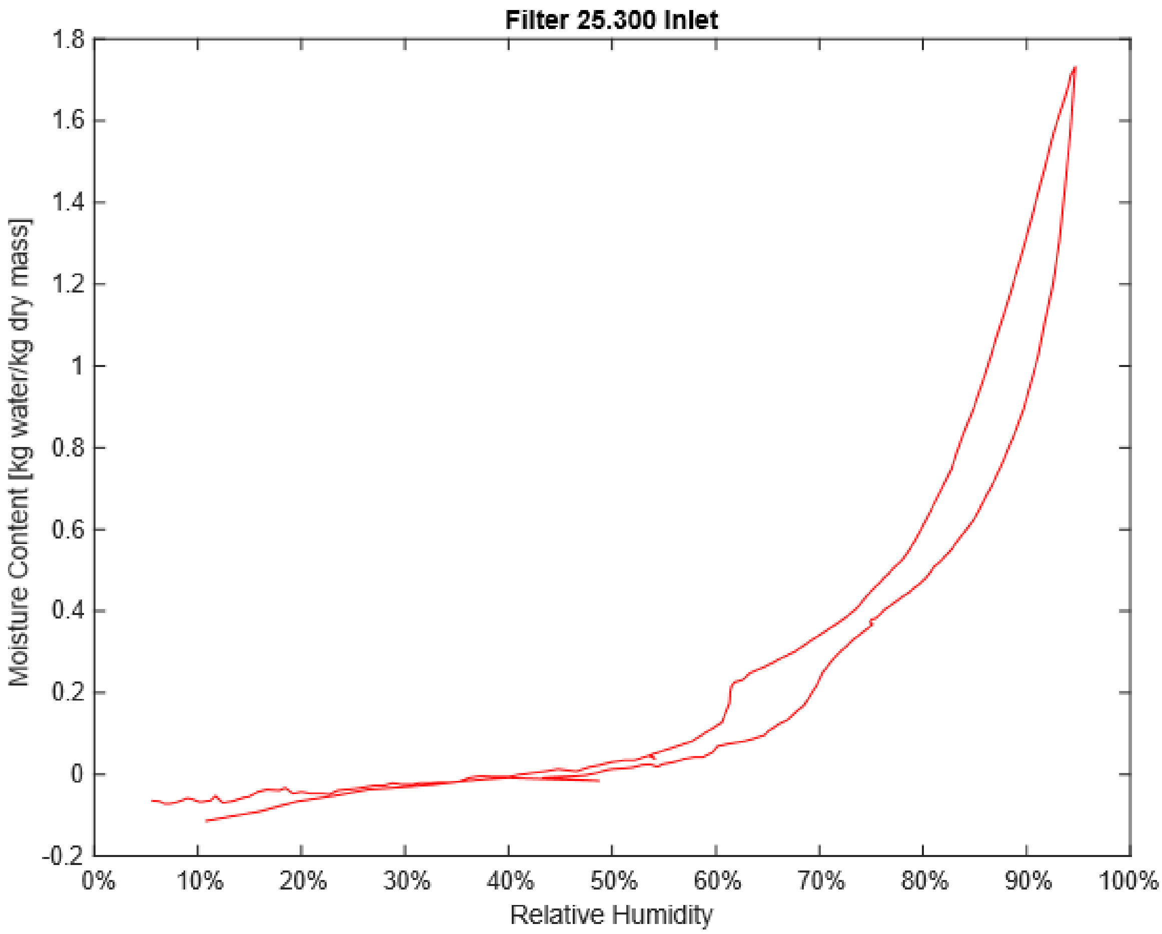


Figure 29 filter 25.300 after VSA analysis [7]

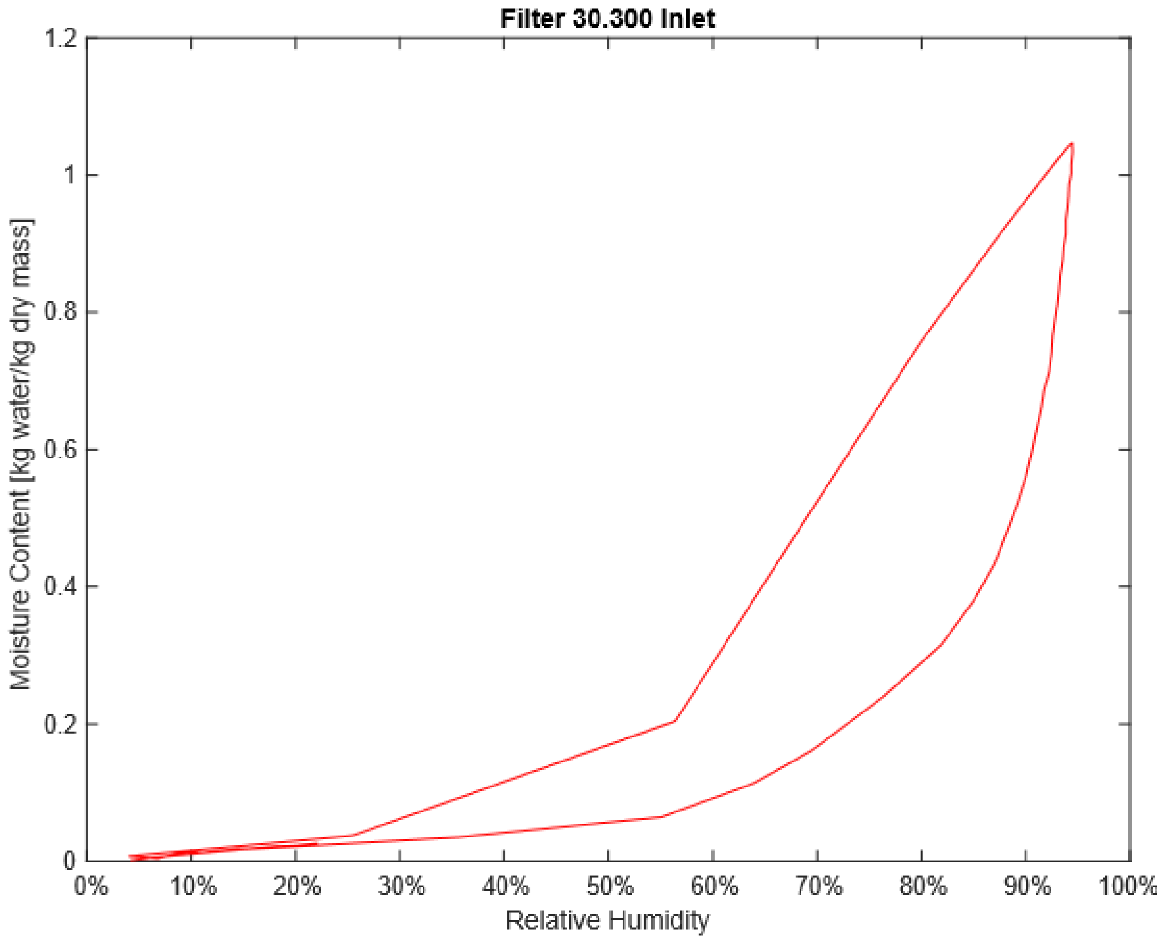


Figure 30 filter 30.300 after VSA analysis [7]

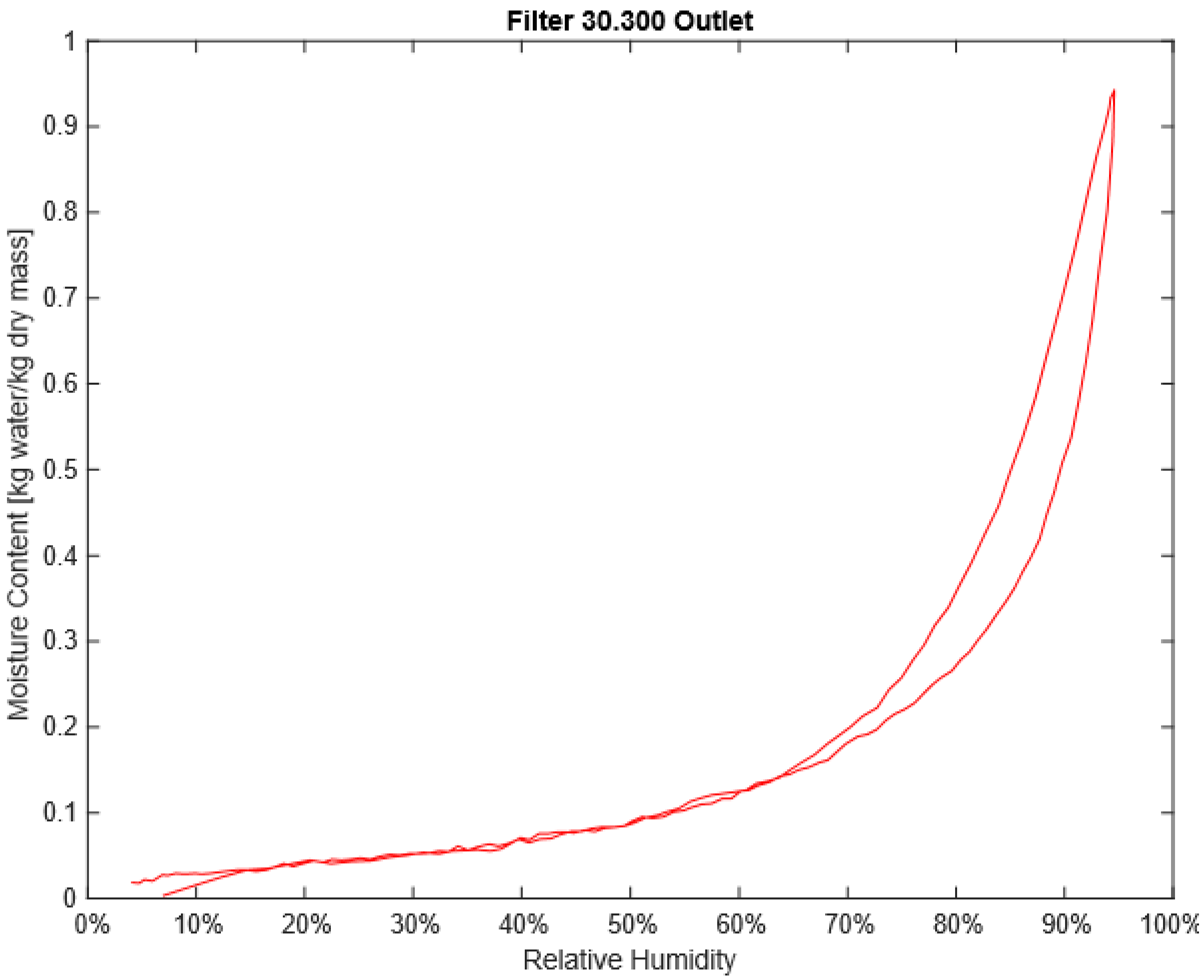


Figure 31 filter30.300 after VSA analysis [7]

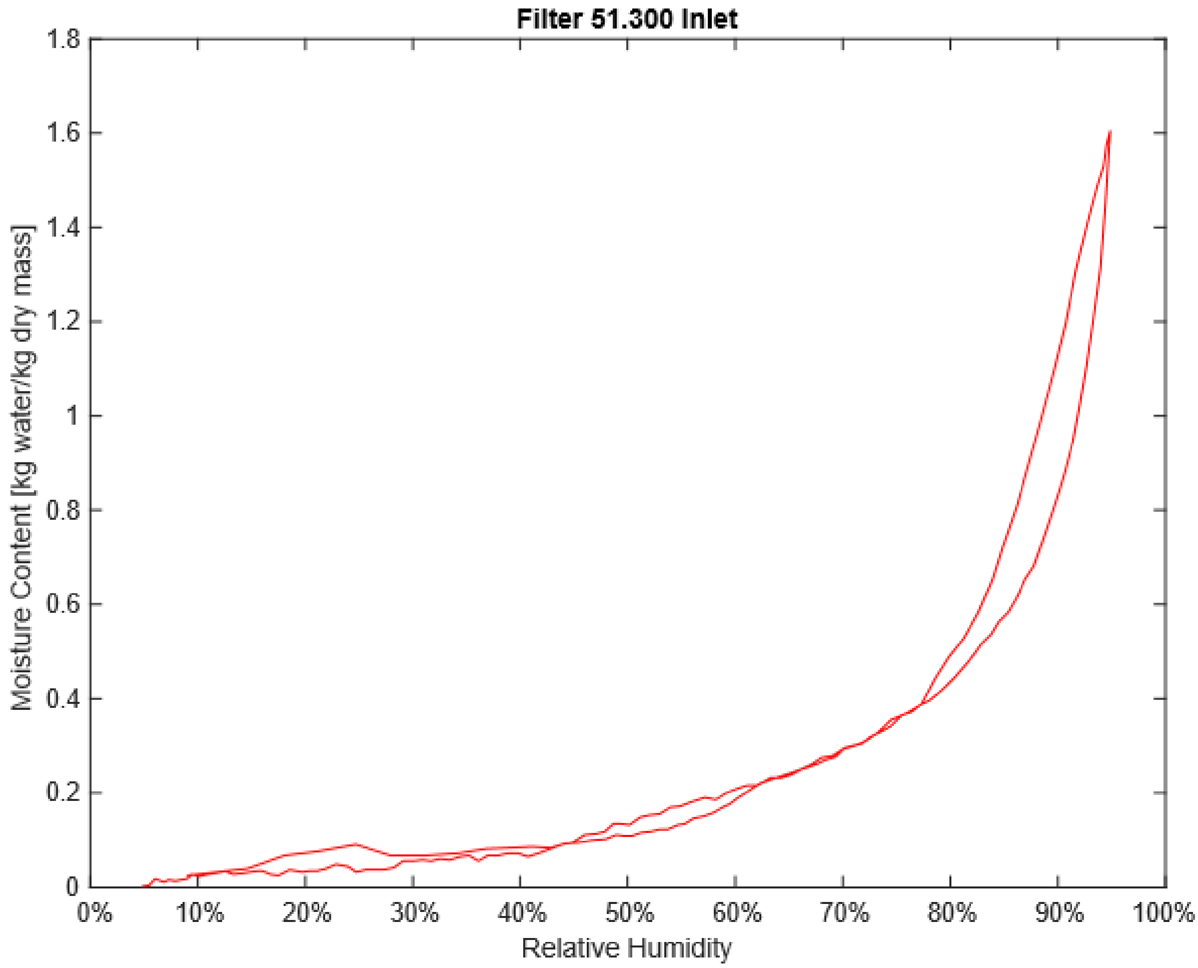


Figure 32 filter 31.300 after VSA analysis [7]