Removal of Odorants in Nursing Homes Using Air Cleaners

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ABSTRACT

This project aims to enhance the odor environment in laundry and linen rooms in nursing homes. The problem arises from the storage of soiled laundry in these rooms for several days before it is collected or washed, leading to the release of odorants. This often causes discomfort for both staff and residents, as the odors can spread to hallways and adjacent spaces. Aarhus Municipality intends to investigate whether this issue can be fully or partially resolved by installing air purifiers in the rooms.

Adsorption, specifically activated carbon, was selected as the primary technology for odor removal among the technologies utilized in air purifiers. Photocatalytic oxidation (PCO) was selected as a secondary focus area. Seven different air purifiers (6 with active carbon, 1 PCO) were selected for further testing in the laboratory. These tests were performed using acetaldehyde, as an indicator of odor, and a reduction in concentration ranging from 19% to 83% after 20 minutes was measured for the six products utilizing activated carbon. However, the product solely relying on PCO did not show a significant effect.

Degassing from the air purifiers with activated carbon filters was also examined in the laboratory and here it was found that all six products re-emitted acetaldehyde after the efficiency test. The degassing of captured acetaldehyde into the surrounding environment counteracts the intended effect and is, therefore, important to investigate. Additionally, five out of seven tested air purifiers emitted traces of other gases, characterized as byproducts, which were identified by an increase in the concentration of specific substances during testing compared to the reference experiment without an air purifier turned on. These byproducts may result from the conversion of one gas to another potentially more harmful substance. However, the concentrations of all identified byproducts were significantly lower than the instated guidelines.

Four nursing homes were chosen to have an air purifier installed in one of their linen/laundry rooms. The concentration of total volatile organic compounds (TVOC) was continuously measured throughout the project period using air quality sensors in laundry rooms at each of the four selected nursing homes. TVOCs are used here as an indicator of odor concentration.

It has been challenging to draw a conclusive statement about the effectiveness of air purifiers on odors, as numerous peaks in TVOC concentration occurred frequently, probably due to the presence of ethanol in the air, caused using hand sanitizers. This significantly influenced the sensor data, potentially overshadowing the contribution from odor compounds in the measurements that often smell even in very low concentrations.

Overall, the project has indicated that the used air purifiers can reduce the concentration of odor compounds, in the form of TVOC, at the four selected locations. The results show the most apparent effect during periods when the average TVOC concentration was highest. In these time periods, the TVOC concentration generally became lower than in the period without the air purifier. However, the average TVOC concentration is not consistently lower at the four nursing homes during the period with an air purifier installed compared to the period without.

KEYWORDS

Keywords: odor environment, air purifiers, activated carbon, VOC concentrations, indoor air pollution.

1 INTRODUCTION

Indoor air quality plays a vital role in maintaining a healthy and comfortable living environment. In recent years, there has been a growing concern regarding the adverse effects of airborne pollutants, such as odor, smoke, pollen, and infectious agents on human health. These pollutants not only cause discomfort but also pose serious health risks, ranging from respiratory diseases to the spread of pathogens. In response to this challenge, the implementation of air purifiers has emerged as a promising approach to reduce the burden of these airborne contaminants and promote a safer indoor environment[i,ii].

Issues related to odors have become a growing concern, particularly with respect to the working environment in eldercare. Odors and volatile organic compounds (VOCs) are closely interconnected. VOCs refer to chemical compounds that can evaporate at room temperature, thus affecting air quality. A significant portion of odors, such as those emanating from urine, are VOCs (e.g., acetone and acetaldehyde[iii]), while certain other odors, such as ammonia and hydrogen sulfide, cannot be classified as VOCs. The odor burden from urine and other sources of human odors consists of hundreds of different chemical compounds, making it a complex quantity to quantify.

In this project, measurements of the concentration of Total VOCs (TVOC) are used as a direct indicator of the concentration of odorous compounds. However, this approach has two main uncertainties. Firstly, as written above, not all odorants can be characterized as VOC. Secondly, the measurements will include VOCs that may not necessarily contribute to the odor issues in the specific laundry rooms under consideration. For example, ethanol from hand sanitizers is not expected to be part of the odor issues related to urine and similar sources but will show up in the measurements of TVOC. Nonetheless, both ethanol and VOCs, in general, should be minimized in terms of occupational exposure, as a wide range of VOCs can be harmful to health.

Air purifiers have gained popularity as effective devices for improving indoor air quality (IAQ) by reducing airborne pollutants. These devices utilize various technologies to capture and eliminate contaminants, providing cleaner and healthier air for occupants. However, the market for air purifiers is characterized by a significant lack of harmonized standards for testing performance. This entails that the acclaimed performance varies greatly between products, and endorsements can be misleading. This is especially the case for air purifiers utilizing filters with activated carbon[iv]. Activated carbon is considered the main technology for eliminating gaseous contaminants such as VOCs and odorants from airstreams[v].

Low-cost sensors have gained significant attention as valuable tools for monitoring and assessing the quality of indoor air. These sensors provide real-time data on various pollutants, such as particulate matter, TVOC, CO_2, and environmental parameters that contribute to IAQ, enabling proactive measures to improve occupant health and well-being. However, like any technology, IAQ sensors possess advantages and disadvantages that need to be carefully considered for their effective implementation. IAQ sensors require regular calibration and maintenance, and failure to do so can lead to inaccurate measurements. Different sensors may vary in accuracy and have limitations in detecting certain pollutants or be sensitive to interference.

2 METHODOLOGY

2.1 Efficiency of air purifiers against odorants through laboratory test

A total of seven air purifiers were tested in the laboratory to demonstrate a documented effect on a specific VOC. The selected VOC was acetaldehyde, as it is often used as a surrogate for the carcinogenic substance formaldehyde in testing air purification solutions. Acetaldehyde can cause unpleasant odor issues at sufficiently high concentrations but can be perceived as fruity at low concentrations. It is well known that acetaldehyde is a significant component of odors emitted from urine[iii]. Acetaldehyde is also included in the Occupational Health and Safety Authority's threshold limit value for air pollution.

The testing of the seven air purifiers was conducted at the Danish Technological Institute in an airtight 20 m^3 chamber. The test chamber is coated with Teflon to minimize the adsorption of gases and particles on the walls, making it highly suitable for testing of air purifiers. The protocol for the test was as follows:

- Prior to each test, the test chamber is thoroughly ventilated until the concentration of acetaldehyde reaches background levels.
- Acetaldehyde is dosed into the chamber until a concentration of 15-20 ppm is achieved.

- A fan in the room further mixes the air in the test chamber for an additional 5 minutes before being turned off.
- The air purifier is turned on at the highest level and runs for a period of 40 minutes, after which it is turned off.
- The test chamber is ventilated for 10-15 minutes until low VOC concentrations are reached.
- The air purifier is then turned on again, and measurements for off-gassing are taken for 15 minutes.

Throughout the entire test, the concentration of acetaldehyde is continuously measured, and air samples are collected for subsequent analysis of byproducts at the 0, 20, and 40-minute marks. Both acetaldehyde and respective byproducts are measured using a PTR-MS (Proton Transfer Reaction – Mass Spectrometry) instrument with a time resolution of 1 second.

2.2 Measurements at nursing homes

A total of 4 nursing homes at different locations were selected for this project.

Nursing home 1: The examined room is a square linen room where soiled linens (typically 3-4 carts) are stored until they are picked up for laundry. Some other items are also stored in the room. The room is enclosed with a sliding door leading to the front room where clean laundry is stored. The staff describes the room as having a foul odor, so the sliding door to the front room is usually closed. The room has no windows. **Air purifier 5** is used in this room.

Nursing home 2: The examined room is a square laundry room that contains a washing machine and a dryer. Bags and baskets with dirty laundry are stored in the room. The room has no windows, and the door is often left open as it becomes hot inside when the dryer is running. This results in the odors often spreading to the hallways. **Air purifier 3** is used in this room.

Nursing home 3: The examined room is a long, narrow laundry room that contains two washing machines and two dryers. Carts and baskets with dirty laundry are stored in the room. Additionally, clean laundry is folded and stored on table surfaces in the room. The room has the option for ventilation by opening windows. The door to the room is often closed as it is located right next to the dining area. **Air purifier 6** is used in this room.

Nursing home 4: The examined room is a square laundry room that contains a washing machine and a dryer. Carts and baskets with dirty laundry are stored in the room. The room has no windows, and the door is often closed as it is located right next to the dining area. During the project, the sensor and air purifier were moved from the originally selected room to an identical room on the floor above due to issues with the electrical network in the room. **Air purifier 7** is used in this room.

The indoor air quality was measured throughout a period of 18 weeks, which includes 7 weeks before installing air purifiers and 10 weeks with air purifiers installed. The measurements were performed with Airthings Space Pro IAQ sensors, which continuously measure the following parameters every fifth minute.

- Particulate Matter (PM1 and PM2.5) [$\mu g/m^3$]
- TVOC [ppb]
- CO_2 [ppm]
- Relative humidity [%] and temperature [^oC]
- Noise [dBA] and relative light [%]

The sensors were placed at head height and with unrestricted airflow around them, as much as possible. When positioning the sensors, considerations were made for access to power and the staff's workflow. Similarly for the installation of air purifiers, considerations were made for airflow, access to power, and the staff's workflow. Additionally, the fan speed level was adjusted with respect to the noise level in the room. The noise from the air purifier was supposed to be equal to or less than other appliances inside the laundry rooms.

3 RESULTS

3.1 Efficiency in laboratory test

The efficiency of each of the seven air purifiers was examined in the laboratory. The reduction of acetaldehyde from the chamber has been calculated as the relative difference in concentration between the starting time of the test and after 20 and 40 minutes, respectively, with the air purifier running at the highest speed. The results are shown in the table below and presented in Figure 1.

Table 1: Overview of results from laboratory test of the 7 air purifiers.

Product	Technology	Reduction (20 min)	Reduction (40 min)	Degassing?
1	Active Carbon filter, EPA-filter, Ionization	32%	44%	Yes
2	Active Carbon filter, HEPA-filter, Ionization	19%	31%	Yes
3	Active Carbon filter, HEPA-filter	57%	73%	Yes
4	Photocatalytic Oxidation (PCO)	6%	8%	No
5	Active Carbon Filter, HEPA-filter	82%	86%	Yes
6	Active Carbon Filter, HEPA-filter, Ionization, PCO	83%	97%	Yes
7	Active Carbon filter and zeolite, HEPA-filter	82%	96%	Yes

Products 5, 6, and 7 have the highest reduction in acetaldehyde after 20 minutes. These three products also have the highest airflow; however, high airflow does not necessarily result in a large reduction of acetaldehyde. For example, product 5 has an airflow that is almost twice as high as product 7, but the reduction after 40 minutes for these two is 86% and 96% respectively. The reason for this is the fact that the quality and quantity of activated carbon plays a significant role in the effectiveness against acetaldehyde and other VOCs. Information about the quality and quantity of activated carbon used in air purifiers is rarely available and it has therefore not been possible to obtain for the examined air purifiers.

Furthermore, products 4, 6, and 7 also use alternative technologies (PCO and zeolite), which potentially can influence the efficiency against VOCs. Note that HEPA/EPA filters and ionization technologies are not expected to have an impact on gases, including VOCs and odors, but are very effective against particles. For products 6 and 7, it is not possible to separate and evaluate the effect of these alternative technologies since the air purifiers were tested with all technologies in place/turned on. For product 4, which exclusively uses PCO, a low reduction was measured compared to the other products that use activated carbon.

The test also shows the known fact that the effectiveness of activated carbon depends on the concentration of the gaseous pollutant. This means that the air purifiers remove acetaldehyde at a higher rate at the beginning of the experiment when the concentration is high, compared to the end of the experiment when the concentration is low. The half-life during the test thus changes continuously, which is not observed, when testing air purifiers with HEPA filters against particles. This can imply that the air purifiers can more effectively reduce peak loads (short-term high concentrations) of VOC pollution, but not to the same extent lower the background levels significantly.

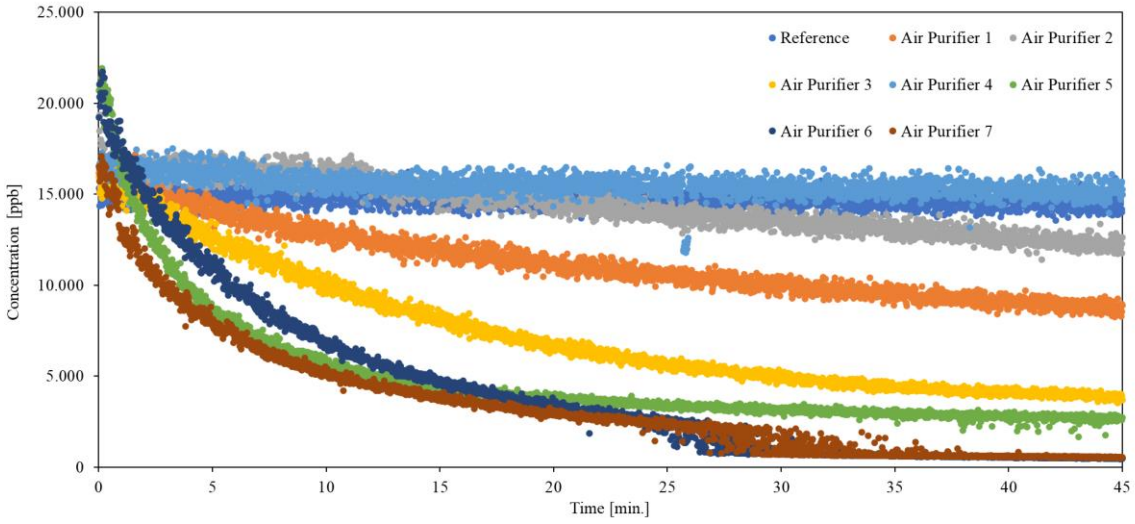

Figure 1: Concentration of acetaldehyde measured for each of the seven air purifiers and the reference in the laboratory test. The time (t=0) is defined as the starting time where the air purifier is turned on.

Off-gassing: Off-gassing was investigated by turning on the air purifiers in a clean test chamber shortly after completing the reduction test. If off-gassing occurs, it means that a portion of the captured acetaldehyde is released from the air purifier into the surrounding environment. The results from the test can be seen in Figure 2.

The test reveals that all products, except for product 4, release acetaldehyde after the reduction test is completed. This test is qualitative as the amount of off-gassing partially depends on the efficiency of the air purifier. For example, products 3 and 5 have captured significantly more acetaldehyde, and therefore, have the ability to release more acetaldehyde, whereas product 2 has captured less acetaldehyde, and therefore, cannot release as much. However, it can be observed that products 6 and 7, which have the highest reduction, also exhibit relatively low off-gassing. This may be due to the high quality of activated carbon used in these products.

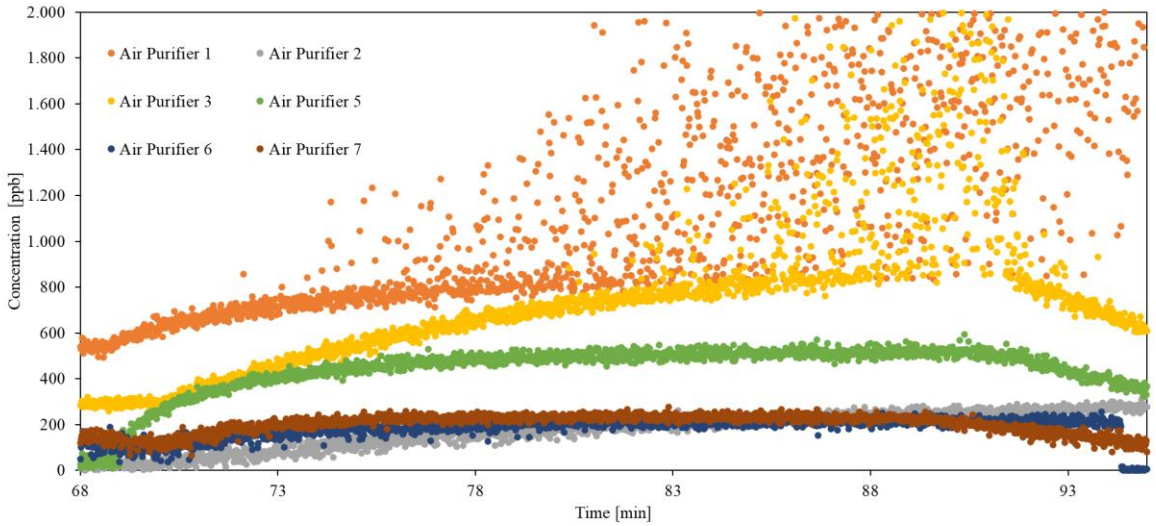

Figure 2: Concentration of acetaldehyde during off-gassing test. Reference and air purifier 4 is omitted from this graph as no adsorption occurs.

Byproducts: For products 1, 2, 3, 5, and 6, small traces of other gases, characterized as byproducts, were detected. The byproducts were identified by an increase in concentrations of specific substances in the air during the test period, which did not similarly increase during the reference test without an air purifier. Byproducts can result from the chemical transformation of gases or off-gassing from components in the air purifier (e.g., heating of plastics during operation). However, the concentrations of all identified byproducts were significantly lower than applicable guidelines (e.g., from occupational health authorities[vi] and NIOSH[vii]) for the respective substances. Therefore, the byproducts formed during the specific test with acetaldehyde were not considered harmful and were not a reason for the elimination of a product for further use in this project.

All air purifiers were tested for ozone emissions by measuring directly at their air outlets. None of the seven air purifiers emitted ozone.

3.2 Sensor

The total VOC concentration was measured at the 4 nursing homes with indoor air quality sensors for the entire test period and is shown in Figure 3. Data for nursing homes 1 and 2 are available for the entire period, while data for nursing homes 3 and 4 have periods excluded where the air purifier has been turned off (nursing home 4) or unexpectedly adjusted by the staff (nursing home 3). The graphs display numerous short-term high concentrations of TVOC for all nursing homes, both during periods with and without the air purifier. The exact cause of these peaks is unknown, but it is presumed that the use of hand sanitizers, which result in ethanol in the air, is a significant contributor.

For nursing homes 1, 2, and 3 there is no measured reduction in the average TVOC concentration between the periods with and without the air purifier. For nursing home 4 a reduction of 30% in average TVOC concentration was observed. However, this air purifier was only turned on for a shorter period than the other, which give rise to some uncertainty.

Figure 3: Measurements of TVOC concentration [ppb] for the 4 nursing homes. The vertical black line indicates the time of air purifier installation. The dark blue line running horizontally represents the rolling average. Data is available for the entire period for nursing homes 1 and 2. Data is missing for nursing homes 3 and 4 due to periods when the air purifier was set to a lower fan speed or turned off.

Table 2: Average TVOC concentration from sensor data

Average TVOC concentration	**Nursing Home 1**	**Nursing Home 2**	**Nursing Home 3**	**Nursing Home 4**
without Air Purifier	138 ppb	244 ppb	223 ppb	232 ppb
with Air Purifier	142 ppb	310 ppb	222 ppb	163 ppb

To examine any potential effect of the air purifiers, a detailed analysis of the TVOC sensor data (see Table 3) has been conducted for each of the 4 locations, which includes the following TVOC parameters for the periods with and without the air purifier:

- Maximum concentration
- Hourly average
- Number of peaks above 250 ppb[viii] per day
- The relative amount of data points above 250 ppb

The last two parameters have been selected to investigate whether the air purifiers can limit the times when very high concentrations of TVOC are present or rapidly reduce the TVOC concentration during these periods of high air pollution.

Furthermore, the remaining measured parameters from the sensor have been qualitatively analyzed. Specifically, CO_2 and light data have been used to estimate whether the conditions regarding the use of the selected rooms were comparable in the two periods. The results show consistent CO_2 and light data for the two periods, indicating that the human activity in the rooms is comparable.

Table 3: Summary of analysis results for TVOC sensor data collected at the 4 nursing homes. Each period is indicated as a without/with air purifier turned off/on respectively and with a final difference between the two.

Parameter	Air Purifier?	Nursing Home 1	2	3	4
Maximum concentration [ppb]	Without	1,963	3,607	2,364	5,796
	With	946	2,515	1,866	2,667
	Difference	52%	30%	21%	54%
Number of peaks above 250 ppb per day	Without	8.1	19.8	26.4	17.6
	With	6.3	36.0	23.0	9.2
	Difference	22%	-82%	13%	48%
Relative amount of data points above 250 ppb [%]	Without	8.6	33.2	35.7	27.3
	With	6.8	52.4	32.6	13.0
	Difference	21%	-58%	9%	52%

For **nursing home 1**, all three parameters are lower during the period with the air purifier installed. The most significant difference was measured for the maximum TVOC concentration. The number of peaks and relative amount of data points above 250 ppb are similar, but still, a reduction is measured for the period with the air purifier turned on.

The hourly average of TVOC from nursing home 1 is presented in Figure 4. The average TVOC concentration is quite similar throughout all time intervals when comparing periods with and without the air purifier installed. It can be observed that there is a daily increase in TVOC concentration in the room around 08:00. This could be attributed to the staff arriving and initiating activities in the room around this time. The TVOC concentration during these hours was on average slightly higher with the air purifier installed. Only the period between 03:00 and 06:00 has a significantly lower average TVOC concentration with the air purifier turned on.

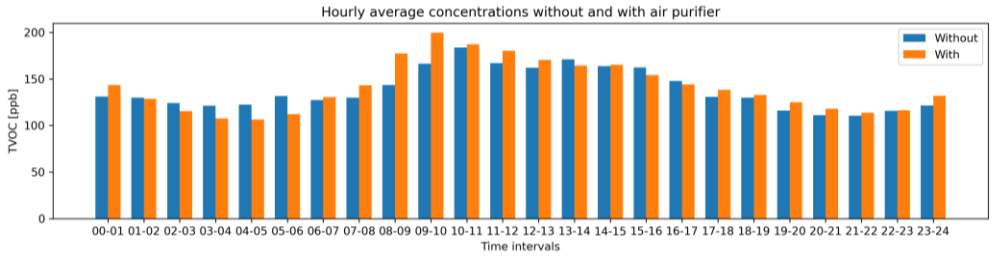

Figure 4: Hourly average of TVOC in nursing home 1.

For **nursing home 2**, higher average values for all parameters, except the maximum concentration, were measured during the period when the air purifier was turned on. Based on the available data, a clear explanation cannot be provided. Possible explanations could be the possibility of the room experiencing an increase in human activity and/or load during the period with the air purifier turned on. However, CO_2 and light data (not shown in this report) from the room suggest relatively similar activity levels in the two periods. Another explanation could be that the airflow from the air purifier results in better mixing of air in the room, leading to a higher, overall concentration observed by the sensor. Referring to the initial laboratory tests conducted on this air purifier, it is assessed that the increased concentrations are not due to the formation of byproducts from the air purifier.

The hourly average of TVOC from nursing home 2 is presented in Figure 5. It can be observed that in the period without the air purifier, the highest concentrations occur between 11:00 and 14:00. In the period with the air purifier turned on, the average TVOC concentrations measured during this period are lower. However, for most other time intervals, the TVOC concentration is higher, which may be attributed to the improved mixing of air caused by the air purifier. The air purifier is placed on a table, which could contribute to increased air mixing in the room and result in higher average concentrations measured by the sensor.

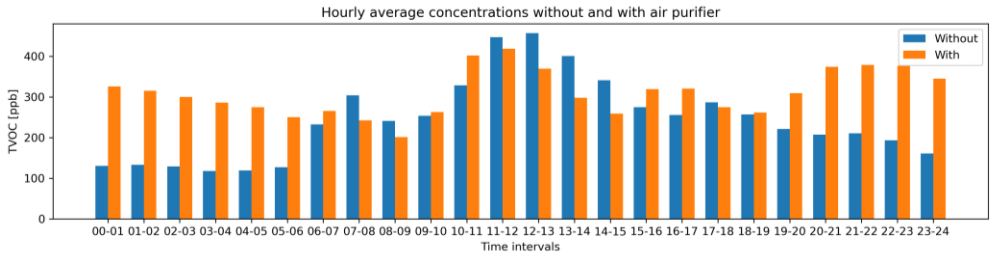

Figure 5: Hourly average of TVOC in nursing home 2.

For **nursing home 3**, the values of all three parameters during the period with the air purifier turned on were slightly lower than the period without the air purifier. This suggests a potential effect of the air purifier on reducing TVOC pollution.

The hourly average TVOC concentration for nursing home 3 is shown in Figure 6. It can be observed that there is a daily increase in TVOC concentration in the room around 06:00 lasting for approximately 3 hours. This could be attributed to the staff arriving and initiating activities in the room around this time. During the period with the air purifier turned on, the average concentrations between 06:00 and 11:00 are lower compared to the period without the air purifier. Like nursing home 2, this could indicate that the air purifier is capable of mitigating some of the peak loads during this specific period but is unable to reduce the average background level in the room.

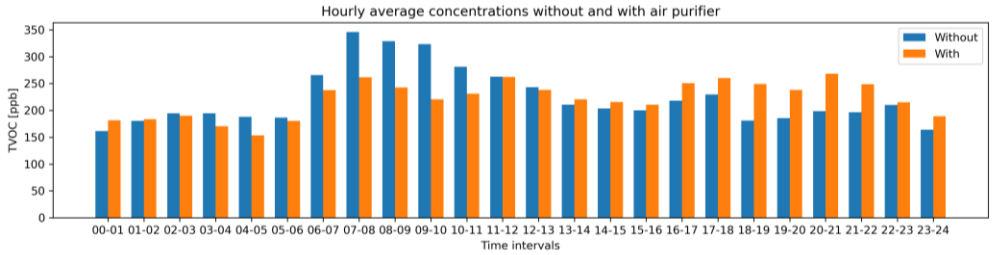

Figure 6: Hourly average of TVOC in nursing home 3.

For **nursing home 4**, it should be emphasized that the measurements during the periods with and without the air purifier were conducted in two different rooms. This introduces a significant source of error, as the human activity and load in the two rooms can be markedly different. However, considering this limitation, the average values show a significant decrease during the period with the air purifier turned on, indicating a positive effect of the air purifier.

The hourly average concentration presented in Figure 7 shows a notable decrease in TVOC concentration, particularly in the time interval from 07:00 to 11:00. This time corresponds to the period with the highest concentration during the time without the air purifier being turned on.

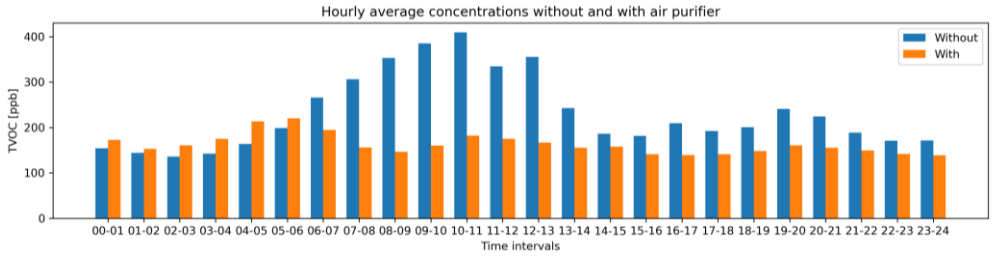

Figure 7: Hourly average of TVOC in nursing home 4.

4 CONCLUSION

Six out of the seven selected air purifiers were able to significantly reduce the concentration of acetaldehyde in the laboratory. A common feature among the six of them was the use of activated carbon filters, in addition to other air purification technologies for addressing different air pollution issues. Among these, the reduction in

acetaldehyde concentration after 20 minutes ranged from 19% to 83%. It was not possible to measure a significant effect from the product that solely utilized photocatalytic oxidation (PCO).

For all six products using activated carbon filters, the off-gassing of acetaldehyde from the product was measured. Off-gassing is defined as releasing acetaldehyde from the air purifier into the surrounding environment, thus counteracting its effect. Off-gassing should be a point of attention for future investigations into the use of air purifiers, as this was observed for all products utilizing activated carbon filters.

Additionally, for five out of the seven examined air purifiers, small traces of other gases (so-called byproducts) were detected apart from acetaldehyde. It is worth noting that byproducts are a significant point of attention for the future use of air purifiers with relevant technologies.

In this project, measurements of total volatile organic compounds (TVOCs) are performed with indoor air quality sensors at four selected nursing homes and are assumed to be a direct indicator of odor concentration. Overall, it is challenging to draw a definitive conclusion on the effectiveness of the air purifiers in mitigating odorants, as the TVOC concentration varies significantly in the sensor data analyzed during the project period. Additionally, ethanol in the air, likely from hand sanitizers, significantly affects the sensor data, which overshadows the contribution of odorants in the measurements.

For the average TVOC concentration, there is an indication of a positive effect of the air purifier in nursing home 4 (30% reduction), while nursing home 2 shows, on average, a higher TVOC concentration in the room during the period with the air purifier. For all four nursing homes, a lower maximum TVOC concentration is measured during the period with the air purifier turned on compared to the period without. Sensor data also shows that, during the period when the air purifiers were installed, there were fewer periods with a TVOC concentration above 250 ppb for nursing homes 1, 2, and 4. Particularly, a reduction in the TVOC concentration during the periods when the rooms experience a high average load is observed. The TVOC data thus suggest that air purifiers using filters with activated carbon can mitigate some of the odor peak loads during specific periods with high concentrations but is unable to reduce the average background level in the room.

5 ACKNOWLEDGEMENTS

We would like to acknowledge the collaboration with Aarhus Municipality and especially Mads Duevang Dahl and Monica Petersson Ekström.

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