Explorations in School Indoor Air Quality

Efficiency Vermont R&D Project: Healthy Buildings

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Contents

Introduction

Efficiency Vermont administered the School Indoor Air Quality (IAQ) Grant Program (Grant Program), distributing over $15 million from the Coronavirus Relief Fund from July 2020 through January 2021 to K–12 schools in Vermont. Schools used the funds to assess heating, ventilation, and air conditioning (HVAC) system performance and make necessary modifications to improve IAQ in an effort to reduce the transmission risk of SARS-CoV-2.

The Grant Program served 314 schools with system upgrades, representing more than 62,000 students and over 6,500 teachers and covering more than 13 million square feet of conditioned space. Forty of the schools previously had no ventilation system. Over 140 engineering and trade companies were contracted, employing hundreds of Vermonters at the height of stay-at-home orders.

Knowing that more funding would likely become available to schools for HVAC improvements, and that continuous monitoring is critical for optimizing system performance, Efficiency Vermont provided a portable IAQ monitor to each of the 365 schools through the Grant Program.

To further analyze IAQ, to explore expanding Efficiency Vermont's IAQ monitoring experience from residential to commercial spaces, and to identify what impacts the HVAC improvements were having in schools, Efficiency Vermont's research and development (R&D) program funded the School IAQ Monitoring R&D Program (Monitoring Program) to monitor pre- and post-HVAC modifications IAQ in 11 of the schools participating in the Grant Program. The study began in September 2020 and ended in December 2021.

This report provides an overview of the Monitoring Program design, lessons learned, and next steps, and is intended for energy efficiency program administrators and policymakers interested in the intersection of energy, IAQ, and health.

Background

Research studies on the effects of buildings on occupant health and performance are steadily increasing, as is information about the underlying building design and systems factors that influence the scale of impact to occupants.[1] Given the substantial energy required to treat and move indoor air in Vermont's cold climate—and the importance of fresh air as a component of indoor environmental quality—ensuring the efficiency of HVAC systems is imperative to achieving comfortable and cost-acceptable healthy buildings.[2] COVID-19 placed a clear

[1] The Harvard T.H. Chan School of Public Health has compiled extensive research on healthy buildings, posting useful information, news stories, and research documents on the website For Health. The WELL Health-Safety Rating system of the International WELL Building Institute provides a framework for designing and operating buildings, appropriate for improving building-influenced occupant well-being.

[2] Lighting, security, food preparation, exterior moisture management, and materials also affect building energy and occupant health, and are not addressed in this research project. In 2020-2021, building managers generally put a priority on reducing virus transmission, because of the COVID-19 pandemic.

spotlight on the connections among building ventilation, filtration, air distribution, and occupant health.[3]

Prior to COVID-19, relatively few building owners concerned themselves with occupant health related to building performance. Barring an acute issue such as sick building syndrome,[4] building-related health issues typically go undetected for years. Because there are wide ranges in occupant susceptibility and responsiveness to environmental triggers, it can also be challenging to identify problems and prioritize the improvement of building issues affecting occupant health.

Efficiency Vermont assumed commercial buildings whose owners were likely to have the most interest in links between building energy and health prior to COVID-19 were schools and State-run facilities. However, neither facility type has traditionally had sufficient funding to support retrofits for building energy or health improvements. Thanks to prior energy assessments and a deep partnership with the Vermont Department of Health's Envision Program for schools and the Department of Health's Asthma Program, Efficiency Vermont has access to energy and health–related information for school buildings. The research team for this project was combing through these data when COVID-19 hit.

A PILOT IS BORN

Vermont school buildings are 61 years old on average, and budget constraints have deferred maintenance. With little funding to make repairs, school facilities personnel are innovation masters in keeping their buildings operational. Ventilation standards for schools have changed over the years. Schools have shifted from the highly ventilated classrooms of the early 1900s, to the tightly sealed and under-ventilated classrooms of the late 1970s and 1980s, to the value-engineered classrooms of the 1990s and early 2000s (which might or might not have been properly ventilated), to the demand-controlled spaces seen in today's new construction.

Vermont school buildings closed in March 2020 in order to help prevent the spread of SARS-CoV-2. Recognizing a valuable opportunity to help the schools as they closed early for the summer, Efficiency Vermont sprang into action, supporting schools with vacancy procedures that resulted in reduced energy consumption and meaningful work for contractors. Efficiency Vermont also worked with school administrators, facility managers, and health and HVAC experts to distill the CDC and ASHRAE indoor air quality recommendations for COVID-19 into digestible, Vermont-specific guidance for schools and their contractor partners. Knowing schools would need to improve ventilation prior to reopening in the fall and that federal resources would become available soon, Efficiency Vermont began working with the Vermont General Assembly and the Vermont Agency of Education to secure funding for the School IAQ Grant Program.

[3] The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) published COVID-specific guidelines and technical resources for buildings, as did the U.S. Centers for Disease Control and Prevention and the World Health Organization.
[4] The U.S. Environmental Protection Agency fact sheet on sick building syndrome.

Through the Grant Program, Efficiency Vermont provided school-specific technical support to identify and scope HVAC improvements. Typical projects were increasing air changes per hour, increasing or adding mechanical ventilation, upgrading existing equipment, improving or adding building controls, creating an isolation space, and installing new filters throughout the system.

The research team used this opportunity to collect pre- and post-HVAC retrofit IAQ data on 11 schools.

VALUING IAQ

The research team set out to increase their experience in IAQ monitoring and data interpretation in commercial environments in order to better identify and drive energy efficiency opportunities. By establishing a baseline for school IAQ performance, the team sought to account for future IAQ improvements associated with energy efficiency measures and the related potential health impacts. This information could inform the quantification of the non-energy health benefits of energy efficiency programs in schools.

The research team also sought to deepen partnerships with the schools, Vermont Department of Health staff, and industry experts as Efficiency Vermont expanded its collaborations on healthy buildings. Efficiency Vermont aimed to be prepared to best support customers and partners in delivering resources to Vermonters if additional funding for improving IAQ should become available.

Methodology

The research team explored the following questions through this pilot:

- What is a baseline value for IAQ in these Vermont schools pre-intervention and post-intervention?
- Which IAQ interventions:
    - Are the most beneficial for IAQ?
    - Are the most customer friendly?
    - Receive the highest customer satisfaction ratings?
- What energy efficiency opportunities can be identified through IAQ monitoring data?
- Which measures are schools interested in pursuing, and what support do schools need to accomplish those measures?
- Which measures further impact IAQ?
- What school-customer value drivers, relationships, and processes can be leveraged for increasing energy efficiency?
    - Do schools of different demographics have different needs?
- What changes might be made to Efficiency Vermont programs as a result of the lessons learned in this project?

In investigating these questions, the research team used IAQ monitors and surveys to collect information, and IAQ reports and other communication to convey that information to schools.

AIR QUALITY MONITORING

IQAir AirVisual Pro (AVP) monitors were used to track fine particulate matter (PM), carbon dioxide (CO_2), relative humidity (RH), and temperature. Efficiency Vermont selected the AVP monitor on the basis of prior experience using the monitors in residential applications and positive facility manager feedback. The Vermont Department of Health donated 17 AVP monitors, which were combined with Efficiency Vermont's existing inventory to support the project.

Efficiency Vermont determined IAQ monitoring locations at school buildings in consultation with school administrators and facilities representatives. Locations were based on:

- A higher incidence of illness and absenteeism, per school nurses
- Occupant complaints about discomfort, headaches, watery eyes, runny noses, and odors
- High occupancy rates
- HVAC configuration, known HVAC equipment problems, and recent or planned repairs
- Retrofitting of rooms to new uses (e.g., a closet converted to an office)
- Use of areas for certain activities—e.g., gyms, kitchens, labs, workshops, or art rooms
- Prior flooding
- Presence of carpets or abundant soft furnishings
- Adjacency to external pollutant sources—e.g., rooms near drop-off / unloading zones

In order to make meaningful comparisons, the team monitored not only rooms anticipating a change in IAQ as a result of HVAC interventions but also rooms not receiving HVAC upgrades.

Researchers or school facilities personnel placed monitors in locations with good airflow, ideally in the air path of an HVAC return, and out of the way of room activities. Efficiency Vermont provided power strips when outlets were fully occupied in the classroom to avoid blocking critical outlets for teachers and staff, and labeled the monitor plugs with "DO NOT unplug" notes. The team placed screen covers on each AVP monitor to deter occupants from tampering with the devices.

Efficiency Vermont installed power meters on a couple of portable air cleaners in each school to capture data on runtime and look for correlations between runtime and PM levels.

In addition to the indoor monitors, the team installed an AVP[5] outside the school where power and shelter were available so that the team would know whether pollutants tracked inside the school were also present outside the school. Where exterior power and shelter were not available, the team installed an Onset outdoor temperature and relative humidity data logger outside the school on the north side of the building in a shaded location.

Efficiency Vermont installed most monitors itself to ensure monitor placement was correct and to collect additional information about the school building and space configurations. The team

[5] AirVisual Pro monitors are not designed for exterior use. Efficiency Vermont placed the monitors in well-protected areas to test how the monitors would perform in Vermont's climate.

took interior and exterior photos of the school, of installed monitors, and of the monitors' surroundings.

Facility representatives of schools not accepting outside visitors installed monitors at those schools and provided notes to Efficiency Vermont describing monitor placement conditions.

The team set up monitors prior to HVAC upgrades being implemented and either left them in place or removed and reinstalled them after the HVAC system changes were completed.

After retrieving the monitors from the schools, the author downloaded data stored on them and generated IAQ reports. Along with those reports, the research team submitted noteworthy observations to school administrators and facilities personnel. Efficiency Vermont provided technical support in identifying IAQ pollutant sources and scoping HVAC modifications to improve IAQ.

OCCUPANT SURVEYS

Using a Lawrence Berkeley National Laboratory (LBNL) IAQ school occupant survey as a template, the team created three survey tools. These surveys targeted school administrators, facilities personnel, and teachers. The surveys covered respondent knowledge of IAQ, school communication concerning IAQ from administrators to staff, occupant perception of IAQ, occupant comfort, IAQ interventions, and potential energy efficiency opportunities.

The team sent surveys to school personnel both pre-HVAC modification and post-HVAC modification. The surveys were intended to provide baseline information about comfort and the quality of the learning environment, before and after the retrofit. Administrators and facility representatives received an additional survey six months post-intervention.

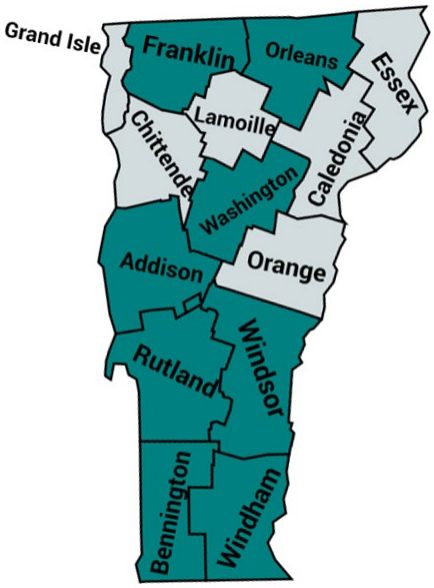
The teacher surveys were anonymous by individual but identifiable by school. The administrator and facility representative surveys were identifiable by individual and school.

Results

MONITOR PLACEMENT

Efficiency Vermont installed AVP monitors in 72 locations across nine schools. School facilities representatives installed 16 AVP monitors in two schools. The schools were located in eight Vermont counties, as shown in Figure 1.

Figure 1: Vermont counties where participating schools were located



The monitors were in place for durations ranging from two weeks to five months. Upon retrieval of the monitors, Efficiency Vermont found 15 AVP monitors unplugged or missing substantial data.

The team replaced one AVP monitor early in the study owing to a malfunctioning PM sensor. The team excluded one AVP monitor from the analysis as the space was presumed not to be in use in the pre-monitoring period.

AVP monitors placed outdoors worked until the temperature reached about 4 degrees Fahrenheit, when the monitors would shut off. In most locations, once the temperature rose, the AVP monitor would turn on again.

AVP DATA ANALYSIS

Prior to monitoring in schools, Efficiency Vermont's IAQ monitoring experience was exclusive to residential applications using one to three IAQ monitors over a two-week period, pre- and post-intervention. In assessing the school data, the team needed new analysis tools for evaluating at least 11 monitors over several months. Efficiency Vermont used Power BI software to generate a new IAQ data visualization report.

As the team began using the new Power BI report, IQAir—the manufacturer of the AVP monitor—made substantial changes to the online dashboard for data access. IQAir provided a backup method for downloading data, but the process was extremely labor intensive, the data came in a different file and structure format, and the data file was much larger, all of which caused Efficiency Vermont to retool the Power BI report and utilize additional data cleaning and processing tools. This led to significant delays in reporting results to schools. Instead of using assigned human resources to optimize the original Power BI report for portfolio-wide analysis,

the team had to focus on building a new data ingest tool and report that would visualize the data that was being received in a new format from the monitors.

SCHOOL IAQ

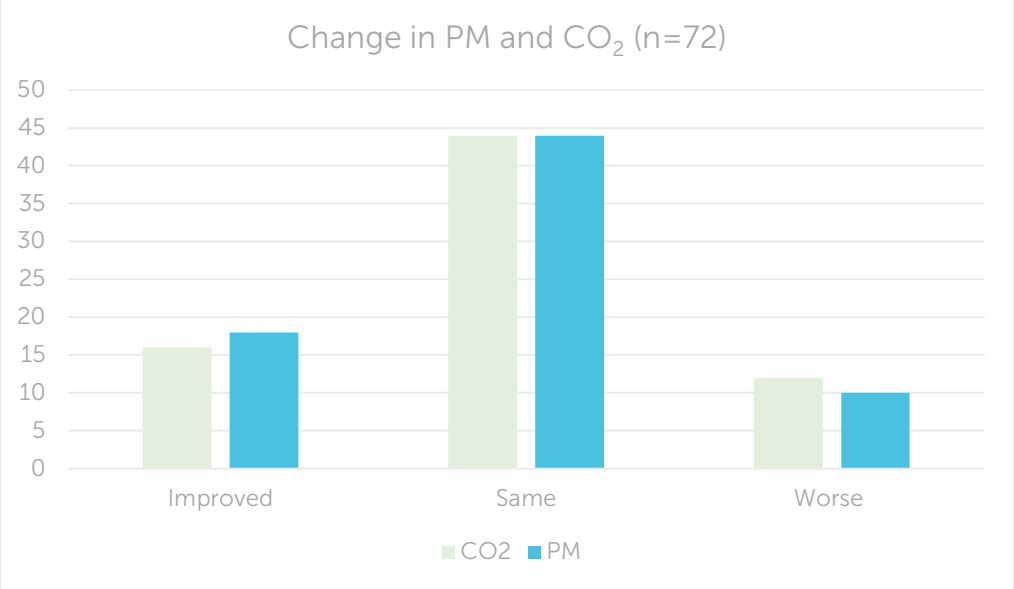
The research team aspired to establish baseline IAQ conditions from the monitor data collected pre-retrofit. During the monitor installation process, it became evident that schools were not consistent in space use or space conditioning owing to their COVID-19 concerns. Occupancy rates varied daily because of both frequent absenteeism and schools moving occupants around to accommodate evolving state and federal COVID-19 requirements and recommendations.

Despite being discouraged to do so by facilities managers, teachers and staff regularly opened windows and used portable fans and space conditioning devices to increase ventilation and comfort in all weather conditions, drastically impacting IAQ. Occupants were more likely to tolerate pre-retrofit outdoor conditions in October through December 2020 than post-retrofit outdoor conditions in January through March 2021, leading to an assumed increase in occupant-driven window ventilation in the pre-retrofit monitoring period.

Given the inconsistency in space conditioning and use, readers must view any comparison of pre- and post-retrofit IAQ monitoring results with these data quality issues in mind. The team provides the following data to support the justification for continued IAQ monitoring in schools, ideally at a time when there is less variability in school space use, indoor environmental conditioning, and occupancy rates.

Figure 2 summarizes the change in PM and CO_2 from pre-retrofit to post-retrofit across 72 AVPs in the schools. Most of the monitor locations showed no significant change in PM or CO_2, and some spaces experienced an increase in PM or CO_2.

Figure 2: Change in PM and CO_2 between pre- and post-retrofit in schools



In reviewing space temperature data, the team identified opportunities for deeper night, weekend, and/or holiday temperature setback schedules in 46 spaces across nine of the schools.

Relative humidity decreased in 34 spaces across eight of the schools, which was to be expected given the significant drop in outdoor relative humidity and increase in outdoor air ventilation.

COVID-19 Isolation Rooms

Each school was required to have a COVID-19 isolation room—a space separated from the rest of the school by a physical barrier and ventilation to the exterior to serve as a waiting area for individuals who had suspected or confirmed COVID infections and who were awaiting guardian pickup. Efficiency Vermont offered to test these spaces for schools with a manometer to confirm the room was negatively pressurized to the rest of the school when the ventilation system was running.

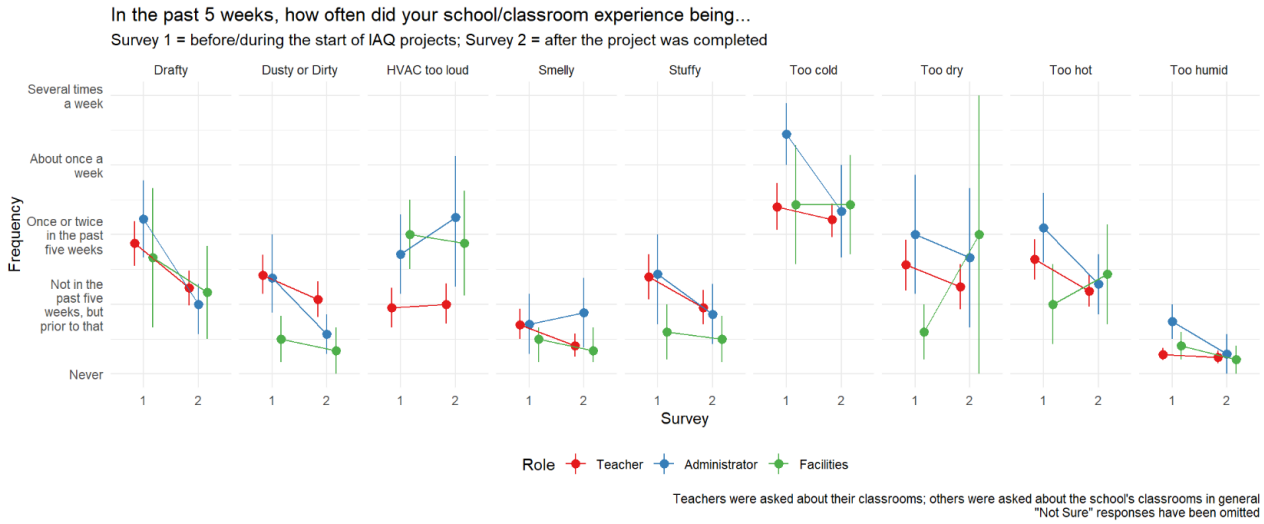
Schools accepting this offer found the testing beneficial. In one school, a newly installed energy recovery ventilator (ERV) was pressurizing the isolation space with respect to the hallway when running. Simple changes to the ERV distribution system corrected this issue.

OCCUPANT SURVEYS

Efficiency Vermont sent occupant surveys to 110 school personnel. Based on survey responses, it is clear that some retrofit work was completed prior to the respondents completing the pre-retrofit survey; however, it is not clear whether that work was the grant-funded HVAC improvements or other school-implemented efforts such as occupant-driven ventilation.

Figure 3 summarizes pre-retrofit (n=83) and post-retrofit (n=81) survey responses related to comfort. According to the survey respondents, comfort generally improved post-retrofit.

Figure 3: Occupant survey summary comfort results

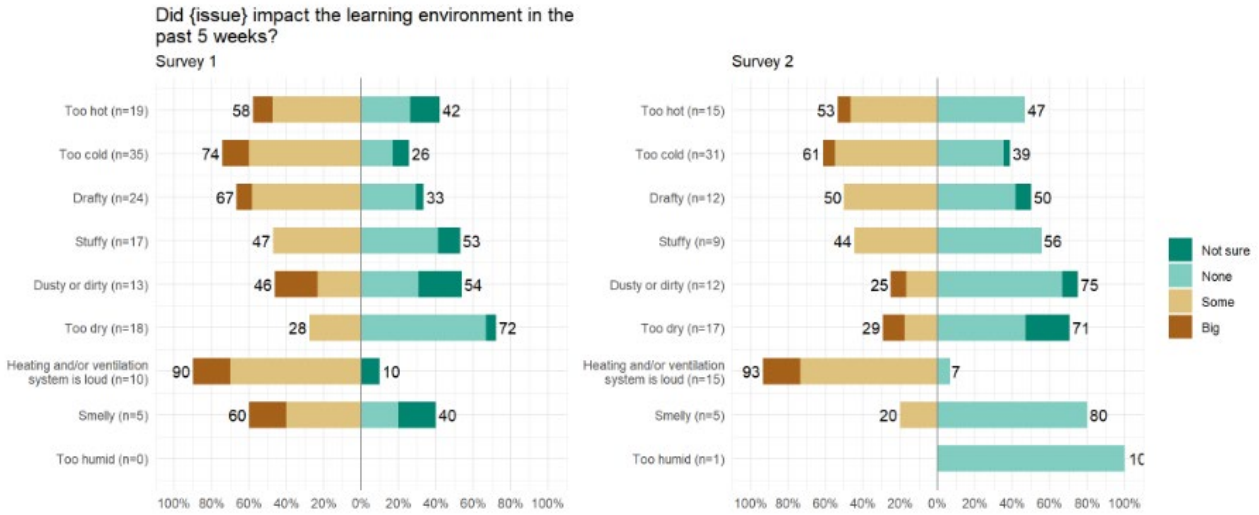


Researchers asked occupants who reported comfort issues when those issues occurred. Figure 4 summarizes occupant responses for timing of issues based on occupant type. Respondents more commonly reported the HVAC system being too loud all the time on the post-retrofit survey.

Figure 4: Occupant-reported timing of IAQ issues

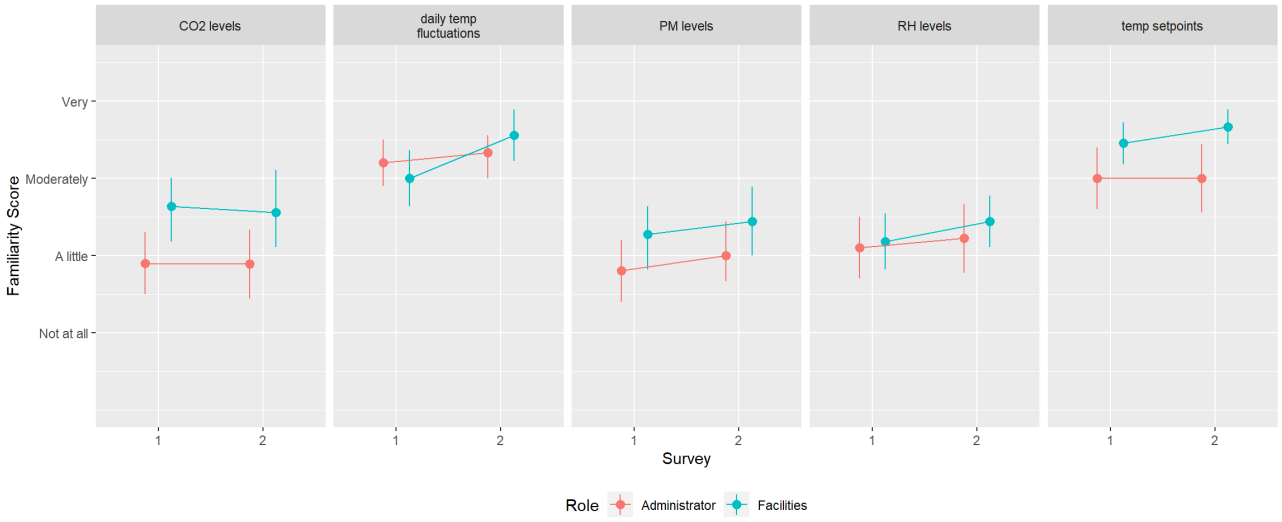
Researchers also asked occupants who reported comfort issues how those issues impacted the learning environment. Figure 5 summarizes the level of impact that comfort issues had on the learning environment, according to survey respondents. The HVAC system noise had the greatest impact on the learning environment pre-retrofit and post-retrofit.

Figure 5: Occupant-reported impact on learning environment of comfort issues



Facilities personnel and administrators expressed some increase in familiarity with school indoor temperature fluctuations, PM levels, RH levels, and temperature setpoints post-retrofit, as seen in Figure 6. The research team expects that improvements in the IAQ report visualizations and frequency of reporting would further improve school personnel knowledge of school IAQ.

Figure 6: Administrator and facilities representatives' familiarity with IAQ pre- and post-retrofit



HVAC UPGRADES

HVAC system modifications varied by school. Possible retrofit measures:

- Portable air cleaners
- Enhanced filtration—higher minimum efficiency reporting value (MERV) filters
- Increased air change rates

- Increased ventilation rates—modified dampers, new / fixed-unit ventilators, new ERV / HRV (heat recovery ventilator), control modifications
- Airflow testing and balancing

Given the variability in space conditioning and occupant behavior pre-retrofit, and the limited number of systems for a given improved measure type, the team was unable to identify which specific measures most improved IAQ. Generally, spaces that successfully implemented increased mechanical ventilation saw a decrease in CO_2 and RH levels; some heating systems were unable to keep up with the increased heating load, leading to cooler room temperatures.

The short implementation time for the Grant Program—funds approved in August and fully spent by end of December 2021—drove schools to choose projects that were already planned or that required little design work to implement.

ENERGY EFFICIENCY OPPORTUNITIES

During monitor installation and removal visits, and following the review of monitored data, Efficiency Vermont staff identified and discussed energy efficiency opportunities with schools. Common opportunities included:

- Installing enhanced lighting and HVAC controls
- Implementing or increasing temperature setbacks during unoccupied hours
- Aligning outdoor air ventilation and air change rates with space use duration and occupancy rates
- Reducing runtime of spot air cleaners during unoccupied hours
- Using plug load management to turn off devices when they were not in use and during unoccupied hours
- Planning for capital replacement projects of major systems to optimize energy efficiency opportunities

Discussion

By establishing a baseline for school IAQ performance, the team sought to account for future IAQ improvements associated with energy efficiency measures and the related potential health impacts. This information could inform quantification of the non-energy health benefits of energy efficiency programs in schools. However, the inconsistency in schools' space conditioning and use during the baseline monitoring period prevented any valid comparison of pre- and post-retrofit IAQ monitoring results.

Schools constantly impressed the team with their dedication to meeting new and evolving COVID-19 standards in short time lines with limited resources. Their participation in this pilot demonstrated their sincere effort to provide the best working and learning environments for occupants.

The School IAQ Monitoring R&D Program enabled Efficiency Vermont and schools to delve into IAQ monitoring and data analysis. The team found IAQ data to be both informative and challenging to interpret given current reporting tools. Based on discussions with LBNL, the team has identified opportunities to improve the IAQ report to by highlighting the 10th and 90th percentile performance metrics for each IAQ parameter (PM, CO_2, RH, and temperature), making it easier to quickly locate areas of concern.

The team experienced the growing pains of the AVP monitor manufacturer and verified the importance of requiring WiFi-connected monitoring devices for faster IAQ insights and measure-response feedback loops.

Although the team was not able to answer all of the research questions posed, they did gain valuable insights into larger-scale IAQ monitoring and reporting. Insights included:

- Creating a path for real-time remote data access
- Ensuring monitor manufacturer consistency in data format and delivery for the duration of the Monitoring Program
- Visualizing and assessing portfolio data analysis for multiple monitors in one building and across multiple buildings
- Documenting additional details necessary for data and program evaluation

Efficiency Vermont identified energy efficiency projects at participating schools. Some no- and low-cost efficiency improvements were completed by the schools, and plans for longer-term capital projects were discussed.

The pilot aided the community momentum of addressing HVAC in schools for IAQ improvements and energy efficiency, and Efficiency Vermont staff deepened their relationships with school personnel, which will support future collaboration on programs and projects.

Next Steps

The Vermont Legislature has allocated an additional $15 million for school IAQ improvements through the American Rescue Plan Act of 2021. The Agency of Education will contract with Efficiency Vermont to, through the School IAQ Grant Program, deliver these grant funds to schools that are under-ventilated in order to reduce the potential for virus transmission.

Using funding from the U.S. CDC, the Vermont Department of Health has contracted with Efficiency Vermont to build upon the School IAQ Monitoring R&D Program and develop a School IAQ Monitoring Program serving 50 schools in 2022 and 2023.

Efficiency Vermont will seek to enroll schools from the School IAQ Grant Program, as well as other schools in Vermont, into the School IAQ Monitoring Program to further assess school IAQ. The project team will research new IAQ monitors and develop an improved IAQ reporting tool in partnership with the Vermont Department of Health, LBNL, and program participants.

Efficiency Vermont will also evaluate opportunities for including IAQ monitoring in other energy efficiency programs, such as HVAC upgrades in manufacturing facilities and low-income housing.