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# High Efficiency Rooftop HVAC Unit Replacements

A Guide for School Boards and their Design Teams for Obtaining the Best Energy Efficiency and Operating Performance

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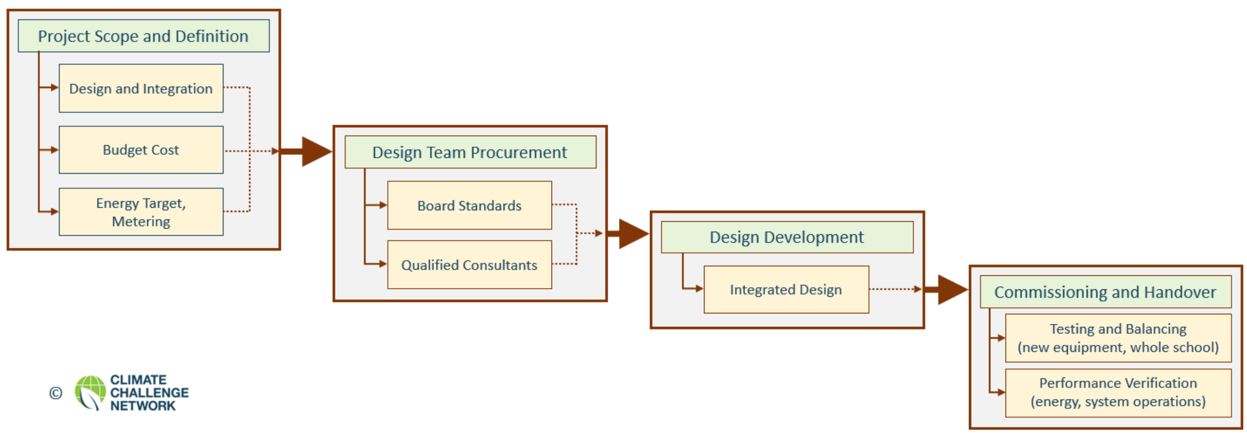
# Contents

*Every year in Ontario, hundreds of rooftop HVAC units are installed to replace older units that have reached end-of-life.  Research into recent installations has shown that there is room for improvement in the RTU replacement process in order to achieve better energy efficiency results. This Guide is aimed at school boards and their design teams with a recommended process, from initial planning through to handover and performance verification, for getting the best energy and operating performance out of these capital investments.*

Questions, comments and suggestions are always welcome: info@sustainableschools.ca

## A Step-by-Step Process for Undertaking High Efficiency Rooftop HVAC Unit Replacement Projects

The diagram below presents the recommended systematic process for project development, implementation and verification which can consistently deliver high energy and operating performance with rooftop unit replacement projects. Key considerations for each of the 4 stages are identified and described in the remainder of this Guide, together with the real-life experience and recommendations arising from the pilot project. Technical Reference Sheets at the end of the Guide provide more detail on use of building automation systems and HVAC testing results to optimize performance.



# Background

## Sustainable Schools

The Sustainable Schools program reports annually on target savings and actual savings for every school board and school in Ontario and for participating boards from other jurisdictions. The publicly available, peer reviewed white paper provides the target and adjustment methodology which can be used by any school board to develop their own Portfolio Utility Data management system. Sustainable Schools conducts applied research to fill knowledge gaps uncovered through energy benchmarking and savings data from thousands of buildings over multiple years, producing evidence-based best practice guides for use by school boards to achieve lasting energy and emissions reductions across their portfolios.

### About This Guide

The Guide is an evidence-based guidance document for use by school boards and their design consultants to help improve the design, equipment selection, BAS programming, and commissioning of future RTU replacement projects. It is the product of a pilot research project conducted by Sustainable Schools in 2022.

## Rooftop HVAC Unit Replacements Cohort Research Project

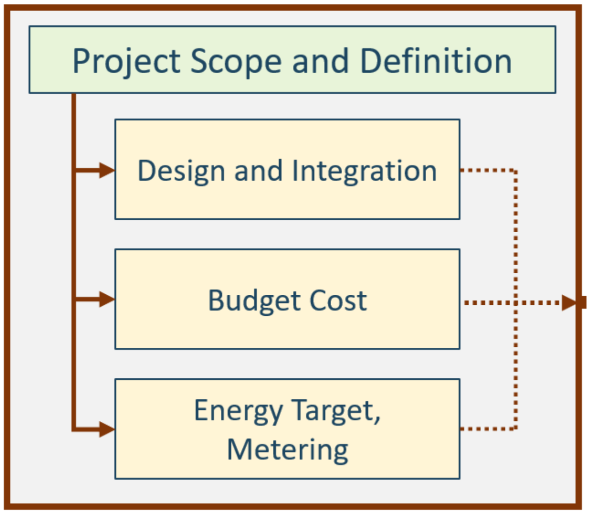
Rooftop units (RTUs) are the most prevalent form of HVAC equipment in Ontario's K-12 schools. Current general practice is to replace end-of-life equipment with the same or an equivalent type which, while more efficient than older technology, does not take advantage of more efficient alternatives. Continuing addition of air conditioning in schools is expected to primarily consist of RTUs and must be done as efficiently as possible to avoid excessive utility costs and strain on the electrical system. Equipment selection, design details, commissioning practices and BAS programming all have a substantial effect on the efficiency of RTU installations. There has been little empirical evidence to help inform school boards' and their design consultants' decision-making on best practices for upcoming projects or to make the business case for higher standards.

The Guide is the product of a pilot research project conducted by Sustainable Schools in 2022, with a total of 10 Ontario schools from Limestone District School Board, Ottawa Catholic School Board, Simcoe County District School Board, Simcoe Muskoka Catholic District School Board, and York Catholic School Board. We acknowledge the importance of the time, effort and openness of these leading boards in the project's success.

The project team evaluated the design, operational performance, and energy efficiency of these recently retrofitted schools. Two schools from each board were selected for in-depth examination. Energy and operating data from the selected schools, before and after their recent project installations, determined absolute and comparative performance of the 10 schools. System design, equipment selection, commissioning practices, and controls were documented for each school and correlated with performance outcomes to help identify best practices. A strategic workshop with the participating boards and project partners was conducted at the end of the project, exploring the boards' processes, internal capabilities and organizational alignment for project development and delivery, and identifying gaps with respect to energy efficiency and operating performance of their installations.

Results of the research were presented, along with a panel discussion among participating boards, at a public webinar held on December 8th, 2022. The webinar recording is available on the Sustainable Schools website. We recognize the technical and financial support provided by Ontario's Independent Electricity System Operator, Carmichael Engineering and Kilmer Environmental. Technical direction of the project was by Enerlife Consulting.

## 1. Project Scope and Definition




High performance outcomes begin at the project planning stage. Time and budget are the primary challenges to be addressed in developing the project definition to deliver the best life-cycle performance, and in setting the stage for achieving and verifying optimal energy efficiency.

### Design and Integration

Replacement of major HVAC equipment affects the energy and operating performance of the whole school, not just the areas served by the new equipment. These projects present opportunities for longer term economies of scale and avoiding future disruption by taking a more holistic approach which may include:

- Upgrades to the downstream air distribution systems, such as rebalancing to current requirements and replacement and conversion of terminal devices to variable airflow.
- Upgrades to the building automation system (BAS) such as additional sensors, trend log archiving and smart operating sequences.
- Looking beyond like-for-like equipment replacements to consider higher efficiency/low carbon options such as exhaust air heat recovery and air source heat pumps.

*Recommendations*

- ❖ Conduct whole-school HVAC system testing prior to design development to identify airflow imbalances, excessive static pressure losses and other deficiencies which can be addressed as part of the project. Correct deficiencies which can affect performance of the project. [See attached Technical Reference Sheet 1: HVAC System Testing]
- ❖ Install or calibrate BAS sensors and set up/archive trend logs needed to verify post-retrofit performance. [see attached Technical Reference Sheet 2: BAS Access, Setup and Action Indicators]
- ❖ Identify and prepare high-level implementation and operating costs for alternative project scopes and designs.
- ❖ Allow sufficient lead time to perform this preliminary work.

## Budget and Life Cycle Costs

These projects are large investments which will affect operating and maintenance budgets for decades to come. Decision-making becomes even more important in considering pandemic response and climate change mitigation/adaptation, including rising carbon prices, and it is worth the effort and cost to thoroughly evaluate alternative approaches to the project.

### *Recommendations*

- ❖ Conduct a feasibility study into life-cycle costs of alternative scenarios.

## Energy Target, Metering

Include the energy efficiency of the school is a primary consideration in defining the scope and developing the financial model for the project. Many inefficient schools have tens of thousands of dollars in annual energy savings potential which can be unlocked through the project with less cost and disruption than a standalone energy retrofit. The Sustainable Schools program reports annually on target savings potential for every school in Ontario and for participating boards from other jurisdictions so check there first. Utility cost savings, including the rising cost of carbon should be included in decision-making around the scope of the project.

This planning stage of the work includes establishing the energy baseline and target for the school which help to identify savings opportunities for inclusion in project design and enable better commissioning and performance verification after the project is completed.

### *Recommendations*

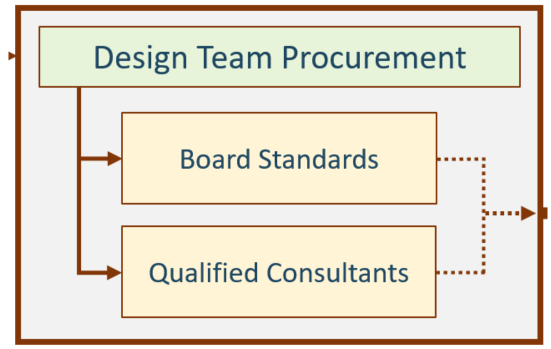
- ❖ Establish the energy use baseline and post-retrofit energy target early in the project development process.
- ❖ Request electric interval metering from your local distribution company, apply for gas interval metering from your gas distributor and obtain pricing for submetering of primary building systems to enable effective post-retrofit monitoring and evaluation.

***What the research project participants said:***

- *Would like to develop projects together with all relevant departments, but time is an issue.*
- *Projects are prioritized based on VFA (building condition) reporting and internal feedback, not energy performance.*
- *We rely on consultants for design, with input from in-house staff:*
    - *interest in including energy targets at development meetings.*
- *Typically, projects are developed over 1-2 years, but since COVID we now require planning further ahead (lead time for equipment delivery).*
- *Submetering and interval metering:*
    - *generally, not used to inform projects or post-retrofit; may be used if required for incentives.*
    - *where we have submetering, data may not be actively reviewed/analyzed (takes time).*
- *Interested in life-cycle costing but needs to be reliable and timely.*

## 2. Design Team Procurement

### Board Standards




Every capital project sets the stage for decades of operations, maintenance and utility costs which add up to far more than the initial cost of construction. Board standards provide consistency between schools that can facilitate O&M while significantly reducing life cycle costs. Standards should be compliant with procurement rules and support competitive bidding and, to the greatest practical extent, focus on required outcomes.

*Recommendations*

Develop, communicate and regularly update Board standards for:

- Equipment. There is a wide range of RTU equipment options to be evaluated in terms of capital cost, ease of operations and energy use/costs as follows:
  - Heating source: fossil fuel combustion (natural gas, oil or propane), air source heat pump, geothermal.
  - Heating type: gas-fired or hydronic.
  - Heat recovery: Energy Recovery Wheels (ERW) or other approach to reclaiming heat and humidity from exhaust airflow to precondition incoming outside air.
  - Outside air and pressurization control: full economizer or power exhaust.
  - Cooling type: DX or chilled water.
- Design. Specify outcomes to be achieved through system design and verified by post-retrofit testing and commissioning:
  - Integration of new equipment with existing building systems.
  - Heat recovery from washroom and other exhaust fans.
  - Design metrics including outside and total airflows (cfm/sf), fan power (Watts/cfm) and pump power (Watts/sf).
- Building Automation System
  - Required sensors, trend logs and archiving capacity.
  - Operating sequences.
  - Graphic user interface.
  - Preferred vendors.
- Metering
  - Required submetering and reporting.
- Commissioning
  - Scope and reporting requirements for project and whole school system testing and balancing.
  - Scope and reporting for individual system commissioning to verify design and operational requirements. Commissioning scope should extend through cooling and heating seasons and be signed off by the project engineer.

## Qualified Consultants

As technology and best practices continue to evolve, pre-qualifying consultants for these projects can help obtain the experience and knowledge needed for consistent high-performance outcomes. Structure formal RFQs and pre-qualification interviews to follow Board Standards and explore bidders' corporate and individual credentials related to each area as well as previous experience with the Board and the particular school.

### *Recommendations*

- ❖ Develop a list of pre-qualified consultants based on experience and knowledge related to the Board Standards.

***What the research project participants said:***

- *Not common to have a list of prequalified consultants (one board does):*
    - *lack prequalification process.*
    - *variation in consultant expertise.*
- *High interest in having board standards and design briefs (one board does).*
    - *difficult keeping consultants in line with the standards.*
- *Commissioning standards vary between boards and are generally limited in scope.*
- *Difficult to maintain communication between maintenance, project managers and consultants.*
- *Not comfortable trying technologies where we lack experience, or which may be difficult to service, especially with schools in distant locations.*

# 3. Design Development

## Integrated Design


Every project involves multiple design decisions which can significantly affect the performance of the final project. Time and budget are challenges at this stage as well, and Board Standards can help limit the number of decisions and deliver more consistent outcomes. Strong project management with clear milestones is essential. As well, Integrated Design principles can be applied with team meetings at strategic intervals with specific agendas ensuring that each element of Board Standards is being adhered to. Integrated Design can streamline the overall design development process and save time, expense and problems with commissioning, start up and ongoing operations by preventing mistakes and oversights.

*Recommendations*

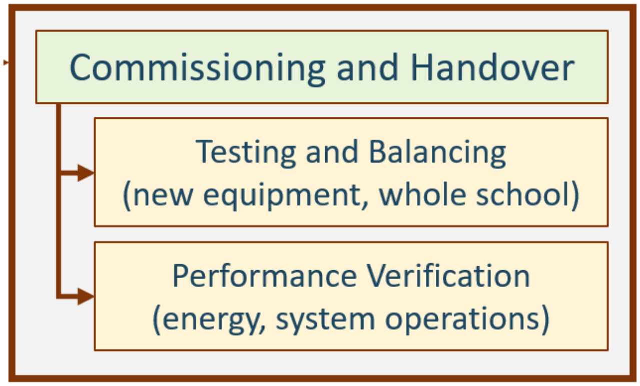
- Establish a formal Integrated Design process at project outset with senior representation from design and construction, finance, the design team and commissioning agent, operations, maintenance, building automation and energy.
- Define and adhere to:
    - project milestones and Integrated Design team meeting schedule.
    - a formal agenda based on Board Standards with records of proceedings.

***What the research project participants said:***

- *Budget takes priority, energy takes second seat:*
    - *detrimental to installation of more expensive options such as hydronic heating which may have better life-cycle benefits.*
- *Staff cannot dedicate needed time and attention due to multiple responsibilities:*
    - *it's challenging to include all stakeholders at every step in the process.*
- *Reliability is a big focus, especially for more remote schools.*
- *Having information about energy targets would be helpful so they can bring it up with consultants.*

## 4. Commissioning and Handover

### Testing and Balancing




Rigorous air and hydronic testing and balancing is necessary for timely identification of deficiencies so they can be corrected sooner rather than later. Testing should be extended to the whole school, not just the new equipment, in accordance with Section 1 Project Scope and Definition. A description of recommended testing procedures, analysis of results and identification of deficiencies to be corrected is provided in the Technical Reference Sheet 1: HVAC System Testing appended to this Guide.

### Performance Verification

Performance verification closes the loop on the baseline setting and metering established in Section 1 Project Scope and Definition and Section 2 Design Team Procurement, ensuring required energy performance is achieved and verifying required equipment scheduling and operation through the building automation system (BAS). A description of recommended BAS access, setup and use for improving energy performance is provided in the Technical Reference Sheet 2: BAS Access, Setup and Action Indicators appended to this Guide.

Electric and gas interval and submeter profiles and metrics should be compared against baselines and targets as soon as the new equipment is in operation, with the commissioning agent required to address variances from target. Monthly billing data should be monitored throughout the project and post-retrofit to inform the Integrated Design team meetings and verify that the energy use targets have been met.

The commissioning agent should measure the building system level metrics defined in the Board Standards (including fan power and airflows) and flag variances for immediate attention. The consultant and board staff should check through the BAS user interface and trend logs that actual system operation is following required programming through cooling, shoulder and heating season periods.

*Recommendations*

- Conduct and report on testing and balancing of new equipment and the whole school, identify variances and initiate corrective action.
    - Measure and report on system-level metrics including airflows, static pressures and fan power).
- Verify achievement of energy targets through interval and submetering and monitoring of monthly energy billing data. Review with Integrated Design team for remedial action.
- Monitor system operation through the BAS and specify corrective action.
- Require the project engineer and the board's project manager to sign off on all testing and performance reports, confirming required performance or approving variances, as the permanent performance record of the project.

***What the research project participants said:***

- *Current commissioning processes are limited, and this is the biggest area for improvement identified through the research project.*
    - *Participating Boards are planning post-retrofit improvements to their monitoring and inspection procedures.*
- *Important to get TAB reports of entire building after new installations to identify and resolve issues:*
    - *"Can't afford not to do it."*
- *One board noted many deficiencies were identified when they had all their rooftop units tested during the pandemic.*
- *One board reported finding deficiencies, which should have been addressed through commissioning, in a recently built project while investigating the unexpectedly poor energy performance identified through this project.*

## 5. Internal Capacity

Major infrastructure projects such as RTU replacements represent generational investments, with lifecycle costs measurable in millions of dollars. This project has demonstrated that post-retrofit energy performance can be optimized by improving design and commissioning process as well as operations. For the schools that took part, potential energy savings from this optimization are estimated at around $100,000/year across the 10 schools. There is a strong business case for many boards to invest in additional staff resources, standards and management processes to achieve better performance outcomes. The opportunity arises for colleges and sponsoring organizations, including the IESO and Enbridge Gas, to work together on production of qualified candidates and training for existing board staff.

### *Recommendations*

- ❖ School boards should assess the business case for additional resources working on energy efficiency, new construction, operations and maintenance along with modified management practices.
- ❖ Colleges and sponsoring organizations should consider training opportunities for ensuring an adequate supply of well-trained people.

***What the research project participants said:***

- *Internal capacity is a constraint:*
    - *things are missed or dropped due to limited time and resources.*
- *We have knowledgeable tradespeople, but limited capacity to tap into their knowledge.*
- *Constantly playing catch-up, even with knowledgeable people on the team.*
- *Challenges with staff turnover and recruitment within the board and with our consultants and contractors.*

# Technical Reference Sheet 1: HVAC System Testing

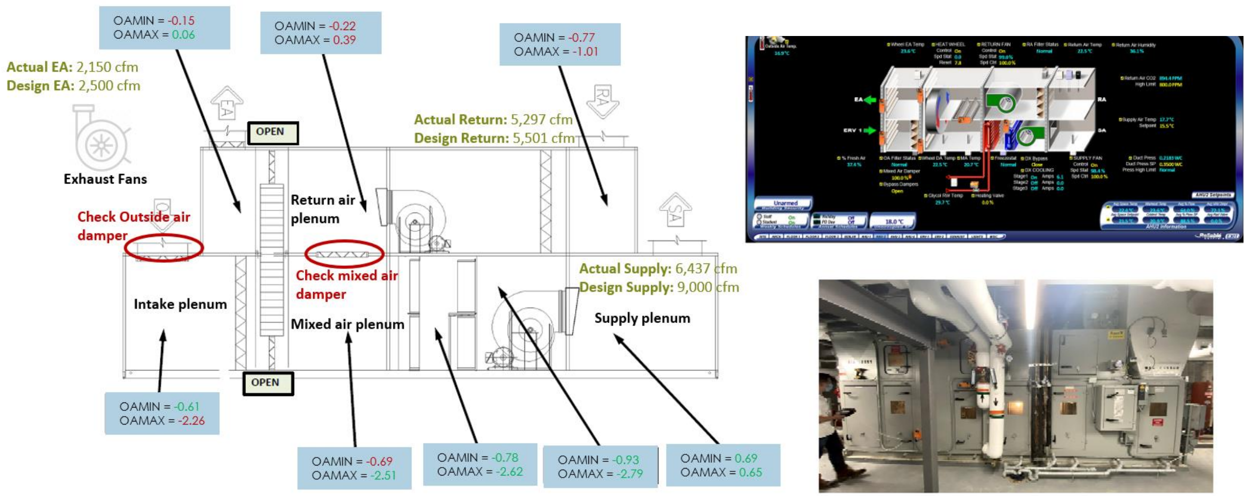



*Figure 1: Air Handling Unit testing results schematic*

Many of the causes of high energy use in schools are hidden inside the HVAC systems. Targeted testing uncovers the inefficiencies, generally leading to improved occupant comfort and air quality as well as energy savings. Figure 1 presents typical schematic test results, highlighting within-range conditions in green and abnormal conditions in red. Key observations from this example are:

1. [Intake plenum] Under OAMAX (100% outside air for free cooling) static pressure is -2.26" indicating a serious obstruction in the outside air intake.
2. [Return air and Mixed air plenums] Under OAMIN (full recirculation in cold or hot weather) the pressure loss across the mixed air damper is 0.47" (from -0.22" to -0.69") indicating that the damper is too small or not fully open.
3. Pressure losses across the filters and heat wheel, heating coil and cooling coil are within range.
4. [Supply plenum] Discharge pressure between 0.6" and 0.7" is within range.
5. [Return plenum] Static pressures (-0.77" and -1.01") are high. Check losses across return air dampers and silencers.
6. [Exhaust plenum] Under OAMIN, pressure is negative (-0.15"), so outside air is being drawn in through the exhaust discharge.
7. [Summary of airflows] Highlighted values should be corrected as described below each table:

| | Supply cfm | Return cfm | Exhaust cfm | Net cfm |
|---|---|---|---|---|
| Design | 9,000 | 5,500 | 2,500 | 1,000 |
| OAMAX | 6,437 | 5,297 | 2,150 | -1,010 |
| OAMIN | 6,908 | 5,399 | 2,150 | -641 |

*While supply airflows are below design, cfm/sf were found to be within acceptable range so return fan should be slowed to achieve positive pressurization.*

8. Summary of fan parameters from air testing report:

| | Supply | | Return | | Exhaust |
|---|---|---|---|---|---|
| | kW | Watts/cfm | kW | Watts/cfm | kW |
| Design | 11.19 | 0.75 | 3.73 | 0.68 | 0.97 |
| OAMAX | 7.22 | 1.12 | 2.77 | 0.52 | 0.97 |
| OAMIN | 3.15 | 0.46 | 1.63 | 0.31 | 0.97 |

*High supply fan power densities (good standard 0.5 Watts/cfm) reflect high static pressure losses to be investigated and corrected. The large difference in Supply Watts/cfm between OAMAX and OAMIN is unusual and should be investigated.*

### *Supply, return and exhaust airflow testing*

Excessive supply airflows, together with imbalances between supply, return and exhaust airflows, are leading causes of high electricity and gas use and opportunities for major savings at relatively low cost. The testing process and related analysis should:

- Measure the total supply and return air volumes and fan speeds (variable frequency drive %) for each air handling unit under normal (mid-season) operation. Measure the building area served to determine cfm/sf.
- Repeat measurements under 100% outside air and minimum outside air operating conditions.
- Record the motor power under these operating conditions to determine Watts/cfm and Watts/sf.
- Tabulate results in order to compare and contrast between systems and comparable schools which can identify good practice standards.
- Measure the main exhaust fans (> 500 cfm) and estimate the rest to determine the total exhaust airflow under normal operating conditions.
- Determine the overall school energy balance and pressurization as the difference between supply airflow and the sum of return and exhaust.
- Reprogram operating sequences for occupied and unoccupied operation accordingly.

### *Static pressures*

Excessive static pressure losses within the air handling units and adjacent ductwork waste fan power. The testing process and related analysis should:

- Measure static pressure losses across each element of the air handling unit and any silencers or balancing dampers in the mechanical room together with the discharge static and the return air intake static.
- Tabulate results in order to compare and contrast between systems and comparable schools which can identify good practice standards.
- Identify excessive static pressure losses due to dampers, air intakes and other airflow impediments.

### *Deficiencies*

Work with BAS, mechanical and air testing and balancing (TAB) contractors to resolve deficiencies uncovered through HVAC system testing and analysis, which may include:

- Cleaning air intakes, coils and fan casings and replacing filters.
- Blanking off any leakage around filters.
- Ensuring dampers fully open and close according to BAS signals.
- Modifying ductwork, air intakes and silencers to reduce excessive pressure losses.
- Repairing air leaks.
- Rebalancing parts of or whole systems as necessary.

### *Previous Research Findings*

- Boards in general only use testing for new construction and to troubleshoot operational problems. No boards reported using testing to identify energy savings opportunities.
- For more information, please see Strategic Energy Management for School Board Portfolios: Guidance Report.

### *Recommendations*

- ❖ Conduct air testing on all air handling units and major exhaust fans over time, prioritizing identified high savings potential schools.
- ❖ Analyze results and take remedial action as indicated.

## Technical Reference Sheet 2: BAS Access, Setup and Action Indicators

Your building automation system (BAS) is an essential tool for identifying inefficiencies, improving HVAC operation and verifying that systems are running as intended. Having fully functional BAS with remote access for staff and service providers makes the operational challenges of achieving and sustaining high efficiency in large building portfolios, often spread over large geographic areas, manageable.

Some investment may be required, as described below, to set up the BAS as a fully functional tool in achieving the energy use target and sustaining that performance level over time.

### *Monitoring points*

The following air handling unit primary monitoring points are considered essential and should be verified through the commissioning process:

- Supply and return fan speeds during occupied periods. Fan power is the biggest single determinant of electricity use in fuel-heated schools and high fan speeds (> 90%) are often associated with high electric savings potential. Target 60-70% for most schools, to be achieved by eliminating excess static pressure losses and optimizing airflows.
- Supply and return fan operation/speeds during unoccupied periods. Fans coming on in cold weather indicate absence or deficiencies in perimeter heating or too-high setback temperature setpoints. Fan speeds should be reduced and matched under these conditions so that supply and return airflows are about equal, avoiding drawing in unneeded outside air. Outside air dampers should be closed tight and exhaust fans turned off.
- CO2 levels in all air handling unit return ducts as indicators of proper outside air volumes. Values below 500 generally indicate excessive outside air (and associated heating and cooling energy losses) while readings over 800 should be examined for inadequate makeup.
- Mixed air damper position. While generally not a reliable indicator of outside air intake volumes, damper position can be correlated with airflows through the system testing described in Technical Reference Sheet 1.
- Heating valve position or gas firing stages. Operation in mild weather conditions is an indicator of excessive outside air or improper control.
- System air temperatures. Outdoor air, return air and mixed air temperatures enable accurate calculation of outside air intake volumes.
- Cooling valve position or DX stages. Operation in mild conditions is an indicator of malfunctioning free cooling.

### *Trend logs, archiving*

Trend logs are a powerful diagnostic tool which should be set up and verified for all the monitoring points identified above. Archiving is recommended at 15-minute intervals for a two-year period to allow seasonal analysis of system performance and examination of causes of substantial changes in electricity and/or gas use.

### *Operating sequence*

Programming and set points should be reviewed for optimized control, with particular reference to:

- Scheduling. Ensure operating periods match actual occupancy.
- Supply air temperatures. Reset control can enable lower fan speeds.

- Outside air volumes. Control based on demand using CO2 readings.
- Heating supply water temperatures. Reset control can avoid over-ventilation in occupied periods and reduce fan operation when unoccupied.

*Previous Research Findings*

- Most schools are found to lack at least some of the recommended BAS monitoring points. Some points are found to be out of calibration, preventing proper analysis.
- A few air handling units are found to cycle on and off during unoccupied periods in cold weather to maintain space temperature setpoints. In most cases outside air dampers were programmed to close but fan speeds were not adjusted.
- Few schools have trend log archiving set up to enable retrospective analysis of causes of unexplained energy increases.

*Recommendations*

- ❖ Install or upgrade BAS as part of all related capital projects and in other high saving potential schools:
  - Obtain remote access capability for board staff and service providers.
  - Ensure primary monitoring points described above exist and are operational and calibrated.
  - Set up trend logs and obtain 2-year archiving capacity for major points.
  - Reprogram operating sequences to optimize energy use (in particular fan power and outside air controls).
- ❖ Review key operational conditions regularly and initiate remedial action. Consider BAS alarms.