Creating a Healthy, Comfortable, Productive and Energy Efficient Classroom

Mary Miller Junior High CERV-1000 Status Report

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Executive Summary

This report provides CERV-1000 operation data and characteristics in an active classroom during August and September, 2023 school year. Indoor air quality and comfort conditioning are discussed for a CERV-1000 unit installed in classroom 111 in Mary Miller Junior High (MMJH) School, Georgetown-Ridge Farm (CUSD#4) in Georgetown, Illinois. Comparisons are made with air quality and comfort data collected from the same classroom prior to CERV-1000 installation. 11 additional CERV-1000 units will be installed in MMJH classrooms, extending the benefits of excellent indoor air quality and comfort conditioning to all students and staff at MMJH.

A survey of indoor air quality and comfort (temperature and humidity) of six classrooms (including room 111 with the CERV-1000) in MMJH from September 6 to 15, 2023 demonstrated the effectiveness of the CERV-1000 in maintaining reduced carbon dioxide and VOC (Volatile Organic Compound) concentrations in comparison to the other five classrooms. In addition, CERV-1000 maintained comfort during August 21-25, 2023 with outdoor temperatures exceeding 100F while maintaining a healthy classroom environment.

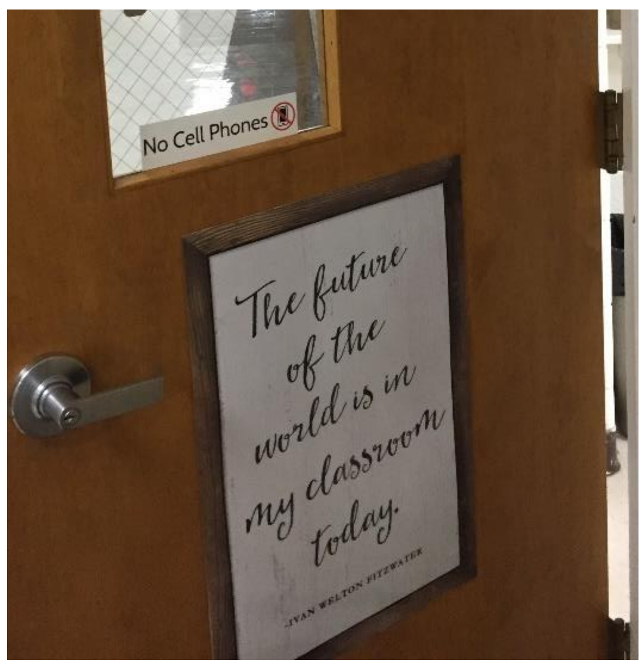
Air quality and comfort significantly impact student performance and absenteeism. The effect of the CERV-1000 in MMJH School classrooms, based on estimates in peer-reviewed literature indicates the following:

1) Carbon dioxide (CO_2) reduction from previous levels is expected to increase student task speed by 12%
2) CO_2 reduction from previous levels is expected to increase student test accuracy by 2%
3) CO_2 reduction from previous levels is expected to improve student standardized test performance by 5%. Student standardized test performance is indicative of cumulative improvement in student performance.
4) Increased ventilation and decreased particulates are expected to reduce classroom absenteeism by 1 to 2 illness-related absence days per student, or 200 to 400 fewer illness-related absentee days per school year for the school's 200 students. The estimate

is based on a study of the impact of ventilation rates and particulates on absenteeism investigation of over 144 classrooms and 3100 students in midwestern US schools.

5) VOC (Volatile Organic Concentration) concentrations are reduced by more than 50% in room 111 in comparison to VOC levels in other classrooms in MMJH.
6) VOCs are primarily due to human occupant emissions and activities rather than other sources of chemicals (eg, formaldehyde, furnishing-off-gassing, pesticides, etc). VOC levels drop to low levels during non-school hours.
7) Current CO_2 level in room 111 is impacted by high CO_2 levels in surrounding hallways and classrooms in MMJH that regularly exceed 2000ppm. Installation of CERV-1000 units throughout MMJH classrooms will further reduce room 111's CO_2, VOCs, and particulate matter concentrations.
8) The CERV-1000 operates more efficiently (40% less energy for cooling in comparison to current classroom air conditioners) with less noise. CERV-1000 sound pressure is 52dB at 1000cfm in comparison to current classroom air conditioner at 63dB.
9) During typical fall school days with warm outdoor temperatures (69-80F, 20-27C), CERV-1000 energy usage is 11kWh per day with an estimated operational cost of $1.70/day per class, or 8 cents per student per day.
10) During extreme warm weather conditions approaching 105F (40C), the CERV-1000 maintained IAQ and comfortable (70-72F, 21-22C) classroom temperature with an average power level of 2kW during class hours. Classroom 111 exceeded 80F (27C) with 95F (35C) outdoor ambient prior to CERV-1000 installation.
11) Student test performance gains of 20% have been found for a reduction of classroom temperature from 86F (30C) to 68F (20C), indicating that the CERV-1000 will also contribute to student performance gains from improved comfort management.

An appendix documents installation of the initial CERV-1000 unit. The system is designed for cost-efficient installation that avoids classroom disruption and school shutdown. In addition, the CERV-1000 is designed for installation by a local community's HVAC installers, retaining school renovation funds within the community. In the case of MMJH School, CERV-1000 units are installed by the school district's facility personnel. An experienced installation crew is expected to install a CERV-1000 unit with 4 person-days of labor.



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Introduction

Build Equinox delivered the first of twelve CERV-1000 air quality and comfort conditioning units to Mary Miller Junior High School (MMJH), Georgetown-Ridge Farm CUSD#4 (Georgetown, Illinois). Georgetown-Ridge Farm's facility staff installed the initial CERV-1000 unit in classroom 111 in MMJH in July, 2023, and will install the next 11 units. Build Equinox will assist with CERV-1000 installation. This status report provides air quality, comfort conditioning, and energy usage data for classroom 111 during August and September 2023. Comparisons to previous indoor air quality and comfort data survey data in MMJH classrooms are also included.

Recent research described the importance of indoor air quality and comfort on classroom performance and absenteeism. Task completion time is reduced, task accuracy is increased, and performance on standardized tests are improved with better air quality and comfort. Reasons for classroom improvements are complex and interrelated. For example, improved air quality impact on student performance may be related to improved cognition, reduced absenteeism, and more effective instruction.

The background section describes the CERV-1000 air quality and comfort conditioning unit installed in Room 111 of MMJH School. Also discussed in the background section is impact of air quality and comfort (classroom temperature) on student performance and absenteeism.

Following the background section is a discussion of air quality, comfort, and energy efficiency aspects of the CERV-1000 on MMJH room 111, an 8th grade mathematics classroom. Data collected from MMJH School examines the following air quality and comfort topics:

- Carbon Dioxide (CO_2)
- Volatile Organic Compound (VOC)
- Particulate Mass and Particulate Count
- Comfort Conditions and Energy Usage
- CERV-1000 performance during hot outdoor ambient conditions (Aug 21-25, 2023)

Background

CERV-1000 Combined Air Quality and Comfort Conditioning Unit Characteristics:

The CERV-1000 combines indoor air quality and comfort conditioning management into a single unit. The system is especially designed for installation in high occupant density indoor spaces lacking fresh air ventilation. Features incorporated into the CERV-1000 are:

- 1000cfm of fresh air ventilation capacity
- 70% energy recovery during fresh air ventilation mode
- 3-ton, high performance, cold temperature operation heat pump
- 75Watts of ultraviolet germicidal irradiation (UVGI)
- MERV13 indoor and outdoor air filtration
- Low noise (less than 60dB) operation at high air flow
- CERV-ICE (CERV-Intelligently Controlled Environment, pronounced “service”) online control, monitoring, and maintenance troubleshooting
- Installation that does not disrupt classroom operation
- Installation by facility maintenance staff and/or local HVAC contractors

The CERV-1000 brings classrooms up-to-date with ASHRAE 241 ventilation, the most stringent indoor ventilation standard. ASHRAE 241 is a new air quality ventilation standard (approved June 2023) developed to reduce airborne disease transmission.

A detailed description of the CERV-1000 and installation of the first unit in Room 111 at Mary Miller Junior High School is in the appendix.

Impact of Air Quality and Comfort on Student Performance and Absenteeism:

Three recent papers in peer-reviewed literature describe how air quality and comfort impact student performance in K12 classrooms (1, 2, 3). Two of the studies (1,3) are based on “meta” data, a compilation of multiple research studies on classroom performance due to classroom air quality and comfort (temperature). The third paper (2) is an investigation of absenteeism related to ventilation and particulates in 144 classrooms with 3100 students from 31 midwestern US schools (Nebraska).

The results of these research studies are used to estimate the impact of CERV-1000 units improving MMJH classroom air quality and comfort in relation to IAQ and comfort data collected prior to CERV-1000 installation.

Student Academic Performance:

Wargocki, et al (1) study of student performance and classroom air quality found that:

- Reduction of carbon dioxide from 2100ppm to 900ppm increases student task speed by 12%
- Reduction of carbon dioxide from 2100ppm to 900ppm improves student test score accuracy by 2%
- Reduction of carbon dioxide from 2400ppm to 900ppm improves student performance on standardized national test by 5% with the largest change occurring from a reduction of 1600ppm to 900ppm

The authors also found that improved air quality reduced absenteeism, which may be another factor impacting student performance and productivity.

Carbon dioxide is a surrogate indicator of air quality and is not necessarily a major factor affecting performance. Rather, high levels of carbon dioxide are associated with low ventilation air flow, high levels of VOCs (volatile organic compounds, primarily emitted from classroom occupants), and high levels of particulate matter (also primarily associated with occupants and their activities).

Student Absenteeism:

Deng, et al (2) found significant correlation of student absenteeism with fresh air ventilation rate and PM2.5 "particulate mass" concentration. PM2.5 is the mass of all particulates 2.5microns and smaller per cubic meter of air.

Fresh air ventilation was found to be statistically significant with an air flow increase of 1liter/second (2 cubic feet per minute) correlated with 5.6 days/school-year per class absenteeism reduction. Decreasing particulate density by 1µg/m^3 (average class size of 21.5 students) reduces absenteeism by 7.4 days/school-year per class.

Note that fresh air ventilation can be changed in a manner that either increases or decreases particulates. For example, outside particulate density may be high (wildfire smoke), air filtration may be poor (MERV8 filters), or other factors (eg, student activity level) that independently impacts particulate denisty.

Comfort Impact on Student Performance:

Wargocki, et al (3) meta-study of classroom temperature found that student performance is impacted as temperatures deviate from optimally preferred indoor temperatures. Decreasing classroom temperature from 30C (86F) to 20C (68F) improved classroom performance by 20%. Optimal classroom temperature range is 20C (68F) to 22C (72F). Although not included in their analyses due to lack of data, temperatures colder than 20C (68F) are expected to also result in lowered classroom performance similar to studies on employee productivity.

Background References:

(1) "The relationships between classroom air quality and children's performance in school", P Wargocki, J Ali Porras-Salazar, S Contreras-Espinoza, W Bahnfleth; Building and Environment 173 (2020), https://doi.org/10.1016/j.buildenv.2020.106749

(2) "Associations between illness-related absences and ventilation and indoor PM2.5 in elementary schools of the Midwestern United States", S Deng, J Lau, P Wargocki, Z Wang; Environment International (2023), https://doi.org/10.1016/j.envint.2023.107944

(3) "The relationship between classroom temperature and children's performance in school", P Wargocki, J Ali Porras-Salazar, S Contreras-Espinoza, Building and Environment 157 (2019), https://doi.org/10.1016/j.buildenv.2019.04.046

Classroom Carbon Dioxide Comparisons

The CERV-1000 unit in MMJH Room 111 continuously monitors carbon dioxide (CO_2) and VOC (Volatile Organic Compound) concentrations. When either CO_2 or VOC concentration exceeds user selected CO_2 and VOC setpoints, fresh air is introduced into the classroom. Outdoor air passes through a set of MERV13 filters, capable of capturing microbes, molds, smoke and other particulates.

After air filtration, fresh filtered air passes through energy exchange cores that recover 70% energy between incoming fresh air and outgoing exhaust air streams. Incoming fresh air then passes through the UVGI (ultraviolet germicidal irradiation) section for air sanitation. Finally, the filtered, sanitized fresh air passes through a 3 ton (nominal 36,000 Btu/hour) high efficiency heat pump. The heat pump operates efficiently at cold outdoor temperatures (-13F, -25C) with more than 75% nameplate capacity.

When indoor air quality does not require fresh air ventilation, the CERV-1000 operates in recirculation mode. Recirculating air passes through MERV13 filters, followed by UVGI sanitation and heat pump conditioning.

Currently, carbon dioxide and VOC concentrations are high in other classrooms and hallways without CERV-1000 units. High levels of indoor pollutants from the hallway and classrooms surrounding Room 111 with the CERV-1000 unit increases Room 111's fresh air ventilation loading. Figure 1 shows predicted carbon dioxide levels for Room 111 based on 20 students and 1 teacher in Room 111 over a range of fresh air ventilation rates.

Room 111 hallway door is frequently open during class changes, which opens the classroom to higher levels of carbon dioxide. Adjacent classrooms 110 and 109 have adjoining doors with room 111, and during break period, these doors may be open. Figure 1 assumes an air exchange flow rate of 200cfm between Room 111 and with surrounding hallway and classrooms assumed to be 2000ppm CO_2 concentration.

An additional effect that can increase CO_2 concentration in Room 111 would be if room 111 exhaust air flow is greater than its fresh air supply air flow. This condition can occur if the building has a differential pressure with room 111. An imbalance of 200cfm, in addition to air recirculation between Room 111 and its indoor surroundings further increases CO_2 concentration in Room 111 as shown in Figure 1.

Installation of the 11 additional CERV-1000 units will reduce the building's overall CO_2 concentration, resulting in a drop of Room 111 pollutant levels (as well as other classrooms with CERV-1000).

Room 111's air quality has improved significantly in relation to its air quality from previous measurements and in relation to other classrooms in MMJH. Figure 2 shows Room 111 CO_2 concentration from September 6-15, 2023. On Wednesday, September 14, the CERV-1000 controls were placed in recirculation mode (no fresh air ventilation), similar to the classroom's operation before CERV-1000 installation. CO_2 levels exceeded 2400ppm (2400ppm is the highest CO_2 concentration our monitoring stations could measure), demonstrating directly the impact of CERV-1000 operation.

Room 111 air was continuously recirculated on September 14, with air passing through MERV13 filter and UVGI air sanitation sections of the CERV-1000, keeping particulates and microbes at low levels. The data in Figure 2 clearly shows the CERV-1000's fresh air venting reduction of classroom CO_2.

Figure 3 is CO_2 data from the CERV-1000's internal sensor, showing similar CO_2 concentration levels as the Build Equinox IAQ monitoring station. Green regions in Figure 3 show time periods when fresh air ventilation is active, which is largely during school hours. The CERV-1000 CO_2 sensor is not limited to the 2400ppm measurement ceiling of the Build Equinox IAQ monitoring stations, and indicates that Room 111 reached 2600ppm CO_2 on Wednesday.

Data from the CERV-1000 is archived on the CERV-ICE (CERV-Intelligently Controlled Environment, "service") dashboard, an online, non-subscription link for Georgetown-Ridge Farm administration personnel to use for convenient monitoring and control of all CERV-1000 units placed in their buildings.

Figure 4 shows CO_2 concentration data from an IAQ survey conducted in MMJH classrooms 111 and 106 during May, 2022, a year prior to CERV-1000 installation in Room 111. High CO_2 levels occurred in both classrooms during the week. A few days exhibited lowered CO_2 levels. Outdoor conditions (described in the section of comfort) show that the days with lowered CO_2 occurred during cooler weather, allowing windows to be opened to help maintain comfort.

Figures 5-9 show CO_2 concentrations during the September 6 to 15, 2023 IAQ survey period. Classrooms 110 and 109 are adjacent classrooms on the same side of the hall (south side) as Room 111. These rooms are also mathematics classrooms and have doors connecting the classrooms (Classroom 110 is between Room 111 and Room 109), allowing direct communication of classroom air when those doors are open. Classrooms 110 and 109 have high levels of CO_2 that regularly exceed 2400ppm similar to Room 111 prior to CERV-1000 installation.

Classroom 108 (Figure 7), on the north side of the hallway, also displays high CO_2 concentration levels during school hours. Rooms 104 and 102 (Figures 8 and 9, respectively) have variable levels of CO_2, reflecting variable occupancy levels in those rooms. During placement and collection of the IAQ monitoring stations, Room 102 had 10 students with 1 teacher, resulting in lowered pollutant emissions in comparison to the mathematics classrooms that regularly have 20 or so students throughout the day.

From the previous discussion of student performance, Room 111's CO_2 concentration has been reduced from 2500ppm to less than 1200ppm, with significant impact on student performance and absenteeism. On average, we should expect to CERV-1000 classrooms in MMJH to have significant gains in task speed and test accuracy. The gains expected should be similar to those reported in (1), with 12% task completion speed reduction and 2% accuracy improvement.

Absenteeism for CERV-1000 rooms should be reduced by 20 to 40 days per school year per classroom, or about 1 to 2 illness-related absences per student per year assuming an average class size of 20 students. For MMJH with approximately 200 students, absenteeism should drop by 200 to 400 illness-related absences per school year.

We note that the above student performance improvements and reduced school absences are statistical estimates and actual classroom performances and absences will vary. Other factors also confound the effects. For example, students in MMJH move from classroom to classroom throughout the day rather than one group of students remaining in the CERV-1000 classroom. Also, students may have siblings and other household members in indoor environments that are not effectively ventilated, resulting in other pathways for IAQ to affect their performance and absences.

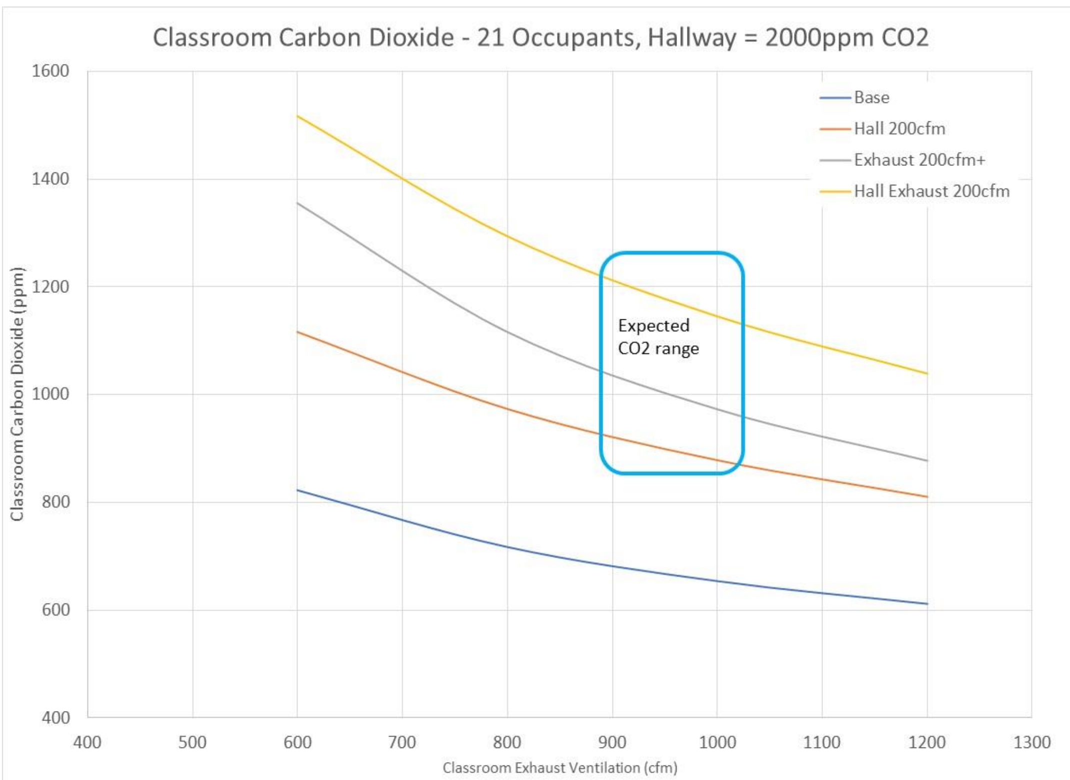

Figure 1 Estimated range of carbon dioxide concentration for classroom 111 in Mary Miller Junior High School with elevated hallway carbon dioxide concentration. Installation of CERV-1000 units for 12 MMJH classrooms will lower hallway carbon dioxide, resulting in further reduction of classroom 111 carbon dioxide.

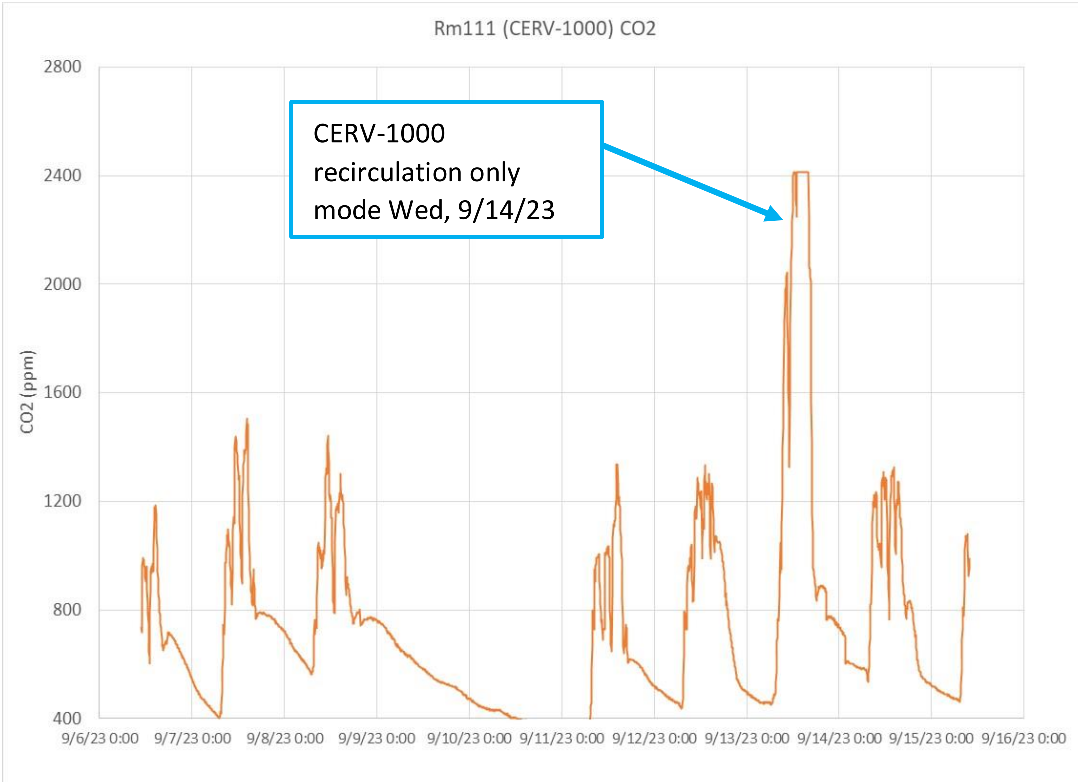

Figure 2 Room 111 (CERV-1000 classroom) CO_2 data from Sept 6 to 15, 2023

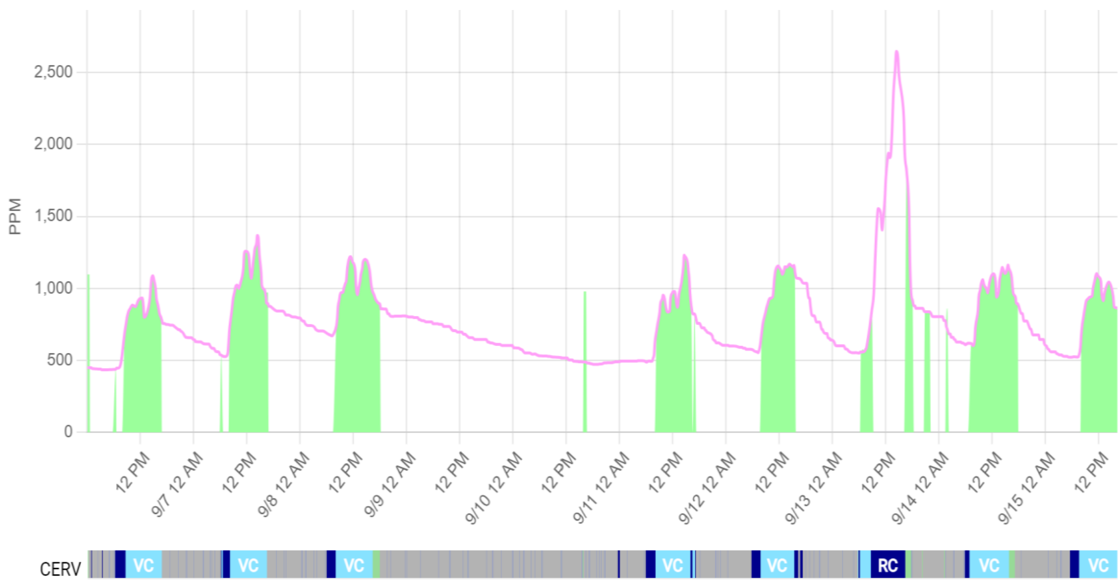

Figure 3 Room 111 CO_2 data from CERV-1000 online monitoring dashboard (CERV-ICE). Green regions show fresh air ventilation for each class day except for Sept 13 when CERV-1000 operated in recirculation mode

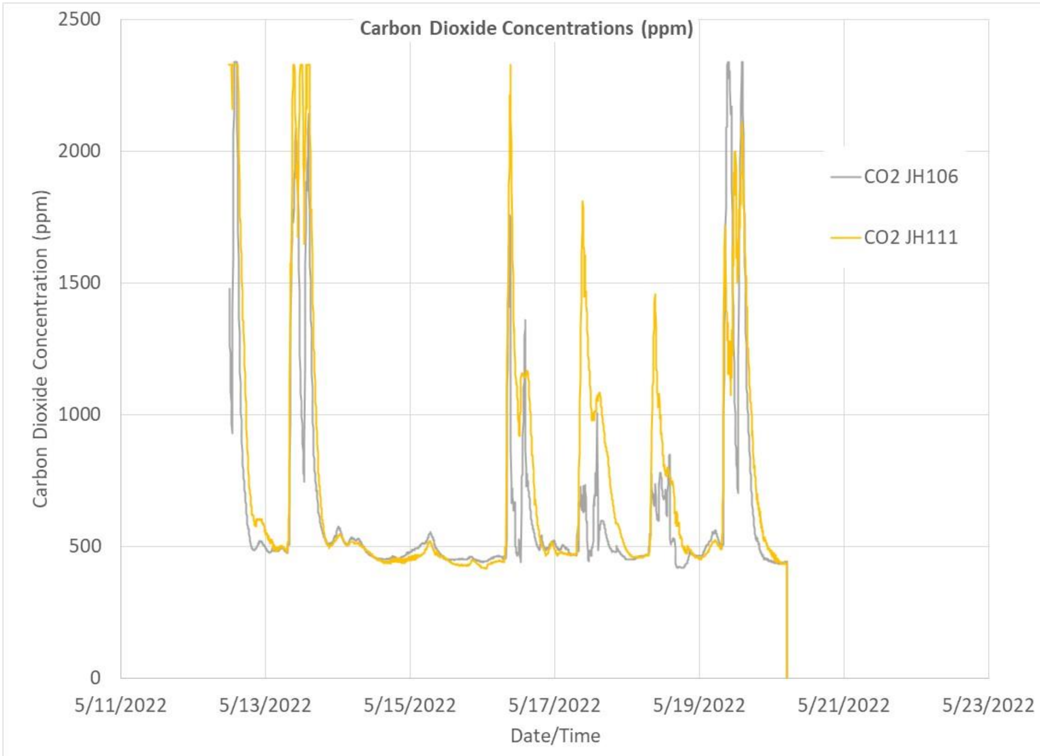

Figure 4 Classrooms 111 and 106 CO_2 data from indoor air quality study, May 2022

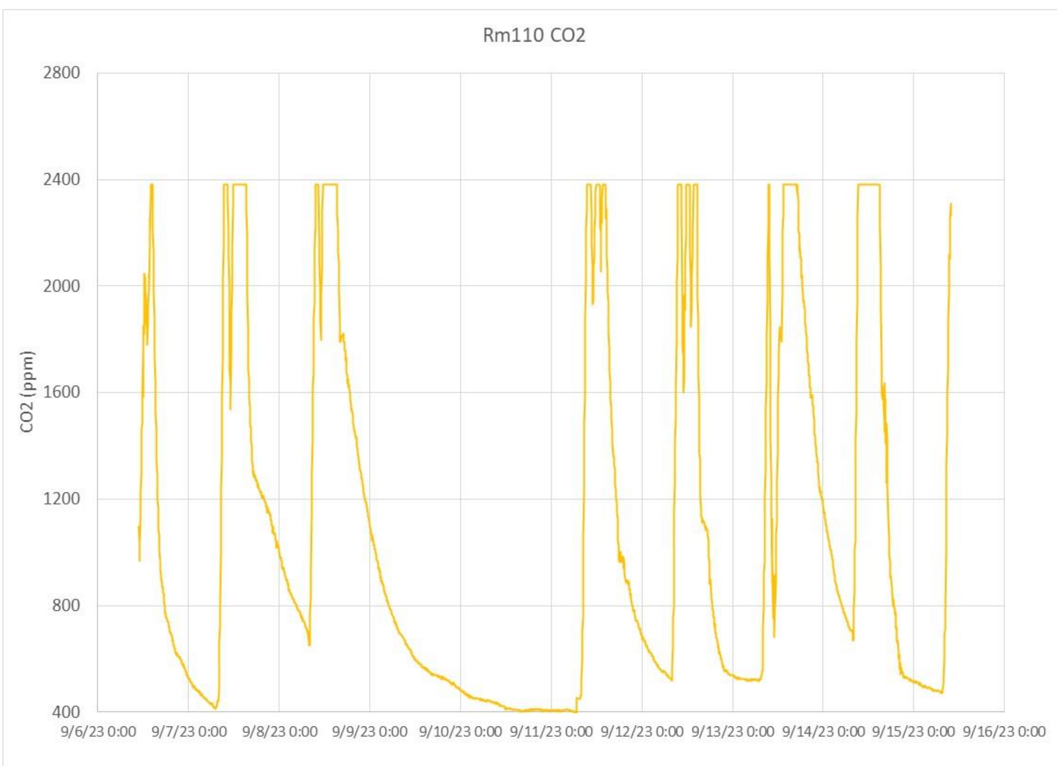

Figure 5 Room 110 (adjacent to Room 111 with door between Rooms 110 and 111) CO_2 data from September 6-15, 2023

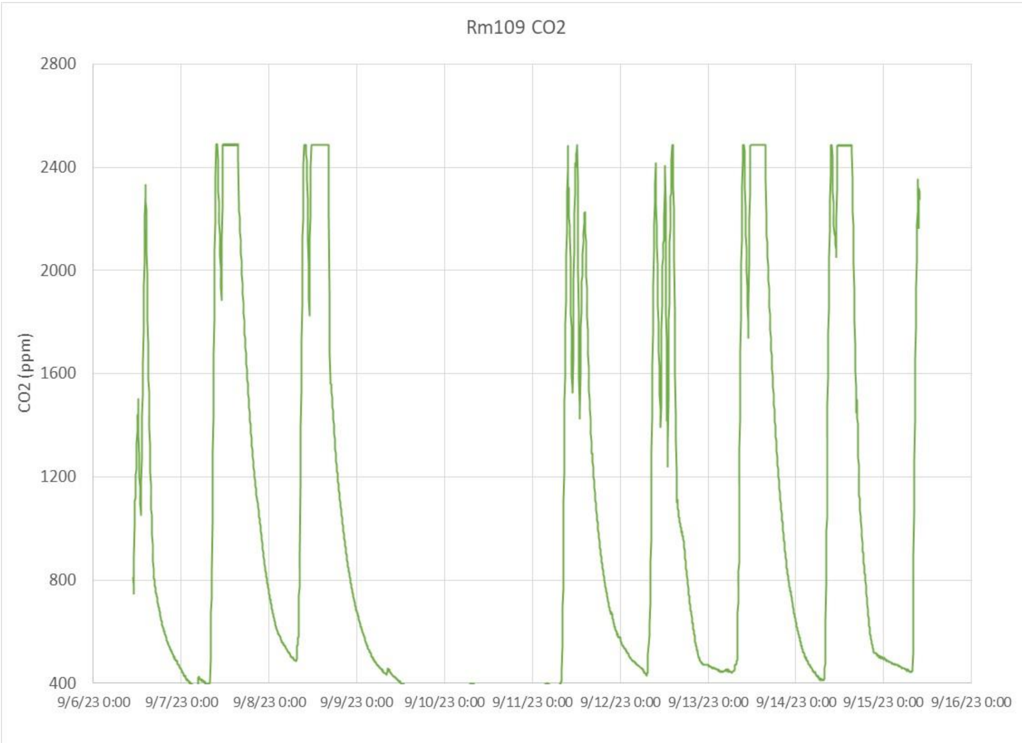

Figure 6 Room 109 (adjacent to Room 110 with door between Rooms 110 and 109) CO_2 data from September 6-15, 2023

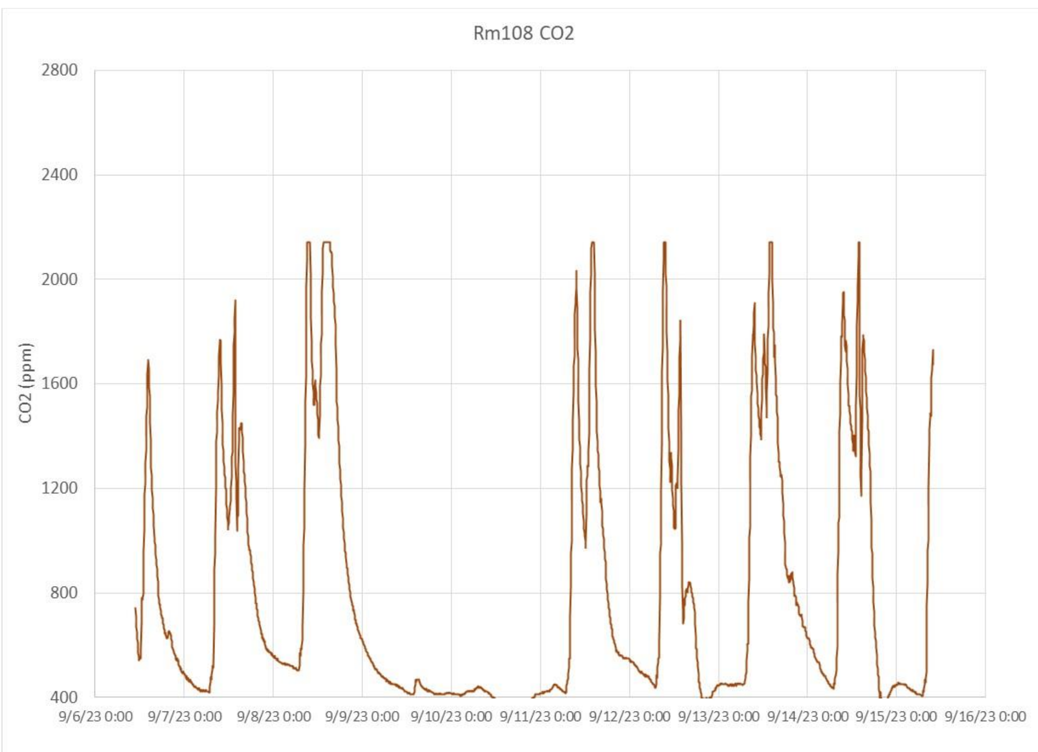

Figure 7 Room 108 (north side of hallway, opposite of Room 111) CO_2 data from September 6-15, 2023

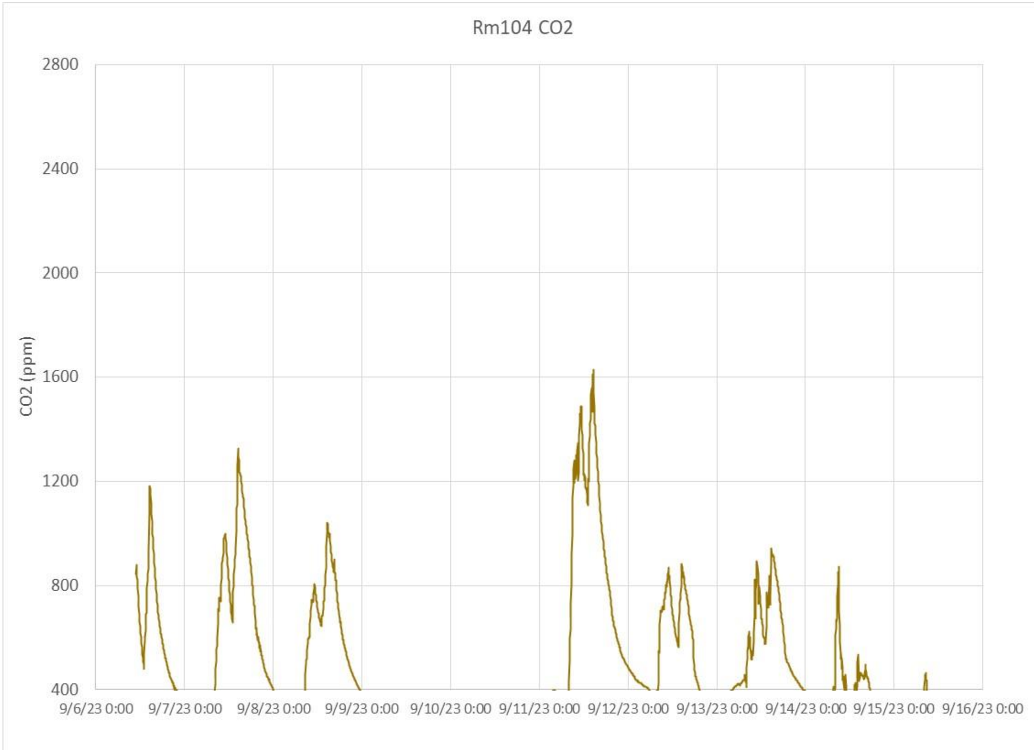

Figure 8 Room 104 (north side of hallway, opposite of Room 111) CO_2 data from September 6-15, 2023

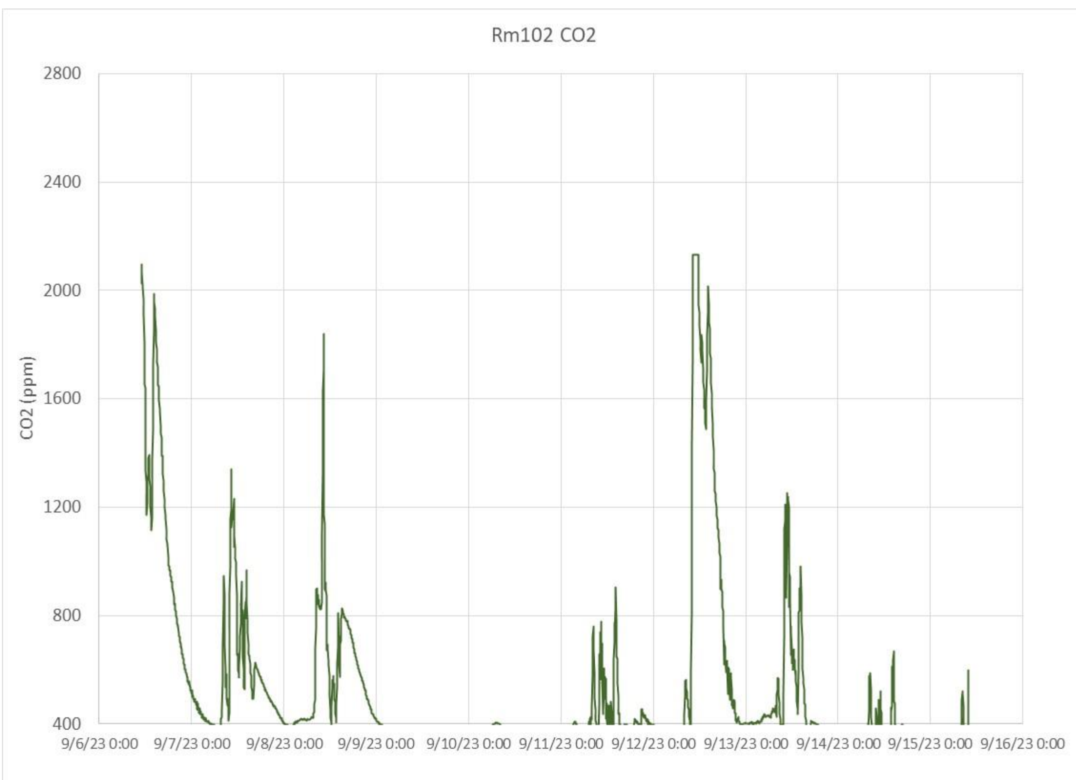

Figure 9 Room 102 (north side of hallway, opposite of Room 111) CO_2 data from September 6-15, 2023

Classroom Volatile Organic Compounds (VOCs) Comparisons

VOCs (Volatile Organic Compounds) are reactive chemicals that are part of our environment and most likely impact our health, performance, and productivity. Multiple sources contribute to VOC concentrations, ranging from off-gassing of building materials, natural sources such as plants and animals, industrial pollutants, and people. People emit VOCs as products of our metabolism, microbe interaction with us (body odor), and from our activities such as cooking, cleaning, and hobbies (eg, painting).

Although VOCs are suspected to be significant contributors to air pollutant impacts on human health, hundreds of VOCs are in our indoor environments. As soon as a human enters a room, VOC concentration increases as we are a major contributor to a room's pollutant loading. Human production of VOCs is highly variable and dependent on several factors such as a specific person's metabolism, and personal hygiene habits, diet, personal care products (perfumes, deodorants, etc).

CO_2, as previously described, is used as a surrogate for VOC and other indoor pollutant levels because CO_2 is a relatively stable molecule that is emitted at a predictable rate from human respiration. The reactive nature of VOCs causes them to continuously change into other substances, some less harmful (eg, water and CO_2), and others that are more harmful than the original chemical. Our ability to monitor a specific VOC among the hundreds that are present in every indoor environment is very limited. Therefore, we use CO_2 as a primary indicator of air quality.

Although VOCs are highly variable, we do know within certain bounds whether the primary source of VOCs are from human occupants, or from other sources (eg, natural gas leak, open chemical containers, pesticides, disinfectants, etc). Ideally, when no one is in a classroom, we would like VOC concentration to drop to very low levels, which indicates that VOCs are primarily from occupants. Excessive VOC concentration from humans, while perhaps less toxic than chemicals such as formaldehyde, are impact our health and wellness.

Figure 10 shows VOC concentrations in Room 111 during the September 6 to 15, 2023 IAQ classroom survey. VOC concentrations are recorded as "equivalent CO_2 ppm" units, which scales VOC concentrations to human CO_2 respiration. When VOCs are primarily from human sources, the scaled VOC output reflects a similar concentration level as CO_2 concentration.

Throughout the test period, VOC concentrations are similar to corresponding CO_2 levels except for Thursday, September 15 when a high VOC event occurred. Wednesday, September 14 exhibits similarly elevated VOC levels, however this was the day when the CERV-1000 unit was placed in recirculation mode for the school. Classroom CO_2 levels on Wednesday (Figure 2) are relatively high in a similar manner to Wednesday's VOC levels. On Thursday, VOC levels were high while CO_2 in classroom 111 was low, indicating a non-human chemical source was contributing to VOC levels.

The source of elevated VOCs on Thursday, September 14 is also strongly detected in classrooms 110, 109, and across the hallway in room 108, as shown in Figures 12, 13, 14. Classroom 104 (Figure 15) shows elevated VOCs for a briefer period, while room 102 (Figure 16) does not show elevated VOCs. Room 102 is the eastern most located room, followed by room 104. Classrooms 111, 110, 109 and 108 are all located within the west wing of MMJH, indicating some VOC release (perhaps a cleaning fluid or disinfectant) in that area.

Figure 11 shows data prior to CERV-1000 installation collected from Room 111 during the May 2022 IAQ survey. Elevated VOCs are observed most days, with Monday and Tuesday (May 18 and 19, 2022) having somewhat lower VOCs most likely due to open window venting during nicer outdoor temperatures, similar to the CO_2 trends discussed (Figure 4).

The CERV-1000 has significantly reduced VOC concentration in Room 111 in a similar manner as reduced CO_2. All classrooms surveyed in MMJH tend to show VOCs are primarily from human occupants, which is a desirable characteristic. The one day with an unknown source of elevated VOCs is indicative of the ability of the CERV-1000 to provide information concerning VOC events. VOCs are not typically “odorous”, however, CERV-1000 VOC sensors are capable of detecting chemical concentrations that our noses cannot sense. With CERV-1000 units deployed to multiple classrooms, VOC sources can be monitored, their location determined, and their source reduced.

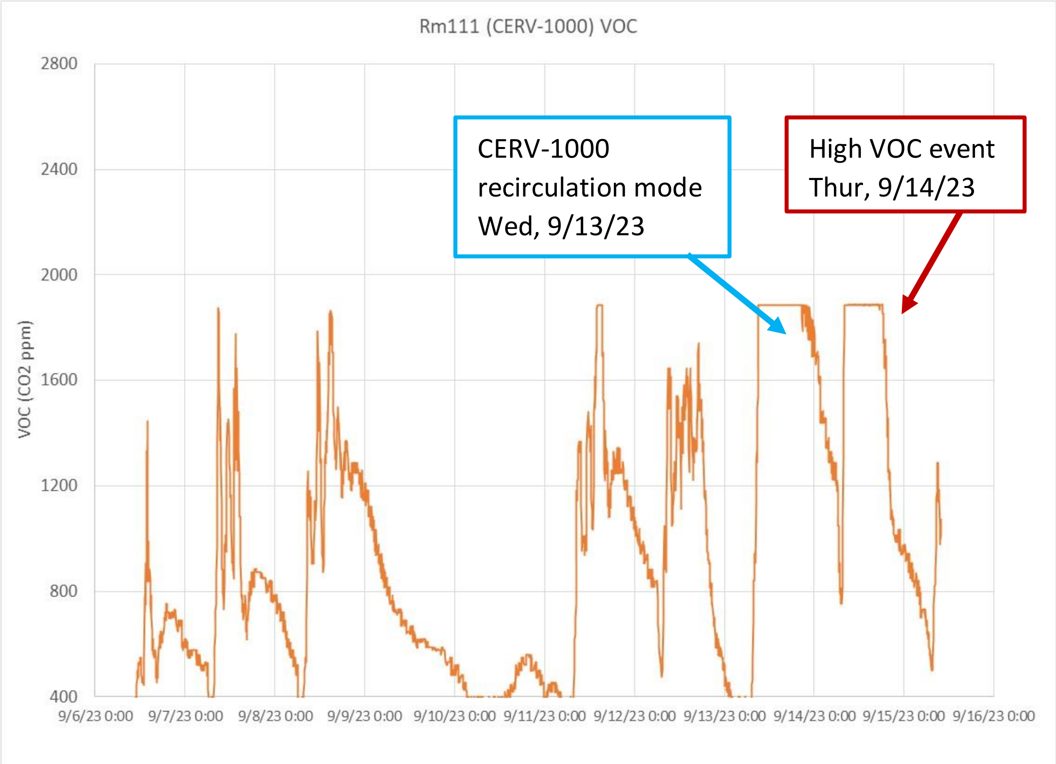

Figure 10 Room 111 (CERV-1000 classroom) VOC data from classroom IAQ monitor from Sept 6 to 15, 2023

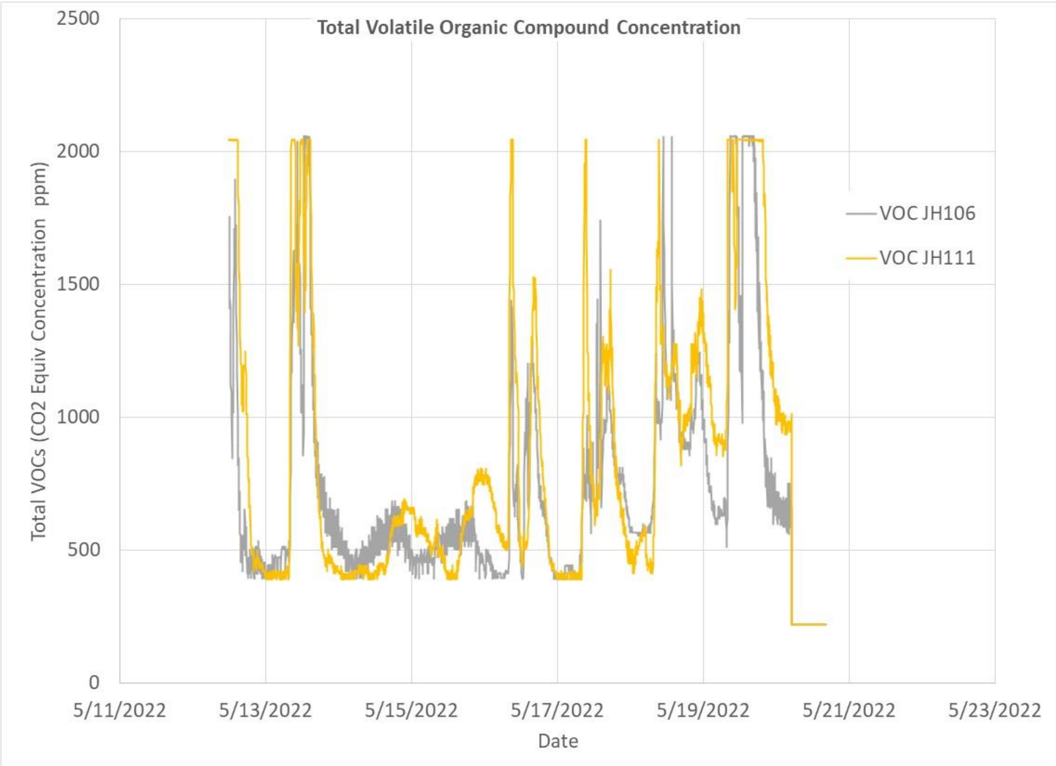

Figure 11 Rooms 111 and 106 VOC data from indoor air quality study, May 2022

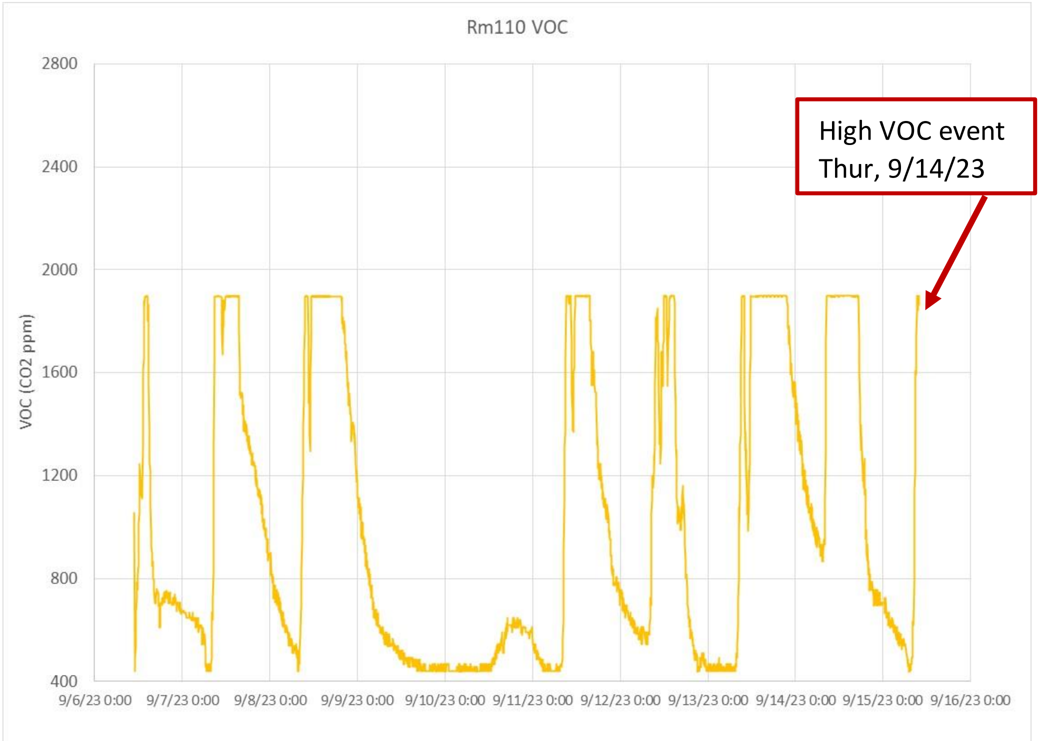

Figure 12 Room 110 (adjacent to Room 111 with door between Rooms 110 and 111) VOC data from September 6-15, 2023

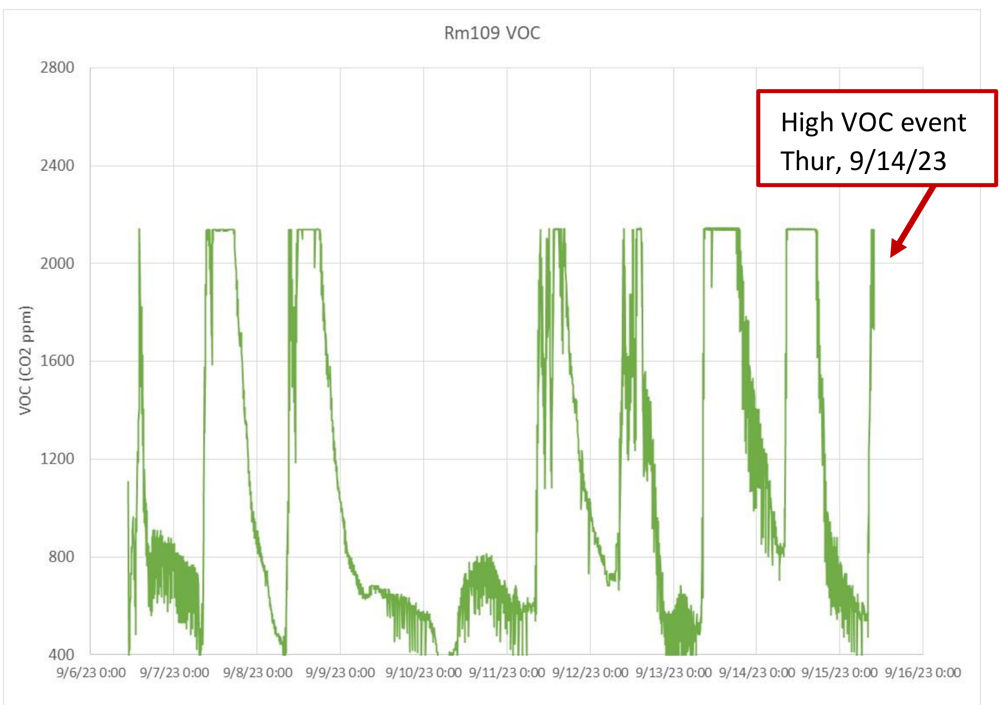

Figure 13 Room 109 (adjacent to Room 110 with door between Rooms 110 and 109) VOC data from September 6-15, 2023

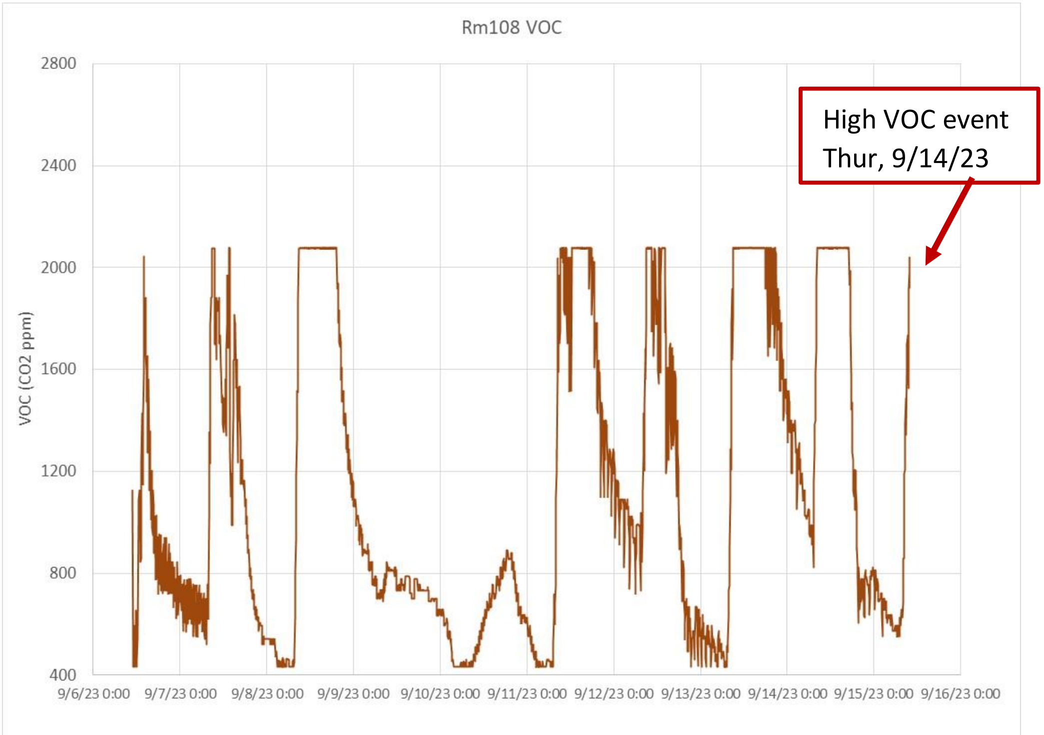

Figure 14 Room 108 (north side of hallway, opposite of Room 111) VOC data from September 6-15, 2023

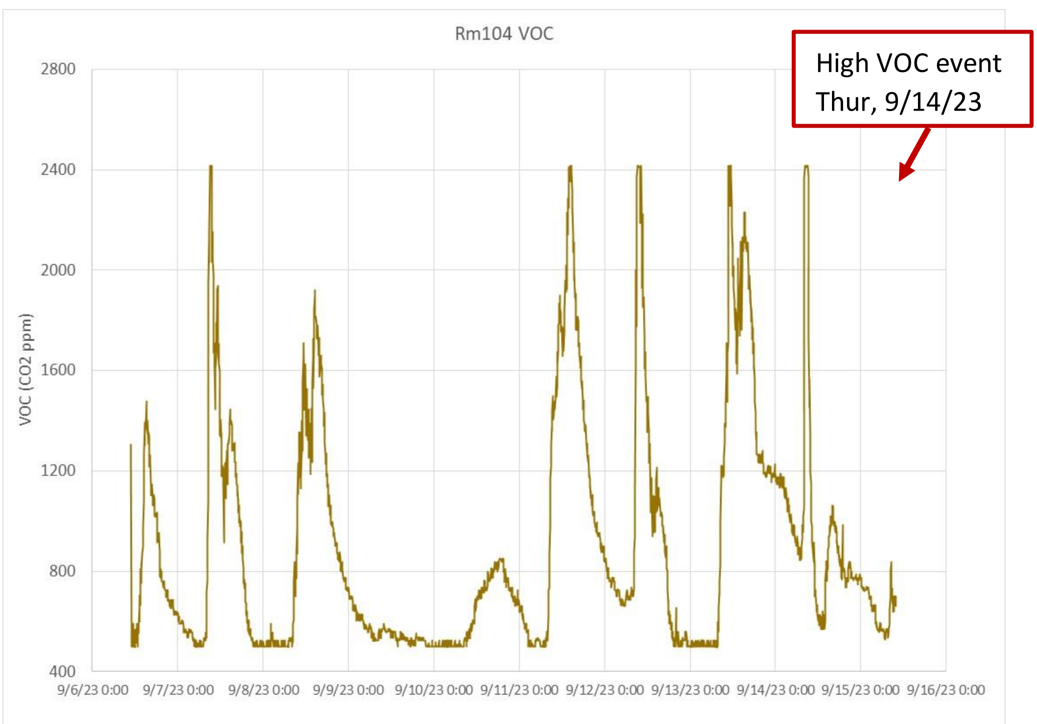

Figure 15 Room 104 (north side of hallway, opposite of Room 111) VOC data from September 6-15, 2023

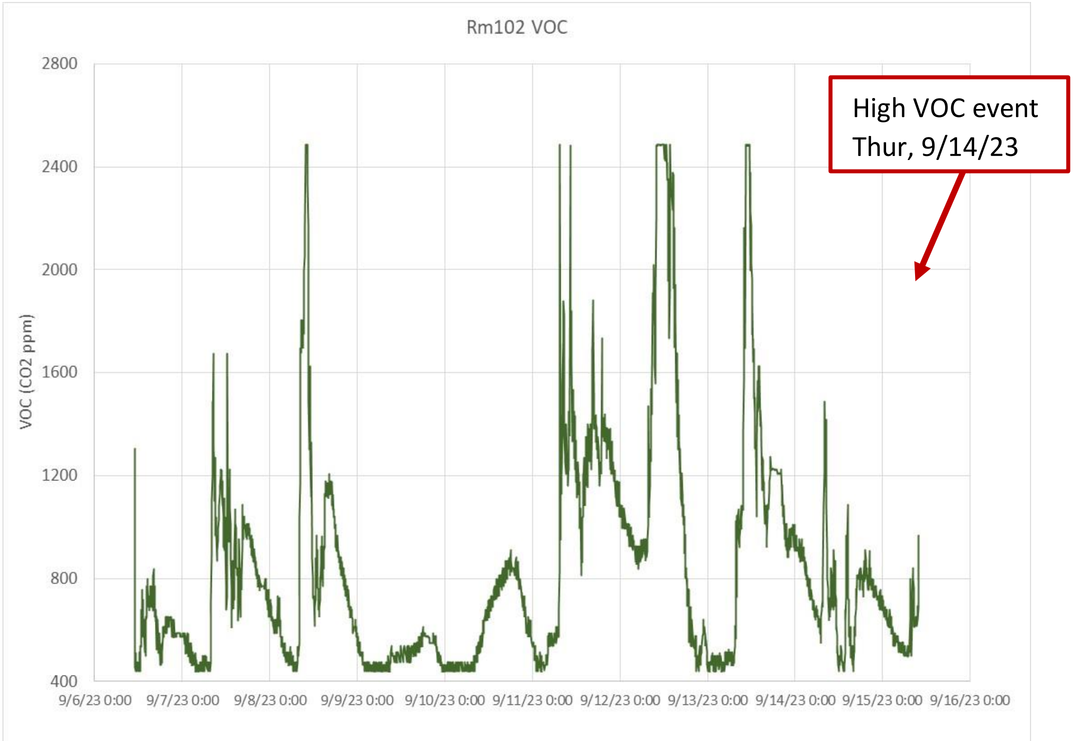

Figure 16 Room 102 (north side of hallway, opposite of Room 111) VOC data from September 6-15, 2023

Classroom Particulates

The ability to cost-effectively monitor particulates is very recent, and the CERV-1000 is the first ventilation system to incorporate a high-quality particulate sensor that can monitor both "particulate mass" and "particulate count" data. Just a few years ago, high quality particulate sensors were very expensive (more than $10,000 per instrument), preventing wide scale field research of these very important pollutants. Significant cost reduction of particulate sensors has made broader studies practical, such as the impact of particulates on absenteeism (3).

The CERV-1000 includes two high quality particulate sensors from Piera Systems for monitoring indoor and outdoor particulates. The Piera Systems sensors can measure particulate mass (PM2.5 and PM10) and particulate count (particulates per liter), with sensitivity to 0.1 microns in size (human hair ~100 microns). Submicron particulates contribute very little to particulate mass, but are very numerous. For example, a classroom with a PM10 level of 20µg/m^3 and a particulate count of 100,000 particulate/liter has 90% of its mass from "large" particulates greater than 1 micron, and 90% of its particulate count from particulates less than 1 micron.

Different types of particulate sources have differing particulate spectrums, too. Outdoor sources, such as road dust, tends to have particulates in the larger end of the size spectrum, while human-source particulates (microbes, skin flakes, smoke, vape) spectrum are in the smaller size range. Particulates smaller than 1 micron tend to stay airborne and are able to penetrate into the deepest areas of the human respiratory system, where they can be transported into the blood stream and organs throughout the body, including the brain.

We have much to learn about sources of particulates and their impact on our health and performance, however, we do know that particulates in general are detrimental, and reduction of particulates with effective MERV13 filtration is important.

We do not have prior particulate data from our earlier MMJH IAQ surveys. Figures 17 and 18 are examples of particulate data being collected in room 111. Figure 17 shows particulate mass data for outside air and inside air. We note that classroom 111 inside air is generally less than half of the particulate mass level of outside air. Inside particulate mass levels tend to mirror trends in outdoor particulate levels, indicating that outside particulate mass influences the building's particulate levels. As discussed for CO_2, particulates entering classroom 111 from the hallway and adjacent classrooms are sources of unfiltered air that elevates room 111 particulates. As additional CERV-1000 units are installed, an overall reduction of building particulates will occur.

Figure 18 shows a similar trend for particulate count measurements, with indoor particulate count mirroring outdoor particulate count. Although the CERV-1000 particulate sensor can detect particulates as small as 0.1 microns, we define a "particulate count" parameter, PC0.3, as the number of particulates 0.3 microns and greater contained in a 1 liter volume. We would like to see PC0.3 below 100,000#/liter. CERV-1000 data is among the very first classroom particulate "count" data collected anywhere.

Smoking and vaping are dominated by sub-micron particulates. CERV-1000 data may help a school's administration detect problems with smoking and vaping in school buildings.

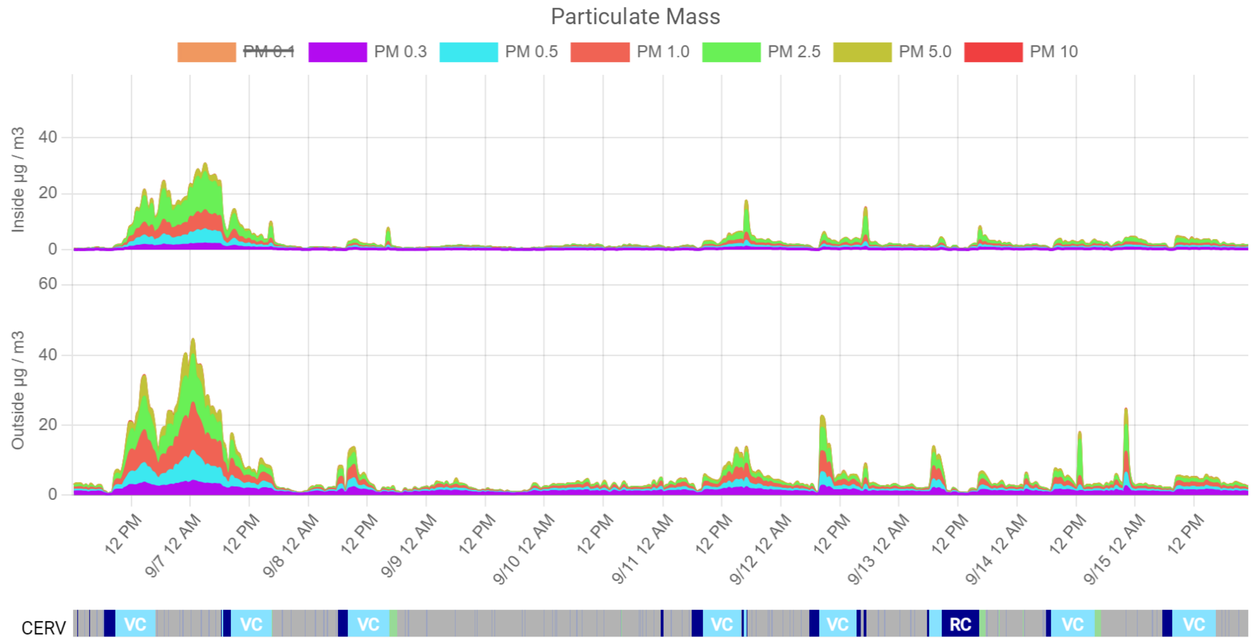

Figure 17 Room 111 particulate mass (PM10, µg/m^3) data (from CERV-ICE) from September 6-15, 2023

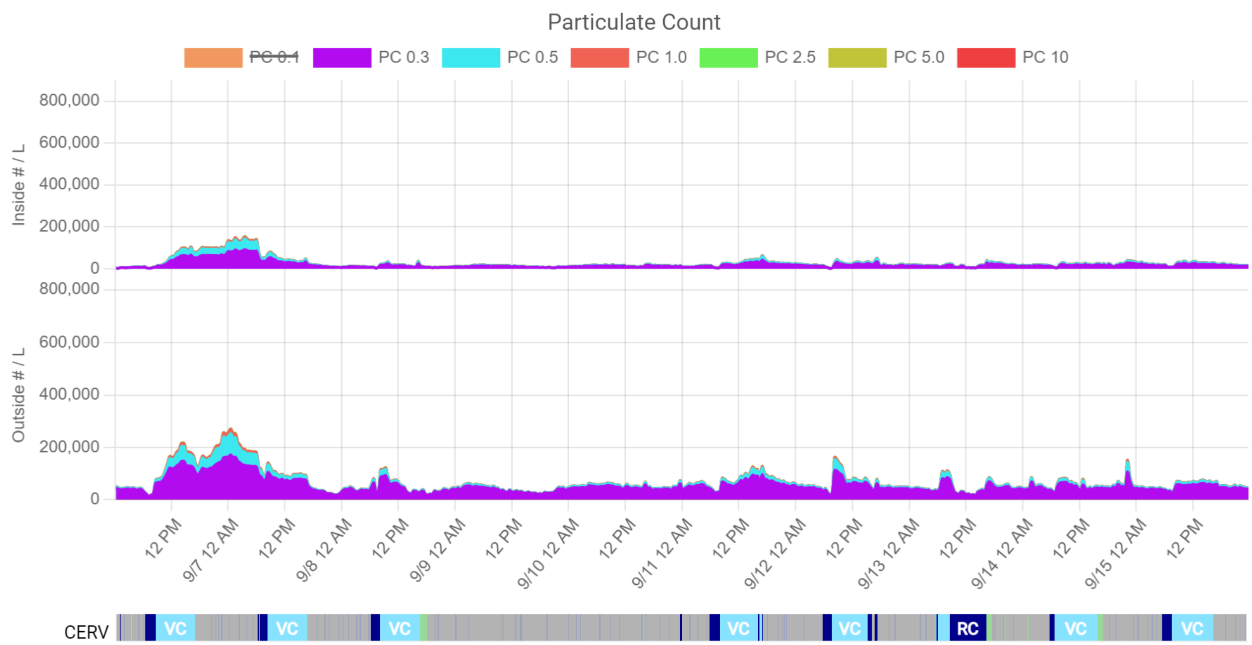

Figure 18 Room 111 particulate count data (PC0.3, #particulates/liter) from September 6-15, 2023

Classroom Comfort and Energy

Classroom comfort is very important for maintaining high levels of student and teacher performance. The CERV-1000 is unique in its ability to simultaneously manage indoor air quality and classroom comfort in a very energy efficient manner. Figures 19, 20, and 21 show classroom temperature, humidity and CERV-1000 power for the September 6-15 time period. The CERV-1000 has energy monitoring integrated into its control system, automatically providing information related to its operational cost.

The CERV-1000 also includes a scheduling tool that is part of the CERV-ICE app dashboard. School administration can define time blocks with differing levels of comfort and air quality conditions such that non-school hours can reduce comfort levels during low and no occupancy periods. Information on the scheduling tool is included in the Appendix.

Additional capabilities will be added to the CERV-1000, including an occupancy sensor that detects room usage, and door sensors that can detect open door conditions. The occupancy sensor will trigger the CERV-1000 unit to return to occupancy conditions if the room us being used during off-hours (eg, a teacher preparing materials during the weekend or a parent-teacher meeting during evening hours).

Figure 19 shows blue shaded regions that represent class hours when CERV-1000 thermostat automatically switches to 72F (off hours are currently set to 76F during cooling season). As observed in Figure 19, the CERV-1000 consistently maintained comfort temperatures in the 70 to 72F during class hours. The block scheduling tool was configured to reduce nighttime 76F room temperature to 72F at 6am. As shown in Figure 19, the CERV-1000 readily reduces classroom temperature to 72F in time for class.

We note that the CERV-1000 is quieter than other MMJH classrooms with room air conditioners. The appendix includes sound data collected in room 111 with the CERV-1000 operating at maximum air flow, and sound data collected in the adjacent Room 110 with its room air conditioner operating. Sound recordings were made from the same central classroom location. The CERV-1000 sound measurements averaged 52dB while the room air conditioner in room 110 averaged 63dB, which is more than 10 times the sound pressure in room 111.

Energy usage is determined by multiplying average power usage (Watts) by the number of hours. For the days shown in Figure 21, the CERV-1000 used an average of 1250W over an 8-to-10-hour classroom time period, for a daily energy usage of 11kWh per day. Assuming an electric utility rate of $0.15/kWh, the daily cost for CERV-1000 in cooling mode is $1.7 per day (or 8 cents per student per day) during this time period.

We measured electric circuit amperage for the CERV-1000 and for two other classroom air conditioning units that will be replaced by CERV-1000 units. The CERV-1000 amperage was 40% lower than the other two classroom air conditioners. That is, the CERV-1000 operates more efficiently while also maintaining an excellent classroom air quality.

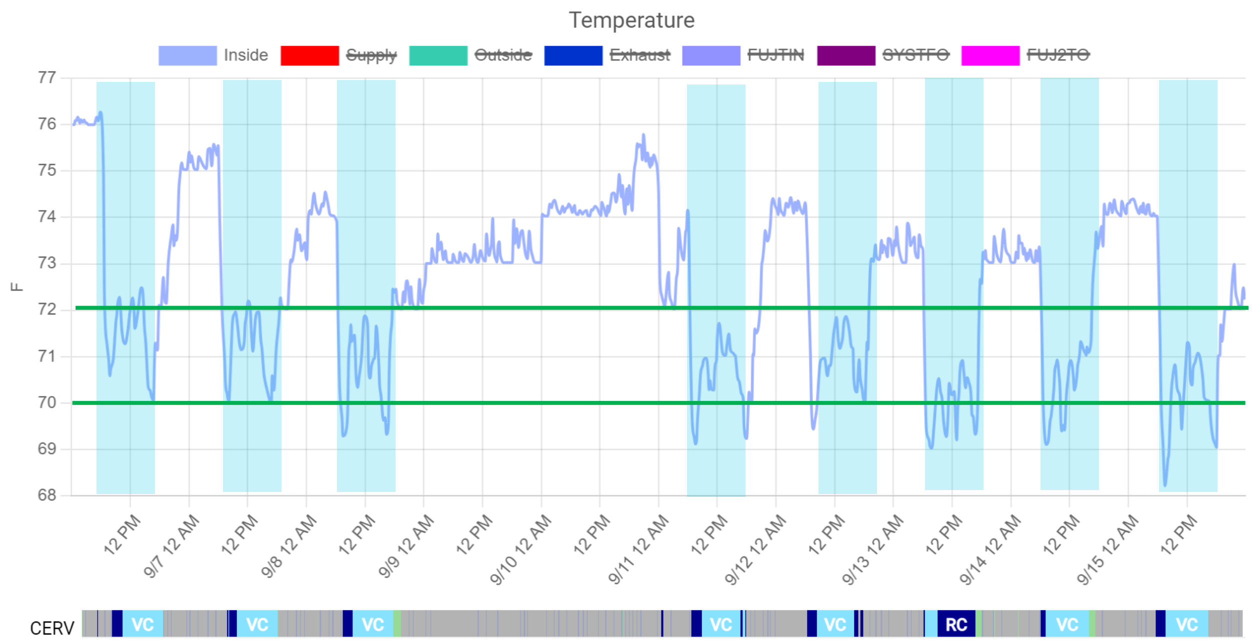

Figure 19 Room 111 temperature data (from CERV-ICE) for September 6-15, 2023

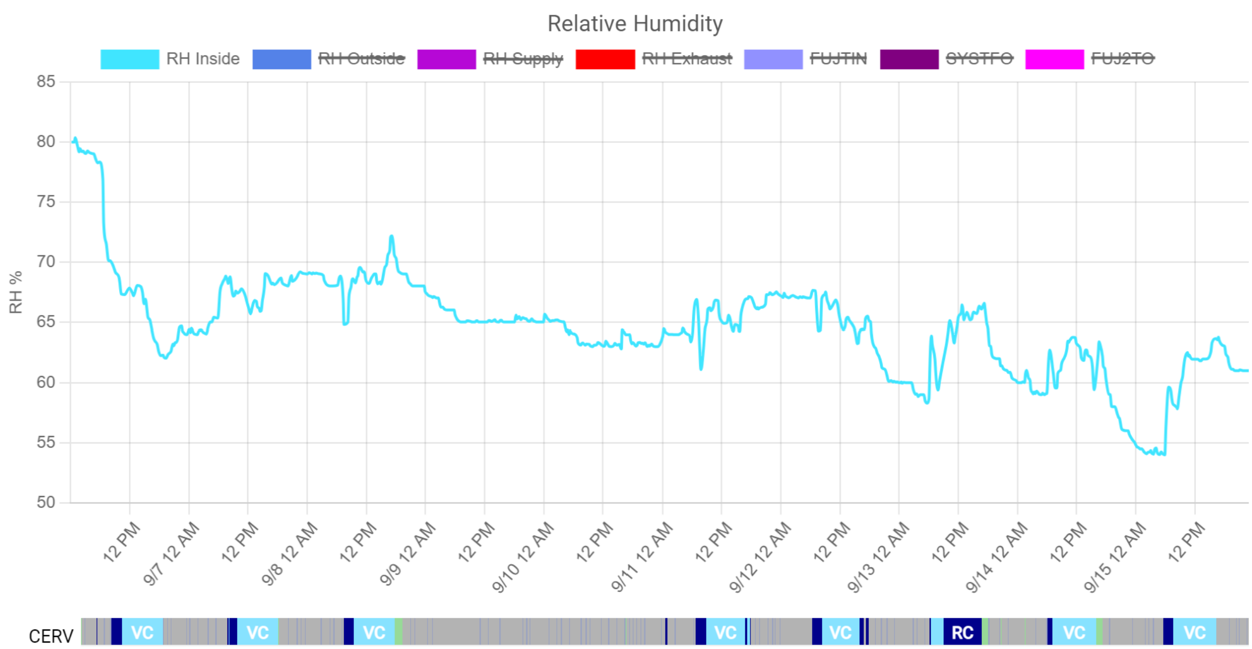

Figure 20 Room 111 relative humidity data (from CERV-ICE) for September 6-15, 2023

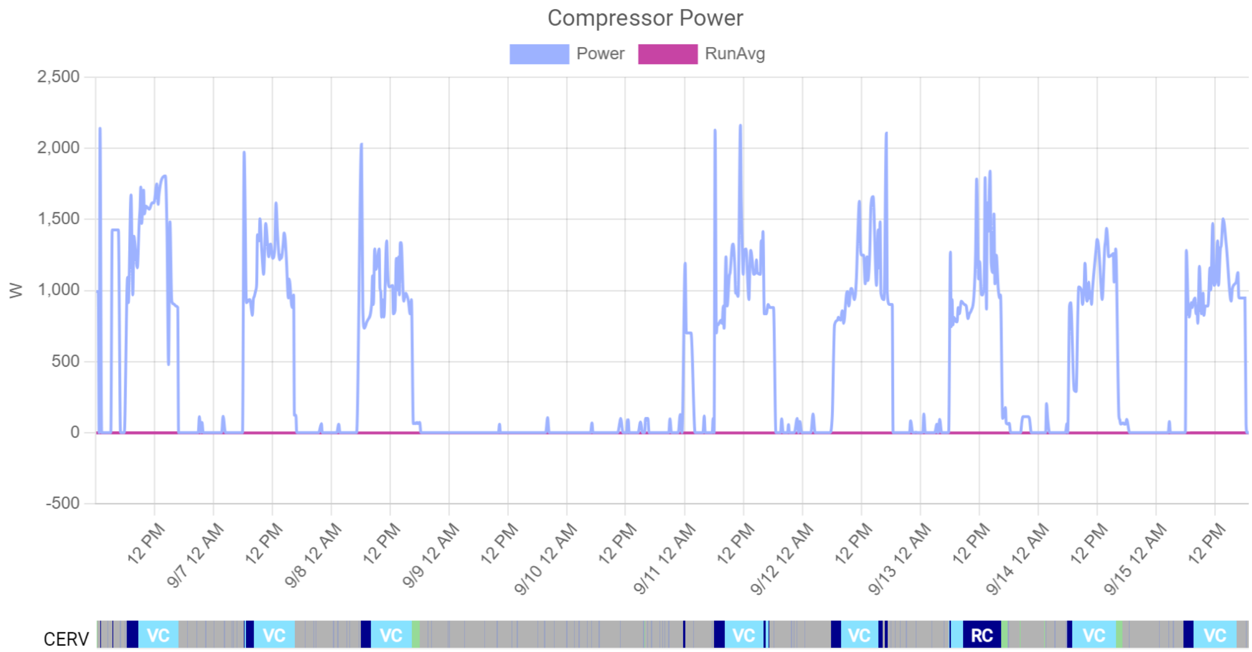

Figure 21 CERV-1000 power (CERV-ICE data) usage from September 6 – 15, 2023 averages 1250W for 10 hours per school day

High Outdoor Ambient Temperature Conditions (August 21-25, 2023)

Abnormally hot temperature conditions occurred at the beginning of the school year, with outdoor temperatures reaching 105F. A comparison of Room 111 comfort conditions with the CERV-1000 is presented in comparison data collected from May 12 to 20, 2022 prior to CERV-1000 installation when warm temperatures occurred.

Figure 22 shows outdoor ambient temperature during the May 2022 IAQ survey period when temperatures were in the 80-95F range. Figure 23 shows classroom temperatures for room 111 (south side of MMJH) and room 106 (north side of MMJH). Room 111 room air conditioner did not have capacity to maintain comfortable conditions, with an average daytime classroom temperature exceeding 80F. The northside classroom was able to maintain comfortable conditions due to lower solar loading. As previously discussed (3), 80F classroom temperature reduces student performance and productivity.

Figure 24 shows data during the August 2023 warm temperature period in which outdoor temperature approached 105F, with several days above 90F. Room 111's indoor temperature consistently stayed in control with room temperature modulated between 70 and 72F.

Figure 25 shows CERV-1000 energy usage increased to an average of 2000W on the warmest day during school hours for a daily energy use of 18kWh, or daily operation cost of $2.7 per day for electricity (assuming $0.15/kWh), or a per pupil energy cost of 14cents per student per day to maintain excellent IAQ and comfort.

During non-school hours, classroom temperature increased to 76F, reducing CERV-1000 energy usage to half of the usage during daytime hours. Prior to the beginning of school, the CERV-1000 rapidly pulled the classroom down to the 72F setpoint.

Figures 26, 27, and 28 display room 111 carbon dioxide, particulate mass and particulate count data during the extreme heat period. Indoor air quality was not sacrificed in order to maintain comfortable classroom temperatures. The CERV-1000 demonstrated the ability to provide 100% fresh air ventilation to the room during this challenging period.

CERV-1000 units deployed throughout MMJH classrooms will transform the school building to an exceptional example of introducing indoor air quality management into an older school while simultaneously providing the school with today's most energy efficient comfort conditioning system.

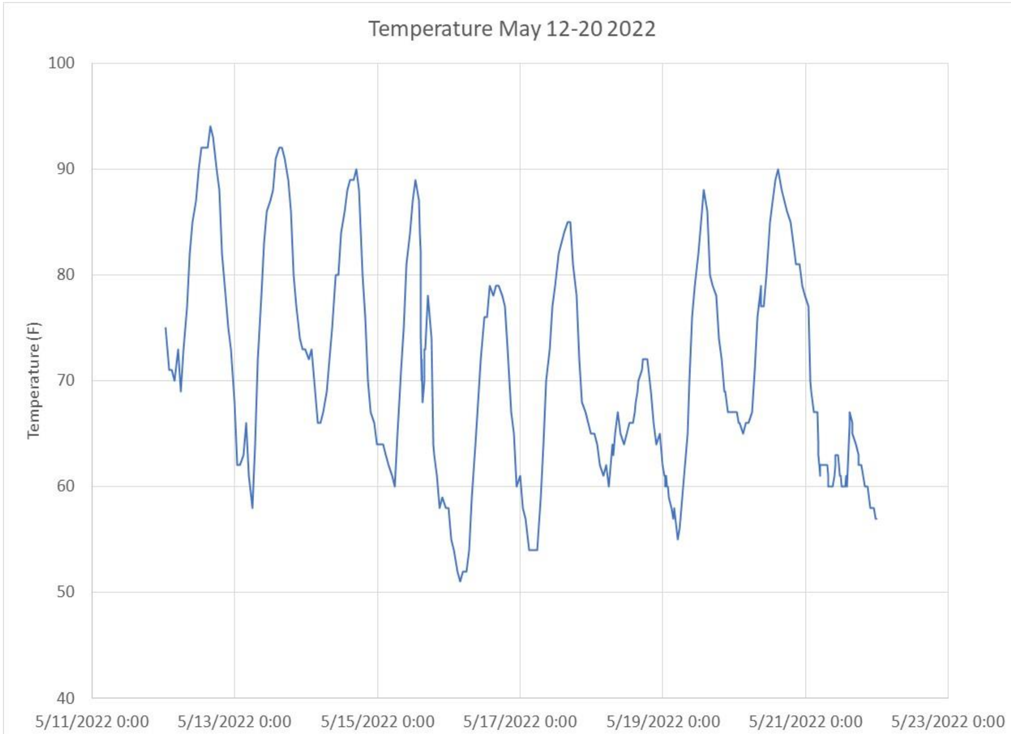

Figure 22 High outdoor ambient temperatures during May 12-20, 2022 classroom air quality monitoring period

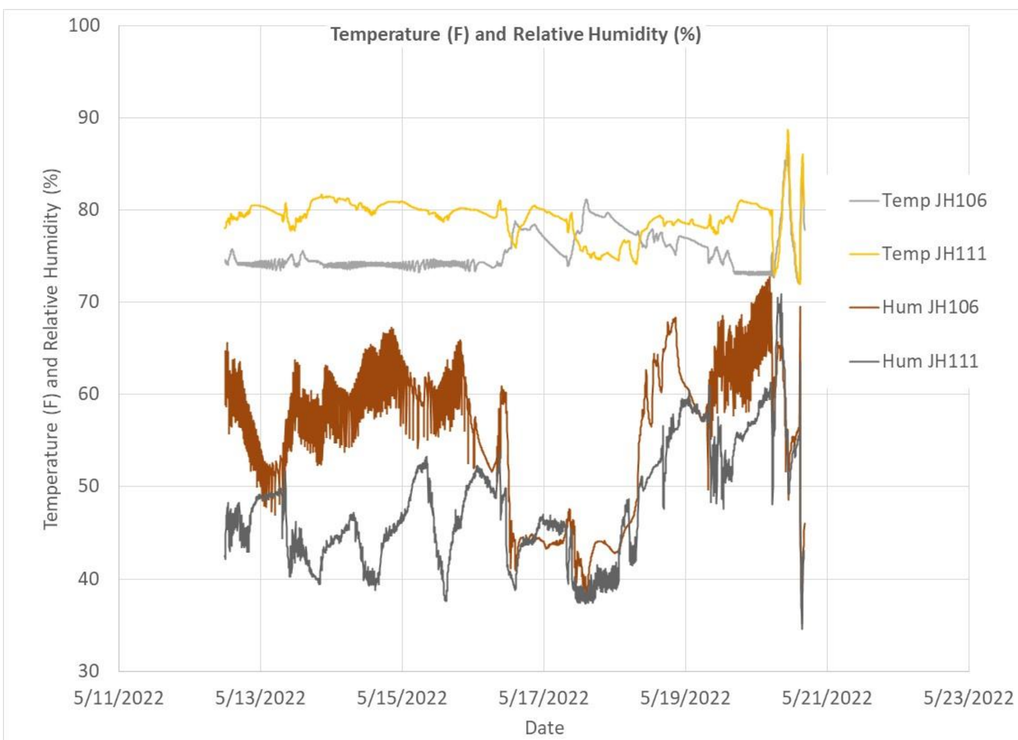

Figure 23 Rooms 111 and 106 temperature and relative humidity data from spring 2022 indoor air quality assessment

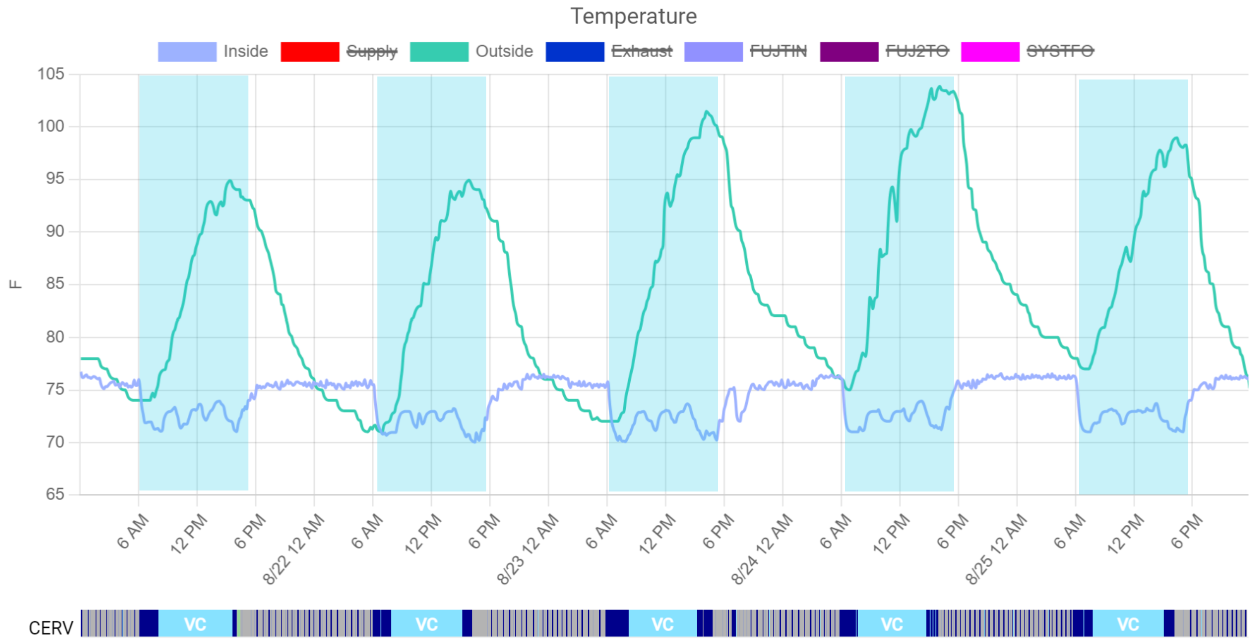

Figure 24 Room 111 classroom temperature and outside ambient temperature (CERV-ICE data) during August 21-25, 2023 high outdoor temperature period. Blue shading shows CERV-1000 in classroom mode

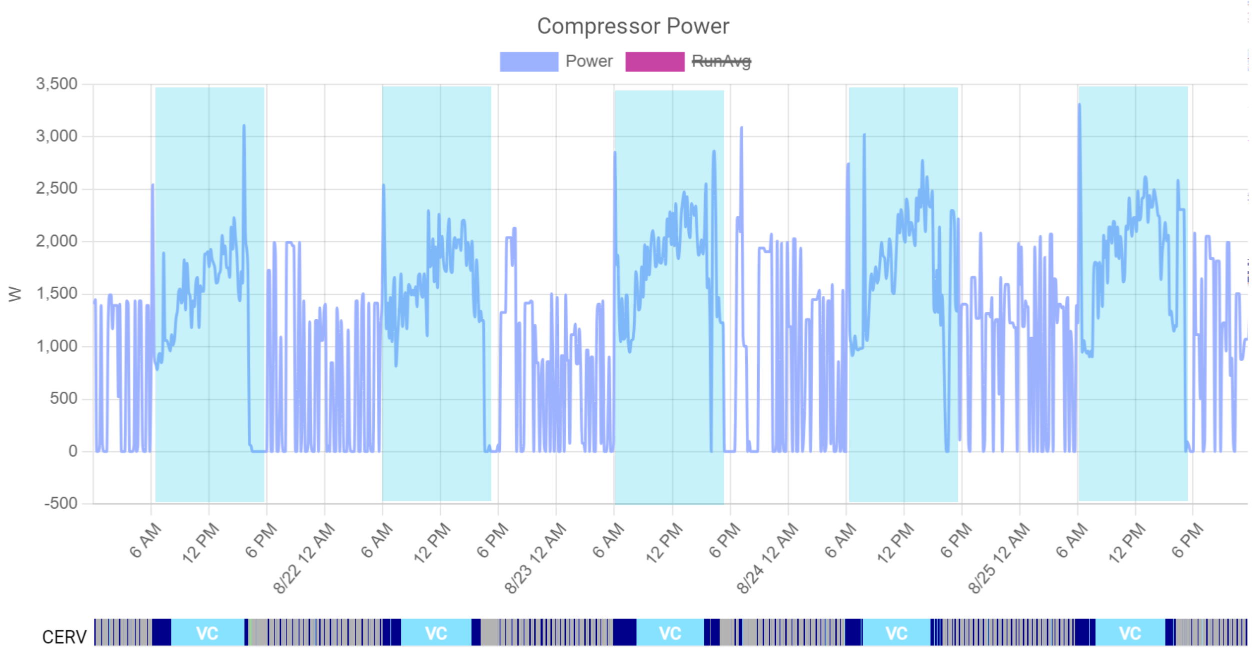

Figure 25 Room 111 CERV-1000 power data (from CERV-ICE) during August 21-25, 2023 high outdoor ambient temperature period. Blue shading shows CERV-1000 operating in classroom mode

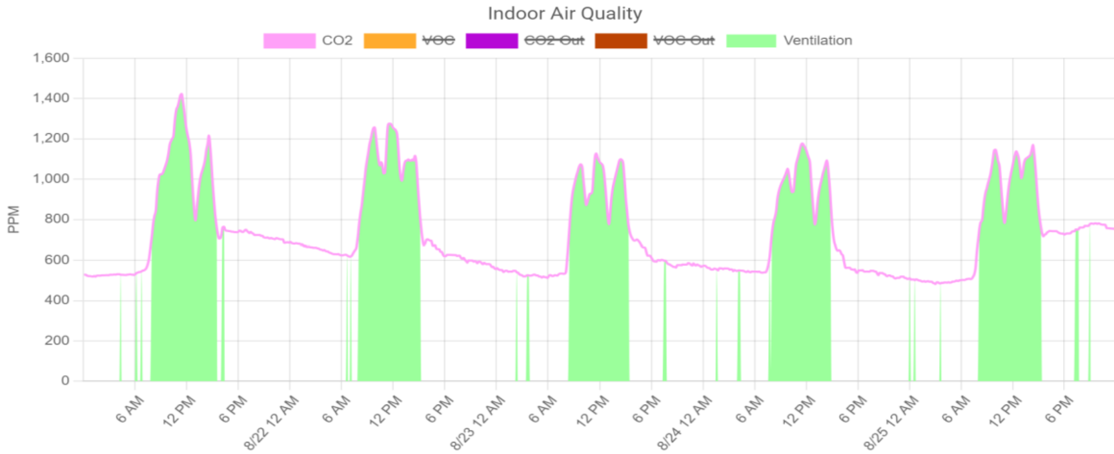

Figure 26 Room 111 CO_2 CERV-ICE data during August 21-25, 2023 high outdoor ambient temperature period. Green shows 100% fresh air ventilation during classroom hours

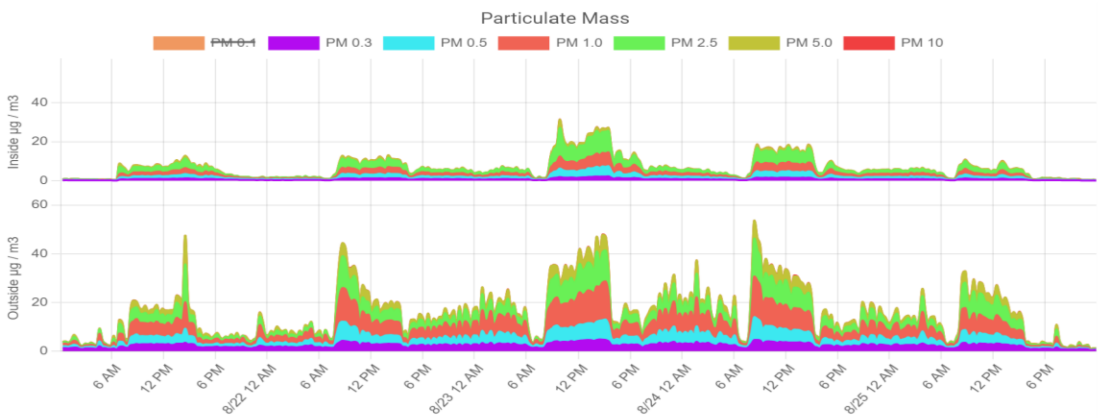

Figure 27 Room 111 Particulate Mass (PM10, µg/m^3) CERV-ICE data during August 21-25, 2023 high outdoor ambient temperature period with 100% fresh air ventilation during classroom hours

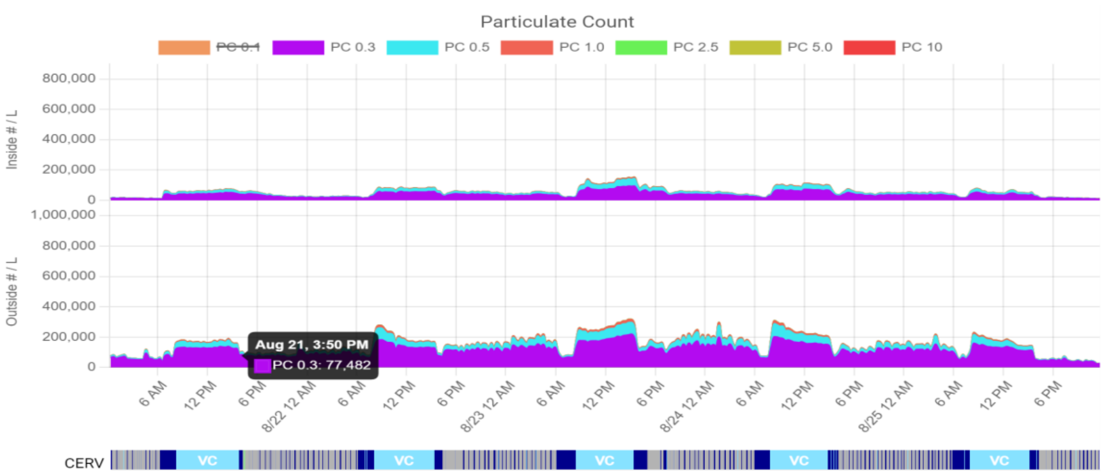

Figure 28 Room 111 Particulate Count (PC0.3, #particulates/liter) CERV-ICE data during August 21-25, 2023 high outdoor ambient temperature period with 100% fresh air ventilation during classroom hours

Appendix – CERV-1000 Installation at Mary Miller Junior High School

Build Equinox announced a new product, CERV-1000, for high occupant density indoor environments in April, 2023. The first of twelve CERV-1000 units was installed in July, 2023 in Mary Miller Junior High School in Georgetown, Illinois. Figure 1 shows the first CERV-1000 unit on its way to school after a few months of shakedown testing at Build Equinox test facility in Urbana Illinois. Build Equinox has worked with the Georgetown-Ridge Farm (G-RF) school district for two years investigating indoor air quality in their schools, and developing solutions for managing indoor air quality in an energy efficient and labor efficient manners.

CERV-1000 units deliver up to 1000cfm of fresh air with 3 tons of high efficiency, cold temperature heat pump comfort conditioning. UVGI (ultraviolet germicidal irradiation) integrated into the unit further sanitizes classroom air while energy recovery cores provide exceptional energy efficiency.

Figure 1 CERV-1000 Unit#1 heading from the Build Equinox facility in Urbana Illinois to Room 111, 8th Grade Mathematics at Mary Miller Junior High School in Georgetown Illinois.

ASHRAE Standard 241 and Improved Health and Productivity

CERV-1000 already meets ASHRAE's recently approved 241-2023 ("Control of Infectious Aerosols") ventilation standard. Build Equinox, for several years prior to the pandemic and today's rampant wildfire smoke, has been urging transition from today's "edge-of-sickness" ventilation standards (ASHRAE 62.1 and 62.2) to ventilation standards based on health and productivity. ASHRAE Standard 241 is a substantial step toward our Build Equinox healthy Indoor Air Quality Standard.

As ASHRAE Standard 241 propagates throughout the US and beyond, we will see a remarkable reduction of sick days and increased productivity. Changing from today's "minimum acceptable" ventilation to human-healthy ventilation will reduce sick days by 40%, or 1 sick day per person per year, for a nationwide potential savings of 330 million sick days with an estimated value of $165 Billion per year.

CERV-1000 units simplify complex balancing of air quality management and comfort conditioning. With three tons of high performance, cold temperature heat pump capacity integrated into CERV-1000 units, older buildings with fossil fuel-fired boilers and no ventilation can leapfrog to de-carbonized comfort conditioning with automatically managed healthy air quality.

Can we reverse the growth of asthma and allergies that have rapidly risen over the past few decades as our buildings have become better sealed, immersing us in unnatural indoor environments filled with chemicals foreign to our bodies? We think so!

CERV-1000 Rolling Renovation and Installation

A major objective for the CERV-1000 is ease-of-installation. Our goal was to design the unit such that a school's maintenance staff or a community's local HVAC businesses can install units on a "rolling renovation" basis. Installation on a classroom-by-classroom basis by a local community's HVAC personnel results in a community spending money on itself to improve their community's school facilities.

G-RF's MMJH school's facility and operations department has HVAC expertise to install their twelve CERV-1000 units. Installation time and labor per unit is less than 2 days with 2 people (4 person-days per unit installation). Installation steps consist of:

- provide power (240VAC, 40amp) to the CERV-1000
- install heat pump outdoor unit (ODU) and electric disconnect
- run two sets of refrigerant "linesets" (1/2" and 3/8" insulated copper tubing per lineset) between the CERV-1000 and ODU
- pressure test and evacuate refrigerant lines
- run ODU power from CERV-1000 to the outdoor electrical disconnect
- run two sets of 3 conductor (14ga) wires from the two CERV-1000 heat pump heads to the ODU
- connect ¾" condensate drainage line to drain outside or inside
- connect CERV-1000 fresh air intake and exhaust air outlet to an external wall opening (12" diameter, insulated ducting)
- switch power on, connect CERV-1000 online to the CERV-ICE (CERV-Intelligently Controlled Environment, pronounced "service"), and begin breathing fresh air

Figure 2 and Figure 3 show the southwest and northwest sides of the school where 9 of the classroom units will be installed. Figure 2 shows the classroom location of the first unit. CERV-1000 Unit#1 will be followed by installation of 11 more units for conversion of 12 junior high school classrooms to automated management of air quality and comfort. Prior to shipment of the next eleven units, G-RF facilities personnel can install heat pump outdoor units and electrical disconnects. CERV-1000 installation is flexible, and can occur without disrupting school operation and installation labor constraints.

Figures 4 through 7 show other aspects of CERV-1000 unit installation.

Figure 2 Three of 12 classrooms on the southwest side of Georgetown-Ridge Farm school district's Mary Miller Junior High School. Highlighted is CERV-1000 Unit#1's classroom location.

Figure 3 Outdoor heat pump units and electrical disconnects can be installed on these 6 classrooms on the north side of MMJH School and on 5 classrooms on the south side anytime G-RF facilities staff schedule allows while awaiting delivery of the next 11 CERV-1000 units. CERV-1000 units can be set in place in their classrooms while awaiting installation scheduling that avoids classroom disruption.

Figure 4 CERV-1000 units are designed to fit through standard 36" doorways. CERV-1000 Unit#1 is moving through Build Equinox's business facility doorway on its way to MMJH School Classroom 111.

Figure 5 Georgetown-Ridge Farm School District's Facilities Director and one of his maintenance staff install CERV-1000 power wiring. The unit requires 8 gauge wire and a 40amp (240VAC) breaker, which is often available in schools that have substituted LED lighting for incandescent lighting.

Figure 6 Conversion of incandescent lighting to energy efficient LED lighting in older schools, such as MMJH, provides electrical panel capacity for CERV-1000 operation. Room 111's original incandescent lights required three 20amp breakers. Each row of LED lights draws only 2amps, allowing all classroom lights to be combined on a single 20amp breaker, making room for the CERV-1000 40amp, 2-pole breaker.

Figure 7 G-RF Facilities Director Reuben and Build Equinox co-owner and Vice President, Alex Long, are checking out CERV-ICE on their phones, our online monitoring and control dashboard. Reuben is looking forward to increased maintenance efficiency of CERV-1000 units. He spends significant time moving among the school district's three campuses (elementary, junior high and high schools). With CERV-ICE, Reuben can conveniently check classroom air quality, comfort, and operation of every CERV-1000 unit in the school district.

Classroom Quiet Operation

CERV-1000 Unit #1's new home is an 8th grade mathematics classroom (Figure 8) in Mary Miller Junior High School (MMJH) in Georgetown, Illinois. We've been told by every junior high school teacher we've met that there is no such thing as a quiet junior high school classroom. That is not an excuse to place noisy machines in classrooms. CERV-1000 units are also designed for other high occupant density spaces such as restaurants and houses of worship in addition to noisy junior high school classrooms.

Designing a 1000cfm air flow ventilation machine that can be placed in the room is not a simple task. Our objective was to be quieter than the classroom's window AC unit we replaced.

As shown in Figure 9 sound data photos, we succeeded. Not by just a bit, but by a lot! Sound data from the CERV-1000 classroom with its indoor fan running at high speed is more than 10 times quieter than noise from an adjacent, identical classroom with its window AC unit operating. Decibel readings are like earthquake readings with a difference of 10dB indicating 10 times louder noise. The window AC unit registers at a level similar to normal conversation while the CERV-1000 is similar to a quiet street.

Figure 8 CERV-1000 Unit #1 is located in a mathematics classroom where quiet concentration, even with junior high schoolers, is important!

Figure 9 Blowing 1000cfm quietly into a classroom, restaurant, house of worship or other high occupant density space requires a lot of considerations to keep noise low. Sound readings shown are from identical, adjacent classrooms with the sound meter placed at the same relative location from the CERV-1000 and window AC unit. The CERV-1000, with ventilation fan on high, is more than 10 times quieter than the window AC unit.

CERV-1000 and CERV-ICE Advanced Control Technology

CERV-1000 controls will look familiar to CERV Community members. The same powerful Build Equinox control technology that powers the CERV2 also controls CERV-1000 units. CERV2 owners will notice some differences on the CERV-1000 control screen that will propagate to their machines with our industry-first OTA (Over-the-Air) updating capability.

The screen shot (Figure 10) from CERV-ICE was taken shortly after CERV-1000 Unit #1 was fired up. CERV-ICE also provide Administration and Facilities personnel with detailed classroom comfort conditions (temperature and humidity) and energy data. Figure 11 shows compressor power for the heat pump's outdoor unit on July 20, 2023. Reuben, G-RF Facilities Director, was putting the unit through its paces as he conveniently altered classroom temperature from his cellphone throughout the day. Figure 12 shows the CERV-1000 temperature responsiveness to temperature setpoint changes.

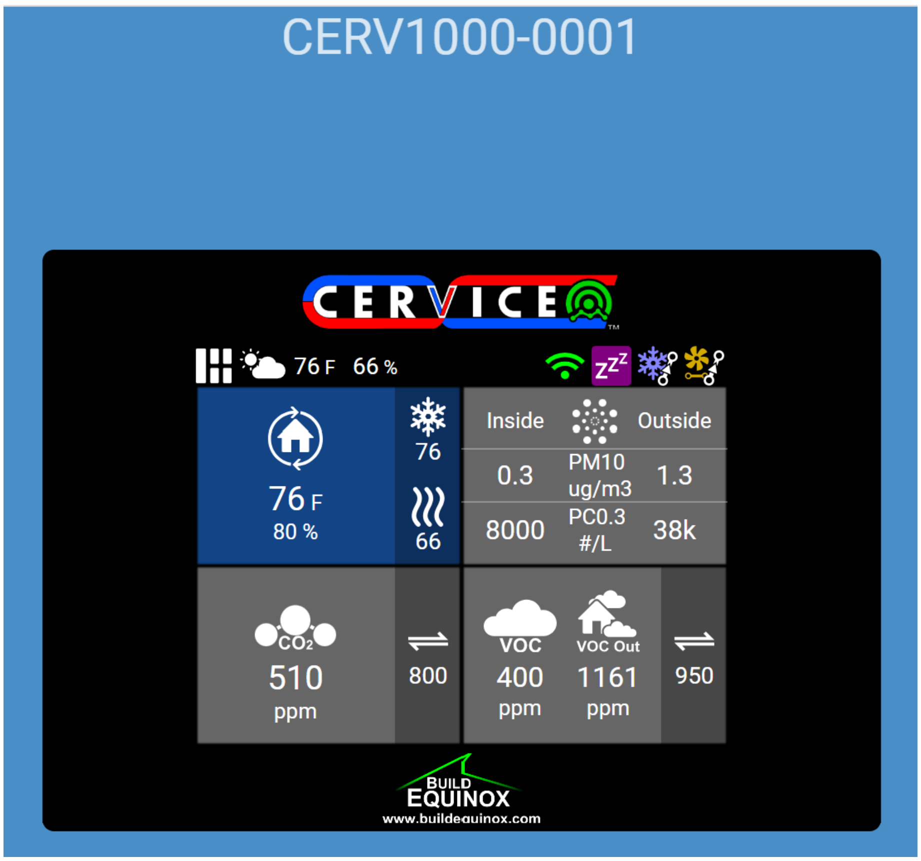

Figure 10 Screen shot from CERV-1000 Unit #1 control screen displayed in CERV-ICE, the online control panel for CERV2 and CERV-1000 units. The classroom windows had been opened during installation with warm, muggy weather. Indoor environments without active comfort conditioning will have higher humidity than outdoors, just like indoor environments have higher CO_2 concentration than outdoor ambient.

CERV-1000 energy flows provide facilities personnel with information for determining system efficiency, energy usage, and for system troubleshooting. Compressor power and classroom temperature are shown in Figures 11 and 12 below for July 20, 2023. In addition to compressor power, power used by other components (indoor heat pump heads, exhaust fan, and UVGI are monitored.

Classroom temperature was programmed to change from 75F to 72F at 6am on July 20. Classroom temperature and CERV-1000 compressor power respond as shown in the plots. At 8am, classroom temperature was changed from 72F to 70F, and from 70F to 68F at 9:30am. At 12:30, classroom temperature was increased to 72F, followed by a classroom temperature setpoint increase to 75F at 4pm.

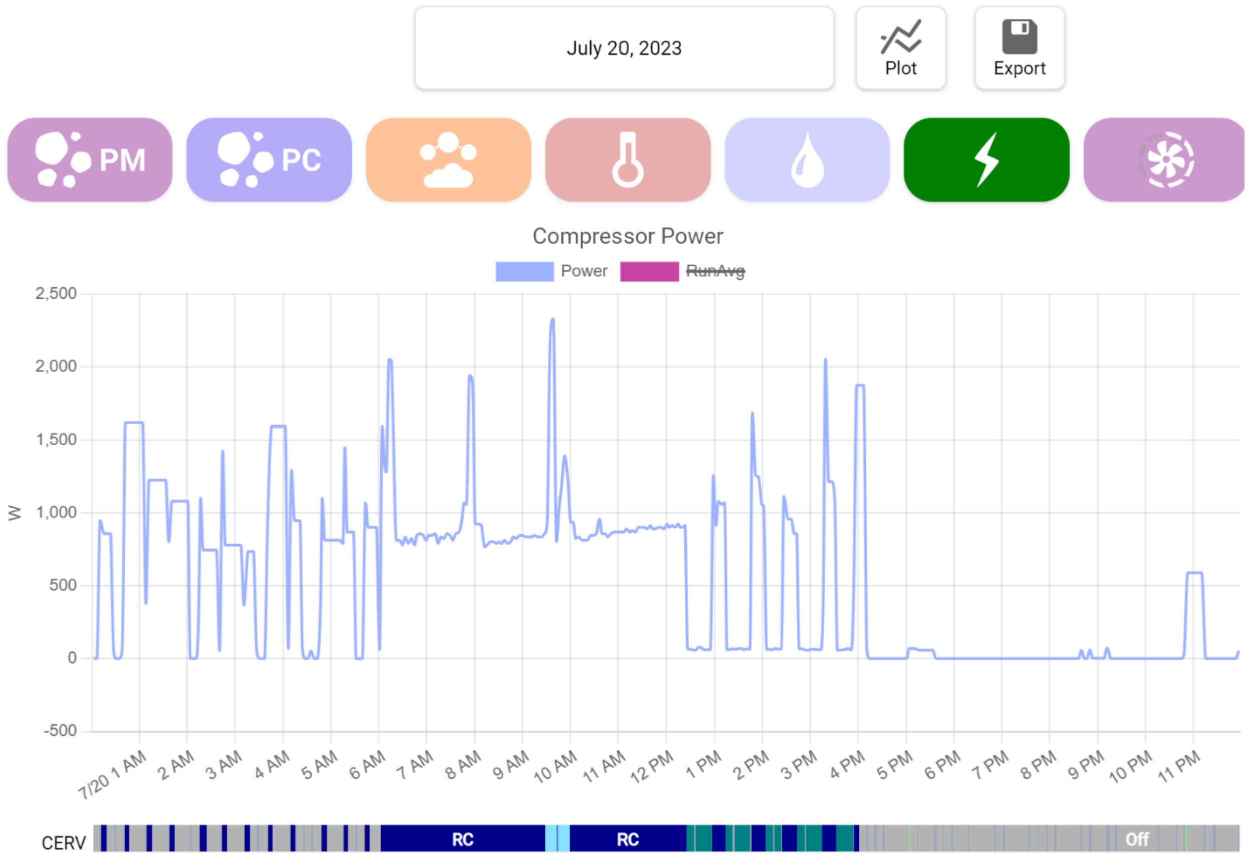

Figure 11 CERV-1000 diagnostics include power monitoring for system sub-components such as compressor power. The high efficiency, variable speed heat pump is controlled by CERV-1000's powerful controller. CERV-1000 response to thermostat setpoint changes at 6am, 8am, 9:30am, 12:30pm and 4pm are shown in the July 20 data above.

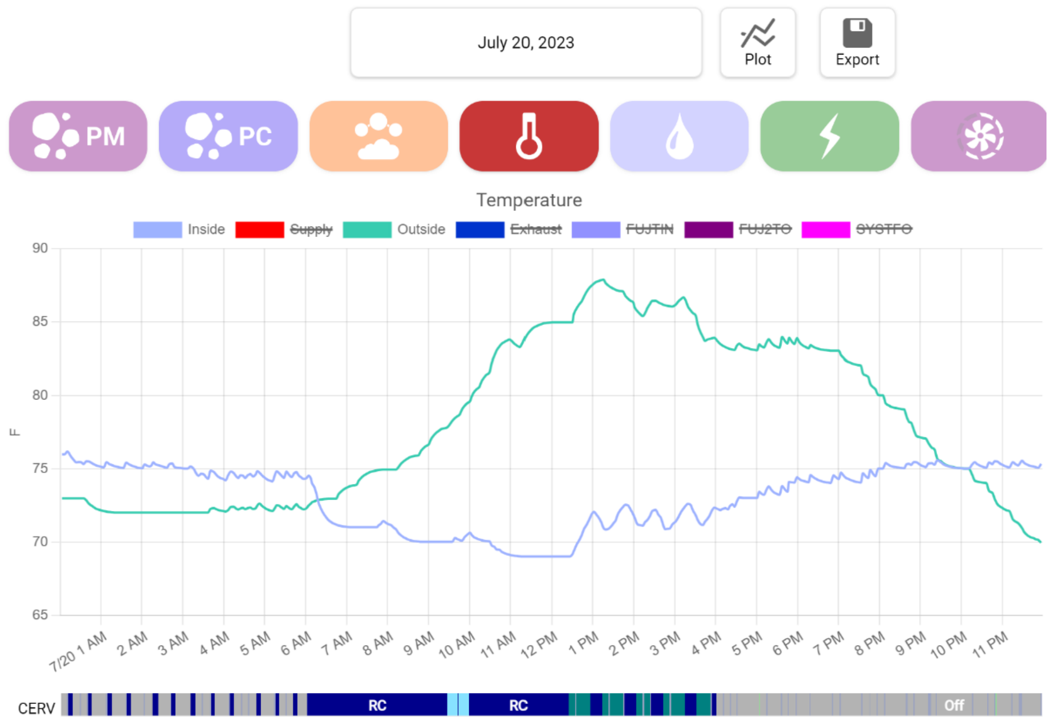

Figure 12 CERV-1000 cooling response on a warm summer day to classroom temperature setpoint changes at 6am, 8am, 9:30am, 12:30pm and 4pm on July 20, 2023 are shown in the plot above.

CERV-1000 units include indoor and outdoor particulate mass and particulate count sensors, in addition to indoor CO_2, indoor VOC, and outdoor VOC sensors. Figure 13 shows "particulate mass" and "Particulate count" levels shortly after the CERV-1000 was placed in operation. Indoor and outdoor particulate levels were similar initially due to open windows and ducts during installation. The CERV-1000's MERV13 filtration reduced indoor particulates on both mass and count bases.

Notice that count was initially high (200,000 to 300,000particulate per liter) while mass was below 20µg/m^3, a reflection of wildfire smoke in our area that is dominated by submicron particulates that register high in "count" but may not be high in "mass". At 250,000particulates per liter count density, at 8liter/minute normal breathing rate, we inhale 360,000 particulates per day! More than enough to deliver one particulate to every alveoli in our lungs each day.

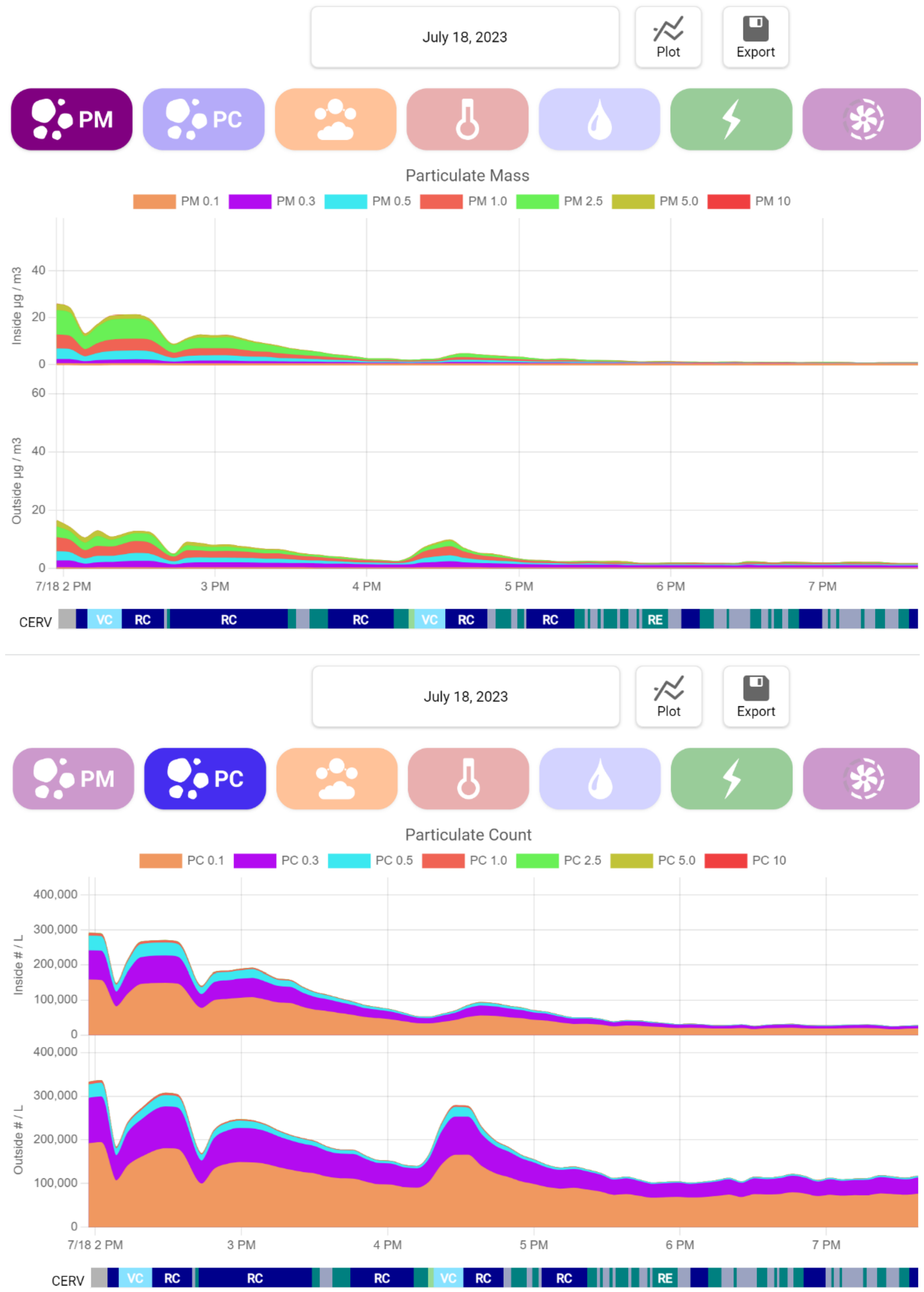

Figure 13 Indoor and outdoor particulate sensors incorporated into CERV-1000 units provide information to school administration on indoor and outdoor particulate conditions. CERV-1000 Unit #1 was switched on at 2pm on July 18, and within a short time the CERV-1000 unit reduced indoor particulate concentrations and particulate count below the outdoor environment.

We have created new features on the CERV-1000 that will propagate to CERV2 owners in the near future. One of the most powerful features is our new scheduling tool. “Blocks” are graphically defined that allow users to choose settings that apply to time periods defined with that block. Figure 14 shows three blocks for Home, Away and Sleep settings. Figure 15 shows time blocks distributed over a weekly schedule. CERV-ICE allows bulk scheduling of multiple classrooms, school buildings, and school districts. Indoor spaces can be defined as needed apart from bulk scheduling.

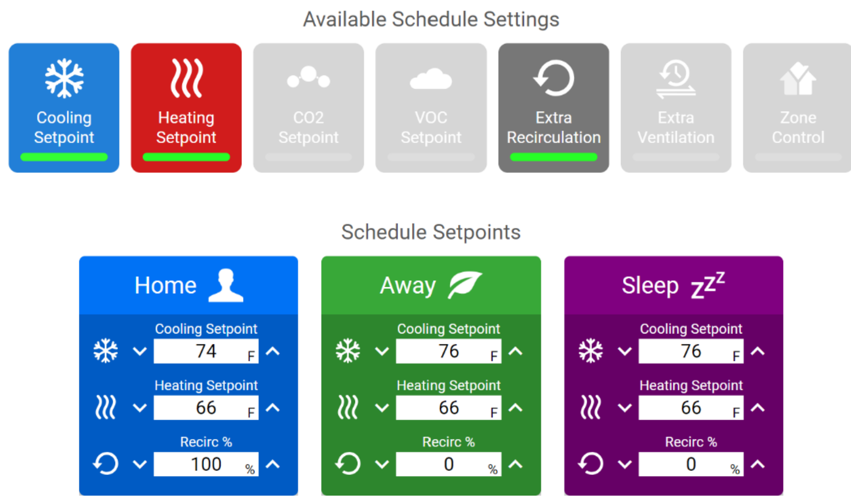

Figure 14 CERV-1000 units (and CERV2 units in the near future, including current CERV2s) will have the new CERV-ICE scheduling feature. CERV-ICE scheduling is an easy-to-use block scheduling format allowing users to define setting blocks.

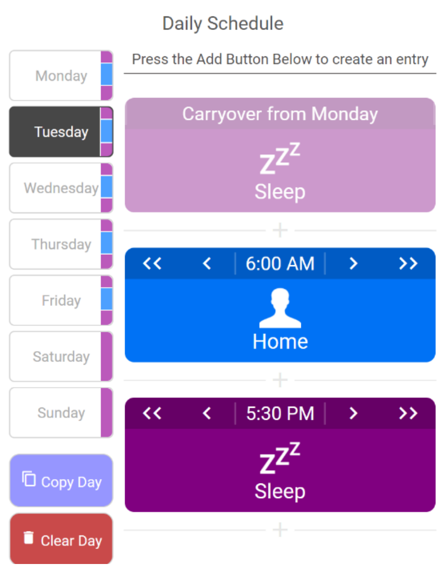

Figure 15 Schedule blocks are selected for any number of time periods over the course of a week, providing a powerful capability to tailor CERV-1000 and CERV2 operation to occupancy patterns, indoor activities, and utility time-of-day pricing schedules.