Indoor Air Quality in Vermont Schools

Efficiency Vermont

Vermont Department of Health

March 2022 through December 2023

Report developed in 2024

Efficiency Vermont

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Executive Summary

Indoor air quality monitoring in Vermont's K-12 schools

Early in the COVID-19 pandemic, the Vermont Department of Health (VDH) was awarded CDC funding to explore the state of indoor air quality (IAQ) management in K-12 schools and assess the impact of HVAC system changes on schools' IAQ. The VDH Environmental Public Health Tracking Program also provided funding to make this study possible. From March 2022 to December 2023, Efficiency Vermont and VDH implemented an IAQ monitoring program that facilitated data collection in 40 Vermont public and independent K-12 schools.

Some believe that increasing indoor air ventilation through mechanical ventilation and cooling systems could reduce the spread of infectious diseases, including COVID-19. It is hoped that the data collected in this study may be studied further to test this and other hypotheses.

During the study, wildfires in Canada caused adverse impacts on outdoor air quality. This showed up in the measurements and may also be an important subject for study as in the case of asthma mitigation.

Schools participating in this study received IAQ reports, on average, every two months. However, the reporting frequency varied by participant and was based on space use and the value of the reporting to the facility managers. Each report illustrated the trended IAQ metric results for a period of three and five weeks. Examples of the data provided in these reports are shown in Figures 2 and 3.

The goal of the reporting was to provide school facilities personnel with comprehensive but digestible information for each of the monitored zones in the school. The occupied hours of the building were highlighted as the analysis period. Each zone and time period were reviewed by Efficiency Vermont engineering consultant staff so that key indicators of chronic problems and potential causes could be identified and highlighted. The long-term trending of the monitored zones was critical to achieving this deliverable to schools. Spot-metering of the four IAQ metrics is not an accurate or comprehensive way to identify systemic heating, ventilation, and air conditioning (HVAC) system problems. For example, the CO_2 concentration in a classroom is a measurable data point that, when reviewed in conjunction with the other data being collected and knowledge about the existing mechanical infrastructure in that classroom, can be used as a proxy for assessing the ventilation strategy and identifying otherwise invisible issues such as a broken air damper actuator or a sensor in need of calibration.

In addition to the customized reports delivered to the participating schools, cohort-level reports were regularly provided to the VDH. The cohort-level reports summarized common observations and trends across all participants and detailed the following industry-standard metrics for IAQ conditions: CO_2, temperature, relative humidity, and PM 2.5. Figures 5 through 7 are examples of cohort-level data.

Throughout the program, 67 customized reports were delivered to 40 schools, and 14 cohort-level reports were delivered to VDH. Of the 40 participating schools, 23 individuals acted as the main contacts. These contacts often represented multiple schools across a district or supervisory union, but some represented only one school. Most of the contacts were facility managers, but some of the contacts at smaller (lower student population) schools had multiple roles in the school unrelated to facilities. Teachers and other administrators were the most common non-facility managers to act as primary contacts.

Reporting Frequency and School Engagement

Reporting frequency varied from school to school. Some schools remained engaged throughout the program, whereas others were more engaged in the early days of the program and then phased out. It was determined that a report every two months was the “sweet spot” for many participants. The two-month window allowed participants to observe trends, but still in a timely enough manner to react to any problems identified in the data.

The graph below represents the total number of connected monitors deployed for the program from August 2022 to October 2023 and speaks to participants' engagement. The total number of installed monitors climbs until it steeply drops in June 2023, around the start of summer vacation. Efficiency Vermont found that many schools performed IT network maintenance in the summer and reset their systems, which disconnected the IAQ monitors and did not allow them to reconnect without updated permissions.

Efficiency Vermont engineers worked closely with the school’s IT staff to reconnect the monitors at several schools. However, other participants chose not to prioritize reconnecting the devices and they remained offline.

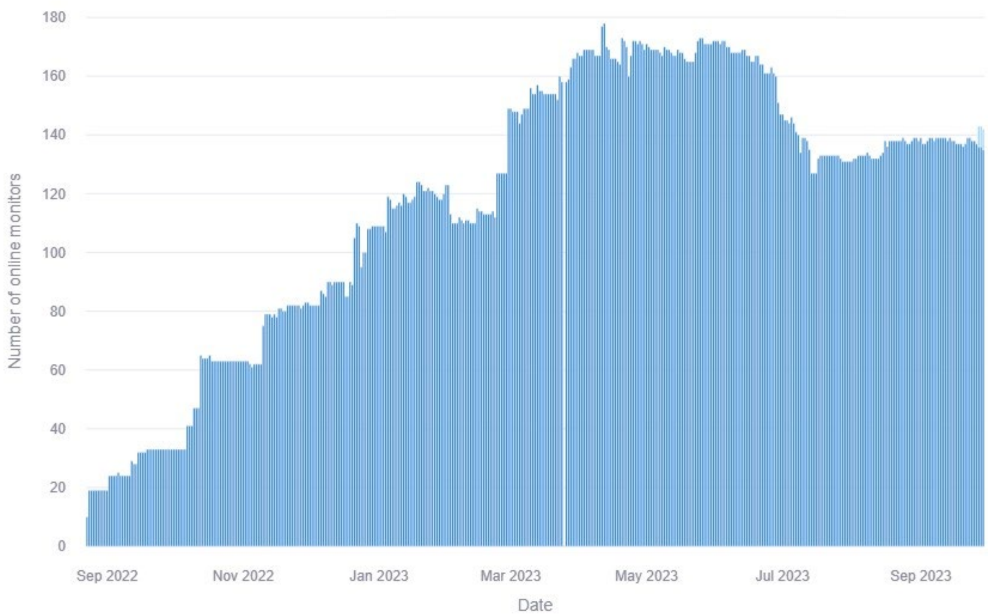

Figure 1

School-level & cohort-level reporting

Efficiency Vermont collaborated with VDH early in the program to define the range that indicated “healthy” levels for each metric and the labels that would be used for each when communicating the data to schools. The labels chosen were integral to delivering valuable and consistent messaging. Labels such as “dangerous” and “unhealthy” were avoided in favor of labels like “concerning” and “needs review.”

Industry Standard Levels for Healthy Air Quality

CO_2 (PPM)	PM 10 ($\mu g/m^3$)	PM 2.5 ($\mu g/m^3$)	Relative humidity (%)	Temperature (F)
< 1,000	< 55	< 15	40 - 60	68- 78

School-level Observations

School-level summary

The level of engagement among the 40 program participants varied widely. Some facility managers were eager to receive and read the reports and worked with Efficiency Vermont engineering consultants to investigate the causes of the IAQ findings to determine the feasibility of implementing the recommendations. Others appreciated the data but did not feel empowered to enact any changes due to limited funding, project support from the administration, or limited expertise and confidence with the systems being evaluated. The scale of HVAC improvement opportunities is often at the limit of the available capacity from school facility decision-makers and access to knowledgeable trade allies with comprehensive familiarity and understanding of the school's HVAC system and controls (or lack thereof).

A consistent observation across all participants was that they prioritized the safety and comfort of the building occupants and recognized air quality as something they should be conscious of and actively managing. Efficiency Vermont kept this at the core of the customized recommendations provided

Common themes of comments provided to schools:

- High PM 2.5 concentrations in all zones over the same few hours most likely indicate that the particulate matter source is outside the building, not generated from within. The pre-filters and low MERV filters on the ventilation air should be checked. Is this an anomaly (forest fire in Canada), or a predictable reoccurring event? Work with Efficiency Vermont to investigate further if modifications need to be made to the ventilation strategy to improve the indoor condition.
- Regular spikes in concentration of CO_2 in gymnasiums and multipurpose rooms outside of typical school hours. This was an indication of a special event or sports practice that was not accounted for in the building management system schedule. When there is projected high occupancy, the building controls should reflect this so they can respond accordingly.
- Very low CO_2 concentrations in classrooms coincident with lower than set point temperatures in the winter. This is an indication that the zone may be overventilated. Trading one IAQ metric (CO_2) for another (temperature) is not an appropriate or healthy strategy. Investigate with Efficiency Vermont staff to balance the control of the ventilation when OA temperatures are low.
- Random, fluctuating space temperature trends during the heating season. This indicates heating system controls could be improved in order to maintain consistent, comfortable space temperature during occupied hours. Work with a controls contractor to determine how to improve heating control. Improving heating system control can improve occupant comfort, prolong equipment/component lifetime, and save on heating energy costs.
- Space temperature rarely drops below 68 degrees throughout the heating season. This indicates that temperature setbacks on nights, weekends, and holidays are not in place or functional. Utilize the building management system’s scheduling function to implement setbacks and request support from a controls service technician as needed. If setbacks are not in place due to concerns with temperature recovery on cold mornings, speak to a controls contractor about implementing an optimal start/stop control sequence that dynamically adjusts the temperature control schedule based on outside air conditions.

Pre & post period measurements in schools that made HVAC changes

Throughout this program, Efficiency Vermont monitored IAQ at several schools that were undergoing a significant change to their HVAC systems. These changes were largely supported by ARPA Indoor Air Quality grant funding administered by the Vermont Agency of Education and Efficiency Vermont, for approved HVAC projects aimed at improving school indoor air quality

The following example is of a school that installed an energy recovery ventilation system (ERV). An ERV mechanically moves indoor air and outdoor air over a fixed plate or wheel-style heat exchanger to efficiently introduce tempered outdoor air into a zone or multiple zones.

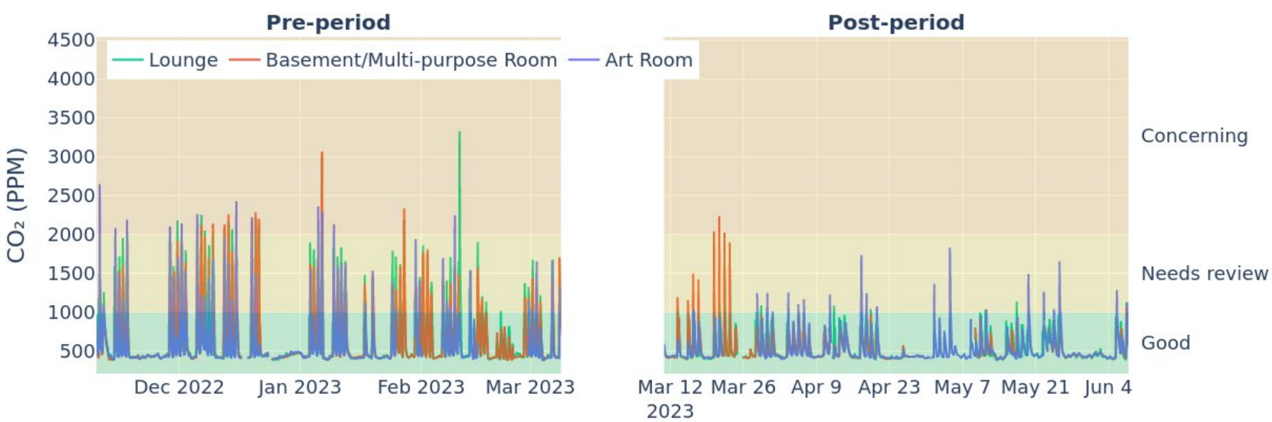

Figure 2

Figure 2 shows the CO_2 concentration in the three zones being monitored. Prior to March 2023, the three monitored zones did not have access to mechanical ventilation. The new ERV equipment was installed and made operational in early March, providing the three monitored zones with mechanical ventilation. The pre-period (before ERV installation) on the left demonstrates that the CO_2 concentration in these spaces increased into the "needs review" range of 1000-2000 ppm CO_2 on a daily basis.

The data on the right shows the post-period (after ERV installation) and illustrates a significant reduction in CO_2 concentration in the affected zones. Most days, the CO_2 concentration in the monitored spaces fluctuates within the "good" range. This trend is confirmed in the pie chart in Figure 3 - prior to the ERV installation, the monitored spaces had "good" CO_2 readings in only 76% of occupied hours, and after the ERV installation, the frequency of "good" readings improved to 95% of occupied hours.

Figure 3 (below) summarizes the hourly average CO_2 statistics in the three monitored zones, during occupied hours, and before and after the ERV installation. In the 90th percentile column, outlined in red, the three zones' peak CO_2 concentrations were in the "needs review" category during the pre-period, and dropped to the "good" category during the post-period. This IAQ data analysis speaks to the effectiveness of the new ERV system in exhausting CO_2 -laden air, and exchanging it with fresh, outdoor air.

Figure 3

Due to the cost-prohibitive nature of larger HVAC projects like the one highlighted above, many schools are unable to take the same measures to improve their IAQ and need a different approach.

Measurement spikes and events

The summer of 2023 included several days where wildfire smoke from fires in Canada blanketed Vermont. Outdoor air quality readings from this period indicated a higher level of particulate matter in the air, measured in this program through PM 2.5.

Several smoke events occurred throughout the summer, and this was observable in the IAQ data collected through this program. Below is a graphic that illustrates the impact of outdoor air quality on indoor air quality.

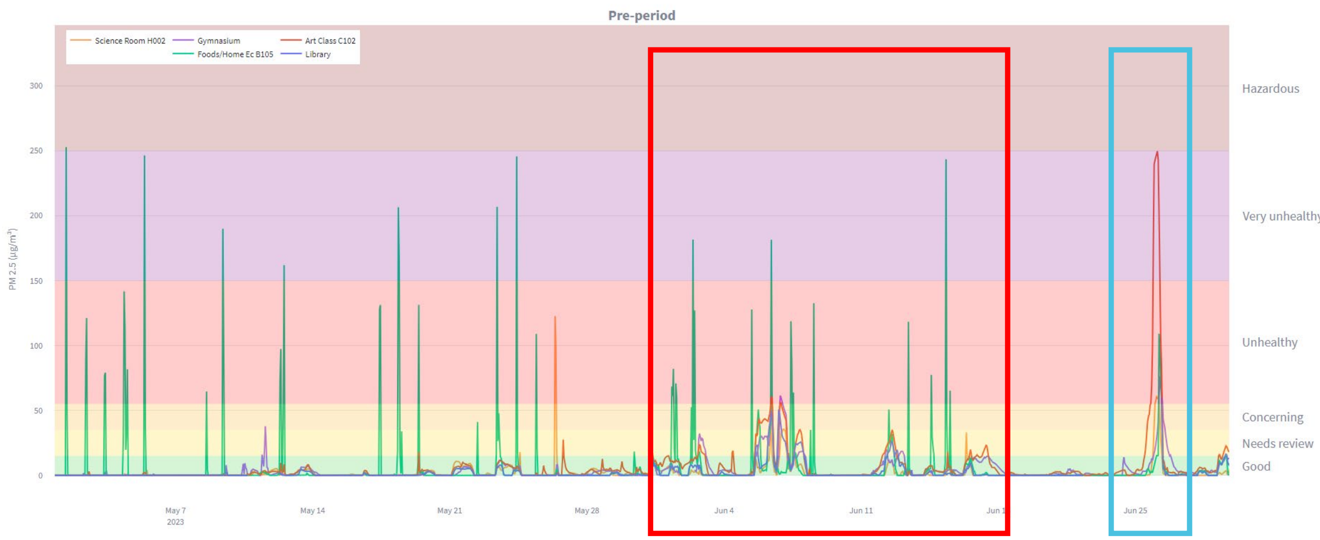

Figure 4

Displayed in Figure 4 are the PM 2.5 levels for a school from May 2023 to the end of June 2023. The weeks of June 6th and June 12th, outlined in red, align with the dates of wildfire smoke covering the state. June 26th, outlined in blue, was a particularly hazy day.

These smoke events had a measurable impact on PM 2.5 levels in this school. This data also indicates that despite the spike, the HVAC systems were able to return to “normal” levels the following day, indicating a well-functioning HVAC system.

The green spikes throughout this graph are PM 2.5 readings from the Food/Home Economics classroom, where students cook every day. This stood out to Efficiency Vermont engineers and was identified to the facility manager at this school. Possible causes include the use/performance of the vent hoods in the classroom. Some changes to improve IAQ are behavior-based and not rooted in mechanical changes.

To quantify the impact of behavior-based changes, school staff is required to record them as they occur. This is challenging due to the simple nature of these changes (using a fan, opening a window, reducing class size, etc.) that are often performed by staff that is not informed or involved with the study.

Cohort-level Observations

Cohort-level summary

Throughout the program, Efficiency Vermont provided VDH with cohort-level reports. These cohort reports included data and observations generated from all participating schools.

Efficiency Vermont has observed through extensive engagement with Vermont K-12 schools that there is a clear order of importance in the heating, ventilation, and air conditioning system designs implemented in Vermont school buildings.

Satisfying building heating load is the predominant factor in mechanical system design in Vermont schools. The extent to which schools have integrated and controlled ventilation systems varies widely across the state. Ventilation air is commonly provided through classroom unit ventilators, heat recovery ventilation units, or rooftop units. Very few schools have central mechanical cooling and/or dehumidification systems. Mechanical cooling through rooftop units or air source heat pumps is more commonly observed in a few key zones, such as administrative areas or zones that are utilized heavily in the summer.

This cascading order of importance is evident in the school IAQ monitoring data – most of the monitored schools' zones were sufficiently heated (and sometimes overheated), some lacked adequate ventilation (according to CO_2 trends), and most lacked cooling and humidity control. In many schools, inadequate ventilation conditions are not necessarily a result of a lack of ventilation equipment but rather under-performing ventilation systems nearing the end of life or needing maintenance or improved control.

Inability to control relative humidity

The most apparent cohort-level observation was that schools across Vermont, no matter their size, have limited ability to manage relative humidity levels in the summer, and no ability to manage relative humidity in the winter within their facilities. Schools' indoor relative humidity levels are strongly influenced by outside air conditions due to the introduction of outdoor air via doors, windows, ventilation systems, and any other building penetrations, and the lack of humidification and dehumidification infrastructure in schools. Generally speaking, outdoor air is dry during the winter and humid during the summer. These outdoor humidity patterns are reflected in the indoor air quality monitor data. Schools' inability to manage humidity had a significant impact on their overall IAQ, as illustrated in the following figures (Figures 5, 6, and 7).

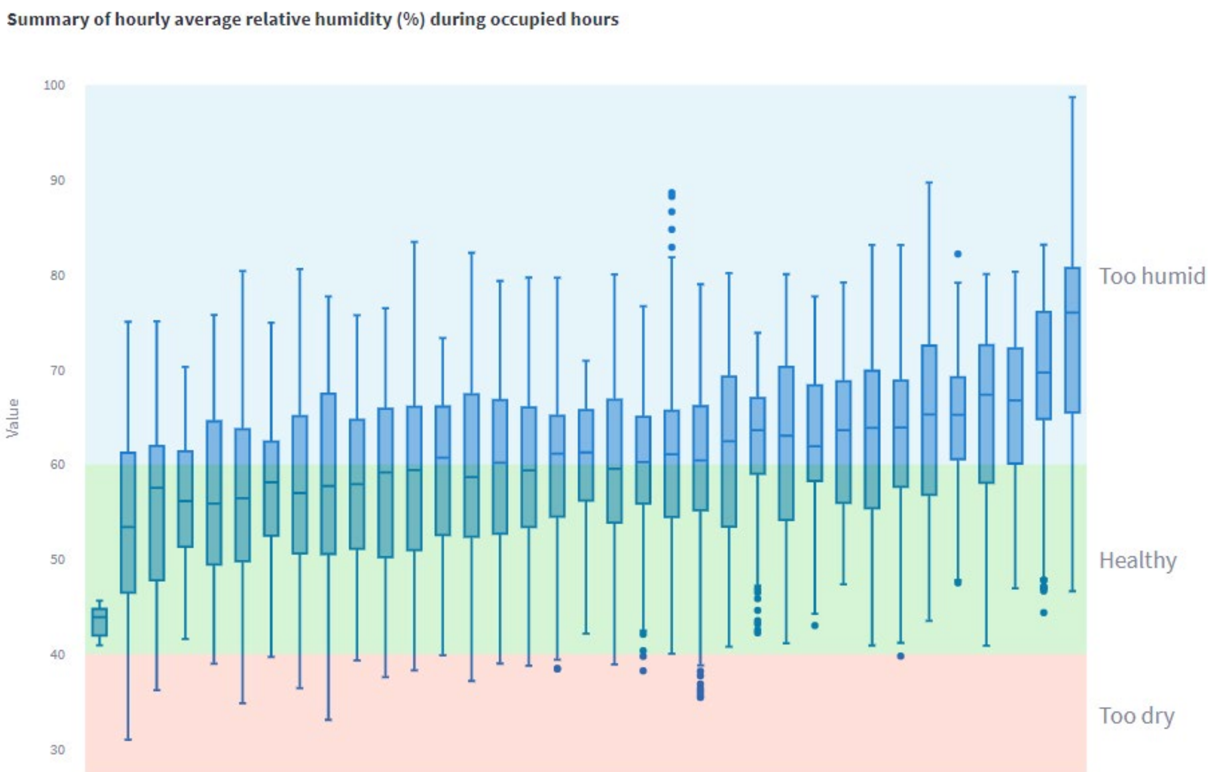

Figure 5

Figure 5 represents the average relative humidity levels (%) during occupied hours. This data was collected from 28 Aug 2023 to 27 Sept 2023, reflecting the first month of school. Half of the participating schools had an average relative humidity reading in the "too humid" range (> 60%) when the 2023 school year started. Schools with a wider box-and-whisker plot indicate a wider range of relative humidity readings within occupied hours. A tighter box-and-whisker plot indicates a smaller range of relative humidity values.

The trend is more pronounced when observing a winter month, as there is no feasible way for schools to add moisture to the air without introducing other problems, like encouraging a suitable environment for mold growth. Below (Figure 6) is the month of December 2023, during which all but four schools had average relative humidity readings in the "too dry" range (< 40%).

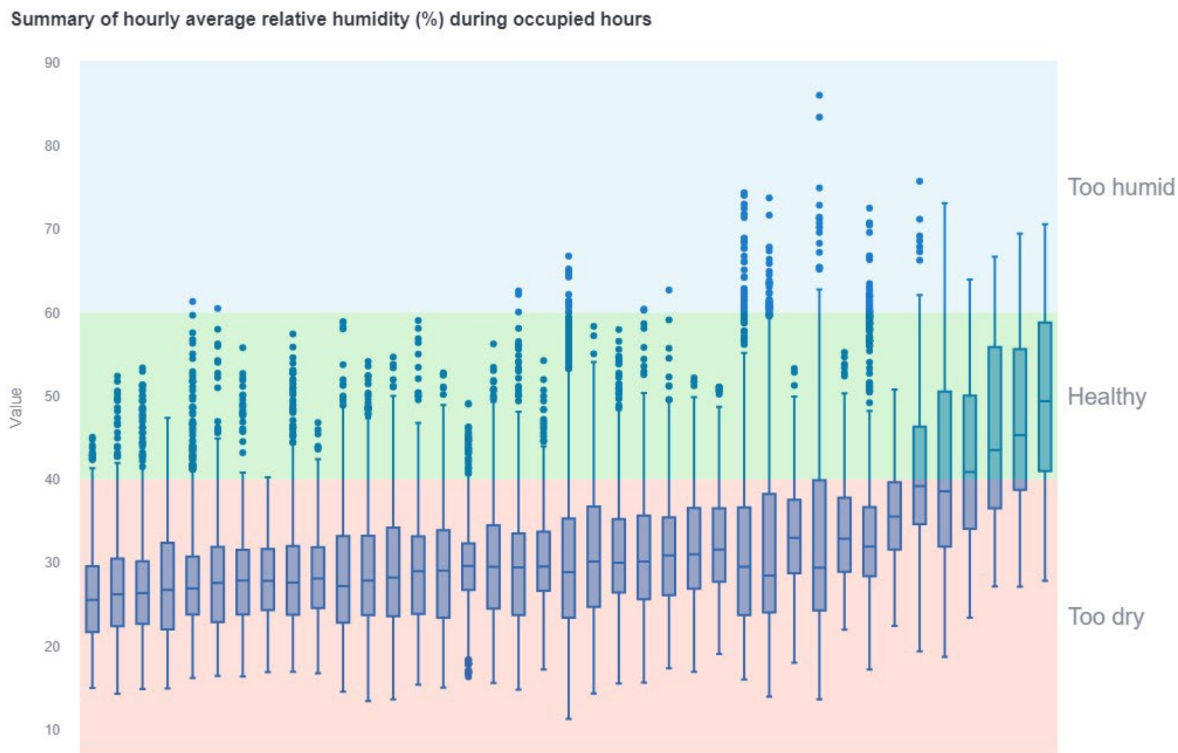

Figure 6

Further observation of this data, shown below in Figure 7, indicates that schools are very dry in the winter, with 90% of readings during occupied hours indicating “too dry” of a space for approximately half of the cohort. For the schools with a 90th percentile reading in the “healthy” range of humidity, many of them were just inside the 40%-60% level.

Oftentimes, when mechanical ventilation is added, relative humidity levels are compromised. This occurs through the introduction of dry outdoor air into an interior space. The dry outdoor air will dilute the more humid air that has been accumulating in the interior space. While it is possible for aspects of IAQ to be improved through the addition of mechanical ventilation, schools sacrifice the ability to control relative humidity when they increase ventilation.

This data suggests that appropriate-sized mechanical cooling systems, in addition to mechanical ventilation systems, may offer a solution to schools' challenges with controlling relative humidity.

Summary of hourly average relative humidity (%) during occupied hours

	Mean	Min	10%	50%	90%	Max
Brewster Pierce Elementary	29	14	17	28	39	55
Browns River Middle School	29	15	19	27	41	59
Cambridge Elementary School	27	15	20	26	35	53
Camels Hump Middle School	28	16	19	28	36	60
Cornwall Elementary School	42	23	31	41	53	64
Craftsbury Academy	31	16	23	30	41	58
Craftsbury Elementary School	35	22	27	36	43	51
Elmore School	28	17	22	28	36	40
Hazen Union Middle & High School	28	16	21	28	35	56
Jean Garvin School	27	15	20	27	37	47
Jericho Elementary School	30	17	24	30	38	54
Lakeview Elementary School	32	17	23	31	41	52
Mary Hogan Elementary School	46	27	33	44	60	67
Middlebury Union High School	47	27	34	45	59	69
iddletown Springs Elementary School	40	19	31	39	50	76
Milton Elementary School	30	15	20	29	42	63
Milton Middle School	33	18	25	33	41	53
Morristown Elementary	29	15	21	29	36	59
Mount Mansfield Union High School	29	15	20	29	40	53
Peoples Academy	28	17	21	28	36	57
Proctor Elementary School	31	16	22	30	41	60
Proctor High School	31	14	20	30	44	58
Richmond Elementary	30	16	23	30	35	49
Rochester Elementary School	41	19	27	39	62	73
Rutland Town School	29	13	19	28	37	54
Shoreham Elementary School	49	28	36	49	62	71
Smilie Memorial School	26	15	19	26	33	45
Stockbridge Central School	29	17	21	28	37	47
Stowe Elementary	27	14	20	26	34	52
Stowe Middle-High School	28	16	21	27	36	61
The Sharon Academy High School	34	22	26	33	44	55
The Sharon Academy Middle School	34	17	25	32	46	73
Tunbridge Central School	34	14	20	29	57	86
Underhill Central Elementary	32	17	22	31	42	63
Wells Village School	30	16	21	30	38	56
Westminster Center School	31	11	20	29	45	67
Westminster West	33	16	20	30	54	74
White River Valley High - S. Royalton	32	19	25	32	41	51
White River Valley Middle School - Bethel	33	14	21	28	59	74
All projects	31	11	21	30	42	86

Too humid 61 - 100 %

Healthy 40 - 60 %

Too dry 0 - 39 %

Figure 7

Conclusion

The Indoor Air Quality (IAQ) Monitoring Program conducted across Vermont's K-12 schools revealed critical insights into the challenges and opportunities for improving air quality in educational facilities.

Key Observations

Challenges in Managing Relative Humidity:
Managing relative humidity emerged as the most significant challenge in improving IAQ. The data highlighted that many Vermont schools struggle with controlling both high and low humidity levels due to inadequate HVAC infrastructure. High humidity could potentially be managed with appropriately sized air conditioning systems, but most schools lack this equipment. Similarly, low humidity conditions, which are prevalent during winter, require humidifiers that are not currently available in these schools. Addressing these issues would require significant funding and infrastructural upgrades.

Impact of Upgraded HVAC Systems:
Schools that were able to implement HVAC system upgrades during the program observed notable improvements in IAQ. For instance, the installation of an Energy Recovery Ventilation (ERV) system significantly reduced CO_2 levels in monitored spaces, demonstrating the effectiveness of such upgrades. However, the cost-prohibitive nature of these projects means that not all schools can afford such improvements, highlighting the need for additional resources and support.

Value of IAQ Monitoring:
The program provided schools with their first opportunity to systematically measure IAQ metrics. This data empowered schools to make informed decisions about managing their HVAC systems and improving indoor air quality. The feedback from participants was overwhelmingly positive, with 86% of respondents expressing high satisfaction with the program, and 100% reporting high satisfaction with the customized reports provided. This suggests that schools found the program valuable and helped enhance their understanding and management of IAQ.

Final Thoughts

The findings from this study highlight the importance of continued investment in HVAC infrastructure in schools in Vermont. Schools need technical and financial support to upgrade their mechanical ventilation systems. This will allow schools to manage relative humidity effectively and maintain healthy indoor environments for students and staff. The success of the schools that implemented HVAC system improvements demonstrates the measurable benefits of these investments. Moving forward, it is crucial to prioritize HVAC system improvements to ensure the health and well-being of all school occupants.