SAVINGS VALIDATION FIELD STUDY OF ADSORBENT AIR CLEANING SYSTEM EXECUTIVE SUMMARY

Release Date
4/13/2020

Prepared For
Commonwealth Edison Company

Prepared By
Slipstream

ComEd
An Exelon Company
powering lives

Acknowledgements

Project manager: Drew Morrison

Other Slipstream staff supporting the project: Andrew Lick, Maddie Koolbeck, Joe Zhou, Allie Cardiel, Scott Hackel

This project was developed as part of the Emerging Technologies offering within the ComEd Energy Efficiency Program under internal project number [P-0157]. Slipstream produced this report for the ComEd Emerging Technologies team with overall guidance and management from CLEAResult. Additional support was provided by the building staff of the test building acting for Able Services and The John Buck Company. For more information on this project or to request the full report, contact EmergingTech@ComEd.com.

Legal Notice

1.0 EXECUTIVE SUMMARY

Adsorbent air cleaning (AAC) devices offer a potential new path to saving energy associated with heating and cooling ventilation air by cleaning air in lieu of introducing more outdoor air into the building, while maintaining a healthy level of indoor air quality (IAQ). These devices filter gas-phase contaminants such as carbon dioxide and volatile organic compounds (VOCs) from building air, reducing the need to introduce outdoor air to dilute these contaminants. While the fundamental technology has been established for decades, it is a relative newcomer to the commercial building HVAC market and has been installed in just a handful of buildings over the past several years. This report provides an assessment of the technology's potential within the target market, including energy savings and potential barriers to adoption.

HVAC systems in commercial buildings introduce a certain amount of outdoor air to ventilate the building. The volume of air introduced in most buildings (both new and existing) is set according to codes and standards such as the International Mechanical Code or ASHRAE Standard 62.1. In a climate like northern Illinois that is both humid in the summer and cold in the winter, large amounts of energy are required to either dehumidify the air in the summer or heat the air in winter. There is a need in the market for more comprehensive solutions that can reduce outdoor air preconditioning energy to a greater extent than existing solutions, while still maintaining IAQ levels.

AAC systems represent a significant opportunity to save energy associated with conditioning ventilation air. However, this technology's potential is largely unrealized within the market due to both a lack of knowledge and familiarity with the technology among market stakeholders and a lack of documented energy savings and IAQ impacts in real-world test installations. And as with most emerging technologies, it has a significant cost premium. By providing quantitative test results and outlining strategies to familiarize stakeholders with the technology, this report addresses the first two barriers. The demonstration will prepare the market and allow ComEd to create a program offering that includes a financial incentive as well as tactics to increase market visibility. All of this will in turn address the third barrier of high cost.

Unlike other filters which remove particulate (solid) contaminants from air, adsorbent air cleaners remove gas-phase contaminants. Air exiting the adsorbent medium is virtually free of contaminants. This air can be recirculated into occupied spaces, reducing the amount of outdoor air required to dilute contaminants and avoiding the associated heating and cooling energy costs.

The specific product tested in this pilot is produced by enVerid Systems, Inc. and is called the HVAC Load Reduction (HLR) system. It is an AAC device designed to be integrated with a commercial building HVAC system, either as a retrofit or in a new construction building. The modules are installed in the return air stream of an HVAC system in a side stream configuration, meaning that a portion of the return air is separated, cleaned by passing through the HLR modules, and then mixed back into the larger air stream. The HLR modules are not a standalone product, but instead must be integrated into the building HVAC system to ensure proper operation. This usually involves integrating the HLRs' controls with a building automation system (BAS) to allow operators to monitor and control the HLRs. An additional cloud monitoring and control system is provided as a service by enVerid.

To best facilitate market acceptance, early projects should involve larger buildings for the economies of scale that better justify installing an AAC system (e.g., fixed cost of some of the installation). Targeted marketing could then be attempted to smaller buildings to determine if AAC could expand to this market. There are two criteria that potentially constrain market applicability of AAC. One is that buildings must have relatively large amounts of outdoor air. This provides the economies of scale necessary for a project to be cost effective. The second criterium is proper control of outdoor air. Without proper control of outdoor air, it can be difficult to maximize savings by reducing outdoor air to the lowest level possible. This criterium is driven by how much ventilation air is required to make up exhaust air and exfiltration (the latter due to a building's leakiness). Failure to meet these criteria will mean some buildings in ComEd's territory are not good candidates for AAC.

Literature documenting the energy savings of AAC prior to the beginning of this pilot was sparse. Whole-building energy simulations predicted that the product would save approximately 4.9 kWh/cfm in buildings without electric heat and 25 kWh/cfm in buildings with electric heat in a Chicago climate. Since ventilation is a universal requirement for buildings regardless of use category, the technology is applicable to numerous building types. The product's modular design can be scaled over a wide range of building sizes down to 10,000 ft2 of floor area, which corresponds to an HVAC system size of approximately 15–30 tons. Overall, we roughly estimate that 300 million kWh is the economic potential for savings in ComEd's territory for this technology.

The assessment study had the following research objectives:

- Determine the energy savings and peak electric load reduction of HVAC systems with enVerid AAC systems applied.
- Compare IAQ of conditioned spaces between HVAC systems operating with enVerid technology to those operating without.
- Ensure energy savings are applicable and maintainable, including installer and operator satisfaction with devices and investigation of code impacts, which impact the maintainability of a program offering.

The pilot study took place at the test building, a 1.1-million-ft2 class A office building owned by The John Buck Company in downtown Chicago. The building underwent a retrofit of its HVAC system with HLR units in the initial phase of the pilot, during which time we installed equipment to monitor energy consumption and IAQ. We then collected operating data through the cooling season of 2019 and the heating season of 2020, alternating periods of HLR operation with periods where we reset the controls to pre-retrofit status in order to compare energy consumption under similar outdoor conditions. During this time, we monitored energy consumption and air quality continuously. After collecting data, we analyzed cooling and heating savings using multiple linear regression to control for weather and non-ventilation HVAC loads.

A summary of data points collected is provided below in
Table 1.

Data Point	Key Indicator Measured	Data Source
Chilled water consumption	Cooling energy	BAS
Plenum heater power	Heating energy	BAS
AHU air flow rates	Cooling/heating energy	BAS
AHU air temperature/ humidity	Cooling/heating energy	BAS
HLR power consumption	HLR energy	Power monitors
AHU fan power consumption	Fan energy	Power monitors
Indoor and outdoor air CO_2 and VOC levels	Air quality	Air quality monitors, spot samples

Table 1. Summary of Data Collected

In conversations with the building staff, we discovered that the building outdoor air controls had been changed several times since the building was originally commissioned. This, and the poor quality of BAS data from before the BAS upgrade, made it impractical to directly compare data from after the HLRs were installed with data from before installation (also known as pre-/post-installation monitoring). To address these challenges, we adopted a controlled experiment approach in which we operated the building in an alternating series of week-long "treatments.” Each treatment has a different outdoor air flow rate setting and corresponds to a unique period the building operated in historically. A summary of each treatment is presented below in
Table 2.

Treatment Name	Description	Outdoor Air Flow Rate (cfm)

Original Design	Original outdoor air flow rate when building was first opened	101,000 (29th floor) 21,050 (3rd floor)
LEED	Outdoor air flow rate set after LEED retrofit project	84,600 (29th floor) 16,400 (3rd floor)
DCV	Outdoor air flow rate set after DCV control was installed; encountered at start of project	52,000 – 100,000 (29th floor) 11,000 – 16,000 (3rd floor)
Air Cleaning	Outdoor air flow rate possible using air cleaning modules. Calculated from ASHRAE 62.1 indoor air quality method.	50,292 (29th floor) 12,706 (3rd floor)

Table 2. Summary of Experimental Treatments

This project involved a wide variety of data streams; therefore, we used several different analysis methods to arrive at results. For cooling energy and fan power we used regression analysis; for heating energy we used a physics-based model matched to observed heating power data; for HLR power consumption we averaged the total electrical energy consumed during HLR operating periods; for IAQ we compared contaminant levels in indoor spaces to when the air wasn't being cleaned.

Our analysis confirmed that cleaning air with the HLR modules and reducing outdoor air flow rates resulted in statistically significant energy savings, including both heating and cooling savings. Additional benefits included electrical peak demand reductions and reductions in peak cooling load (and therefore required cooling capacity). Savings in the pilot building during a typical year would be expected to be approximately 3.5 kWh per cfm of outdoor air reduced. These savings are based on measured data from the particular test building monitored in this pilot, and savings in other buildings may vary based on a building's operating schedule, the design and control of its HVAC system, and the efficiency of its cooling plant and choice of heating fuel.

By allowing for reduced outdoor air flow, the HLRs reduce seasonal cooling loads by approximately 180,000 ton-hours, or 11 percent of the seasonal cooling, when normalized for weather and extrapolated to the entire cooling season. This is slightly less than, but still relatively close to, the manufacturer's initial estimate of 214,000 ton-hrs. The building utilizes district chilled water, but if cooling was provided by a chilled water plant with an average COP of 4.02, the resulting annual electricity savings would be approximately 158,000 kWh. Reducing outdoor air flows also reduced the peak cooling load by approximately 280 tons. This would translate into approximately 250 kW of electricity demand reduction with the same cooling plant assumptions. This peak demand reduction occurs in the afternoons and early evening, coincident with peak demand per the TRM.

The subject building utilized electric heaters to heat incoming air. Our measurements predict 6–19 MWh of heating energy savings during the heating season. The subject building had an abnormally low supply air temperature. In these plots:

- Low temperature reset represents the relatively low supply air temperatures in the pilot building: 48oF design condition, resetting to 58oF as the outdoor air temperature approached 20oF.
- High temperature reset represents a more standard control scheme with 50oF supply air resetting to 65oF as the outdoor air temperature approaches 20oF.

Predicted savings are also higher for a higher supply air temperature reset schedule. With full OA control and a high temperature reset schedule, predicted savings are 49 MWh. Ahigh level of uncertainty surrounds the heating savings predictions due to the low number of observations.

When we combine impacts from cooling, heating, fans and HLR usage, we find the energy savings outlined in
Table 3. Savings are presented as measured and normalized by both amount of outdoor air reduced and building floor area.

	kWh	kWh per cfm	kWh per ft2
Cooling energy savings	158,265	4.06	0.14
Heating energy savings	19,000	0.49	0.02
HLR energy consumption	(40,902)	(1.05)	(0.04)
Additional fan power	(0)	(0)	(0)
Net energy savings	136,363	3.50	0.12

Table 3. Overall energy savings

The energy savings we have observed are specific to the conditions we encountered in the building where the pilot took place. However, several key drivers of savings present in the test building will differ in a substantial portion of the commercial buildings market. These drivers are:

- **Pre-installation outdoor air flow.** The benchmark outdoor air flow of the pilot building set by the LEED retrofit was 13 percent of the design supply air flow rate. Other buildings often have much larger outdoor air flows, often 20 to 30 percent of the design supply flow in commercial buildings. This would likely make larger reductions in cfm available in those buildings, which would correspond to larger savings.

- **Cooling plant efficiency.** This building uses district-chilled water, so we are measuring chilled water energy usage and not directly measuring electricity savings from the chilled water plant. The efficiencies of cooling plants in some buildings will also differ. We assumed a seasonal COP across all cooling plant equipment (chillers, pumps, condenser loop equipment) of 4.0. Energy savings would increase or decrease if cooling plant efficiencies differ from this assumption. To give a sense of scale of differences in savings, we made additional estimates with an assumed high-efficiency cooling plant (COP 5.0) and low-efficiency plant (COP 3.6).
- **Heating fuel.** The pilot building was electrically heated. A substantial population of other buildings use other fuels for heating, with the majority using natural gas. Buildings which heat with natural gas do not have the opportunity for electricity savings from reduced heating demand, although an opportunity would exist for natural gas savings.
- **Operating hours.** The pilot building operated its HVAC systems for 60 hours per week (12 hours per day on weekdays only). Other buildings may have more operating hours to accommodate night and weekend occupancy, during which full ventilation would be required.
- **Demand control ventilation.** The energy savings would be significantly smaller if taken versus the DCV case. But as discussed, the current DCV sequence at the site is much more aggressive than is typical and does not even meet current IAQ standards. Regardless, the level of DCV in place at a given site will have some impact on savings.

In terms of Indoor Air Quality (IAQ), the levels of key contaminants of concern (CO_2 and total VOCs) remained below guidelines established by recognized air quality standards during both periods when the HLRs were actively cleaning air and when the HLRs were inactive. Generally speaking, CO_2 and total VOC concentrations during air cleaning were roughly equal to or slightly greater than concentrations in non-air cleaning times. The AAC technology demonstrated at test building that it could maintain IAQ while outdoor air is significantly reduced. IAQ did not improve but was maintained. Two additional potential outcomes should be considered. First, the HLR runtime has an impact on IAQ. This project prioritized IAQ and energy somewhat equally. If an owner aimed to improve IAQ at the expense of some of the energy savings, the HLRs could be run more. And secondly, the technology does to an extent decouple IAQ from outdoor air quality — in other words, IAQ becomes less dependent on conditions outdoors. In environments where levels of outdoor air pollution are high, this has the potential to greatly improve the health and safety of the indoor environment.

During the pilot, we identified several technical and non-technical barriers to widespread deployment of this technology:

- **Integration with existing systems.** The HLR product is really a component of a larger building system rather than a standalone device. As such, its performance is affected by the proper functioning of other parts of a building's HVAC system, including measurement devices, control systems and building staff operational decisions. Candidate projects should be carefully evaluated in the planning phase to ensure that the HLR product can be successfully integrated; this includes proper measurement and control of outdoor air, the ability to reduce outdoor air levels and a building automation system that the HLRs can communicate with. The optimum case in a retrofit scenario would likely be to implement an HLR installation either immediately following or as a companion to retrocommissioning or monitoring-based commissioning projects.
- **Stakeholder knowledge and awareness.** Although AAC devices have gained some industry recognition in recent years, they are still a relatively unfamiliar product both to building owners and industry practitioners. Stakeholder education programs, perhaps in partnership with enVerid or other manufacturers, are a promising means to overcome this barrier.
- **Proper system operation and training.** In the first six months after the HLR modules were installed, the building operator encountered some challenges in getting the HVAC system to operate as proposed. enVerid did provide training to staff on operation of the HLRs. But operators could have used more instruction on how to accurately control their HVAC system to reach the reduced outdoor air flow rates enVerid recommended. As a result, proper outdoor air levels were not achieved until several months after the HLRs came online.

The use of adsorption air cleaning can involve building code considerations in a few separate ways. The most critical reference for consideration on a given project is the local mechanical code. But ASHRAE Standard 62.1 is also an important reference; it serves as a foundation for those local mechanical codes and is often followed as a best practice (and so has impact on the natural baseline). At the test building, the building owner and their design and construction team submitted permit applications for the air cleaning device installation. The application met all local code requirements and was efficiently approved. It should be noted that adjustments to airflow resulting from the devices – which are necessary for energy savings – were not included in the permit. Those adjustments were considered by the designer and contractor to be an operational decision that came after installation. It's possible to imagine a similar scenario where the building is designed for normal Illinois or Chicago code-compliant ventilation rates, then those ventilation rates are decreased after the building is fully operational (as the air cleaning devices have their desired effect). AAC also has interactive effects with DCV, which is regulated by both code and ASHRAE Standard 62.1. The amount of ventilation reduction allowed under DCV is limited to ensure acceptable air quality, regardless of building occupancy, due to other indoor contaminants. Furthermore, typical DCV is only implemented in the most densely occupied spaces of a building (conference rooms, training rooms, etc.), and so affects well less than half of most buildings' area. Substantial outdoor air conditioning savings would remain for AAC to address in a manner that allows for sufficient IAQ.

The investigation thus far has shown that the enVerid HLR product is a net energy saver. Cooling season savings are in line with, though possibly slightly smaller than, manufacturer predictions. Heating savings at the subject building were much lower than manufacturer predictions, due in part to the temperature and outdoor air control conditions we encountered during the project. IAQ results suggest that during enVerid operation (and lower outdoor airflow) the levels of the contaminants of concern remain within acceptable limits and reasonably similar to existing building operation.

AAC shows technical promise to deliver energy savings with the right building conditions. Needs still exist to address the barriers to deployment identified earlier: addressing challenges related to integrating the technology with existing building systems, building awareness among customers in the target market, and facilitating code adoption — especially in new construction. We therefore recommend the following steps to facilitate uptake of this technology:

- Develop a framework for screening candidate buildings to identify those with the best chance of success and in contrast those with large barriers such as exhaust air and exfiltration requirements and existing ventilation operation.
- In partnership with manufacturers, develop thorough training steps for building operations staff and implementation contractors to educate them on proper system operation.
- Develop a program offering that both 1) promotes the technology as an effective means to energy savings and 2) provides financial incentives to offset cost.

Although this pilot focused on the retrofit of an existing building, AAC has applications in both building retrofits and in new construction. The technology is therefore appropriate for the commercial and industrial new construction program as well as the prescriptive/custom program.