Emerging Technology Program

Project #1113: Air Deflector for Unit Ventilator (ADUV)

Interim Pilot Assessment Public Report[1]

October 29, 2018

Technical Contacts

Hardik Shah
Principal Engineer, Project Manager
Hardik.Shah@gastechnology.org

Feibi Yuan
ETP Analyst
Feibi.Yuan@gastechnology.org

Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018

Nicor Gas Contact

Gary Cushman
Program Manager, Research and Emerging Technology
GCushma@aglresources.com

Nicor Gas Company
1844 Ferry Road
Naperville, IL 60563

[1] Final report will be generated after the receiving behavioral surveys from the teachers occupying the monitored classrooms. However, **the energy savings data presented in this interim public report will not be affected or changed in the final report.**

Table of Contents

Legal Notice

This report was prepared by Gas Technology Institute (GTI) for Nicor Gas Company (Nicor Gas). Any use of or reliance on this report and/or any information contained in this report by any party is at that party's sole risk. Neither GTI nor Nicor Gas, or any person acting on behalf of either of them:

a) *Makes any warranty or representation, express or implied with respect to the ownership, accuracy, completeness, or usefulness of the information contained in this report. Inasmuch as this work is experimental in nature, the technical information, results, or conclusions cannot be predicted. Conclusions and analysis of the results by GTI represent GTI's opinion based on inferences from measurements and empirical relationships, which inferences and assumptions are not infallible, and with respect to which competent specialists may differ.*
b) *Assumes any liability with respect to the use of, reliance on, or for any and all damages resulting from the use of or reliance on this work and/or any information, apparatus, method, or processes disclosed in this report.*

The results within this report relate only to the items tested.

Executive Summary

Introduction

As a part of the Nicor Gas energySMART energy efficiency program, the Emerging Technology Program (ETP) assesses new technologies that have the potential to realize natural gas savings for the 2.2 million Nicor Gas customers in Northern Illinois. The Gas Technology Institute (GTI) provides program implementation for the Nicor Gas ETP. This report summarizes the findings on Supply Air Deflector for Unit Ventilator (ADUV) product and its potential to provide energy savings to Nicor Gas's public and commercial customers.

Background

Unit ventilators (UVs) are the primary means of space conditioning found in schools, meeting rooms, offices, and other areas where local codes require controlled ventilation based on occupancy density. UVs are capable of heating, cooling, and ventilating a space using steam, hot water, electric heating, chilled water, or remote direct expansion cooling. UVs have historically been placed next to perimeter exterior windows to serve as a draft stop while also conditioning and ventilating the space. As building envelopes tighter and windows became better insulated, the draft stop function of UVs has diminished while their positioning under large windows exacerbates unwelcome space heating effects. Air delivered upward from UVs does not mix well with air in the room and creates air stratification. Warmer air stays near ceilings and cooler air stagnates near floors. Longer equipment runtimes are now required to satisfy thermostat set-points, thus wasting energy. The evaluated product claims to solve the air mixing and stratification issue in UVs, thereby saving energy.

Results

GTI targeted demonstration of the ADUV technology in a varied sample of school classrooms that used unit ventilators as the main space conditioning apparatus. GTI selected 12 classrooms to monitor in one (1) 91,141 square-foot two-story middle school in Nicor Gas territory. The classrooms ranged from 1st to 2nd floor locations; ranged in end-use from instruction-based spaces to skills-based laboratories to technology/media storage spaces; and contained external walls and windows oriented toward the north, south, east, and west. A field test agreement was utilized to secure the participating school, and end user surveys were distributed to the classrooms.

Energy savings results from the demonstration are provided in Table 1. The data shows that classrooms with north-, east-, and west-facing windows and exterior walls saved an average of 16.9%, or 1,512 Btu per HDD, in space heating. It appears that classrooms with south-facing windows and exterior walls saw no energy savings. Therefore, this technology is most cost-effective when used with north-, east-, and west-facing unit ventilators. Projection of these savings to a full year in a representative school building in Nicor territory served by a central, non-modulating system and no nighttime setback yields 2,760 therms or $1,380 saved per year at a rate of $0.50/therm. The expected whole-building payback is 8.3 years. A utility bill analysis at a later date will help to verify building-wide gas savings. A summary of results is available in Table 2.

Table 1: Retrofit Savings for Six (6) Monitored Middle School Classrooms, 2017-2018

				Baseline Energy			Retrofit Energy			
Room #	Room Type	Window Orientation	UV CFM Capacity	BTU Delivered	HDD	BTU/HDD	BTU Delivered	HDD	BTU/HDD	Savings (%)
108	Classroom	North	1000	2,235,236	459	4,870	6,998,070	1624	4,309	11.5%
126	Classroom	East	1250	8,610,255	574	15,000	22,961,627	1665	13,791	8.1%
206	Classroom	North	1000	4,048,543	540	7,497	9,867,119	1619	6,095	18.7%
210	Classroom	North	1000	5,556,431	540	10,290	11,773,638	1619	7,272	29.3%
									Average Savings	**16.9%**

				Baseline Energy			Retrofit Energy			
Room #	Room Type	Window Orientation	UV CFM Capacity	BTU Delivered	HDD	BTU/HDD	BTU Delivered	HDD	BTU/HDD	Savings (%)
103	Classroom	South	1000	351,785	434	811	1,254,319	1487	844	-4.1%
107	Classroom	South	1000	692,579	245	2,827	2,037,366	623	3,270	-15.7%
									Average Savings	**-9.9%**

Table 2: Summary of ADUV Pilot Results for Nicor Emerging Technologies Program

	Site #1
Site Type	Public School
Annual Gas Savings (therms/yr)	2,760 therms/yr
Percent Gas Usage Savings	16.9% for N-, E-, & W-facing windows; No savings for S-facing windows
Annual Electric Savings (kWh/yr)	N/A
Percent Electric Usage Savings	N/A
Number of Test Units Installed at Site	6 ventilators in 6 classrooms
Annual Gas Savings per Unit (therms/yr)	80 therms/yr, in N-, E-, & W-facing rooms
Annual Electric Savings per Unit (kWh/yr)	N/A
Annual Water Savings (gal/yr)	N/A
Simple Payback for Site (yrs)	8.3

Nomenclature

Nomenclature	Term
HDD	Heating Degree Day
BTU or Btu	British Thermal Units
Therms	A unit of measure for natural gas. 100,000 BTUs
UV	Unit Ventilator
RH	Relative Humidity
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CFM	Cubic Foot per Minute
EFLH	Equivalent Full Load Hours

Project Background

Project Overview

The ADUV technology is a destratification product that has the potential to impact a sizeable market, achieve significant energy savings, and improve occupant comfort, thus warranting a field review to validate the savings claims. Though other applications of destratification technologies have been an emerging trend in the market, the biggest obstacle to further adoption may be educating consumers to be more cognizant of airflow patterns.

Previous Study Results

This technology lacks previous independent energy savings analysis. GTI performed a preliminary savings calculation based on equivalent full load hours (EFLHs) from Section 4.4 of the Illinois TRM V6.0 at 10 to 15% savings, shown in Table 3 and Table 4.

Table 3: Preliminary EFLH Savings Calculation at 10% Energy Savings for various Building Heating Load

Building Area (SQFT)			15,000	25,000	50,000	75,000	100,000
Building Heating Load (BTUH)			600,000	1,000,000	2,000,000	3,000,000	4,000,000
Building Type	Location	Equivalent Full Load Hours (EFLH)	Boiler Gas Savings (@10% reduction) in Therms				
Elementary School	Rockford	1781	1,069	1,781	3,562	5,343	7,124
	Chicago	1736	1,042	1,736	3,472	5,208	6,944
High School	Rockford	1845	1,107	1,845	3,690	5,535	7,380
	Chicago	1857	1,114	1,857	3,714	5,571	7,428

Table 4: Preliminary EFLH Savings Calculation at 15% Energy Savings for various Building Heating Load

Building Area (SQFT)			15,000	25,000	50,000	75,000	100,000
Building Heating Load (BTUH)			600,000	1,000,000	2,000,000	3,000,000	4,000,000
Building Type	Location	Equivalent Full Load Hours (EFLH)	Boiler Gas Savings (@15% reduction) in Therms				
Elementary School	Rockford	1781	1,603	2,672	5,343	8,015	10,686
	Chicago	1736	1,562	2,604	5,208	7,812	10,416
High School	Rockford	1845	1,661	2,768	5,535	8,303	11,070
	Chicago	1857	1,671	2,786	5,571	8,357	11,142

Technology

An ADUV retrofit is a passive device that claims to improve air distribution and mixing in a room. The ADUV mounts over existing unit ventilators and utilizes an angled grille to direct airflow from the unit ventilator into the center of a room. Savings from this technology are achieved via reduced equipment runtimes to meet the set-point temperature demand.

Market Overview

Unit ventilators are a popular means of space conditioning in public school, especially those constructed in the mid-1900s. The estimated market size of unit ventilators in Illinois public schools is roughly 68,000 units, calculated from the total 2016 Illinois K-12 student population of 2,041,779 and 30 students per classroom. A typical classroom by Illinois design standards calls for at least one unit ventilator per classroom.

This product is a passive system that consumes no energy to operate. A manufacturer of this technology applied to the Nicor Gas ETP in Q2 of 2017 and was selected for a pilot evaluation in Q4 2017.

Objectives

The following objectives were established as the goals of this project:

- Validating energy (and, by proxy) gas savings

- Validating cost effectiveness
- Determining a deemed savings value
- Demonstrating the product in the field for the local market
- Verifying sensible improvements to occupant comfort

Methodology

Site Requirements

GTI selected a site that met the following required criteria:

- 1st and 2nd floor room locations
- Classrooms with windows/exterior walls in all four cardinal directions (N, S, E, W)
- Central boiler system with no modulating capability – This ensured a constant heat output from the boiler when the system was on.
- 1 thermostat controller per classroom
- 1 unit ventilator per room, as prescribed by the typical classroom design
- Allowed periodic access to visually verify data acquisition devices are intact

Experimental Design and Procedure

GTI collected data using multiple stand-alone data loggers varying in size and application for numerous practical reasons. Given the expected occupant behaviors in schools, the data loggers were small, discreet, and non-intrusive enough to not disrupt the learning environment as well as evade curious tampering. The large relative size of each classroom and the distances to be covered between monitored points would have made a remote data logging system which requires communication wiring and cellular modem signals prohibitively intrusive and impractical. The sheer number of relevant locations for temperature measurements was served well by the relative low cost of the data loggers used in this study. Some trade-offs for convenience to the site were the labor-intensive installation, the highly hands-on data processing requirement, and the higher probability that any single sensor could fail to record.

Key metrics for assessing energy usage at the unit ventilator terminals included: outdoor air temperature, return air temperature measured at the sensor nearest the ground-level grate, temperature of air supplied to the room measured at the vent grille, supply and return temperatures of the heating steam delivered across unit ventilators, and fan motor runtimes in the form on on-off pulse signals. Key metrics used to assess thermal comfort and air stratification included: temperature at multiple points around a room. Table 5 summarizes the data acquisition devices, data frequency, and inherent measurement errors.

Table 5: Data Collection Equipment, Collection Frequency, and Error Ranges

Sensor	Description	Equipment	Data Frequency	Equipment Error Ranges
T	Temperature	Indoor Temperature 3.5% Data Logger	5 minutes	±0.38°F (over 32°F to 122°F)
T	Delivered Air Temperature, from the Unit Ventilator	Surface Thermocouples – 5 pack	1 minute	±1.08°F (over -436°F to 752°F)
CS	Fan On/Off Current Switch	Current Switch	Upon trip	Trip point set value 0.15A
CS	Fan On/Off Data Logger	State Data Logger	Upon trip	Maximum Frequency 1Hz
TRH	Outdoor Temperature & RH into Ventilator	Outdoor Air Temperature Logger	30 minutes	±0.38°F (over 32°F to 122°F) ±2.5% RH (from 10% to 90%)

Some field modifications to the original data acquisition plan were necessary during installation. The highly-accurate T-Type surface thermocouples used to measure the delivered fluid temperatures could only attach to the exterior of the steam pipes. This gave rise to physically impossible measurements for the steam return line. Due to lack of alternative, noninvasive methods to record steam temperature, steam-side delivery temperatures across the unit ventilators were removed from the experimental design. Bare T-Type thermocouples were installed at the unit ventilator grille to record supply air temperature to the room, due to lack of space to fit a data logger. The gas savings were assessed by observing heating load reductions within classrooms.

Figure 1 shows a typical classroom installation. T sensors captured data at various heights and locations, fan motor sensors and thermocouples captured data at the unit ventilator, and a T sensor (marked by “T”) captured temperature data at the control thermostat. The red arrows show a path to sensors that are most likely to capture temperature extremes, later visualized in this report.

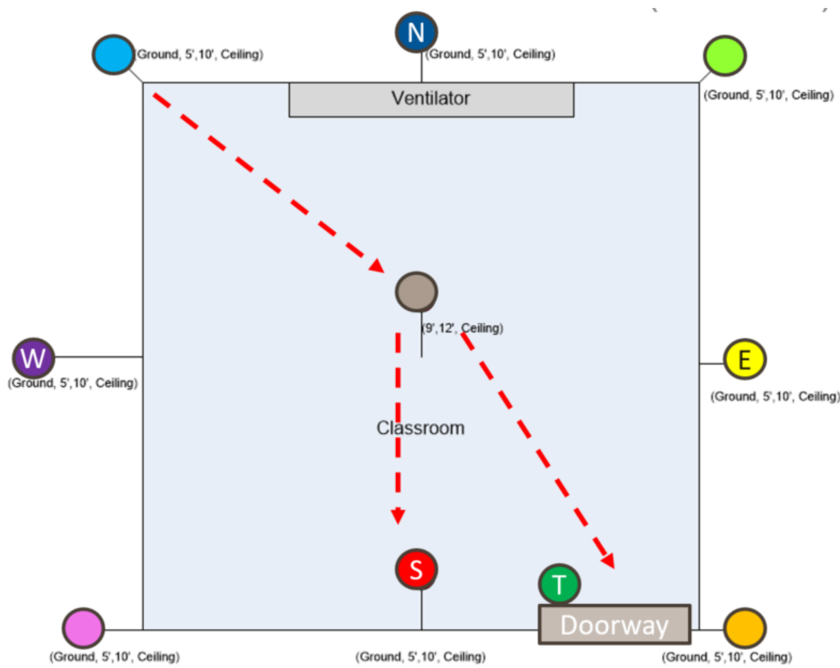

Figure 1: Representative Classroom Sensor Installation, North-facing Windows and Exterior Wall shown

Analytical Methods

The selected pilot site was monitored in baseline mode (without ADUV installations) for a 6-8 week period. Approximately 4 weeks of cleaned baseline data from November 27th, 2017 to December 22nd, 2017 was collected in the 2017-2018 heating season. Following the baseline period, ADUV retrofits were reinstalled over the winter break. The same classrooms were then monitored in retrofit mode in the same heating season for a 12-14 week period, producing 10-11 weeks of cleaned retrofit data. The standardized retrofit data period ran from January 8th, 2018 to March 23rd, 2018.

Portions of time with missing or invalid critical data (fan motor or air supply temperature) due to sensor failure or sensor tampering were excluded from the cleaned data sets. All communications by facility staff regarding maintenance and repair events affecting unit ventilators were documented and excluded. Times when outdoor air was allowed into the classroom by the ventilator for cooling purposes (i.e. air was allowed to bypass the unit ventilator's heating element) were excluded from the total space conditioning load, because this temperature adjustment was a passive conditioning technique that did not use energy from the central boiler system. The heating system only ran during prescribed occupied hours, which were generally 6AM to 6PM on most school days.

Results

Installation and Commissioning

GTI staff installed all data collection equipment and sensors in all 12 participating classrooms over the course of 2 weeks. Examples of the installed loggers can be seen in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6. Baseline data collection was performed by GTI staff in-situ (i.e. without removing the data acquisition equipment from their installed locations) during the winter break in the middle of the 2017-2018 heating season. Installation of the ADUV system was performed by the pilot site's facilities staff following baseline data collection. Final retrofit data collection and uninstall of all data collection equipment was performed by GTI staff at the end of the heating season, during spring school break.

Figure 2: Outdoor Temperature & RH Sensor outside window and near UV Air Intake grates

Figure 3: Fan Motor State Logger magnetized inside UV

Figure 4: Thermocouple Logger magnetized inside UV

Figure 5: Air Supply Temperature Thermocouple Wire secured and hidden within UV grille

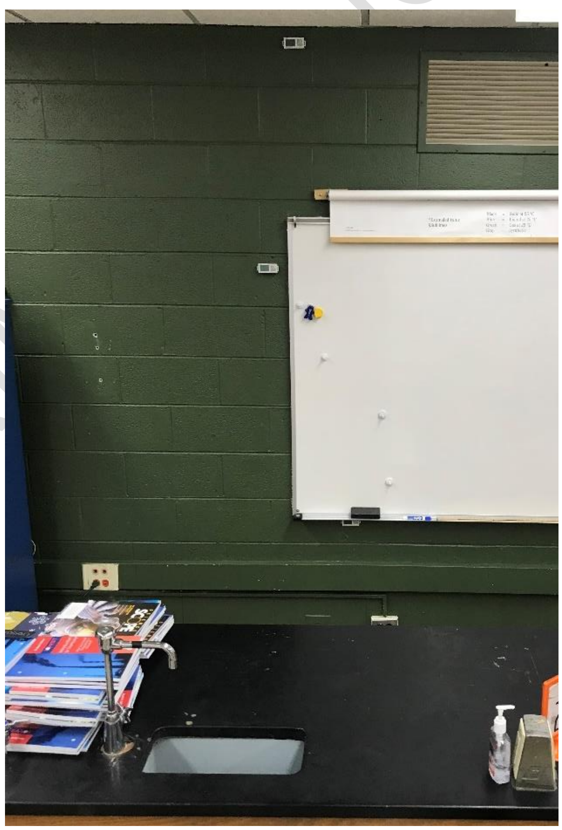

Figure 6: Indoor Temperature stratified along a wall

Energy Savings and Economic Performance

Overall savings calculated from unit ventilators' supply air (e.g. air delivered to the room) prior to and after ADUV retrofit are summarized in Table 6 and Table 7. Due to the different lengths of the baseline and retrofit period, heating degree days (a standardized measure of "how much heating" during a specific period of time requires to maintain an indoor temperature of 65°F) was used to normalize the rate of energy delivered to each room.

The north-, east-, and west-facing classrooms consumed energy at an average rate of 9,414 Btu/HDD compared to a retrofit rate of 7,867 Btu/HDD. The average baseline energy usage in south-facing classrooms was 1,819 Btu/HDD, which showed no savings in retrofit mode. Calculated Btu/HDD savings can be seen in Table 7. South-facing windows are known to have a higher solar gain, which naturally drives air convection in a room.

Table 6: Average Retrofit Savings, Based on Six (6) Monitored School Classrooms

				Baseline Energy			Retrofit Energy			
Room #	Room Type	Window Orientation	UV CFM Capacity	BTU Delivered	HDD	BTU/HDD	BTU Delivered	HDD	BTU/HDD	Savings (%)
108	Classroom	North	1000	2,235,236	459	4,870	6,998,070	1624	4,309	11.5%
126	Classroom	East	1250	8,610,255	574	15,000	22,961,627	1665	13,791	8.1%
206	Classroom	North	1000	4,048,543	540	7,497	9,867,119	1619	6,095	18.7%
210	Classroom	North	1000	5,556,431	540	10,290	11,773,638	1619	7,272	29.3%
				Average Baseline		9,414	**Average Retrofit**		7,867	
							Average Savings (%)			**16.9%**
							Average Savings (BTU/HDD)			1,548

				Baseline Energy			Retrofit Energy			
Room #	Room Type	Window Orientation	UV CFM Capacity	BTU Delivered	HDD	BTU/HDD	BTU Delivered	HDD	BTU/HDD	Savings (%)
103	Classroom	South	1000	351,785	434	811	1,254,319	1487	844	-4.1%
107	Classroom	South	1000	692,579	245	2,827	2,037,366	623	3,270	-15.7%
				Average Baseline		1,819	**Average Retrofit**		2,057	
							Average Savings (%)			**-9.9%**
							Average Savings (BTU/HDD)			**-238**

Table 7: Calculation of Btu/HDD Savings, Based on Six (6) Monitored School Classrooms

North-, East-, and (assumed symmetrical) West-Facing Classrooms	Baseline Energy Consumption Rate	9,414 Btu/HDD
	Retrofit Energy Consumption Rate	7,867 Btu/HDD
	Savings in Energy Consumption (Baseline – Retrofit)	1,547 Btu/HDD

South-Facing Classrooms	Baseline Energy Consumption Rate	1,819 Btu/HDD
	Less Retrofit Energy Consumption Rate	2,057 Btu/HDD
	Savings in Energy Consumption (Baseline – Retrofit)	-238 Btu/HDD

To project these classrooms savings to a whole-building retrofit, it would be effective to install ADUVs on only north-, east-, and west-facing UVs and leave south-facing UVs as-is. Assuming a school faces cardinal directions, the energy usage from 1 north-, 1 east-, 1 west-, and 1 south-facing classroom would represent a whole-building energy usage rate for every 4 classrooms. This savings rate can be proportionally scaled to the total number of classrooms in a whole school building. The representative school has approximately 45 classrooms with unit ventilators. Examples of these calculations for both the baseline and retrofit energy usage rates are seen in Table 8 and Table 9.

Table 8: Calculation of Whole-Building Baseline Energy Use for a 45-Classroom School

Baseline Energy Consumption Rate, 4 Classrooms	North-Facing Classroom	9,414 Btu/HDD
	East-Facing Classroom	+ 9,414 Btu/HDD
	West-Facing Classroom	+ 9,414 Btu/HDD
	South-Facing Classroom	+ 1,819 Btu/HDD
		= 30,061 Btu/HDD
Scaled Baseline Energy Consumption Rate, per school of 45 classrooms	Baseline Energy Consumption, 4 Classrooms	30,061 Btu/HDD
	Scaled 45-to-4 Classrooms	$* \frac{45}{4}$
		= 338,186 Btu/HDD

Table 9: Calculation of Whole-Building Retrofit Energy Use for a 45-Classroom School

Retrofit Energy Consumption Rate, 4 Classrooms	North-Facing Classroom	7,867 Btu/HDD
	East-Facing Classroom	+ 7,867 Btu/HDD
	West-Facing Classroom	+ 7,867 Btu/HDD
	South-Facing Classroom	+ 1,819 Btu/HDD
		= 30,061 Btu/HDD
Scaled Retrofit Energy Consumption Rate, per school of 45 classrooms	Retrofit Energy Consumption, 4 Classrooms	25,420 Btu/HDD
	Scaled 45-to-4 Classrooms	$*\frac{45}{4}$
		= 285,975 Btu/HDD

The total energy usage per year is calculated via representative heating degree days for a given year. The Chicago area had 5,287 heating degree days in the 2016-2017 heating season.[2] Table 10 shows the total energy usage in baseline and retrofit modes calculated for a representative year.

Table 10: Total Whole-Building Energy Consumption Based on 2016-2017 HDD Data

Baseline Energy Consumption, 2016-2017	Baseline Energy Consumption Rate	338,186 Btu/HDD
	1 Year of HDDs	* 5,287 HDD
		= 1,787,989,382 Btu/Year, Or 1,788 MMBtu/Year
Retrofit Energy Consumption, 2016-2017	Retrofit Energy Consumption Rate	285,975Btu/HDD
	1 Year of HDDs	* 5,287 HDD
		= 1,511,949,825 Btu/Year, Or 1,512 MMBtu/Year

[2] http://w2.weather.gov/climate/xmacis.php?wfo=lot

The projected savings between a baseline and retrofit whole-building is 276 MMBtu per year (1,788 MMBtu – 1,512 MMBtu), or 2,760 therms saved per year. At a rate of $0.50 per therm, this representative whole-building retrofit saves $1,380 per year (2,760 therms/year * $0.50/therm).

Table 11: Cost of Whole-Building Retrofit for a 45-Classroom School

Classrooms per School	45
Proportion of Classrooms with ADUVs Installed	$* \frac{3\ ADUVs\ Installed}{4\ Classrooms}$
	= 33.75 Installed ADUVs
Installed ADUVs per School	33.75 ADUVs
Annual Therm Savings per School	2,760 therms/year
Natural Gas Utility Rate	$0.50 per therm
Total Natural Gas Savings	$1,380
Simple Payback	~ 8.3 years

Throughout the course of testing, it was discovered that an external control retrofits dictated all unit ventilators' fan operation according to a strict time-based setback schedule. Since the UVs were on a controlled schedule no significant reductions to equipment runtimes were seen in the course of this study. Had the unit ventilator fans not been set to "on" the entire day, savings from reduced electricity use would likely have further reduced the technology's simple payback. Fan runtime reductions and electrical savings could not be evaluated at this time. The savings summarized in this report represent space heating fuel (natural gas) savings alone.

Of the original 12 monitored classrooms, six (6) were later discovered to be unfit to represent a typical classroom due to uncontrollable factors confounding the data. Three of the six monitored classrooms encountered challenges in baseline mode and prevented a baseline from being generated. The remaining three classrooms produced inadequate data. After many educated engineering assessments, discussions, and considerations into whether quality results could be obtained following each of these setbacks (Figure 7-

Figure 14), GTI determined the best course of action for the treatment of these data was to exclude them from the cumulative savings results.

Figure 7: Classroom 137, Hidden Uncontrolled Radiator behind Bookshelf

Figure 8: Classroom 205, Unit Ventilator had a Previously Undiscovered Air Leak between Left-hand Side of Cabinet Assembly and Structural Column

Figure 9: Classroom 104, Movable Computer Carts and Technology Storage Area

Figure 10: Classroom 147, Steam Leak Maintenance Ticket within North Unit Ventilator

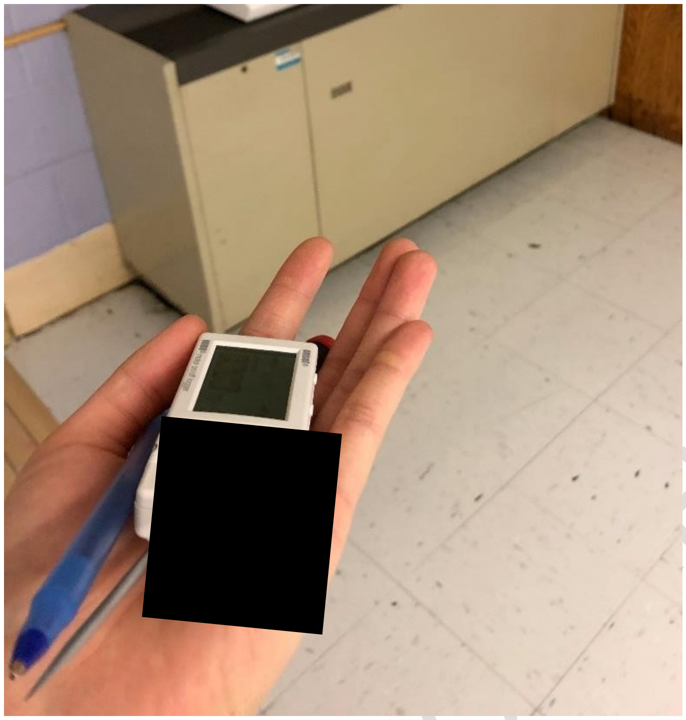

Figure 11: Classroom 147, South Unit Ventilator with a Maintenance Ticket for Grinding Fan Motors/Potential Motor Failure

Figure 12: Classroom 203, Air Supply Thermocouple as Installed Prior to Baseline Period

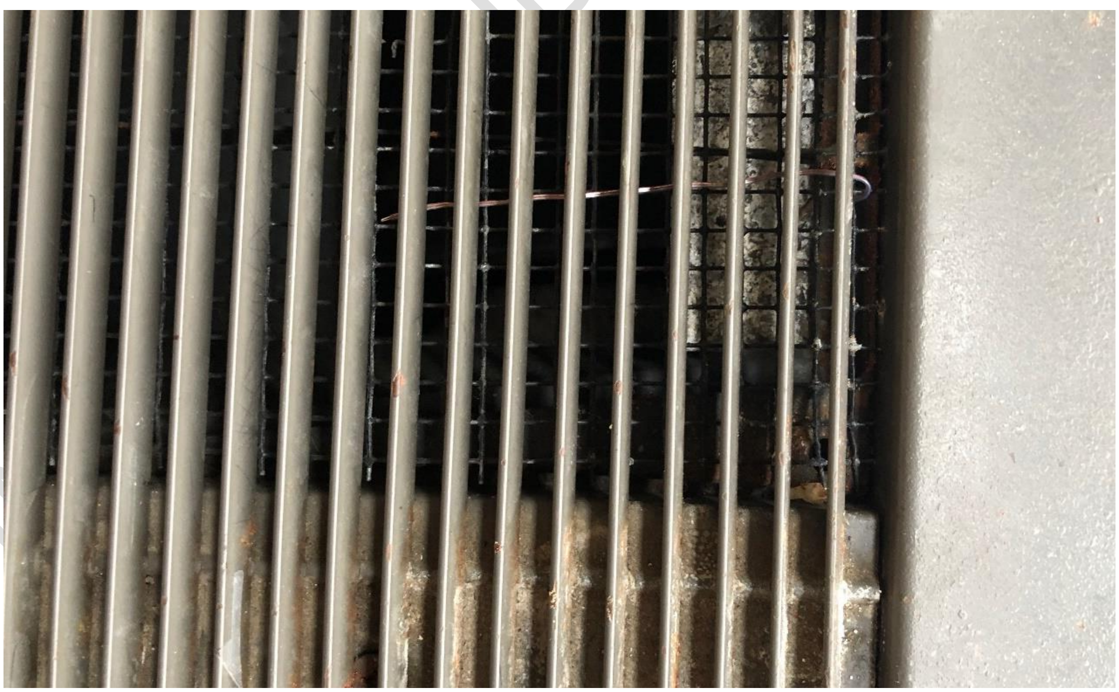

Figure 13: Classroom 203, Air Supply Thermocouple Tip Visible at Installed Position during Baseline Collection Period

Figure 14: Classroom 203, Visible Break in Thermocouple Line below the Unit Ventilator Cabinet Entry-Point

The whole-site payback was driven by the magnitude of savings in certain orientations outweighing the lack of savings in south-facing rooms.

The technology also showed slight reductions in temperature stratification in the effective orientations. Representative thermal profiles below for 1st floor classroom 126 (Figure 15) and 2nd floor classroom 206 (Figure 16) over a 1-week period show temperature fluctuation differences between the monitored baseline and retrofit periods. One key visual observation at the start of nighttime setbacks (e.g. as the temperatures naturally decline at the end of the day) is that baseline period temperatures around the room are spread farther apart compared to the same times of day in the retrofit period. In 20°F outdoor weather conditions, for example, quantifiable reductions in the variance of temperatures by the room thermostat and narrower temperature bands across the room were seen. The maximum width of the temperature stratification band within a given day decreased from 7.16°F to 5.38°F and from 7.35°F to 5.58°F, respectively, for the two classrooms. Sampling the temperatures around the room gauges how closely the different areas of the room tracked with the average room temperature (e.g. how well-mixed was the air in a given classroom). Classroom 126 saw temperature deviations from average decrease to 1.4-2.2°F, from the baseline 1.6-2.4°F deviations. Classroom 206 saw temperature deviations of 1.0-2.1°F, compared to the baseline 1.5-2.5°F deviation. Given that the temperature sensors used in this study each had an accuracy of ±0.38°F for indoor temperatures in the range of 32-122°F, these temperature results indicate the technology's effect on air mixing was more consistent and more substantial than simple instrumentation error. Occupant comfort feedback on how sensible these temperature differences were will be incorporated into a final version of this report as participant surveys are returned to GTI.

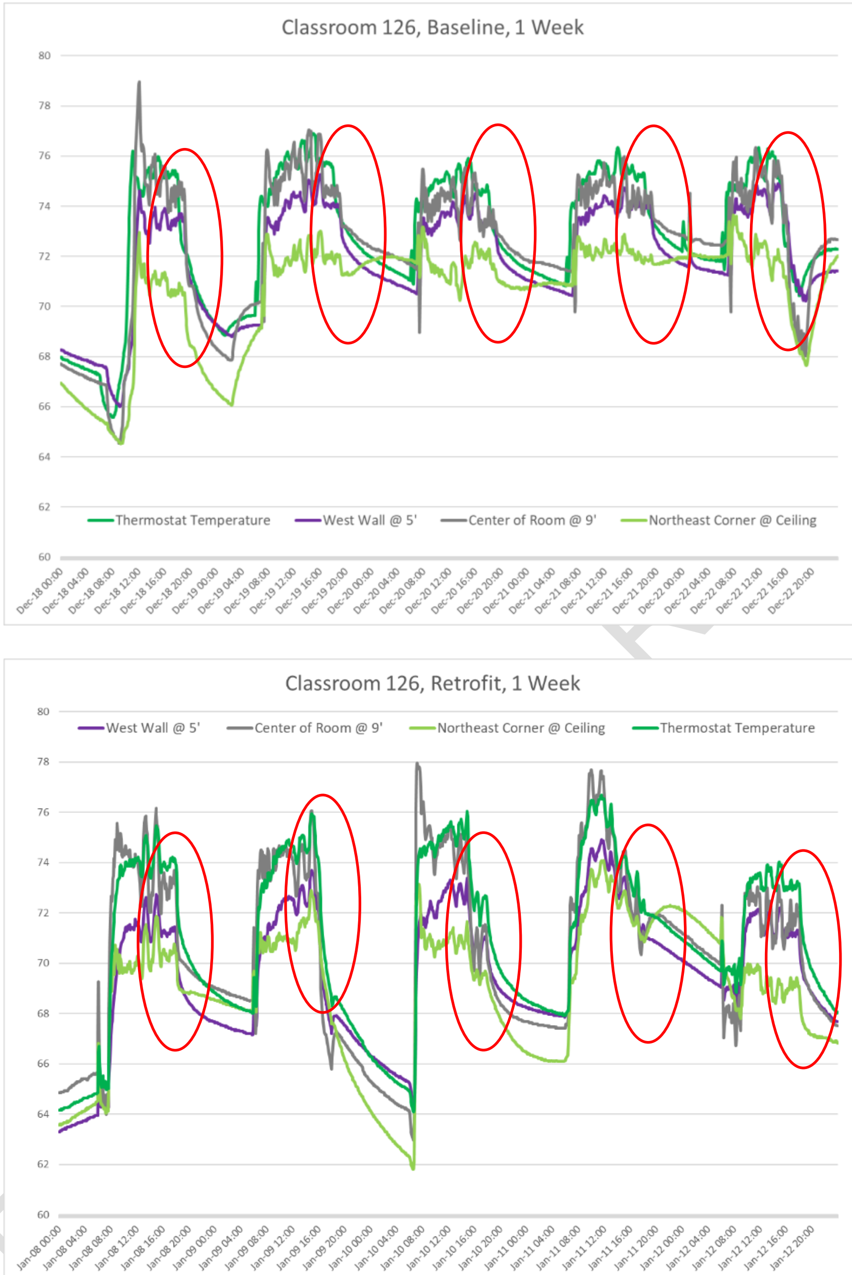

Figure 15: Classroom 126 (East-Facing, 1st Floor) Temperature Stratifications

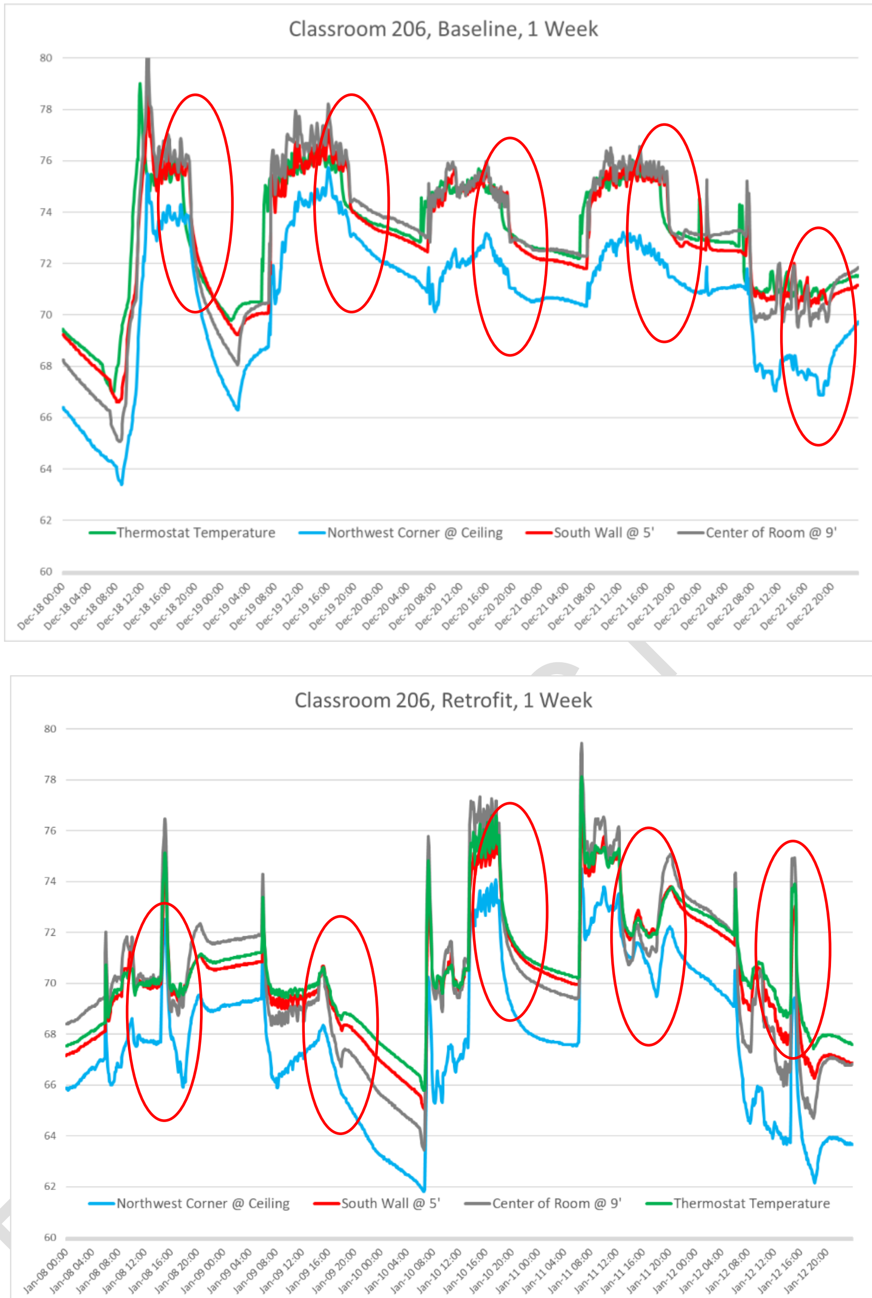

Figure 16: Classroom 206 (North-Facing, 2nd Floor) Temperature Stratifications

Similar visual inspection of Figure 17 for south-facing classrooms shows that not only do room temperatures generally trend higher (e.g. visuals scaled between 60-90°F, as opposed to 60-80°F in earlier examples), but also there are no drastic changes in the size of the representative temperature bands. This supports the conclusion that south-facing windows are unlikely to see sizable positive impacts from the ADUV due to pre-existing natural convection.

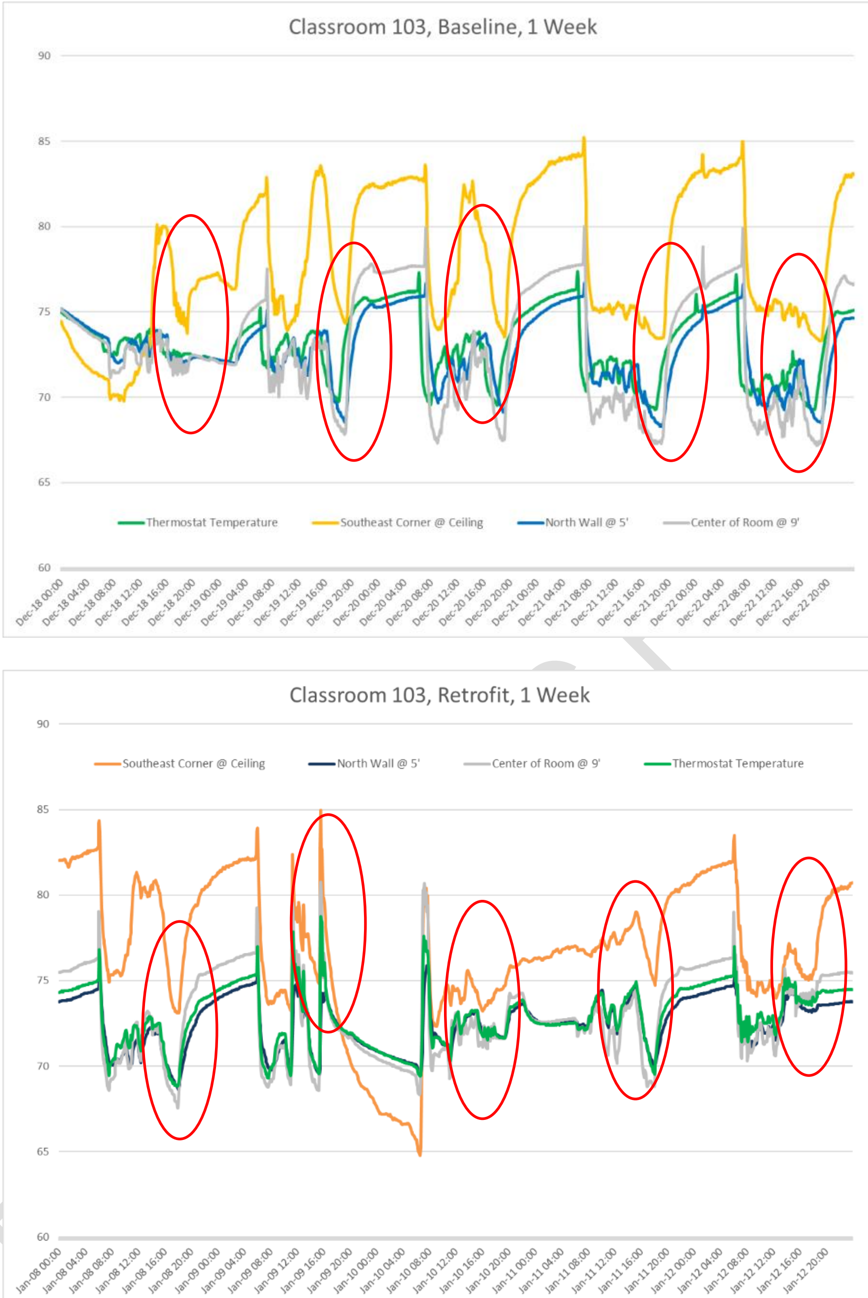

Figure 17: Classroom 103 (South-Facing, 1st Floor) Temperature Stratifications

Discussion and Conclusions

Lessons Learned

The issues encountered in installing data collection sensors as designed and excluding data due to uncontrollable factors could be better addressed going forward. In general, more robust site evaluation against the design conditions and improved communication of data needs would be beneficial in future pilot studies of this scale.

Key challenges with possible solutions include:

1) Periodic Data Collection & On-Going Analysis to Ensure Proper DAQ System Operation
2) Review Data Sensors and DAQ System Integrity Periodically
3) Thorough Site Review
4) Consider Employing a Wireless, Non-Intrusive Data Acquisition System

Recommendations for Further Study

This pilot confirmed the estimated savings and produced orientation-specific results that Nicor Gas can use to structure incentives for unit ventilator-targeted air destratification products. However, due to existing equipment conditions at the pilot site and the challenges faced in plan execution, the data sample in this study was limited. Future studies' data can further verify the energy savings of this air destratification product for unit ventilators. Design considerations for the future include incorporation of backup data loggers into the monitoring plan, more frequent QA checks for data integrity, and streamlining or reducing the data collection burden with smarter data acquisition systems.

References

Shah, H.; and Schuetter, S. (2017) *Emerging Technologies For public and income eligible sectors*. Des Plaines, IL and Madison, WI: Gas Technology Institute and Seventhwave.

(2017) Illinois Statewide Technical Reference Manual – Volume 2: Commercial and Industrial Measures, Version 6.0. Section 4.4, *HVAC End Use*. Burlington, VT: VEIC.

Appendix A: Detailed Analyses of Energy Savings and Economic Performance

The data processing for this study was performed mainly in Python using jupyter notebook. The final data visualization was performed using Microsoft Excel. Baseline and retrofit data-frames that characterized each room contained time-aligned series data for air temperature, fan motor operation, humidity measurements, and partial heating degree days calculated from locally measured outdoor air temperature.

Since the heating system did not operate during night setback periods, the negligible temperature gains or losses outside of the defined operating days (generally due to extracurricular activity or installation activity by GTI and site staff) were not included in the energy demand, or heating load, calculation. Heating load, or heat delivered by the ventilator to the room, was calculated from air-side temperature data, using Equation 1:

Equation 1[3]

$$Energy\ Delivered\ \left[\frac{BTU}{hr}\right] = airflow\ [cfm] ** 1.08 * (Temperature\ Exiting\ the\ Ventilator\ [°F] - Temperature\ Entering\ the\ Ventilator[°F])$$

The temperatures of air entering the unit ventilator were treated as a mix of 15% outdoor air and 85% air from the ground-level sensor closest to the unit ventilator, where the intake air grate is located. The site was unable to provide actual intake air fractions through its records and visual inspection of grates proved inconclusive across many classrooms. A check on the 15% outdoor air fraction assumption was performed in Python, where air fractions were iteratively guessed between 0.08 and 0.35 full outdoor air to verify the plausibility of cumulative Btus of heat delivered per HDD. Each unit ventilator's volumetric output was provided by the original installation records, detailed below:

- (2 units inside) Classroom 147: 750 cfm
- Classrooms 103, 104, 107, 108, 203, 205, 206, 210: 1000 cfm
- Classrooms 123, 126: 1250 cfm
- Classroom 137: 1500 cfm

Heating degree days, a measure of how cold a specific period of time was, were calculated via Equation 2 on a second-by-second basis to retain the effects of changes in fan motor state and summed over the course of the operating day:

Equation 2[4]

$$HDD\ [DD, basis\ 1\ day] = (65°F - Outdoor\ Temperature\ Measurement\ [°F])$$

$$To\ accurately\ account\ for\ temperature\ changes\ throughout\ a\ day, divide\ HDD\ by\ 86{,}400\ seconds\ and\ sum\ all\ the\ partial\ degree\ days\ over\ 1\ day.$$

The cumulative metric used to evaluate classroom energy usage was the average energy delivered normalized to one unit of "coldness," given by Equation 3:

[3] Equipment Size Based on Ventilator Airflow, from ASHRAE Standard 62. *Unit Ventilators: A Primer*. http://www.utcccs-cdn.com/hvac/docs/1001/Public/03/811-10177.pdf
[4] Heating Degree Days Calculated in the United States. https://en.wikipedia.org/wiki/Degree_day#United_States

Equation 3[5]

$$A\ Room's\ Energy\ Draw\ \left[\frac{Btu}{Hr * HDD}\right] = \frac{\sum Energy\ Delivered\ \left[\frac{Btu}{hr}\right] over\ a\ period}{\sum HDD\ over\ the\ same\ period\ of\ time}$$

Appendix B: End User Survey and Results

The End User Survey to the participating classroom teachers will be reviewed in Q3 and Q4 of 2018. A revised report containing the updated Conclusions and Appendix C will be available in Fall 2018.

[5] See: The Use of Degree-Days for Weather Normalization"
Eto, J.H.*On Using Degree-days to Account for the Effects of Weather on Annual Energy Use in Office Buildings*. Lawrence Berkeley National Labs: 1988. https://simulationresearch.lbl.gov/sites/all/files/energy-bldgs-degree-days.pdf