CLEANLINESS OF AIR FILTERS IN THE EXPERIMENTAL PASSIVE HOUSE

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ABSTRACT

An inherent element of the passive house is the system of exhaust ventilation in air supply. According to their class, air filters used in ventilation systems stop the contamination, but may also be the main source of secondary indoor contamination during long-term use.
The aim of the study was to determine the contamination of different air filters after several months of their continuous work. The weight of the filter and its pollution with dust and microbiological contamination were determined. Research was carried out for four sets of filters working in the experimental passive house in the Poznan University of Technology – DoPas. The measurements were focused on the quality of the microbiological contamination of air filters. During microbiological examination of filters, the following microorganisms were determined: the general count of mesophilic bacteria, the general count of psychrophilic bacteria, the count of Staphylococcus (*Staphylococcus*) mannitol positive (type α) and mannitol negative (type β), the count of *Pseudomonas fluorescens* bacteria, actinomycetes (*Actinobacteria*) as well as the general count of microscopic fungi. Performed measurements of studied microorganisms count revealed that psychrophilic bacteria, microscopic fungi and mesophilic bacteria were most numerous. Their count was about ten times higher in the intake duct filter than in the exhaust duct filter. After disinfecting air ducts their cleanliness level dropped from moderate contamination to low.

KEYWORDS

Passive house, office building, air filters, microbiological contamination, ventilation installations

1 INTRODUCTION

Recent years have witnessed a growing focus on the quality of air in buildings, since people spend over 70% of their time there. More and more buildings (especially office complexes) are equipped with mechanical ventilation systems, which is connected, among others, with limiting the amount of energy supplied to the building through air flow control. Moreover, the purposed of ventilation systems is to eliminate contamination generated indoors or dilute it till it reaches an acceptable level. Despite vast interest in indoor air cleanness, some parameters that contribute to the quality of air have not been fully known. One of these elements is an air filter whose purpose is to stop physical as well as microbiological contamination of air. Depending on the quality of filtering material and the type of filter, it stops:
– insects, dust, plant spores, bacteria – on coarse filters and fine filters,
– microorganisms, viruses, particles floating in the air – on HEPA, ULPA and special filters.
The quality of filtering depends not only on proper class of filter used for various expected results but also on the filter's own cleanness which deteriorates while the filter is in service. Figure 1 presents a picture of both a clean filter and a contaminated one, magnified 160 times.

a) b)

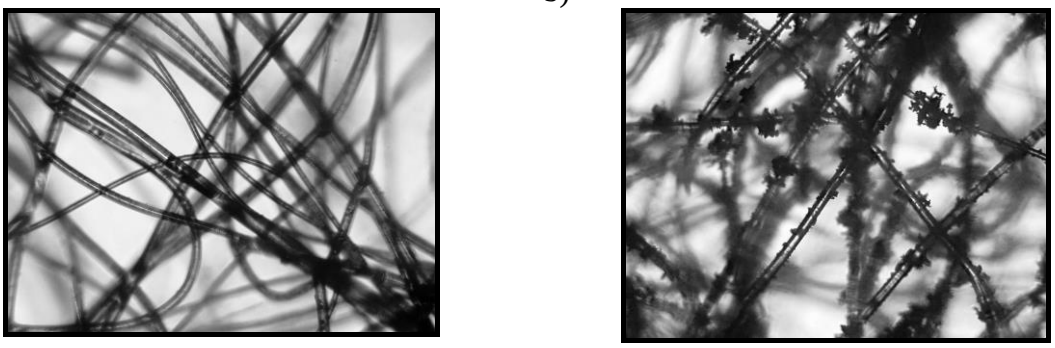

Figure 1: Air filter cleanness level, magnification 160 times, a) clean filter, b) contaminated filter

Chin (Chin 1999) writes that a hygroscopic filtering material can absorb moisture from the air and when moisture level on dust particles stopped by the filter is high enough, a process of sprouting and growth of a fungus colony may start. The author claims that the primary bio-contamination is fungi and bacteria, the next is mites, insects and nematodes, whose count is related to the growth of fungi. The dampness in a ventilation system also leads to an increase in the count of bacteria in the system, which was proven a study by Ahearn (Ahearn et al., 1997) who revealed that an air conditioning system can contribute to an increase in fungi contamination indoors.

In order to evaluate the cleanness of filters after an eighteen-month use period, a microbiological contamination assessment of the filters was performed. The measurements were taken in an experimental passive house in the Poznan University of Technology – DoPas, modernized in 2007 to meet the standard of passive construction. Having a light frame structure, the building is a detached house, with single floor, fully cellared. The cellar has mass structure, with walls made of concrete. Total area of the building is 143,7 m^2, with cubage of 620 m^3. As a heat source, the building utilizes a central AHU 1 (Air Handling Unit) with two EU5 type filters mounted on intake and exhaust lines. As an independent source (an option to diversify heat sources) a compact heating and cooling unit can be installed, connected with a ground heat exchanger and a solar collector (AHU 2). External air, having been initially cooled in the exchanger, can be a bottom heat source for the heat pump in the unit. One of the elements of the passive house ventilation system is a GWC ground exchanger with a pipe that is 38 m long with a diameter of ϕ=200 mm, placed in the ground at a depth of 1.8 to 2.2 meters.

2 MATERIALS AND METHODS

The operation of replacing filters in the ventilation system in the DoPas passive house in Poznan University of Technology allowed to perform a microbiological examination of contamination in air filters. Replacement of filters after an eighteen-month use period, performed by a specialized company, was completed with cleaning and disinfecting the ventilation system. During the operation, the ventilation system, the AHU 1 ventilation unit, as well as the intake and exhaust were mechanically and pneumatically cleaned and disinfected. Mechanical cleaning was done with power brushes driven externally and with compressed air. During the process of duct cleaning, the cleaning machinery collected impurities do level I and II bags. For the purpose of disinfection, a biocide was used, registered as medical product, with CE conformity marking and approval from the National Institute of Hygiene.

Microbiological examination employed:

- EU5 type filter from the AHU 1 ventilation unit, mounted on air intake – **Filter 1**,
- EU5 type filter from the AHU 1 ventilation unit, mounted on air exhaust – **Filter 2**,

- level I bag type EU 5 from cleaning machine, used for mechanical and pneumatic duct cleaning – **Filter 3**,
- level II bag type EU 5 from cleaning machine, used for mechanical and pneumatic duct cleaning – **Filter 4**.

Table 1 presents the parameters of aforementioned filters and bags.

Table 1: Characteristics of examined filters

Filter	Filter pack weight [g]	Filter type	Filter parameters
Filter 1	230,0	EU5	Ventilation unit, intake line,
Filter 2	1100,0	EU5	Ventilation unit, exhaust line,
Filter 3	320,0	EU5	Bag from ventilator of level I cleaning machine (acc. to PN-EN 779)
Filter 4	190,0	EU5	Bag from ventilator of level II cleaning machine

Filters and bags were dismounted very gently and packed in sterile gauze. Complete filters with their casing were weighed in the laboratory, then filter packs were removed and also weighed. Segments were cut out from the removed filter pack and weighed on sterile Petri dishes. After weighing they were placed in glass-stoppered flasks containing 100ml of sterile water. Next, flasks with water and filter pack segments were shaken and the obtained water-based suspension with microorganisms was used for microbiological examination.

Water samples with microbe suspension were used to make deep inoculations on Petri dishes, flooded with proper nutrients. Various kinds of dilutions were used while making inoculations and only those dishes that yielded from a dozen to 100 microorganism colonies were selected for calculations. Knowing the volume of the inoculated fluid, the value of dilution, the count of microbes grown and the weight of the shaken segment of filter pack it was possible to recalculate the results from the culture into 1g of dry filtering material and the entire weight of the filter pack.

While conducting microbiological examination of filters and bags, the following microorganisms were determined: the general count of mesophilic bacteria, the general count of psychrophilic bacteria, the count of Staphylococcus (*Staphylococcus*) mannitol positive (type α) and mannitol negative (type β), the count of *Pseudomonas fluorescens* bacteria, actinomycetes (*Actinobacteria*) as well as the general count of microscopic fungi. Examination results were presented as number of colonies (colony forming unit [CFU]) which had grown on the Petri dish. Microbiological examination utilized nutrients and culture conditions recommended for the analysis of microbiological contamination of air according to Polish Standards PN-89/Z-04111.02 and PN-89/Z-04111.03 (table 2).

Möritz and Martiny (Möritz, Martiny, 1997) used similar methodology of isolating bacteria and microscopic fungi from filters used in HVAC systems.

Table 2: Culture conditions of selected microorganisms according to Polish Standards (PN-89/Z-04111.02, PN-89/Z-04111.03)

Microorganisms	Type of medium	Temperature incubation [°C]	Time incubation [h]
Mesophilic bacteria	Nutrient agar culture	37	48
Psychrophilic bacteria *	Nutrient agar culture	22	72
Staphylococcus	Chapman medium	37	48
Actinobacteria	Pochon medium	26	120
Pseudomonas fluorescens	King B medium and identification of colonies in UV rays	26	120
		4	168
Microscopic fungi	Waksman medium	26	168
	Czapek-Dox medium	26	168

* not included in the Polish Standards

After culture period was finished, microorganism colonies that had grown on Petri dishes were counted. The obtained results were recalculated into 1g of filtering material and the entire weight of the filter.

3 EXAMINATION RESULTS

Tables 3, 4, 5 and 6 compile the examination results for microorganisms taken from the filtering material of the dismounted filters and bags from the cleaning machine. Microbes obtained from the culture were recalculated into 1g of filtering material and the weight of the entire filter or bag.

Table 3: Average count of mesophilic and psychrophilic bacteria (CFU) abd standard deviation [σ] in the examined filtering material

Filter	**Average bacteria count**			
	Mesophilic		Psychrophilic	
	CFU/1g of filter	CFU/ entire filter	CFU/1g of filter	CFU/ entire filter
Filter 1 – intake	14 700 σ=1152,9875	3 381 000	25 640 σ=3041,7810	5 897 200
Filter 2 – exhaust	1 235 σ=91,9967	1 358 500	2 980 σ=284,5182	3 278 000
Filter 3 – level I cleaning machine	1 990 σ=636,2199	636 800	19 250 σ=1341,4436	6 160 000
Filter 4 – level II cleaning machine	3 910 σ=150,8235	742 900	15 325 σ=2002,9593	2 911 750

Table 4: Average count of staphylococcus (CFU) and standard deviation [σ] in the examined filtering material

Filter	**Average count of staphylococcus**			
	Mannitol positive		Mannitol negative	
	CFU/1g of filter	CFU/ entire filter	CFU/1g of filter	CFU/ entire filter
Filter 1 – intake	1 370 σ=184,9711	315 100	170 σ=25,0233	39 100
Filter 2 – exhaust	300 σ=50,8299	330 000	128 σ=9,2171	140 800
Filter 3 – level I cleaning machine	186 σ=58,3811	59 520	62 σ=13,3936	19 840
Filter 4 – level II cleaning machine	80 σ=8,6410	15 200	40 σ=8,6410	7 600

Table 5: Average count of microscopic fungi (CFU) and standard deviation [σ] in the examined filtering material

Filter	**Average count of microscopic fungi**			
	Waksman medium		Czapek-Dox medium	
	CFU/1g of filter	CFU/ entire filter	CFU/1g of filter	CFU/ entire filter
Filter 1 – intake	17 100 σ=1847,0111	3 933 000	20 500 σ=5447,0569	4 715 000
Filter 2 – exhaust	2 550 σ=261,9876	2 805 000	1 280 σ=92,1705	1 408 000
Filter 3 – level I cleaning machine	12 420 σ=1105,0776	3 974 400	16 150 σ=3550,1899	5 168 000
Filter 4 – level II cleaning machine	2 420 σ=183,3578	459 800	7 650 σ=1150,6156	1 453 500

Table 6: Average count of actinomycetes and *Pseudomonas fluorescens* (CFU) and standard deviation [σ] in the examined filtering material

Filter	Average bacteria count			
	Actinomycetes		*Pseudomonas fluorescens*	
	CFU/1g of filter	CFU/ entire filter	CFU/1g of filter	CFU/ entire filter
Filter 1 – intake	855 σ=298,2304	196 650	0	0
Filter 2 – exhaust	850 σ=91,8105	935 000	0	0
Filter 3 – level I cleaning machine	2 485 σ=182,8910	795 200	0	0
Filter 4 – level II cleaning machine	1 610 σ=150,6017	305 900	0	0

4 EXAMINATION CONCLUSIONS

Analyzing the count of the examined microorganisms present in 1g of filtering material it is concluded that most numerous microbes in Filter 1 (intake line) were psychrophilic bacteria (25 640 CFU/1g), microscopic fungi (17 100 – 20 500 CFU/1g) and mesophilic bacteria (14 700 CFU/1g). Among staphylococcus, mannitol positive staphylococcus (type α) prevailed over mannitol negative staphylococcus (type β), with eight times the count than the latter. Actinomycetes were found at relatively low numbers – 855 CFU/1g of filtering pack weight (Fig. 2-4). Most numerous microbes in Filter 2 (exhaust line) were also psychrophilic bacteria, microscopic fungi and mesophilic bacteria, however their count was 10 times less than that of Filter 1 in some cases. The count of staphylococcus was also lower, especially mannitol-positive staphylococcus, while actinomycetes indicated similar strength to the ones in Filter 1. In level I cleaning machine bag (Filter 3) the prevailing microbes were psychrophilic bacteria (19 250 CFU/1g) and microscopic fungi (12 420 – 16 150 CFU/1g) in 1g of filtering material, while in level II cleaning machine bag (Filter 4) the count of psychrophilic bacteria and microscopic fungi was lower than in Filter 3, however the count mesophilic bacteria was much higher (by 100%) reaching 3 910 CFU/1g. In both bags, staphylococcus count was low while the count of actinomycetes was higher than in Filter 1 and Filter 2. In all examined filters, no presence of *Pseudomonas fluorescens* was recorded. Figures 2-4 compile average count of microorganisms from all examined filters, recalculated into 1g of filtering material.

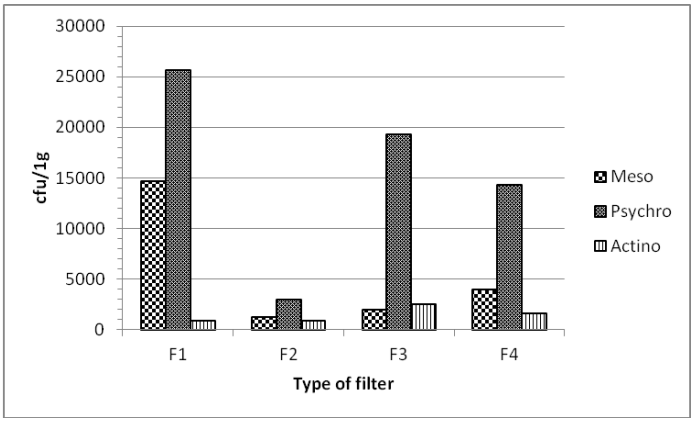

Figure 2: Count of mesophilic bacteria (Meso), psychrophilic bacteria (Psychro) and actinomycetes (Actino), recalculated into 1g of filtering material

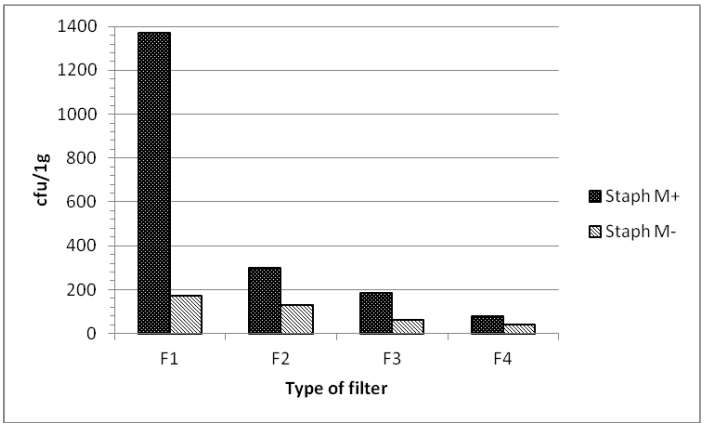

Figure 3: Count of staphylococcus mannitol positive (Staph M+) and mannitol negative (Staph M-) recalculated into 1g of filtering material

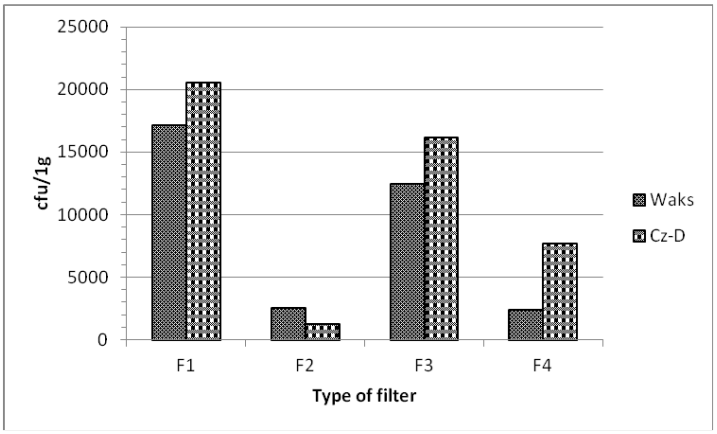

Figure 4: Count of microscopic fungi grown on Waksman medium (Waks) and Czapek-Dox medium (Cz-D) recalculated into 1g of filtering material

Because of different weight of the examined filter packs, other values were obtained after recalculating the count of microorganisms on the weight if the entire filters (table 3-6). Each filter pack had the following weight: Filter 1 = 230 g, Filter 2 = 1100 g, Filter 3 = 320 g, Filter 4 = 190 g. Considering these values, the highest count of mesophilic bacteria was recorded in Filter 1 (over 3.3 million CFU/230g), the highest count of actinomycetes and staphylococcus mannitol positive and mannitol negative was recorded in Filter 2 (over 935 thousand CFU/1100g, 330 thousand CFU/1100g and over 140 thousand CFU/1100g respectively) and the highest count of psychrophilic bacteria and microscopic fungi was recorded in Filter 3 (over 6.1 million CFU/320g and over 5.1 million CFU/320g respectively). Filter 4 normally yielded the lowest count of the examined microbe groups. One might understand that if Filter 1 and Filter 2 functioned as air cleaners for external air inflowing from outside environment and for air contained indoors, with users inside the building, these filters stopped mostly human-related microbes (mesophilic bacteria and staphylococcus) as well as microscopic fungi that penetrated indoors from outside environment. While the mechanical cleaning of air intake ducts was in progress, numerous impurities found there were released from the surface where they settled and penetrated the bags of the cleaning machine. Thus, especially in level 1 bag (Filter 3), the strength of numerous microbes naturally present in the environment was high (psychrophilic bacteria, actinomycetes, microscopic fungi), while the count of human-related microbes (mesophilic bacteria, staphylococcus) in the bags of the cleaning machine was lower. In vast majority of the examined microorganisms, their count was higher in level 1 cleaning machine bag than in

level II bag. This proves, that the first stage of duct cleaning was already very effective in terms of eliminating bacteria and fungi that settled in the lines supplying air indoors to the rooms of the passive house.
In order to assess the influence of filter replacement and air duct cleaning on the quality of indoor air in the passive house, the level of microbiological contamination in the air was analyzed before and after filter replacement. Air examination, performed with MAS-100 Eco microbiological air sampler and using impact method, was conducted by the same company that performed the ventilation system cleaning and disinfecting process. The examination revealed that, after a complex procedure, the microbiological quality of air supplied to the rooms of the passive house was good. At the same time, it was revealed that after cleaning and disinfecting the system, a decrease in the general count of microbes was noted, compared to the quality of air before replacing the filters and cleaning the ducts (table 7). During identification process of the detected microorganisms, microbes were grown that form saprophytic and opportunistic flora represented by *Micrococcus spp.*, mould fungi and sporulating bacilli.

Table 7: Microbiological cleanness of air from intake duct before and after the ventilation system cleaning and disinfecting process

Determination	**Before cleaning [CFU/m^3]**	**After cleaning [CFU/m^3]**
General microorganism count	107	40
Air pollution level [4]	Moderate	Very low

Air quality assessment was also performed in the experimental house, according to the guidelines of Polish Standards (PN-89/Z-04111.02, PN-89/Z-04111.03). The examination confirmed an improvement in the quality of air and a decrease in the general count of mesophilic bacteria, psychrophilic bacteria, staphylococcus bacteria (*Staphylococcus*) mannitol positive (type α) and mannitol negative (type β), *Pseudomonas fluorescens*, actinomycetes (*Actinobacteria*) and the general count of microscopic fungi.

5 CONCLUSIONS

Usage period of filters and the condition of the ventilation system in the building has a very big influence on the quality of indoor air. Polluted filters in the passive house (DoPas) caused a drop in the effectiveness of air filtration. The impurities gathered and the growth of microorganisms in filters could influence their filtrating capabilities making the filters contribute to a deterioration of the quality of indoor air. Over many years, ventilation ducts had gathered numerous physical and gas impurities. Apart from blowing new impurities from external air, various substances concentrated in ventilation ducts could also penetrate indoors. They could be dust and solids dated back to the construction of the system, soot, grease particles, gases and bioaerosol-forming biological impurities, including flower pollen, viruses, bacteria and fungi. They can impair the well-being of people in the building. It depends on the count of substances blown indoors and the type of negative effect they have on humans. Ventilation system contamination is a problem connected both with the health of residents in the ventilated rooms and with the technical condition of the system which for instance may be subject to biological corrosion due to large numbers of microbes. Such situation contributed to the deterioration the quality of indoor air, one symptom of which being the so-called sick building syndrome (SBS). The occurrence of ailments related to SBS is mainly connected with insufficient amount of supplied clean air and its bad quality. The sources of indoor air contamination may be construction materials, furnishing elements, also residents themselves, microbe metabolites (endotoxins, enterotoxins, mycotoxins, glucans), contaminated ventilation and air conditioning systems and low quality of outdoor air. Symptoms of SBS

include headaches, dizziness, fainting, malaise, fatigue, allergic reactions and other ailments described by researchers such as (Charkowska, 2003; Joshi, 2008; Gąska-Jędruch, Dudzińska, 2009; Joe et al., 2013; Miaśkiewicz-Pęska, Łebkowska, 2011).

With favorable temperature, humidity and access to nutrients, air filters can become a habitat for numerous microbes. Examining the filtering material can yield the presence of both harmless and pathogenic microorganisms, among them dangerous species of bacteria, e.g. *Pseudomonas aeruginosa* and *Legionella pneumophila*, as well as fungi, e.g. *Alternaria spp*., *Aspergillus spp*., *Fusarium spp*., *Mucor spp*., or *Rhizopus spp*. In order to limit the growth and colonization of microbes in filters and air ventilation and conditioning systems, it is necessary to perform periodical maintenance and cleaning of the systems and use antibacterial agents (e.g. $AgNO_3$), to cover the filtering material (Charkowska, 2000; Miaśkiewicz-Pęska, Łebkowska, 2011).

Organic particles stopped in filters are a source of carbon for microbes and moisture contained in the flowing air is their source of water. Such conditions not only help microbes survive but also help them grow in significant numbers. As a result, it leads to an emission of microorganisms from filters and secondary contamination of the treated air. An examination of used filters conducted by Miaśkiewicz-Pęska (Miaśkiewicz-Pęska et al., 2007) revealed very high concentration of living microorganisms, among which most numerous were moulds (10 000 CFU/cm^3 of filter), and the number of bacteria reached 6000 CFU/cm^3 (Miaśkiewicz-Pęska et al., 2007).

Therefore, it is necessary to perform periodical inspection, cleaning and disinfection of ventilation systems as well as regular filter replacement (according to manufacturer recommendation) to ensure proper operation of the system and to create air comfort in rooms (Fanger et al., 2003; Gołofit-Szymczak, Skowroń, 2005; Charkowska, 2000; Miaśkiewicz-Pęska et al., 2007).

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