C18

Results of Monitoring Indoor Air Quality (IAQ) in Anchorage, Alaska

Getu Hailu, PhD
Associate Member ASHRAE

Dawn Adamson
Student Member ASHRAE

Chris Carter

ABSTRACT

In Alaska air pollution is problem throughout the year. During wintertime, cold temperatures, and strong surface-based temperature inversions, which can trap locally emitted pollution, are common. This pollution trapping is exacerbated when population centers are located in valleys or bowls (such as Anchorage), where terrain further decouples surface winds from upper-level airflow. In the summer, large forest fires, are prevalent and can result in major air pollution episodes. In Alaska, there is also higher potential of particulate matter in the atmosphere adversely affecting health and well-being of the residents. According to the 2018 Alaska Housing Assessment, in Alaska, an estimated 56% (141,000) of occupied homes have a moderately higher risk of moisture and indoor air quality issues because they are relatively airtight and lack mechanical ventilation. Hence managing IAQ is important for the health and well-being of the people living in the Alaska is even more crucial. Recently, University of Alaska Anchorage (UAA) established a new IAQ lab. A 12 x 24 lofted gambrel-style building, constructed with T111 exterior siding, insulated walls and plywood interior cladding is used to monitor indoor air quality under different conditions. To mimic a residential building, the interior plywood walls were painted with bright white semigloss interior/exterior urethane alkyd enamel and the floor was covered with carpet tiles. Pollutant (CO, CO2, NO, NO2, SO2, TVOC) concentrations were monitored over a relatively long period of time under different conditions. At the same time indoor and outdoor temperature and relative humidity data were recoded. At a given time, it was found that pollutant concentration is different at different location in the monitored building, indicating the need to develop efficient and cost-effective IAQ mitigating strategies targeting the pollutant concentration areas.

INTRODUCTION

The American Lung Association "State of the Air" report found that Alaska has some of the worst air quality in the nation (American Lung Association 2018). The situation is expected to worsen. As the Arctic thaws, new economic opportunities, such as tourism, resource exploration and new shipping routes will be created. With increased transportation, increase in emission of air pollutants such as particulate matter and greenhouse gases is expected. As glaciers melt, black carbon is exposed and released to the atmosphere. Swelling temperatures and increasing amounts of CO_2 in the atmosphere create favorable conditions for increased pollen seasons, and increased amount of pollen produced. Frequent wildfires and dust from gravel/dirt roads in Alaska is another source of air polluting particulate matter and gases. Consequently, the air quality in the Alaskan homes will be adversely affected, resulting in poor indoor air quality (IAQ). In Alaska air pollution is problem throughout the year. During wintertime, cold temperatures and strong surface-based temperature inversions, which can trap locally emitted pollution, are common (Serreze, Schnell, and Kahl 1992), (Tran and Mölders 2011). This pollution trapping is exacerbated when population centers are located in valleys or bowls (places with high population), where terrain further decouples surface winds from upper-level airflow (Schmale et al. 2018). In the summer, near-constant sunlight and accompanying atmospheric heating induce stronger vertical mixing, as well as more clouds and the removal of pollutants by

Getu Hailu is associate professor in the Department of Mechanical Engineering, University of Alaska Anchorage (UAA), Anchorage, AK. **Dawn Adamson** is a mechanical engineering student at UAA, Anchorage, AK. **Chris Carter** is a mechanical engineering student at UAA, Anchorage, AK.

precipitation is possible. However, large forest fires, on the other hand, are prevalent in the summer and can result in major air pollution episodes (Kelly and Fussell 2015). In Alaska, from 2015 to 2020, the yearly average of fire incidences was more than 500 affecting more than 1.5 million acres of land. Although air pollution is a huge problem in Alaska, data for many places are unavailable and pollutant motion and dispersion in the Alaskan homes is poorly understood (American Lung Association 2018). Warming conditions also promote the microbial conversion of carbon that is stored in permafrost into greenhouse carbon dioxide (Commane et al. 2017). With the melting of glaciers, the release of black carbon aerosols, originating from incomplete combustion of fossil fuels and biomass to the atmosphere will be enhanced (Winiger et al. 2019). Warming temperature creates favorable conditions and extended period for plant growth (Hatfield and Prueger 2015). This in turn will lead to higher pollen concentrations and longer pollen seasons. Airborne allergens, like pollen, decrease air quality and cause health problems (National Center for Environmental Health 2020). The generation and dispersion of all these pollutants will negatively affect the indoor air quality. In addition to nature driven air quality issues, economic driven air pollution is a concern. The Arctic's socioeconomic development is already underway and will continue to be crucial in the future. With the rise of natural resource extraction, Arctic destination shipping is projected to increase, and tourism will expand (Schmale et al. 2018). This development will lead to increased number of people living in the Arctic, as well as increased types and magnitudes of emissions. Consequently, climate and economic driven poor outdoor air quality will lead to poor IAQ, adversely affecting the health and economy of Alaskans. Some of the health concerns associated with poor IAQ include increased frequency of emergency department visits and hospitalizations for asthma, increased incidence and development of asthma, and pollen allergy and even cancer.

In indoor spaces, people generally sit or lie down instead of standing, and toddlers and infants always breathe at lower heights. Hence, it is better that IAQ measurement be done at multiple heights to cover true breathing zones. Furthermore, in the absence of mechanical ventilation, indoor air may not be well mixed in neither vertical nor horizontal directions due to the presence of internal heat sources and air dispersion. Hence, it is important to investigate vertical and horizontal variations in pollutant concentration. In addition, indoor air contaminants have a wide range of concentrations over time at different spots in a space. Hence taking measurement for a short duration of time at one spot only will lead to substantial bias. This project emphasizes on the importance of capturing the spatial variations of pollutant concentrations. In this work, a small wooden cabin was constructed for monitoring IAQ for extended period of time throughout the yearly seasons under various conditions. We present here preliminary results of the monitoring.

EXPERIMENTAL SETUP

For this work, a 14' x 36' lofted gambrel-style building, constructed with T111 exterior siding, insulated walls and plywood interior cladding was used to monitor indoor air quality (Fig. 1). Fresh painting and carpeting were applied at the start of the experiment. The roof is assembled of Oriented Strand Board (OSB) roof sheeting covered with ice and water shield and steel roofing. The whole cabin sits on 4, 4" x 6" treated skids for ease of transportation.

Figure 1 Solid works model of the experimental cabin

Instrumentation

The following sensors were used to monitor gaseous substances and particulate matter:

1. Temtop PMD 331 Particle Counter for Air Quality Measurement. Manufacturer: Temtop, Shanghai, China.
2. YES Plus LGA 15-Channel IAQ Monitor. Manufacturer: Critical Environment Technologies, British Columbia, Canada
3. HOBO Carbon Dioxide – Temperature and Relative humidity Data Logger. Manufacturer: Onset Computer Corporation, Bourne, MA, USA

The Temtop PMD 331 particle counter was used to monitor particulate matter of 0.3μm, 0.5μm, 0.7μm, 1.0μm, 2.5μm, 5.0μm and 10μm diameter, with an accuracy of ±10%. The YES Plus LGA sensor was used to monitor NO_2, SO_2, NO, CO, O_3, CO_2 and VOC. Temperature and relative humidity of the cabin were also monitored with HOBO and YES Plus LGA sensors. The HOBO sensor was also used to monitor CO_2 at different locations in the cabin (Figure 2). WEN 3410 3-speed remote-controlled air filtration system was used to circulate air in the cabin. The filtration system was equipped with factory supplied 1-micron filter. The filtration system was hanging from the ceiling as recommended by the manufacturer ensuring that it was situated at least 7' above the floor and at least 3' away from a corner and from any heating or air vents. The cabin was not air-conditioned, or no activity (such as cooking) took place. Except for during downloading data, the cabin remained unoccupied with a closed window and a door. A blower door setup (Retrotec Model US5100) was used to measure the air change per hour (ACH), which was found to be relatively high with 5.8 ACH.

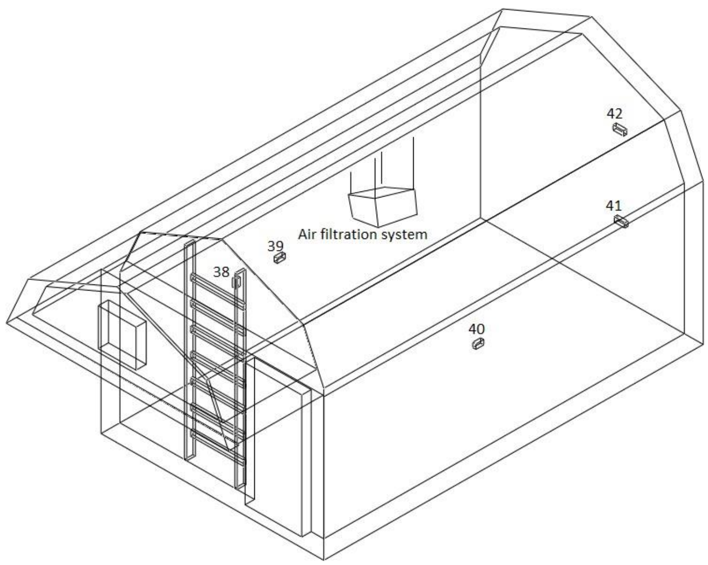

Figure 2 Sensor locations. 38, 39, 40, 41 and 42 are locations of HOBO sensors. The air purification system hanged from the ceiling as shown.

Data collection

Two sets of data were collected, one before installation of the air purification system: and the second one after installing the air purification system. CO_2 concentration data were collected using HOBO sensors from June 13, 2022, June 2022, and from June 24 to July 08. Particulate concentration data were collected using Temptop from June 13 to July 30, 2022. YES Plus LGA sensor was used from June 13 to July 08 2022 to collect data on NO_2, SO_2, NO, CO, O_3, CO_2 and VOC concentration in the cabin. Particulate concentration data were collected using Temptop after installing the air purification systems, from August 2 to August 16, 2022.

RESULTS

Particulate matter monitoring

Figure 3 shows particulate matter concentration measured using Temtop sensor. Generally, the concentration of smaller particles is higher as compared to larger particles. The highest concentration was found for 0.3µm particles on June 24. In a nearby station (Laurel Street), 1.6miles away from the experimental site, the highest particulate concentration was measured at around 11am on that day. It is plausible to assume that the high indoor value on that day is a result of this high outdoor particulate concentration (Figure 4). Figure 4 shows outdoor and indoor $PM_{2.5}$ concentration on June 24, 2022. The highest concentration of 2.5µm particles was measured in the experimental cabin around 3pm. Particulate matter is driven by wind and the time difference of the peak value can be due to wind effect. The 4-hour difference could be due to the time it took for particulate matter to travel the 1.6 miles distance between the 2 sites.

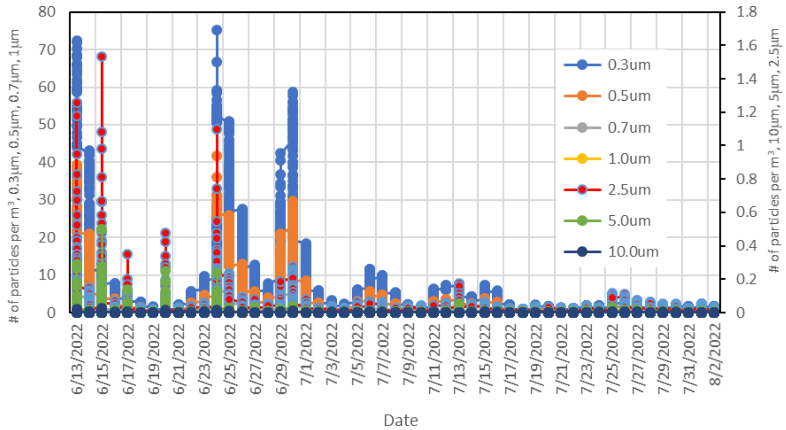

Figure 3 Particulate matter measured using Temtop sensor. Values for 03µm, 0.5µm, 0.7µm, 1µm are on the left vertical axis, while those for 2.5µm, 5µm and 10µm are on the right vertical axis.

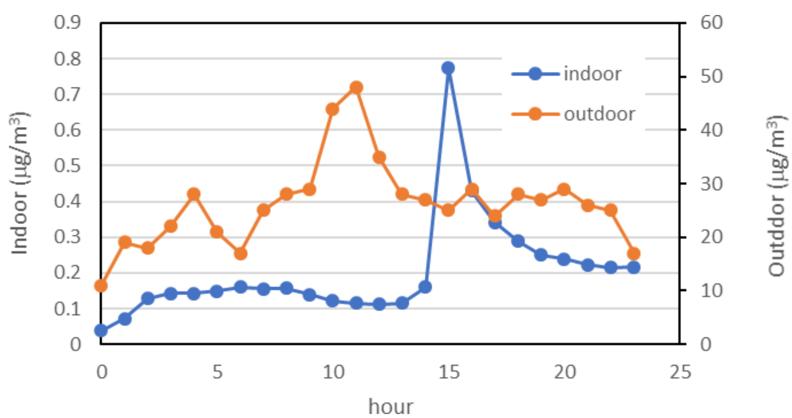

Figure 4 Comparison of outdoor and indoor 2.5µm particles on June 24.

The concentration of smaller size of particles is a concern because it is directly linked to their potential for causing health problems (EPA n.d.-a). Small particles less than 10 micrometers in diameter pose the greatest problems, because they can get deep into lungs, and some may even get into bloodstream (EPA n.d.-a). The EPA Ambient Air Quality standard for particles less than 10 microns is 50 µg/m³ per hour for an annual average and 150 µg/m³ for a 24-hour average (EPA n.d.-b). World Health Organization (WHO) air quality guideline levels for PM10 (45 µg/m³ 24-hour, 15 µg/m3 annual) and PM2.5 (15 µg/m³ 24-hour, 5 µg/m³ annual) are more stringent than US EPA and States' requirements for PM (Hoy Bohanon, et al., 2022). The smallest particles (0.3μm particles) are above this range on some days. It is noted that this level of concentration of particulates was measured in an occupied space and if occupied, the levels could be more. Figure 5 shows particulate concentration after application of air purification system. WEN 3410 3-speed remote-controlled air filtration system was used to circulate air in the cabin. The clean air delivery rate was the purification systems was 300cfm. It's seen that the system was able to reduce the particulate to the level that is not a health risk.

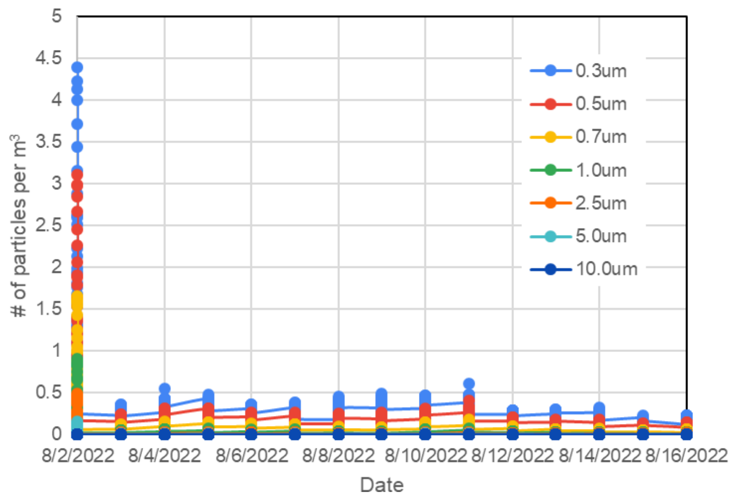

Figure 5 Particulate matter measured using Temtop sensor after use of air purification system.

Gas monitoring

Fig. 6 shows CO_2 concertation in the experimental cabin measured by YES Plus LGA sensor. During the monitoring time the concertation was around 400ppm, except on June 15, when the value reached 1097 ppm. The increase was possibly triggered by smoke from wild fires (Smiley 2022). On June 15 it was reported that the Anchorage and the Fairbanks areas have been dealing with smoke as a result of wild fire (Smiley 2022). Measured concentration of NO_2, NO, SO_2 and CO in the experimental cabin from June 13 to July 08, 2022 given in Figure 7.

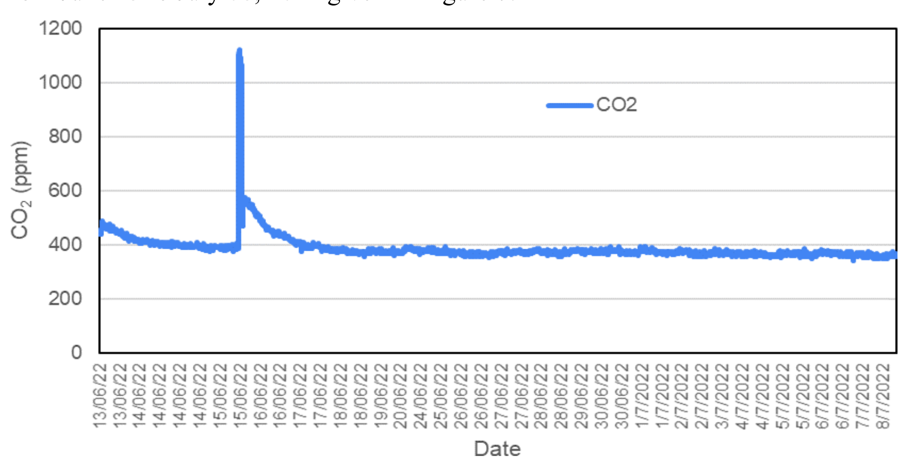

Figure 6 CO_2 concentration in the experimental cabin from June 13 to July 08, 2022.

The ASHRAE Standard 62.1-2016, "Ventilation for Acceptable Indoor Air Quality", US Environmental Protection Agency and the World Health Organization limit CO level to 9 ppm over an 8-hour exposure. Hence, the CO level inside the cabin is

considered to be acceptable. The maximum level of NO_2 concentration was 0.181ppm (Figure 7). No standards have been agreed upon for nitrogen oxides in indoor air.
ASHRAE and the EPA National Ambient Air Quality Standards list 0.053 ppm as the average 24-hour limit for NO2 in outdoor air (EPA 2022). The measured NO_2 concentration in the cabin is above the allowable outdoor limit 0.053ppm for 24-hour average. It is noted that this level could increase if gas stoves and space heaters are present in the cabin.

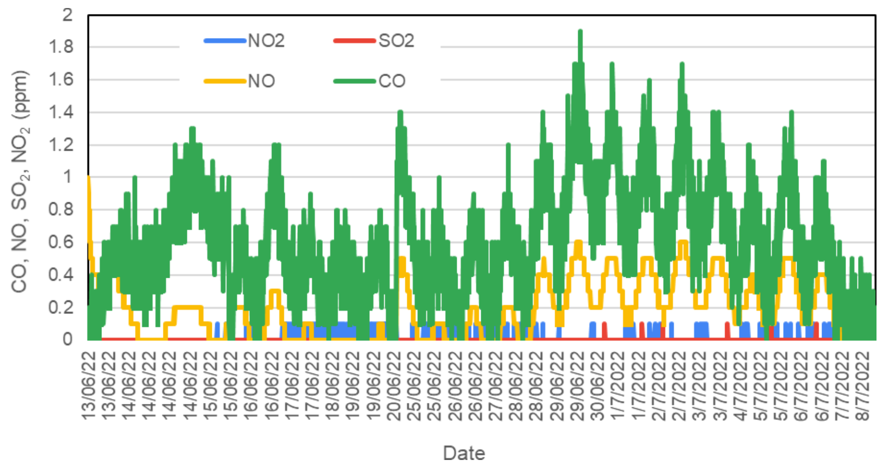

Figure 7 Concentration of NO_2, NO, SO_2 and CO concentration in the experimental cabin from June 13 to July 08, 2022.

Figure 8 shows measured CO_2 concentration at different locations in the experimental cabin measured using HOBO sensors designated as 38, 39, 40, 41 and 42. From June 13, 1pm until June 14, 12:50pm sensor 41 showed higher values of CO_2 as compared to other sensor measurements.

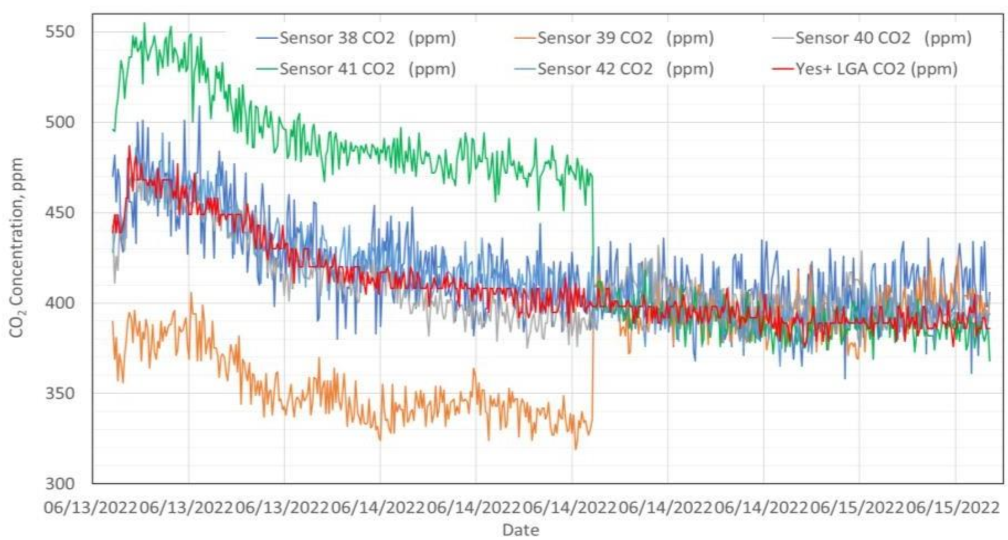

Figure 8 Concentration of CO_2 at different locations of the cabin as shown in Figure 2.

On the other hand, sensor 39 showed low concentration of CO_2 for the same day/time. An attempt was made to relate these results to temperature and/or relative humidity measurement at those locations. The temperature at the location of sensor 41 fluctuated between 18°C and 22.4°C (for night and day, respectively). The lower temperature differs only by 1°C from the temperature recorded by sensor 40. Sensor 40 recorded temperatures varying between 19°C and 22°C. The relative humidity recorded by the sensors is shown in Figure 9. Generally, the humidity recorded by Sensor 41 is the highest, fluctuating between 52.7% and 59%. It has been reported there is strong correlation between CO_2, temperature and relative humidity (Liu et al. 2017), (Singh and Malarvili 2020). Starting June 24, 12:55pm, sensor 41 did not record higher CO_2 even when the relative humidity registered by it was higher than the relative humidity registered by other sensors. Hence, in this study, we cannot conclude that CO_2 recorded by sensor 40, which was initially at higher level of concertation was the result of higher relative humidity. More data is needed to confirm this.

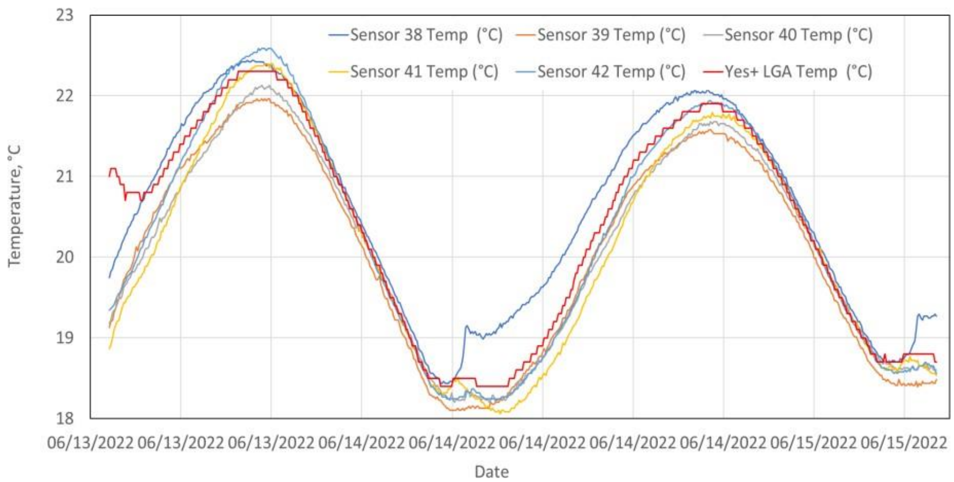

Figure 9 Temperature at different locations of the cabin shown in Figure 2.

It is noted that the CO_2 concentration measured by YES+LGA sensor is similar to the CO_2 concentration measured by HOBO sensors 38, 40 and 42. This is encouraging results because it implies that much less expensive sensors can be used to get accurate results.

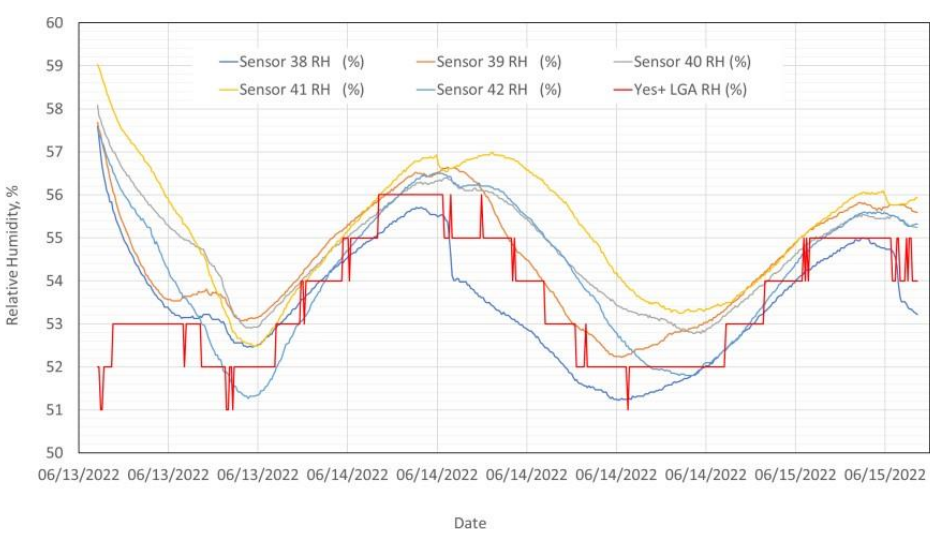

Figure 10 Relative humidity at different locations shown in Fig. 2.

CONCLUSION

The main conclusions of this work are:

- High particulate matter concentration was found in the cabin. It was possible to substantially reduce the concentration of these particles with the use of relatively inexpensive air filtration system,
- The CO level inside the cabin was at acceptable level, however it is noted that the cabin was unoccupied during data collection and this level could increase when the cabin is occupied and human activities increase,
- 3 HOBO sensors gave similar data on CO_2 concentration to the YES Plus LGA sensor (much more expensive) indicating that CO_2 could be monitored with relatively an inexpensive sensor with good accuracy,
- Sensors located at different locations in the cabin showed that the concentration of CO_2 varied in the cabin for approximately 1 day. More study is needed to determine the cause of this variation.

ACKNOWLEDGMENTS

The authors would like to thank Alaska NASA EPSCoR and UA for financial support.

REFERENCES

American Lung Association. 2018. *State of the Air 2018*.

Commane, Róisín, Jakob Lindaas, Joshua Benmergui, Kristina A. Luus, Rachel Y. W. Chang, Bruce C. Daube, Eugénie S. Euskirchen, John M. Henderson, Anna Karion, John B. Miller, Scot M. Miller, Nicholas C. Parazoo, James T. Randerson, Colm Sweeney, Pieter Tans, Kirk Thoning, Sander Veraverbeke, Charles E. Miller, and Steven C. Wofsy. 2017. "Carbon Dioxide Sources from Alaska Driven by Increasing Early Winter Respiration from Arctic Tundra." *Proceedings of the National Academy of Sciences of the United States of America*. doi: 10.1073/pnas.1618567114.

EPA. 2022. "Nitrogen Dioxide's Impact on Indoor Air Quality." *EPA (United States Environmental Protection Agency)*. Retrieved October 10, 2022 (https://www.epa.gov/indoor-air-quality-iaq/nitrogen-dioxides-impact-indoor-air-quality).

EPA. n.d.-a. "Health and Environmental Effects of Particulate Matter (PM)."

EPA. n.d.-b. "What Are the Air Quality Standards for PM?"

Hatfield, Jerry L., and John H. Prueger. 2015. "Temperature Extremes: Effect on Plant Growth and Development." *Weather and Climate Extremes*. doi: 10.1016/j.wace.2015.08.001.

Hoy Bohanon, Bill Bahnfleth, Chandra Sekhar, Luke Leung, Meghan McNulty, Kathleen Owen, Marwa Zaatari, Max Sherman, Junjing Yang, Wane Baker. 2022. *Increased Awareness of Health Impacts of Indoor PM2.5 and Need for Particulate Matter Control in Occupied Spaces*.

Kelly, Frank J., and Julia C. Fussell. 2015. "Air Pollution and Public Health: Emerging Hazards and Improved Understanding of Risk." *Environmental Geochemistry and Health*. doi: 10.1007/s10653-015-9720-1.

Liu, Yuliang, Xiang Ni, Yuanxi Wu, and Wei Zhang. 2017. "Study on Effect of Temperature and Humidity on the CO2 Concentration Measurement." in *IOP Conference Series: Earth and Environmental Science*.

National Center for Environmental Health. 2020. "Allergens and Pollen." Retrieved May 9, 2021 (https://www.cdc.gov/climateandhealth/effects/allergen.htm).

Schmale, J., S. R. Arnold, K. S. Law, T. Thorp, S. Anenberg, W. R. Simpson, J. Mao, and K. A. Pratt. 2018. "Local Arctic Air Pollution: A Neglected but Serious Problem." *Earth's Future*. doi: 10.1029/2018EF000952.

Serreze, Mark C., Russell C. Schnell, and Jonathan D. Kahl. 1992. "Low-Level Temperature Inversions of the Eurasian Arctic and Comparisons with Soviet Drifting Station Data." *Journal of Climate*. doi: 10.1175/1520-0442(1992)005<0615:lltiot>2.0.co;2.

Singh, Om Prakash, and M. B. Malarvili. 2020. "Effect of Temperature, Pressure and Humidity on Carbon Dioxide Concentration-Simulation Study." in *IOP Conference Series: Materials Science and Engineering*.

Smiley, Sage. 2022. "Smoke from Alaska Wildfires Reaches Southeast."

Tran, Huy N. Q., and Nicole Mölders. 2011. "Investigations on Meteorological Conditions for Elevated PM2.5 in Fairbanks, Alaska." *Atmospheric Research*. doi: 10.1016/j.atmosres.2010.08.028.

Winiger, P., T. E. Barrett, R. J. Sheesley, L. Huang, S. Sharma, L. A. Barrie, K. E. Yttri, N. Evangeliou, S. Eckhardt, A. Stohl, Z. Klimont, C. Heyes, I. P. Semiletov, O. V. Dudarev, A. Charkin, N. Shakhova, H. Holmstrand, A. Andersson, and Gustafsson. 2019. "Source Apportionment of Circum-Arctic Atmospheric Black Carbon from Isotopes and Modeling." *Science Advances*. doi: 10.1126/sciadv.aau8052.