Advanced RTU Controls – Opening up a New Retrofit Market

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ABSTRACT

Constant volume to variable volume RTU retrofits are cost effective, reliable and extremely valuable as a conservation resource. The rooftop unit retrofit market is vast, however, cracking open this market is only a recent discovery. For years, utility program audits have passed over single zone RTU units, relying primarily on prescriptive incentives when replacing for exceeding code efficiency levels. These small incentives were never enough to influence early retrofit, but did offer something in a tough-to-serve market. Now there is a new cost-effective solution referred to as Advanced RTU Controls that converts existing systems from constant volume to variable volume. As an energy engineering firm serving the delivery of custom conservation programs, we have real world experience retrofitting these controls on hundreds of systems. This paper shares our experience, analyzes findings, provides programmatic recommendations, and explores the following:

- Where these retrofits are happening
- The economics of retrofitting
- Present obstacles to overcome
- Control methods, options and results
- Cost-effectively verifying savings
- Results from hundreds of system retrofits, including: trend data, pre- and post-metered data
- End-user feedback after system retrofit

Key takeaways for the reader/audience will be to:

- Understand that there is now significant and cost-effective energy savings opportunity for packaged RTUs
- Share experiences in approaching a difficult market to engage
- Explore control options, retrofit methods and configurations

Introduction

A single zone refers to a conditioned space served by an HVAC system controlled by a single thermostat located in the space. Variable air volume (VAV) refers to an HVAC system type in which the volume of air supplied varies with the heating/cooling load within the space. Traditionally, single zone systems were designed as constant volume. From an energy efficiency perspective, this presents an opportunity to retrofit existing single zone systems to VAV in order to lower energy consumption. System designers have used VAV for decades in buildings around the world but predominantly in multizone systems. VAV strikes a balance of system cost, energy efficiency, reliability and performance. In 2006, Taylor Engineering proposed to the state of California that single zone unitary systems be mandated to operate with variable air volume

(Hydeman, Stein, and Zhou, 2006). In 2008, California incorporated the change into code becoming effective January 1, 2012 (California Energy Commission 2018).

With the adoption of ASHRAE 90.1-2010 or later, single zone VAV is trending toward a new construction code requirement throughout the United States.[1] However, there is a large existing stock of single zone units that need to be retrofitted. This is a rich energy efficiency resource. Thanks to numerous organizations for groundbreaking work on emerging technologies and field studies[2], there are now numerous products on the market to tap into this resource. For packaged Rooftop Units (RTUs), the industry has consolidated naming to Advanced Rooftop Unit Controls (ARC) as an energy efficiency measure. Single zone VAV retrofit opportunities include the addition of ARCs, as well as custom conversions for other system types (e.g. hydronic and built-up air-handlers).

Energy 350 is a technical, energy engineering firm with involvement in hundreds of energy efficiency projects each year, primarily on behalf of utilities. Over the past few years our engineers have studied and verified a number of ARC projects. In addition, we have been pushing facilities with custom air handlers to retrofit with Variable Frequency Drives (VFDs) and implement a VAV sequence of operations to recover the investments and save energy. This paper discusses the challenges with ARCs, the economics of an upgrade, results of many projects and key findings in verifications. Included is a discussion of what to look out for and what to work on as an industry.

Where has ARC Taken Off?

Recently there has been a lot of interest in retrofitting RTUs in retail, manufacturing facilities and restaurants. The recent uptick is likely attributable to the developments in retrofit technologies. Companies with portfolios of properties have valued the capability to remotely control their HVAC systems as an added benefit. Some key characteristics for a cost-effective retrofit opportunity include:

1. RTUs greater than or equal to 60 kBtuh cooling capacity
2. Existing oversized equipment relative to average operating conditions
3. System portfolios with facility managers needing better understanding and control of their systems
4. Fans run continuously during occupied hours, they do not cycle on/off

Understanding where ARCs should not be applied is equally important, either because the application can result in little to no savings or persistence of savings will be an issue. The following list of conditions should be screened for retrofit opportunity, but are discouraged.

1. Equipment that is near end of its useful life
2. Cooling load is high and/or near unit capacity at all hours. This is common with process cooling load applications

[1] At present 15 states have commercial building energy code requiring ASHRAE 90.1-2010 or better. https://www.energycodes.gov/status-state-energy-code-adoption

[2] Pacific Northwest National Laboratory, Emerging Technologies Coordinating Council and Northwest Energy Efficiency Alliance to name a few, have all evaluated Advanced Rooftop Controls as an emerging technology.

3. Fans operate in a cycling mode on/off. We have often observed this in small commercial settings where simple programable zone thermostats are applied. Systems are commonly controlled in “Auto” fan mode. While not compliant with ventilation code, the baseline energy consumption is much lower thus negating the opportunity for savings. Owners should not expect a return on investment in this case
4. Systems already operating as variable volume

Barriers to Upgrading

Single Zone VAV retrofits offer excellent energy savings, reasonable returns on the investment and they are capable of operating in many facilities. So why aren’t they being upgraded? In order to identify market barriers for RTUs and ARCs, Northeast Energy Efficiency Partnerships (NEEP) held a workshop with stakeholders for their recent study (Northeast Energy Efficiency Partnerships 2016, 20).

NEEP assessed market transformation in RTUs, including early replacement of RTUs with new high-performance models, as well as installing advanced RTU controls. Some barriers identified are applicable to ARCs, while others are more relevant to high performance RTUs as described below. NEEP categorized the barriers in two primary categories with the first focused on Financial Barriers, including:

- The predominant and most apparent barrier is availability or prioritization of capital to cover the High Performance RTU’s incremental cost. A business owner who has limited liquidity may not be in a position to consider extended break-even payback for a marginal up-front cost. Often when a business owner has available cash, the preference is to make business investments that raise profits rather than reduce costs.
- While hard costs may be a barrier, hidden costs can dwarf incremental costs for High Performance RTU adoption. In addition to the incremental cost of the unit, High Performance RTUs may require added architectural costs. For example, the roof structure may need to be strengthened to accommodate additional weight. The geometry of the new unit may not perfectly match the existing one, so structural modifications or curb adaptors make a different installation cost more than a like-for-like replacement.
- Compounded by occasionally weak business cases for High Performance RTUs, customers’ willingness to take on debt is low. Borrowing for an incremental costs can be a barrier to preserving the business’ ongoing credit availability. A business owner may be naturally averse to borrowing any more than absolutely necessary. The perceived lack of value for High Performance RTUs, coupled with the higher price of the units, stops many retrofits before they begin.

The following barriers are categorized as Business and Cultural Barriers by NEEP:

- Limited education and knowledge for both contractors and customers can hamper sales of High Performance RTUs in the region. Contractor education and perceived risks of new technology are considerations that often drive decision makers to the same existing and inefficient model rather than upgrading to a new and more efficient option.

- Availability of efficient options, especially in the case of failed unit replacement, can be a major barrier in the industry. This is especially critical in high-load periods such as mid-summer. Just as important to resolve is the assurance needed from distributors that the stocked, efficient units will make a positive impact for their business.
- Decision making authority in owner-tenant relationships can have an important impact on product selection. The 'Split Incentive', when the person making the selection and paying the capital cost (building owner) is different from the person paying the operating costs and reaping the savings (tenant of leased space) can inhibit selection of a High Performance RTU over a standard RTU. Even in cases where the building owner is responsible for both capital costs and operating costs, the owner may be indifferent to power bill savings since this is often dwarfed by rent payments from tenants.

In addition to these barriers identified through NEEP, our firsthand experience working with facilities identifies the following barriers specifically observed in single zone VAV retrofits:

- The retrofit kits are manufactured by companies that do not make RTUs. In some cases, hesitation from owners and/or contractors have been raised because there is no 3rd party brand awareness.
- Retrofitting RTUs may void manufacturer's warranties. While this is a concern, applicability may be limited as most new units (under warranty) may already be VAV. It is more likely the target RTUs are not currently covered under a warranty.

The efficiency industry is aware of these barriers, both perceived and real. Energy incentives are designed to lessen financial barriers and many utilities offer free studies or technical services to help alleviate the technical barriers. ASHRAE, Retail Leaders Industry Association (RILA) and US DOE all deserve recognition for leading efforts to market retrofit through the Advanced RTU Campaign[3].

Air Northwest[4], a Trade Ally Organization sponsored by Bonneville Power Administration (BPA), was created to further develop trade ally awareness of ARCs and influence higher penetration into the markets. There efforts are just underway.

Overview of Control Methods, Options and Results

Utilities in the Pacific Northwest understand the barriers presented with a new technology and the perceived risks. Therefore, BPA maintains a list of qualified suppliers for its energy incentives. There are only a small number of ARC suppliers that are qualified[5]. Each supplier has a similar control sequence. Suppliers have termed the applications as full or "lite" depending on the level of control being implemented. The lite application is typically intended for RTUs less than 5 tons rated capacity, where fan loads are modest and do not already include a fan VFD. For the full application, the primary source of savings is reduced supply fan energy. Both lite and full additionally offer energy savings from: optimized economizer controls, scheduling and demand controlled ventilation. With non-RTU projects, custom controls are applied either by a controls and/or mechanical contractor. Most mechanical contractors that have a controls division install

[3] See www.advancedrtu.org for more information.
[4] See www.airnorthwesthvac.com for more information.
[5] BPA maintains a qualified products list. https://tinyurl.com/bpa-arclist

these retrofits. The components are all similar but off-the-shelf retrofit kits typically do not exist. Rather, they are assembled and custom designed for each project. Controls integration is then typically completed on a central Building Automation System (BAS).

Control Methods

Regardless of the full or lite application, each RTU (or AHU) is controlled independently with a 3rd party controller mounted to each unit. For a full installation, each RTU is also retrofitted with the following:

- Demand Controlled Ventilation (DCV)
- Economizer Control w/ enthalpy sensors
- VFD for the supply fan
- Temperature Sensors (Outside Air, Return Air, Supply Air and Mixed Air Temperatures)
- Proprietary Controller
- Network Interface, communications (optional and dependent upon manufacturer)
- Fault Detection Analytics (optional and dependent upon manufacturer)

Pivotal to the performance of ARCs is the sequence of operations. The control sequence related to the supply fan VFD is bound by the constraints of the system type. The table below illustrates many of the considerations when manufacturers establish the sequence of operations to balance energy savings with safety, reliability and comfort.

Table 1. Supply Fan VFD Control Constraints by System Type

<table>
<tr><th>System Type</th><th>Heating</th><th>Ventilation Only</th><th>Cooling</th></tr>
<tr><td>DX Cooling – Gas Heating (Non-Modulating)</td><td>Supply temperature is solely dependent on airflow. Fan must operate near design airflow when heating.</td><td rowspan="6">Airflow can turn down to a minimum acceptable ventilation volume.</td><td rowspan="5">Supply temperature is dependent on both the stages of cooling and airflow. Airflow can be dynamic but dependent on compressor capacity online.</td></tr>
<tr><td>DX Cooling – Gas Heating (Modulating)</td><td rowspan="2">Supply temperature is dependent on both airflow and heating stage. Airflow can be dynamic but dependent on heating capacity online to limit supply air temperature.</td></tr>
<tr><td>Heat Pump</td></tr>
<tr><td>DX Cooling Only</td><td>N/A</td></tr>
<tr><td>DX Cooling – Steam or Hot Water Heat</td><td>No constraints, fully modulating</td></tr>
<tr><td>Chilled Water Cooling*</td><td>See note below</td><td>No constraints, fully modulating</td></tr>
</table>

*For brevity, we have not listed all the different heating systems that can be found with chilled water cooling. However, the constraints listed under DX cooling for the heating systems can be replicated exactly for a unit with chilled water.

Trane has developed an excellent technical resource to communicate best practices with single zone VAV control sequences (Murphy and Bakkum 2013). They illustrate three graphics (for air volume control), as shown in Figures 1-3 below, which are instrumental to understanding the operation of the unit depending on the constraints of the particular system.

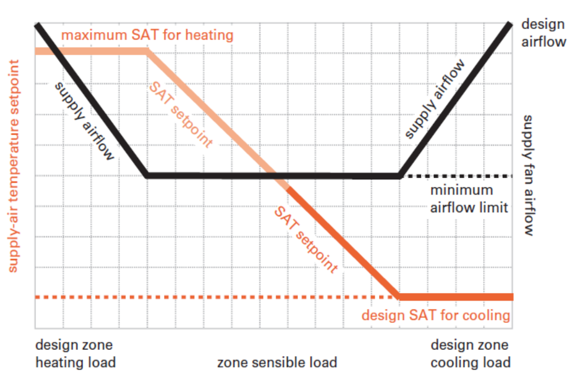

Figure 1. Single Zone VAV control with VFD fan, no constraints. *Source*: Trane 2013.

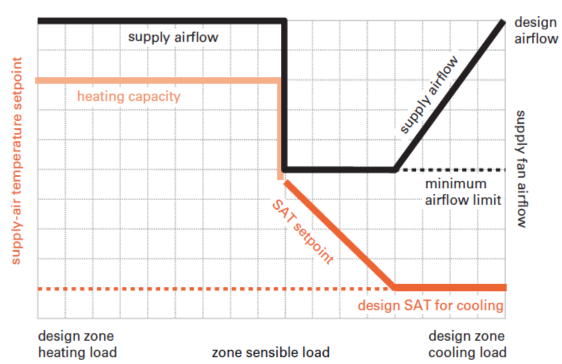

Figure 2. Single Zone VAV control with VFD fan and constrained airflow when heating. *Source*: Trane 2013.

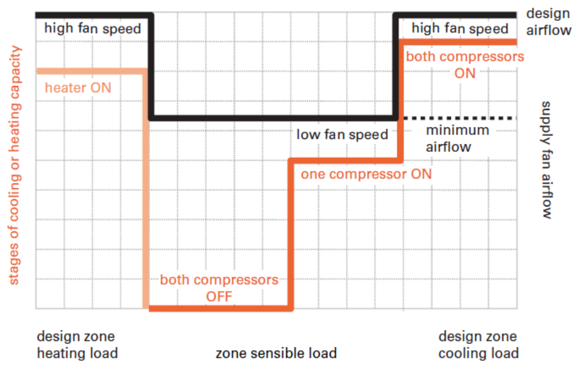

Figure 3. Single Zone VAV control with VFD fan and constrained airflow when heating and cooling. *Source*: Trane 2013.

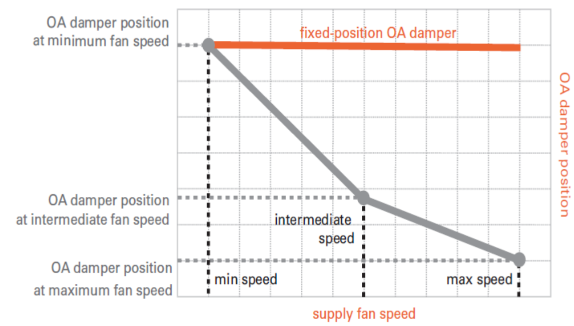

Figure 4. Outside Air (OA) damper control. *Source*: Trane 2013.

Figure 4 above depicts the need to monitor and actively control ventilation because outside air flow is directly related to damper position and mixing box static pressure (which is influenced by supply fan speed).

A commonality in figures 1 through 3 above is the minimum fan speed while systems are neither heating nor cooling. The run hours at this stage can be significant and therefore this parameter is one of the most important setpoints for energy savings. In practice, it is most common to observe Figure 3 with packaged RTUs and Figure 1 with custom or chilled water systems.

Often the sequence of operations is not listed in a vendor's documentation, however, we have observed post-install sequences and can provide a sense of common operating modes. ARCs typically operate the fan at 40% (adjustable) when there is no call for cooling or heating and return air CO2 is below the setpoint. When the first stage of mechanical cooling is required, the fan operates at 75% (or 90% when only a single stage exists) and then 90% for the second stage of cooling. Though setpoints are adjustable, we have found these to be common default settings. One vendor, Bes-Tech, publishes their sequence of operations for their "Digi-RTU" product line[6] which align with those listed above.

Results

Energy 350 has studied and verified retrofits on numerous facilities over the past few years. We pulled data from a sample of available projects that represents 275 HVAC systems on 13 unique buildings. In most cases the analysis was sampled by established groups of units with similar operating schedules and loads (e.g. production vs. office). The smallest group in our data set comprised a single unit and the largest group consisted of 32 units. The smallest RTUs were 3 tons each and the largest custom built-up system was 95 tons of rated capacity. Systems operated between 3,000 hours/yr and 8,760 hours/yr.

Electric energy savings varied between 15% and 81% of baseline consumption.[7] Upon further review, low savings were a result of two primary factors: high minimum speed setpoints and lack of a VFD on ARC-lite installs (less than 3 tons capacity). If these projects are excluded,

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[6] See http://www.bes-tech.net/wp-content/uploads/2016/09/Bes-Tech-Digi-RTU-Control-Logic-9-6-most-recent.pdf

[7] Due to utility eligibility and therefore inconsistent modeling practices, natural gas consumption was excluded from the analysis. However most of these projects also verified natural gas energy savings from the reduced ventilation loads on the systems.

the minimum energy savings are 30%. The highest percentage energy savings projects were reported with fan energy only. If cooling energy were included, the percentage savings would be less, as cooling energy consumption is only modestly impacted by these retrofits. The figure below plots the average energy savings by group. A group was a population of units on a project site that all had similar loads and run hours. The data is colored based on whether it was custom or an ARC.

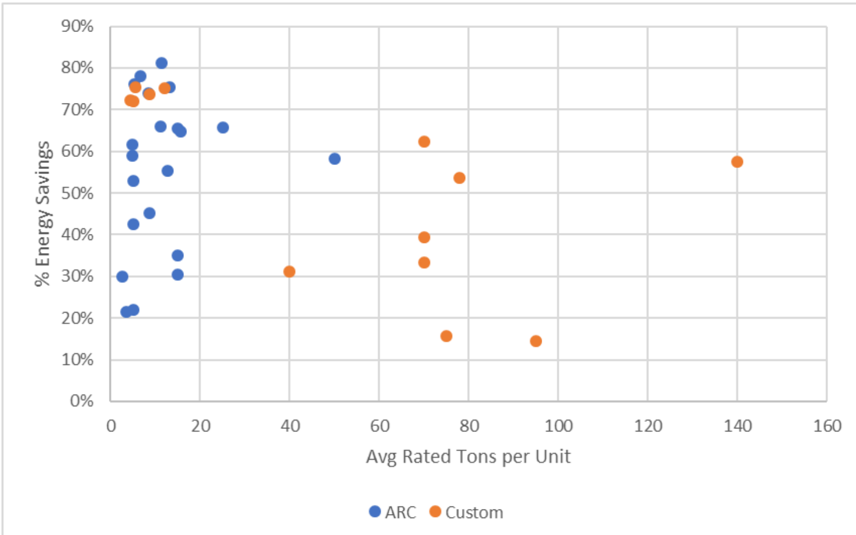

Figure 5. Percentage energy saved. Each data point represents a group of systems at a facility. *Source*: Energy 350

What are the Economics of Retrofitting?

We have divided the installed costs with the value of the annualized energy savings to quantify a simple payback. Economics vary based on traditional factors in energy efficiency measures. These include hours of operation, project location, space heating/cooling loads, equipment size and configuration. Figure 6 below illustrates the simple payback before incentives, the count of units in each project and annual operating hours. Note only 11 of the 13 buildings are plotted below. Two buildings were excluded, as cost was not available.

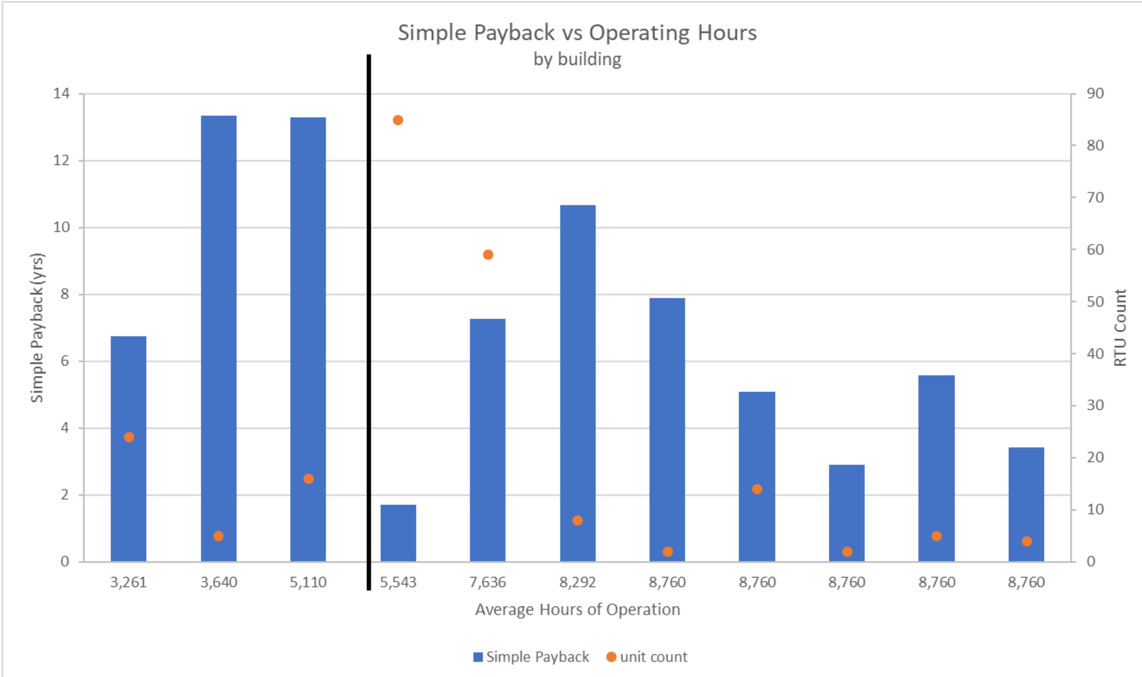

Figure 6. Simple Payback before incentives, annual operating hours and unit count.
Electric rate used is $0.072/kWh. *Source*: Energy 350

Simple payback presented is electric energy charges (kWh) only. Gas savings slightly improve the payback. Some technologies allow integration with a demand response market offering additional revenue and benefits.

Non-Energy Benefits

A large but unquantifiable benefit is the added capability of remote monitoring through a web based system. The ARC retrofits include an option to network to a web gateway that allows owners remote visibility into their systems. This powerful tool has sold retrofits on its own, validating previous findings that suggest energy may only be one component leading to a successful retrofit opportunity. Owners with large portfolios of properties value the remote monitoring ability as they can change setpoints, receive fault alerts, monitor energy consumption and respond to issues all through a remote interface. A recent implementation of remote monitoring capabilities at Leatherman Tool in Portland, OR had such a positive impact that Scott Bacon, the facilities maintenance manager, quoted:

> "By giving us the ability to monitor and fine-tune our rooftop units, these controls took us from a reactive to a proactive mode. Before, we typically didn't know there was a problem with a unit until we received employee complaints. Now, facilities personnel often identify issues and resolve them before occupants arrive. We're not only cutting operating costs, we're improving comfort."[8]

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[8] Scott Bacon, "Leatherman Tool Group, Portland" Success Story. https://www.energytrust.org/success-stories/leatherman-tool-group-portland/

Tips for Verifying Energy Savings Cost Effectively

RTUs[9] and heat pumps provide HVAC service to 66% (over 57 billion sf) of buildings surveyed in the 2012 CBECS table B41 data set (U.S. Energy Information Administration 2017). Due to the sheer volume of project opportunity, utilities must be cost-effective when approaching verification of energy savings. There are essential parameters needed to ensure the realization of energy savings. We have observed little to no issues with the implementation of ARCs. However, we have observed many flawed sequences of operations on custom hydronic systems and custom control projects. Therefore, we have developed different verification processes for different types of projects and recommend the following approaches to balance technical intricacy with time efficiency:

- Request an operating schedule for every project, as well as an inventory of equipment being retrofitted and copies of the invoices. For custom systems it is important to request a written sequence of operations from the controls contractor.
- Determine how the fan VFD is being controlled and correct if needed. Duct static pressure sensors should not control fan VFDs. A single zone VAV retrofit should use the supply air temperature (SAT) to its full potential (high for heating, low for cooling) prior to increasing airflow. This is a common multizone VAV control strategy that is sometimes mistakenly applied to single zone VAV systems.
- Conduct post installation site visits. If a project is not commissioned correctly, neither the participant nor the utility benefit. A sampling plan to accomplish project measurement and verification thresholds should be planned up front. Though sampling thresholds are typically defined by the utility and can vary by region, we recommend increasing the sample size if performance or installation quality issues arise. Control parameters should be reviewed for consistency and implementation as planned.

Though a post measurement and verification (M&V) effort should be consistent with utility guidelines, we do not believe it is necessary to meter power after every implementation. Only when uncertainty or concern arises do we meter to help communicate the proposed changes to the owner and contractor. When metering is done, it is recommended to include both the outdoor air (OA) and SAT, along with power measurements. A relationship between power and SAT should be clearly delineated from the logged data. If patterns are not present, controls sequence needs to be modified. Below are some examples of projects that were implemented.

[9] Referred to as Packaged air conditioning units in CBECS.

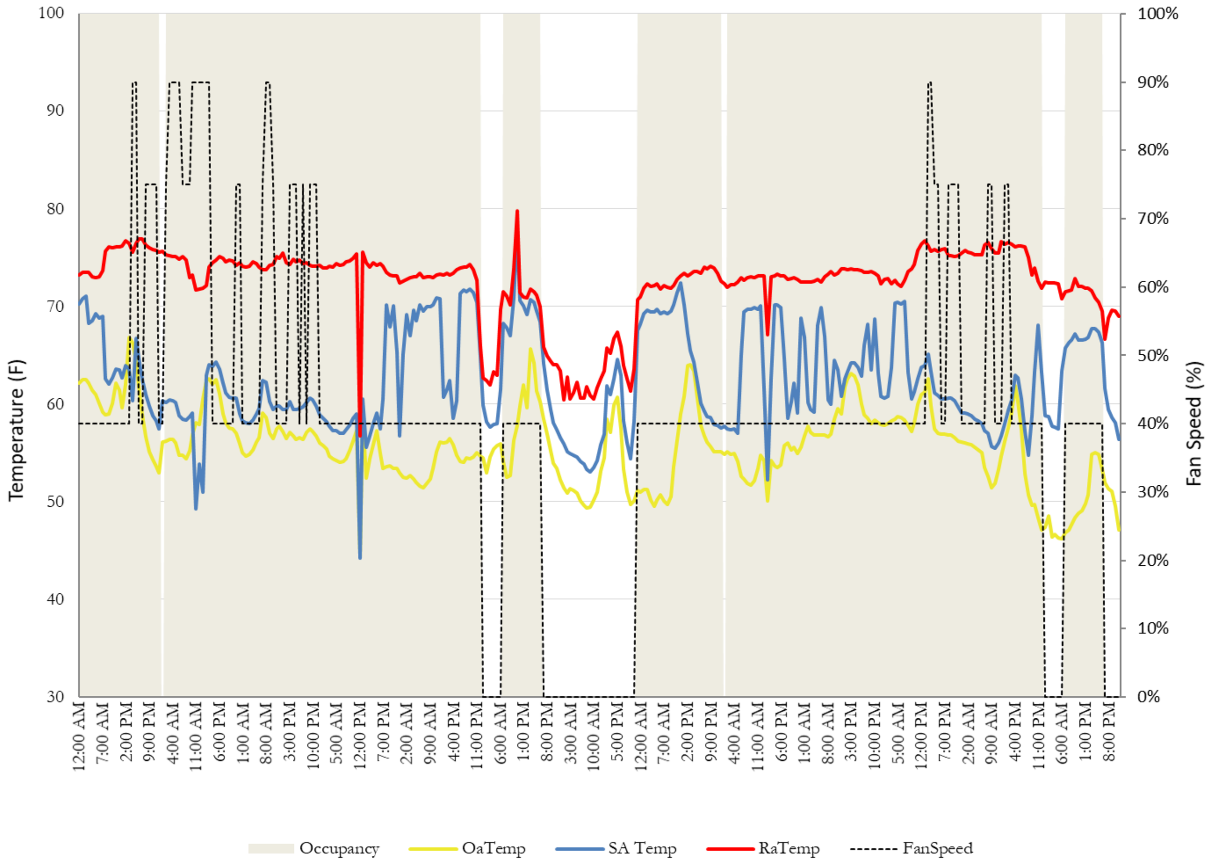

Figure 7. Trend data from project verification of an ARC. Unit is operating over a few days while economizing and varying the fan speed to satisfy the cooling load. *Source*: Energy 350

Figure 7 shows excellent modulation of the supply fan with mostly low VFD speeds. As can be seen by the dashed line above, the fan speed increases when necessary but then returns to a pre-set minimum level indicating that the control strategy is operating correctly.

Below, figure 8 illustrates a custom project that required changes after the ARC was retrofit onto the unit. When the facility requested incentive payment we performed a site verification to find that the electrical contractor had installed the fan VFDs as required. However, they placed all VFDs in “Hand” mode locally, meaning that the benefit of a VFD was not being realized as the unit was operating at a constant speed. The data in figure 8 below clearly shows when the VFDs were under control and the BAS could modulate to maintain space conditions.

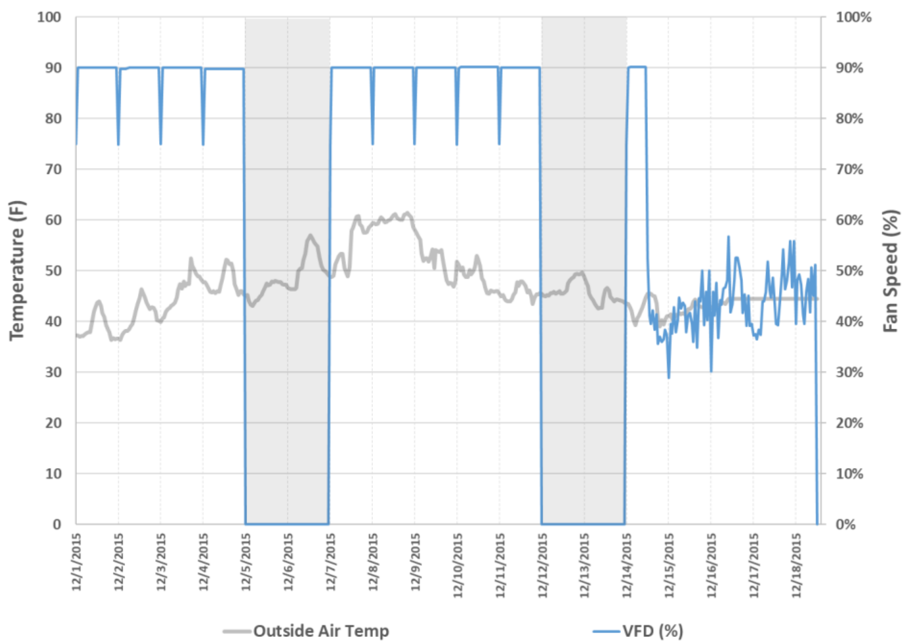

Figure 8. Trend data from project verification of a custom single zone VAV project. *Source*: Energy 350

Figure 9 below illustrates what happens when duct static pressure is incorrectly used as a control method for a single zone VAV retrofit. It simply does not work and the fan operates at a constant volume.

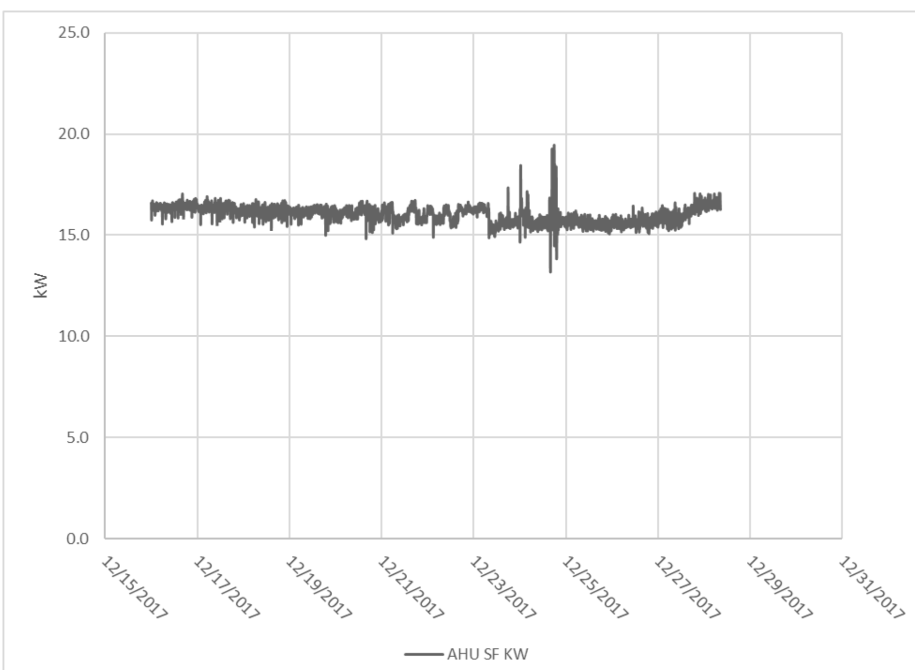

Figure 9. Trend data from project verification of a custom single zone VAV project with duct static pressure control method. *Source*: Energy 350

Conclusion

The RTU retrofit market is vast and full of opportunity. About a decade ago, ARCs were being first developed. It wasn't until about five years ago that product was readily available and the technology opened the door to cost-effective energy retrofits. Results from several years of installations are strong and significant. System energy savings median value was 59%, totaling over 3.9 GWhs annually across a sample of 275 retrofits on 13 buildings. Given the sheer volume of RTUs on commercial buildings, we believe these retrofits present an unprecedented source for potential future energy savings.

Customers have noted the added value of controls and remote access to unit information. These non-energy benefits should accompany marketing efforts by utilities to capture a wide audience and establish new retrofit leads.

The barriers are clear, however, and utilities must market to decision makers within commercial facilities and educate them on the benefits and value of ARC retrofits. These projects will not occur without influence, which must be both technical as well as financial.

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