Critical Facility Cooling Energy Optimization

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

With the current state of the world in turmoil due to the COVID-19 virus, there has never been a time in history when cable, internet and communication networks have been so heavily stressed. Corporations, businesses, schools, healthcare and families have been thrust into new ways of meeting, learning, socializing and transacting business -- with almost all of them flowing through cable and Internet providers. With this massive increase in traffic on all of the broadband networks comes an increased use of electricity to power all of the components needed to keep the critical infrastructure (CI) up and running. This increased consumption of energy to deliver internet and cable television services is being offset by continued conservation efforts across the industry. This paper will identify how Comcast is contributing to those efforts with three case study results which show substantial savings potential if deployed across the cable operator industry.

The production spaces, where the servers, modems, switches and routers are housed, are called headends, which divide their energy usage into 2 main categories. The first is IT production load (modems, switches etc.) and second is the cooling load, with both expressed in kilowatts (kW). This paper will look at our efforts to reduce energy consumption from the cooling load at the headends. The pilot initiatives include set point adjustments on air conditioners, blanking panels in racks, and economizer options on air conditioners (also known as "free cooling"). Although these strategies have been publicly promoted in the past by trade groups, engineering firms and vendors, this paper will provide specific applications and verifiable results which have far exceeded the expectations of this author.

These programs will demonstrate saving opportunities primarily associated with computer room air conditioner (CRAC) cooling energy, ranging from **12% to 50%** without any negative impact to operations or reliability. These significant savings will be shown to measurably reduce operating expenses, carbon emissions and preserve capital with payback periods from less than 1 year to 3.5 years.

2. Historical Perspective

The issue of energy efficiency has long been a Comcast initiative, as evidenced by the partnership with the SCTE (Society of Cable Telecommunications Engineers), CableLabs and corporate commitments to building a more resource-efficient company, including the retention of a Chief Sustainability Officer in 2016. Comcast was a signatory to industrywide voluntary agreements in 2012 for energy efficiency improvement to set top boxes (STB) and again in 2015 for energy efficiency of small network equipment (SNE). The substantial savings from the STB initiatives across the entire cable operator companies are expressed in Figure 1 . Additional information can be found at www.energy-efficiency.us and www.cablelabs.com.

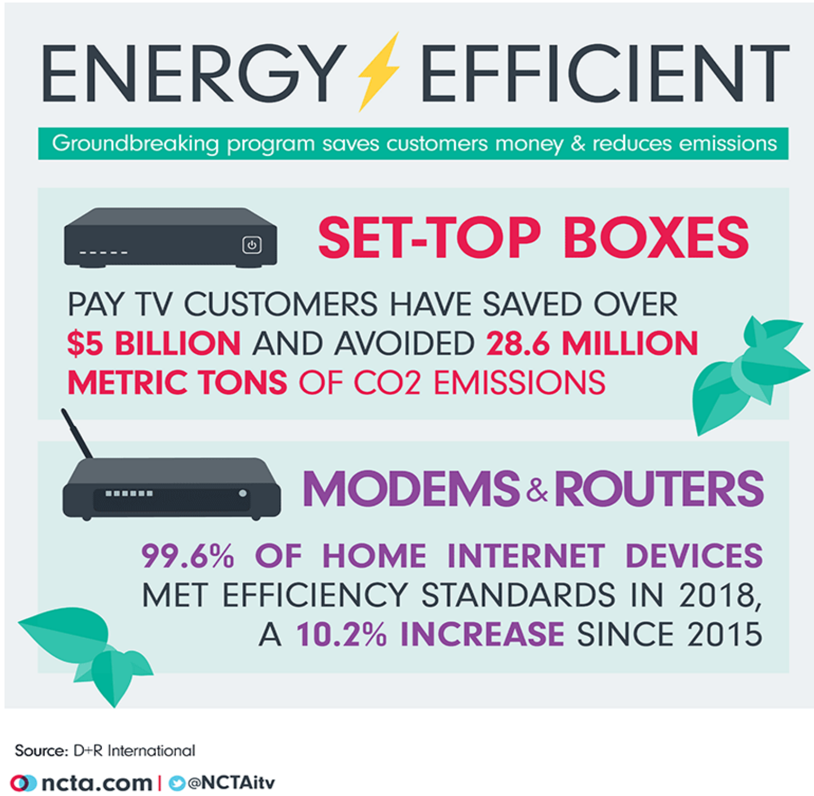


Figure 1 - Cumulative Industry Savings Through 2018 for STBs and SNE Efficiency Compliance (D+R international/ NCTA.com)

In its continued drive for efficiency and environmental impact reductions, Comcast agreed to participate in the SCTE Energy 2020 program, developed in 2014 as a multi-year program. This objective covered all aspects of the industry product delivery systems with three main goals to reduce energy use. These Energy 2020 goals include reducing power consumption by 20% per unit, reduce energy cost by 25% per unit and reduce grid dependency by 5%, by 2020. With the adoption of these goals Comcast and the many other members of SCTE, including vendors and contractors, joined forces with their respective Sustainability Offices and embarked on aggressive energy reduction strategies, including the case studies referenced herein, to provide measured and verified data to various applications for cable operators.

The Energy 2020 program initiatives took a hard look at the breakdown of the major areas of energy consumption in the cable operators' system, and it is abundantly clear that outside-plant access network, and specifically power supplies and edge facilities (aka hubs & headends), represent the major energy user groups for cable and internet, as shown in Figure 2.

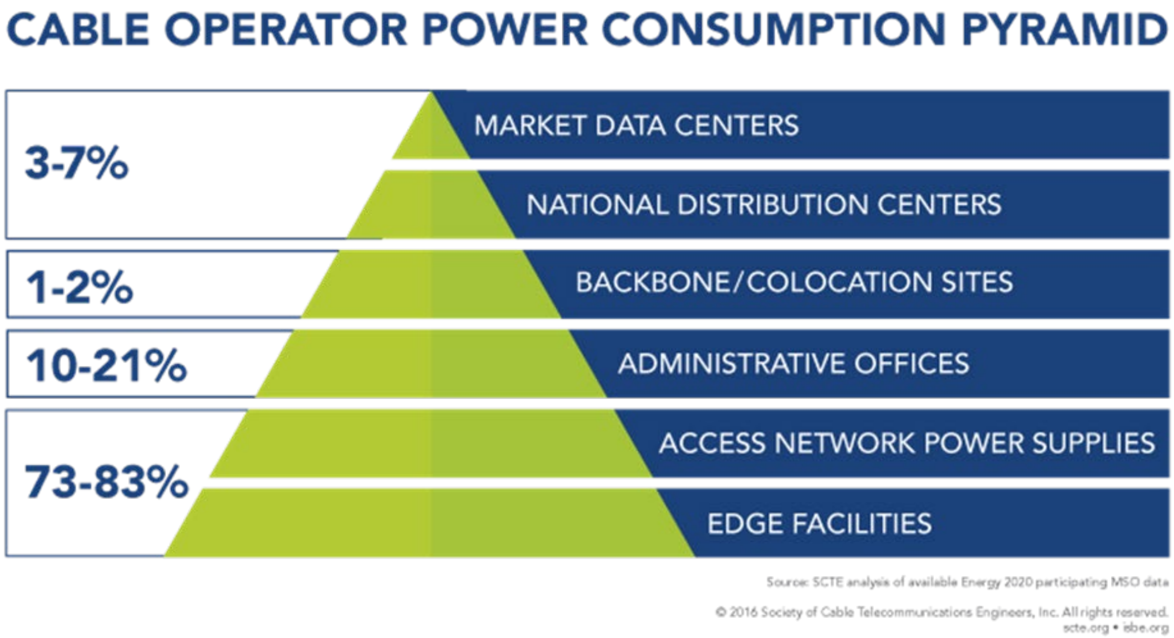


Figure 2 - Cable Operators Power Use Distribution (SCTE)

In the single use edge facilities referenced above (also known as Headends), the power breakdown consists of the production energy load (servers, modems, routers & switches), typically utilizing 45% to 55% of overall space electricity, and the Heating Ventilation and Air Conditioning (HVAC) load, using 40% to 45%. Miscellaneous office and lighting load use 3% to 5%. These loads are expressed in Kilowatts (kW) for point-in-time measurements, or, more accurately as kilowatt Hours (kWh) to capture the amount of Watts consumed by a device over 1 hour, that is, the energy consumption. The cost varies widely across the US, from $.06 to $.023 per kWh. California and the northeast states are in the highest electricity cost groups. It is also more likely that the higher priced areas will have more aggressive utility incentives, and the three case studies included below have been eligible for incentives either individually or as part of site upgrades. See the following link for state incentive opportunities: https://www.dsireusa.org/ with a focus on the HVAC systems. In most incentive programs the measures addressed by this document typically are included under the Commercial & Industrial programs (C&I). In this paper we will be looking only at the reduction of kWh from HVAC cooling power usage.

Many papers have been written on the subject of energy conservation measures (ECMs) for data centers. In particular, this very similar industry attracted worldwide attention in 2014 for reports that it was consuming nearly two percent of the total energy consumption (Arman Shehabi, 2016) with projected staggering growth. This growth did not materialize, thanks to the many efficiency efforts of manufacturers, engineers and end users. Data centers require many of the same infrastructure equipment as cable headends, and efficiency applications discussed in this work are very much applicable, with just as promising a savings potential. As indicated in Figure 3, a data center contains many more servers and storage elements for business applications (e.g. accounting, human resources, marketing, purchasing, legal), while the cable headends contain modems, switches, fiber terminations, router and other broadband equipment. Although slightly different in rack contents, the energy use percentages compare fairly closely.

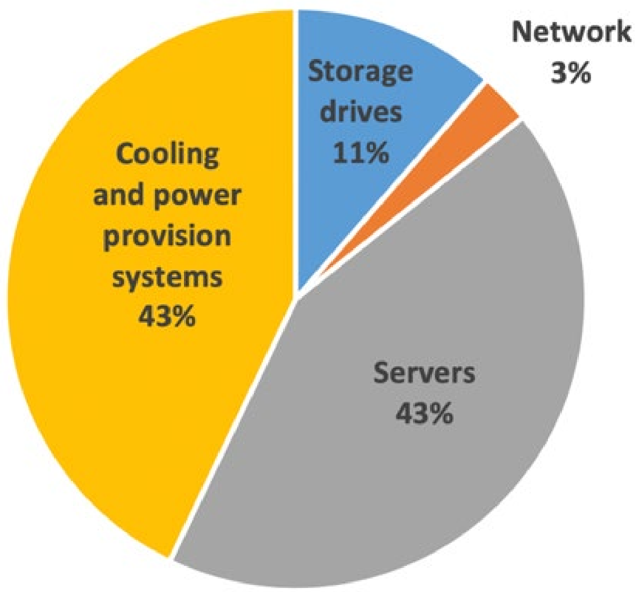


Figure 3 - Data Center Power Use Distribution (Shehabi, 2016)

A 2017 SCTE Expo technical paper titled "ECM Recommendations for Cable Edge Facilities" *(Dan Marut Senior Manager of Sustainability, 2017)*, detailed similarly combined ECMs that had been deployed, and the savings aggregated. This author is in full support of the recommendations from that paper and intends to show specific individual element savings.

3. Case studies and results

3.1. HVAC Set Point Adjustments

In this case study, 10 sites within the greater Chicago metro area were identified as candidates to raise the current HVAC set points in small (600 square feet) to medium (1,200 square feet) size power rooms. These sites were selected to minimize any adverse or customer-impacting events. Simultaneous with this effort was the installation of lockable and programmable thermostats used to control the CRAC devices. The installation of these secure thermostats ensured that they could not be adjusted by occupants. The addition of these devices served as qualification for a significant Commonwealth Edison (Com Ed) utility incentive. At the outset of the project, we estimated a potential energy savings of 3% to 5% for the cooling energy used, that would be attributable to the raising of return air temperature set points on the air conditioners from 68°F (Fahrenheit) to 75°F.

3.1.1. Set Points And Sensors

Set points are the numeric control positions used to operate HVAC and many other types of equipment. The most common example is a thermostat which controls when an air conditioner or heater comes on or shuts off. The difference between the settings for when a unit cycles on and off is referred to the set point deadband. When conditions are within the deadband range, no action (to provide heat or cooling) is needed by the device. In headends, the air conditioners have historically run 24/7 365 days a year to maintain a consistent operating temperature in the room. This continuous duty requires greater reliability than a seasonal device, which may run 3-6 months a year.

There are multiple sensors located within and outside the HVAC equipment to measure and monitor various environmental conditions and the operating status of the system and components. Some of the sensors can have user adjustable settings while others are non-adjustable and meant to keep the unit operating safely per the manufacturer. Examples of other sensors include smoke detectors, air filter pressure differential to indicate a clogged or dirty filter, exterior ambient air conditions, high or low power supply voltage and current, fan state, cooling status and stages, refrigerant temperature and pressure and many more. When a component fails, malfunctions or strays out of set operating boundaries (set points), alarms or alerts are displayed or automatically forwarded to a building monitoring system. During the following case studies, the data from devices and space conditions were obtained via direct IP connections or data aggregators and exported to a third-party monitoring system branded Foreseer® (Eaton). This system allows remote site visibility and device alarming, so we can track and trend space conditions and device operational status.

The example power dashboard shown in Figure 4 shows the various areas of power monitoring available at this site including service entrance, generators, direct current (DC) plant, fuse panels, HVAC with environmental relative humidity (RH), and 3rd party aggregators:

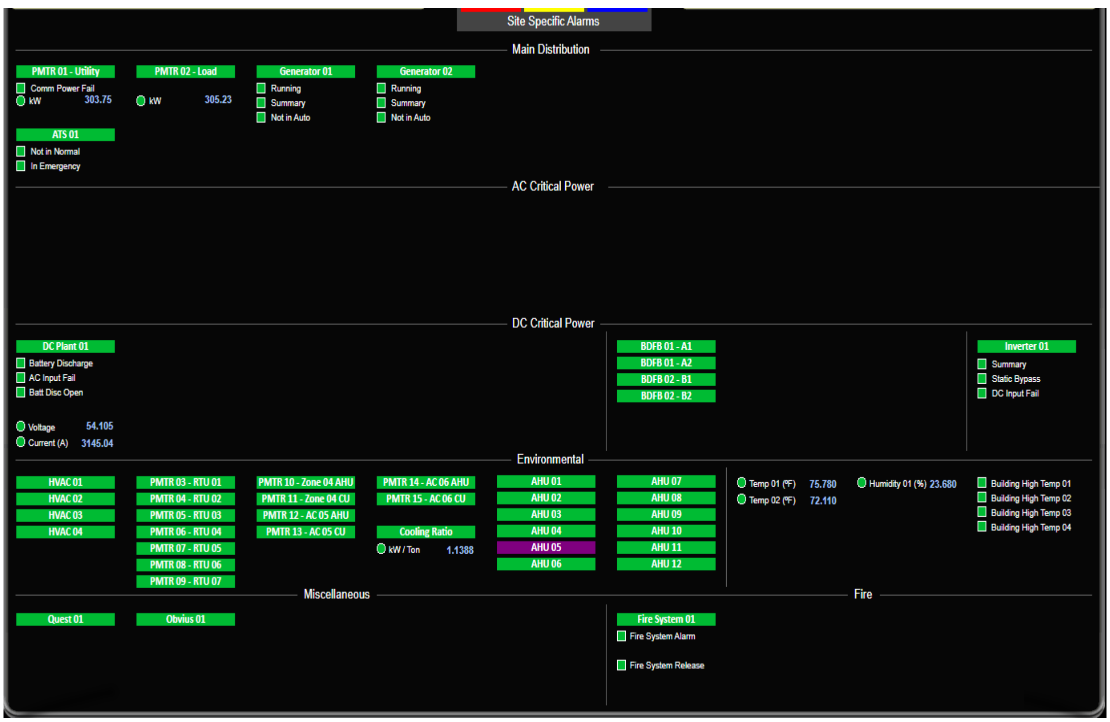


Figure 4 - Power Monitoring Dashboard Example From Foreseer®

In Figure 5 below we see the actual Return and Supply air temperatures as displayed at the CRAC unit and informed by on-board sensors along with room and outside air (OA) temperature. One can see that the cooling and room setpoint of 71°F is activating the cooling mode, as the recorded temperature in the room is 73.3°F -- indicating that the likely dead band setting is 2°F. Note that the Delta T (or ΔT is the difference in Temperature) between supply and return temperatures is only 5.7°F and the mechanical cooling is operating only Stage 01. Typical discussion of set points at this site would be described as: "temperature set points are 71°F/2°F and RH set points are 40%/10%," indicating set point and deadband setting.

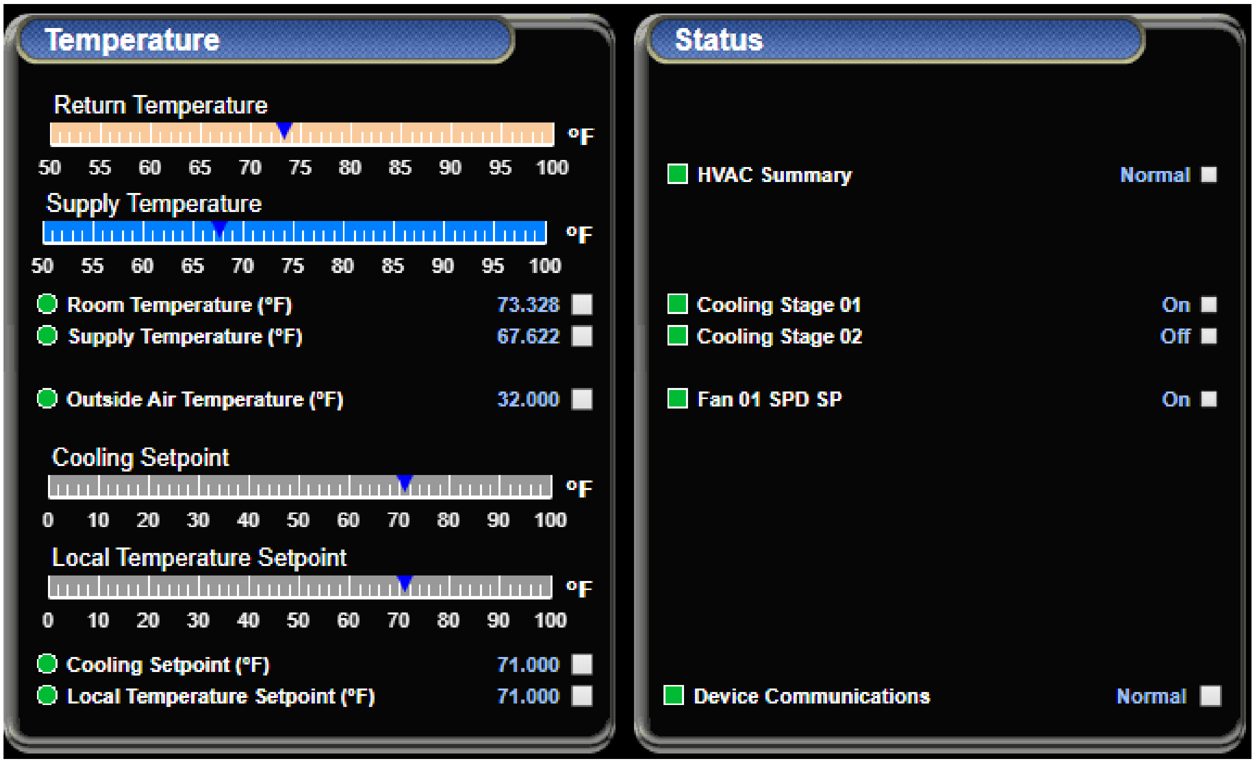


Figure 5 - HVAC Set Point Monitoring And Operational Display From Foreseer

3.1.2. ASHRAE Standards And Operating Ranges

The cable and data center industries, as well as state and local municipalities, have adopted many code requirements from various governing or advisory bodies. Of specific reference to this case study is the ASHRAE (American Society of Heating Refrigeration and Air-conditioning Engineers) 90.1-2019 "Energy Standards for Buildings Except Low-Rise Residential Buildings" and subsequent 90.4 -2019 "Energy Standard for Data Centers." Generally accepted addendums also include publications from a formal ASHRAE Technical Committee (TC) TC 9.9, comprised of ASHRAE members who are subject matter experts in HVAC and data centers. Although headends are not yet called data centers, by definition many meet the criteria: Having a conditioned space, greater than 20Watts per square foot, and a production equipment load (commonly referred to as IT load) of more than 10 kW (ASHRAE, 2019). This widely accepted standard provides tables with ratings for various electronics equipment and the recommended safe operating temperature and humidity ranges (A1-A4), as shown in Figure 6.

In this case study, it was identified that many sites were operating at cooler than necessary space temperatures. Per the ASHRAE guidelines, the *recommended* area of the standard indicates that the temperature range is 18°C (64°F) to 27°C (80.6°F). Let it be noted that the *allowable* range is 15°C (59°F) at 80% RH up to 32°C (89.6°F) at 40% RH. This allowable range indicates the conditions that the production equipment can operate at occasionally, but only for limited transgressions and duration. These temperature and humidity ranges are meant to be measured at the face of the rack, where airflow is drawn in by the IT/Production equipment. The recommended ranges are the basis for this pilot, given that the premise is that raising the setpoints closer to the upper end of this range can be safely achieved, while significantly reducing energy costs, with little or no implementation or maintenance costs.

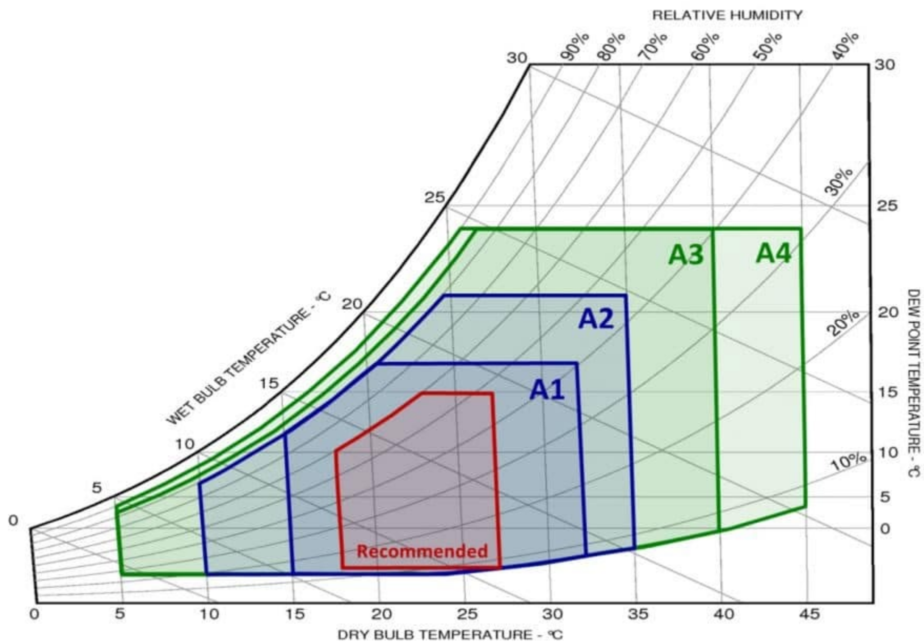


Figure 6 - 2015 Recommended And Allowable Envelopes For Air-Cooled Equipment

©ASHRAE www.ashrae.org, *Equipment Thermal guidelines for Data Processing Environments, Fourth Edition* (2015)

3.1.3. Capacity Impact

All major HVAC manufacturers test and rate their devices at various operating conditions, and both openly publish that data and include it in design specifications. Per their testing, the higher the operational limit is to a device, the greater the capacity of the unit. As shown in Figure 7, data from the Vertiv™ system design catalog has the lowest operational limit published, of 75°F, or 27.5 kW. If the space is maintained at this lower limit, then the operator is reducing the sensible kW capacity of the unit to approximately 20% lower than the same output at 85° (34 kW). If we follow the shown reductions of almost 2 kW per 5°F then a set point of 70°F would have a capacity of approximately 26 kW, or a 24% difference from 34 kW. This is stranded capacity and forces a de-rating of the units when capacity models are run. Further, it will require additional HVAC units brought online or purchased in order to match the heat rejection capability of the production load. This de-rating does not include the many other factors that could also reduce the capacity of the HVAC unit, such as poor airflow distribution, low Delta T and low humidity levels, all of which are great discussions for another paper.

2.1 Air-cooled Units Application and Performance Data

Table 2.1 Application data—Air-cooled, under-floor discharge[1] with EC fans

Model Size	028	035	042	053	070	077	105
Net Application Data kBTUH (kW), Standard Air Volume and Evaporator Fan Motor							
Semi Hermetic Compressors (4 Step Cooling) with EC Fans							
85°F DB, 64.5°F WB, 52.3°F DP (29.4°C DB, 18.1°C WB) 32.4% RH							
Total kBTUH (kW)	116.4 (34.1)	143.6 (42.1)	163.6 (47.9)	210.6 (61.7)	247.1 (72.4)	270.3 (79.2)	352.5 (103.3)
Sensible kBTUH (kW)	116 (34)	141.2 (41.4)	160.9 (47.9)	210.2 (61.6)	245.9 (72)	269.2 (78.9)	337.5 (98.9)
80°F DB, 62.9°F WB, 52.3°F DP (26.7°C DB, 17.1°C WB) 38.2% RH							
Total kBTUH (kW)	110.5 (32.4)	136.8 (40.1)	156.1 (45.7)	198.9 (58.3)	234.8 (68.8)	257.1 (75.3)	338.2 (99.1)
Sensible kBTUH (kW)	105.9 (31)	128.1 (37.5)	146.2 (45.7)	193.9 (56.8)	226.6 (66.4)	248.8 (72.9)	307.2 (90)
75°F DB, 61.1°F WB, 52.3°F DP (23.9°C DB, 16.2°C WB) 45.1% RH							
Total kBTUH (kW)	105.3 (30.9)	130.8 (38.3)	149.5 (43.8)	189 (55.4)	223.9 (65.6)	245.8 (72)	325 (95.2)
Sensible kBTUH (kW)	93.9 (27.5)	113.8 (33.3)	129.9 (43.8)	173.3 (50.8)	201.3 (59)	221.5 (64.9)	80 (273.1)

Figure 7 - Vertiv Application And Performance Comparison

3.1.4. Set Point Modifications And Results

Figure 8 is a screenshot of a Vertiv CRAC unit with a return temperature set point of 67°F and sensor readings of 68°F and 39% RH. The fan is operating at 81% and mechanical cooling is at 72% of capacity.

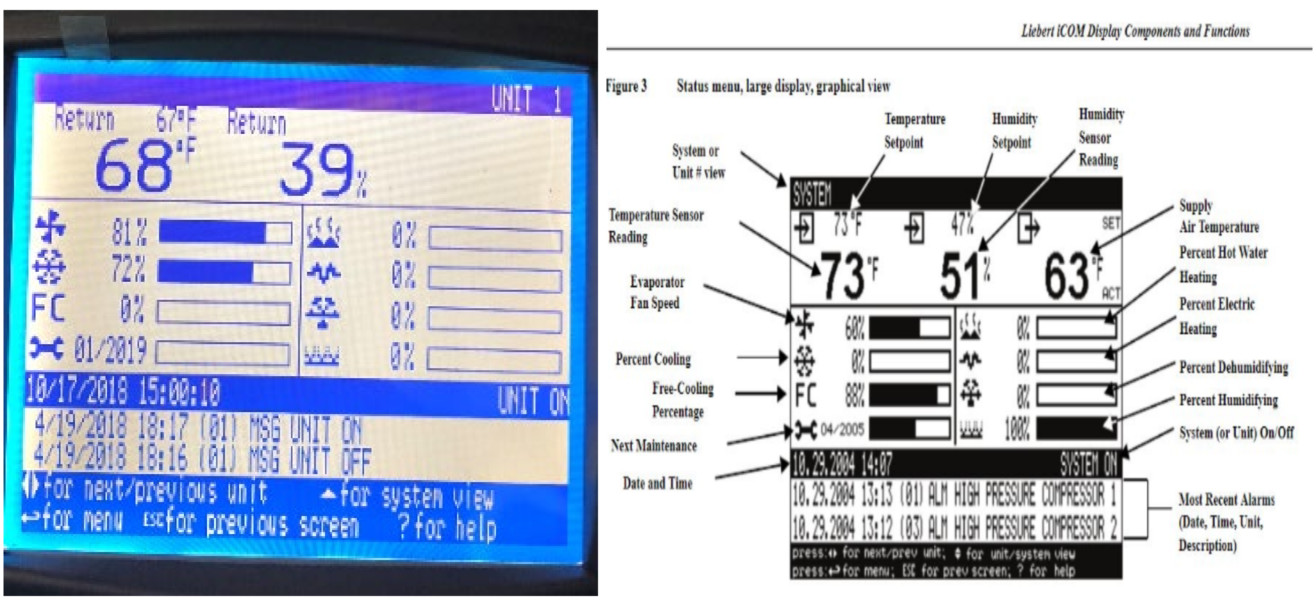
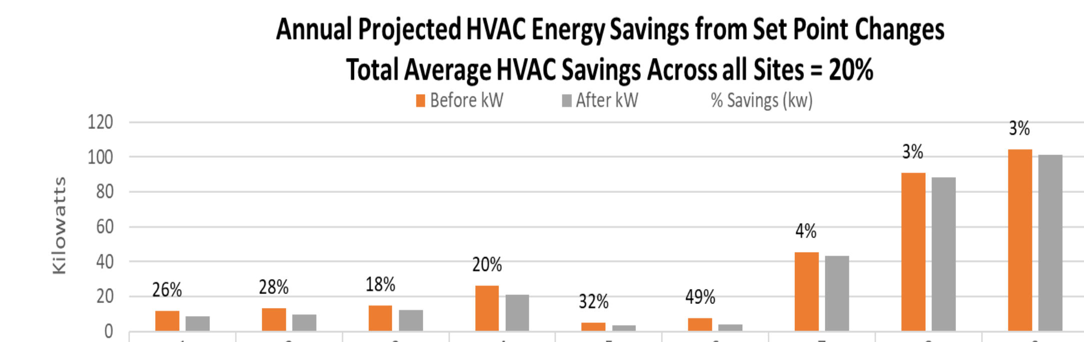


Figure 8 - Vertiv Performance And Set Point Display With Function Key

Nine sites were selected for this pilot (see Table 1) in conjunction with adding lockable and programmable thermostats to control the room temperatures. Utility incentives were awarded by Com Ed

to supply and install the thermostats and raise the set points. Energy use data was recorded and averaged 30 days prior to any changes (August 2019) and averaged for 30 days after the adjustments (September 2019). All sites were within 40 miles of each other, to maintain consistency of local weather impacts. The typical CRAC settings we encountered on this project had temperature set points of 68°F with a 2°F deadband. Humidity was 40% RH with a 10% deadband. The set points were raised by approximately 1°F per day over 2 weeks. There were no recorded thermal events or issues during this time.
The average outdoor temperature during August 2019 = 74°F and RH = 68%
The average outdoor temperature during September 2019 = 71°F and RH = 75%

Table 1 - Site Energy Reduction Percentages After Set Point Increase



	1	2	3	4	5	6	7	8	9
Before kW	11.6	13.27	14.91	26.24	5.1	7.6	45.28	90.8	104.3
After kW	8.58	9.5	12.19	21.1	3.47	3.88	43.28	88.44	101.2
% Savings (kw)	26%	28%	18%	20%	32%	49%	4%	3%	3%

Project payback period without incentives = 19 months

Project payback with incentives = 6 months

Summary

- Pre-adjustment energy savings estimate for this pilot was 5% of HVAC energy per site. Actual results averaged 20% of HVAC kWh savings.
- Addition of lockable thermostats allowed for a 60% project cost reduction via utility incentive
- Actual cost to adjust set points = $0 (self-performed by Comcast engineers)
- To date thermal events or impact at these sites with raised set points = 0
- Results of this pilot exceeded expected results

3.2. Blanking Panel Installation

Blanking panels (BPs) are a generic term for any device or product that will block open rack unit (RU) spaces in a typical production load cabinet, to prevent cold air from by-passing the in-rack devices. This by-pass conditioned cold air is considered wasted cooling, as it did not enter any production equipment and will return to the CRAC units unused. The BP is meant to plug the open rack gap and reduce the wasted cooling resource. See Figure 9 below. Blanking panels are an essential part of airflow management in a headend or data center and considered low hanging fruit to save energy and improve airflow distribution.

Figure 9 - Open RUs On Left, PlenaForm Systems Blanking Panels Installed On Right

3.2.1. Types Of Blanking Panels

There are various sizes of pre-manufactured products fitting 1,2,4,6 and 10 RU in a single piece of material. The material is generally a fire rated molded plastic, sheet stock or sheet metal panels. One of the most common rack sizes is 42 RU, any time there is an open RU space, a blanking panel should be installed to maintain industry best practices for airflow efficiency. Common product types are shown below in Figures 10 and 11.

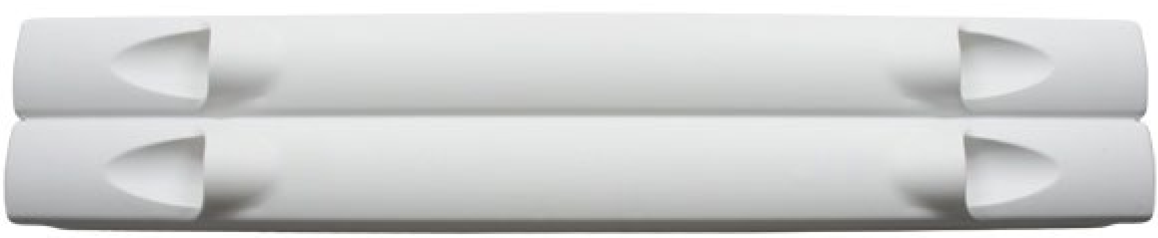
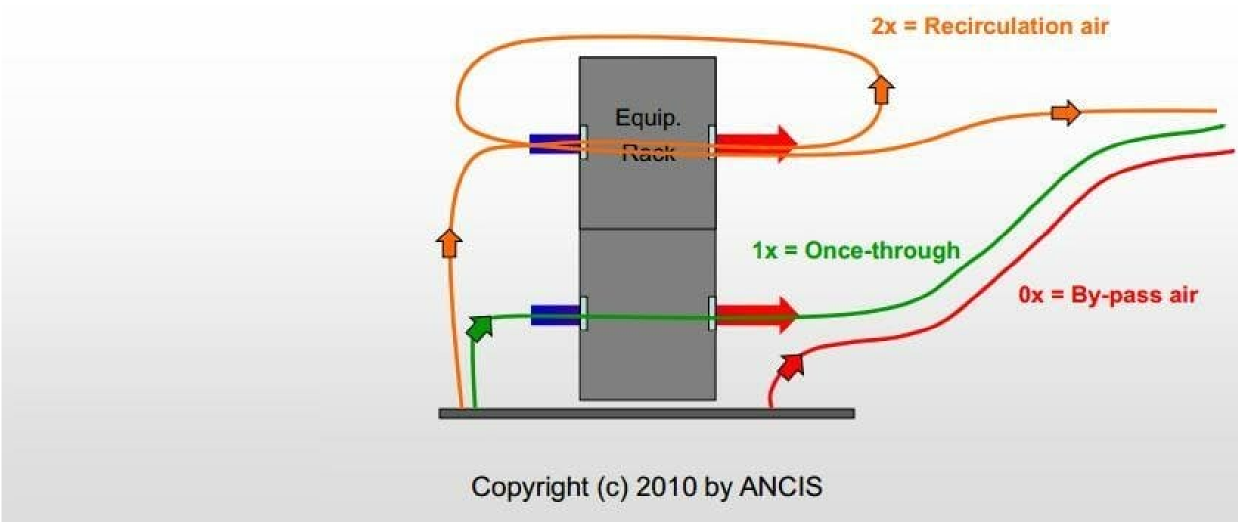


Figure 10 - Upsite Technologies 2 RU White Molded Blanking Panel

Figure 11 - Polargy PolarFlex Sheet Blanking Panel

3.2.2. Airflow Efficiency

The visual depiction of airflow through and around an IT rack is well described below in Figure 12 which is still relevant and accurate to show where energy and efficiency is lost. This timeless summary by Dr. Magnus Herrlin (Herrlin, 2010) represents the good, the bad and the ugly from an airflow perspective. Cooling resources that are introduced into a space that move through an IT device (router, switch, modem or server) to perform work is the good. Airflow that never reaches its intended target (the in rack devices) is downright bad and that air that gets caught in an endless recirculating loop over the top of a rack, at an aisle end or through a gap where the BP should be is just plain ugly. Airflow management is comprised of several components and variables including rack layout, rack equipment orientation, CRAC positions, ceiling height and more, yet blanking panels are simply a must and diligence to this requirement is critical for efficiency. Many spaces today do not have full BP installations, yet the rooms stay mostly in compliance by brute force of the air conditioning (i.e. always running). It is not necessarily that the space needs more cooling tons but rather that the airflow distribution is so poor that many units are running with fan only. This has unintended consequences as the HVAC fan motor produces heat which is now added to the room. As well by operating in fan only mode the HVAC unit is pulling in warm return air and pushing this warm air back into the room without conditioning, meaning the supply air temperature is actually being raised by the HVAC unit.



In the illustration above, from Herrlin's presentation titled Room-Level Energy and Thermal Management in Data Centers: The DOE Air Management Tool, you see that once-through cooling passes through the equipment rack only one time before returning to a cooling unit while recirculation air passes through twice. Bypass airflow on the other hand, does not pass through the equipment rack at all before returning to a cooling unit, hence bypass airflow.

Figure 12 - Visual Display of Airflow Anomalies

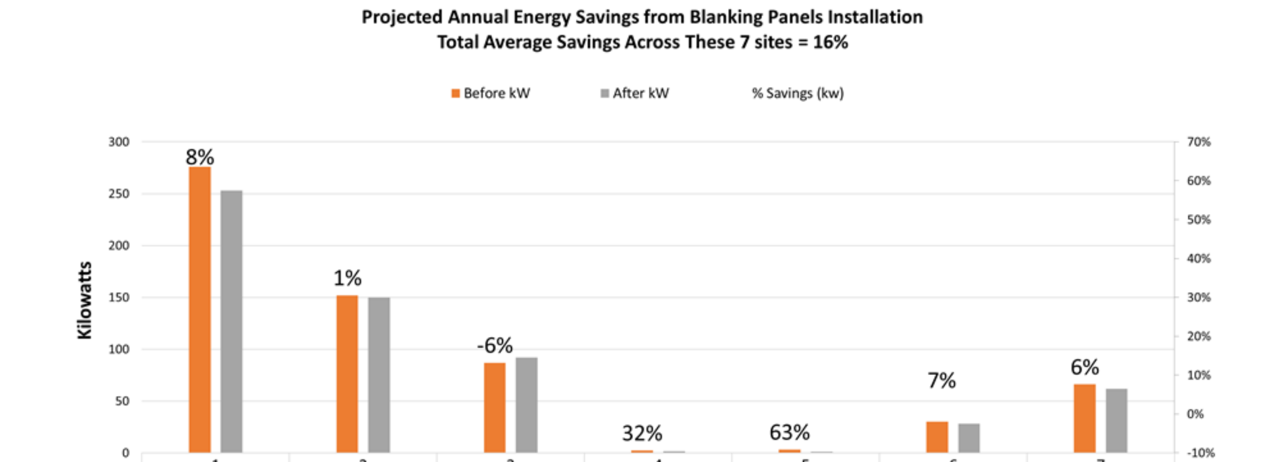
3.2.3. Blanking Panel Case Study Results

In this study we selected 7 sites across the US which were of varying sizes. We recorded the HVAC kW consumption before and after installation and examined consumption over the following 60 days. Weather changes were accounted for and data was averaged accordingly. One site in the west experienced an increase in energy use that was traced back to installation just before a prolonged and significant heat wave moved into this location. Labor to install was mostly self-performed with 3 sites using outside labor. Primary blanking panels used were the one and two RU molded plastic snap-in place devices.

Summary

- Pre-installation projections for HVAC cooling energy savings after blanking panel installation was 3-5%.
- The average energy savings reported as calculated from data in Figure 13 below was 16%. If we remove both the high and low readings from the list our average savings is 12%.
- The installation of blanking panels does not require any special tools or knowledge.
- Low cost low tech with high impact to cost reductions and reliability

Table 2 - Site Energy Reduction Percentages After Blanking Panels Installation



	1	2	3	4	5	6	7
Before kW	276	152	87	2.27	3.18	30	66
After kW	253	150	92.1	1.55	1.17	28	62
% Savings (kw)	8%	1%	-6%	32%	63%	7%	6%

3.3. HVAC Economizer Options

The term economizer has become a generalization for many of the technologies or components that make an HVAC device more energy efficient. These include variable speed drives (VSD) for fans and pumps, electronically commutated motors, dual circuits (refrigerant and glycol/water mix) at the condensers, variable compressors and direct outside air. The technology discussed here will pertain specifically to airside economization for packaged ground mount or roof top HVAC units (RTU), where ambient outside air is mixed or directly fed into the headend space when temperatures are favorable for use. Typically, this is an add-on option on many devices, but the investment is worthwhile as the payback period is quite short due to substantial energy savings achieved in most parts of the US and Canada as shown in Figure 14. With the exception of the states bordering the Gulf coast most of North America can support over 5000 hours of economizer operation which is 57% of the hours in a year (8,760 hrs annually). This is a significant reduction of time required to run mechanical cooling which reduces operational expenses (OpEx) and extends the life of equipment.

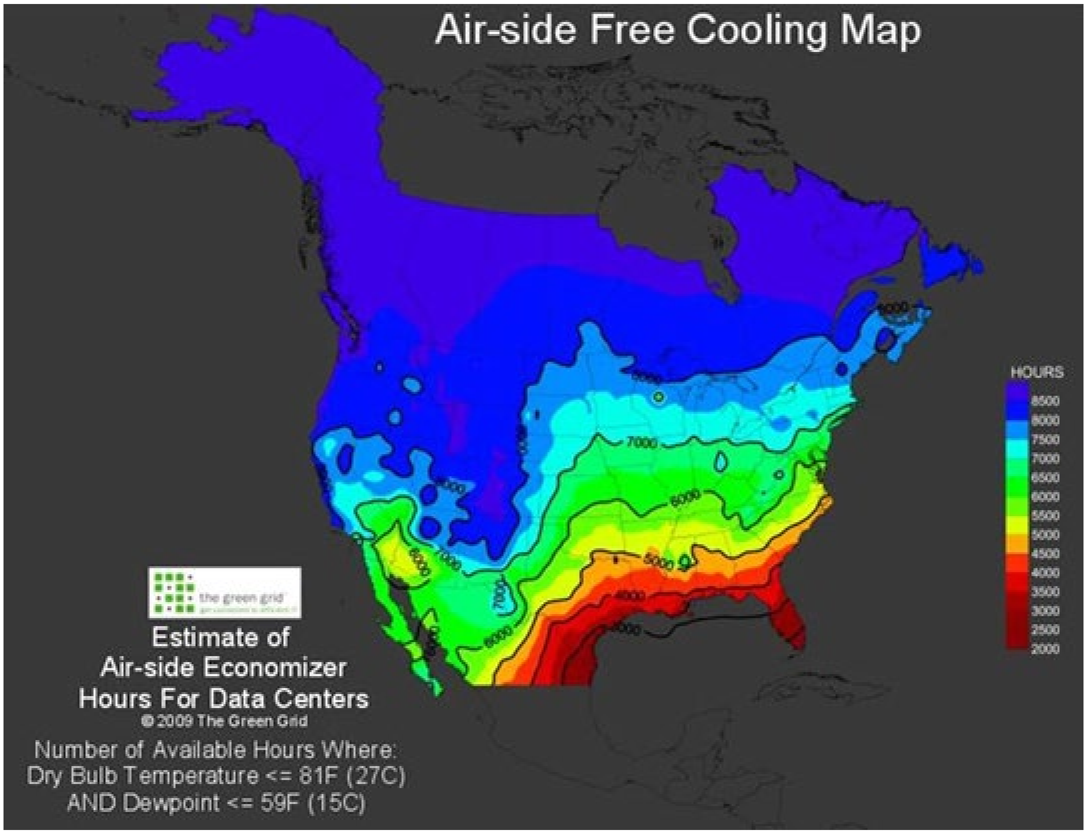


Figure 13 - Hours With Ideal Conditions For Air-side Economization (DOE And The Green Grid)

3.1.1 Economizer Operations

Most of the HVAC manufacturers combine the control operations of the Direct Expansion (DX) packaged HVAC device with the economizer components to provide for an automatic engagement when the outside weather is favorable or meets the requirements of the economizer set points (See chapter 1.4 of this paper). The economizer control setpoints will identify what the ambient exterior conditions need be to activate the dampers and louvers for fresh air mixing. Direct introduction of cold outside air into a space can create problems so the economizer should be mixing warm return air from the space with the colder air so thermal shock, low temperature alarms or condensation does not occur. This blending is necessary during colder winter months. Many geographical locations experience long term ideal conditions for economization and can position the set points for temperature, humidity, enthalpy or dewpoint control. It is typically the interior temperature set point that is the main controller or restrictor to full economization capability. If the set points for temperature and humidity are set higher than the economizer hours can be extended. Many manufacturers are using dew point temperatures as a more accurate and reliable control point for higher efficiency of their HVAC systems. The industry now recognizes that by allowing a wider range of RH, and given proper controls, a great deal of energy and water can be saved while maintaining acceptable IT performance. (Sorell, 2017). Simply stated the control system activates dampers to allow outside air into the device supply duct assembly providing cooling to the space and exhausts the hot room air directly outside. This can occur on one or all of the HVAC units per the sequence of operation set by the end user. As shown in figure 14 below of a sample HVAC unit dashboard the outside air (OA) is sufficiently cold for economization and the relative humidity is also sufficient to allow for economization.

The unit is allowing the OA damper to open to 46% mixing it with warmer return air to bring the supply temperature up to 54.3°F. The set point (return air temperature) for this space is set at 68.2°F which is unnecessarily low thus reducing many potential hours of economization.

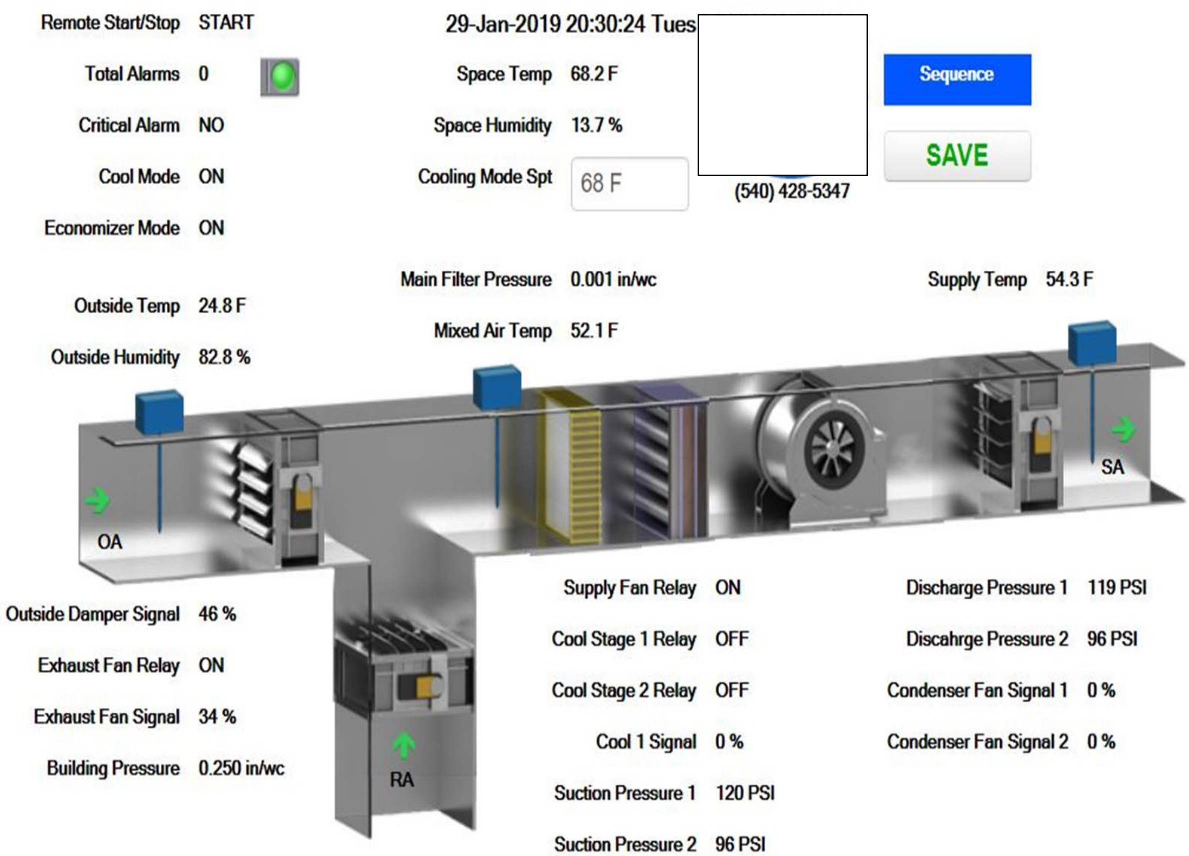


Figure 14 - Aaon Dashboard With Operational Performance Of Economizer

Figure 15 below shows a comparison of average Amps without Economizer engaged 55.6A (red) and with economizer engaged 28.9 (green) which results in a 48% energy reduction. The orange bottom line indicates when the economizer cycled on and off in October and November. This location seasonal climate change provides for 5 to 6 months of economization hours at a minimum when the control set point for activation of the economizer is set at 50° F.

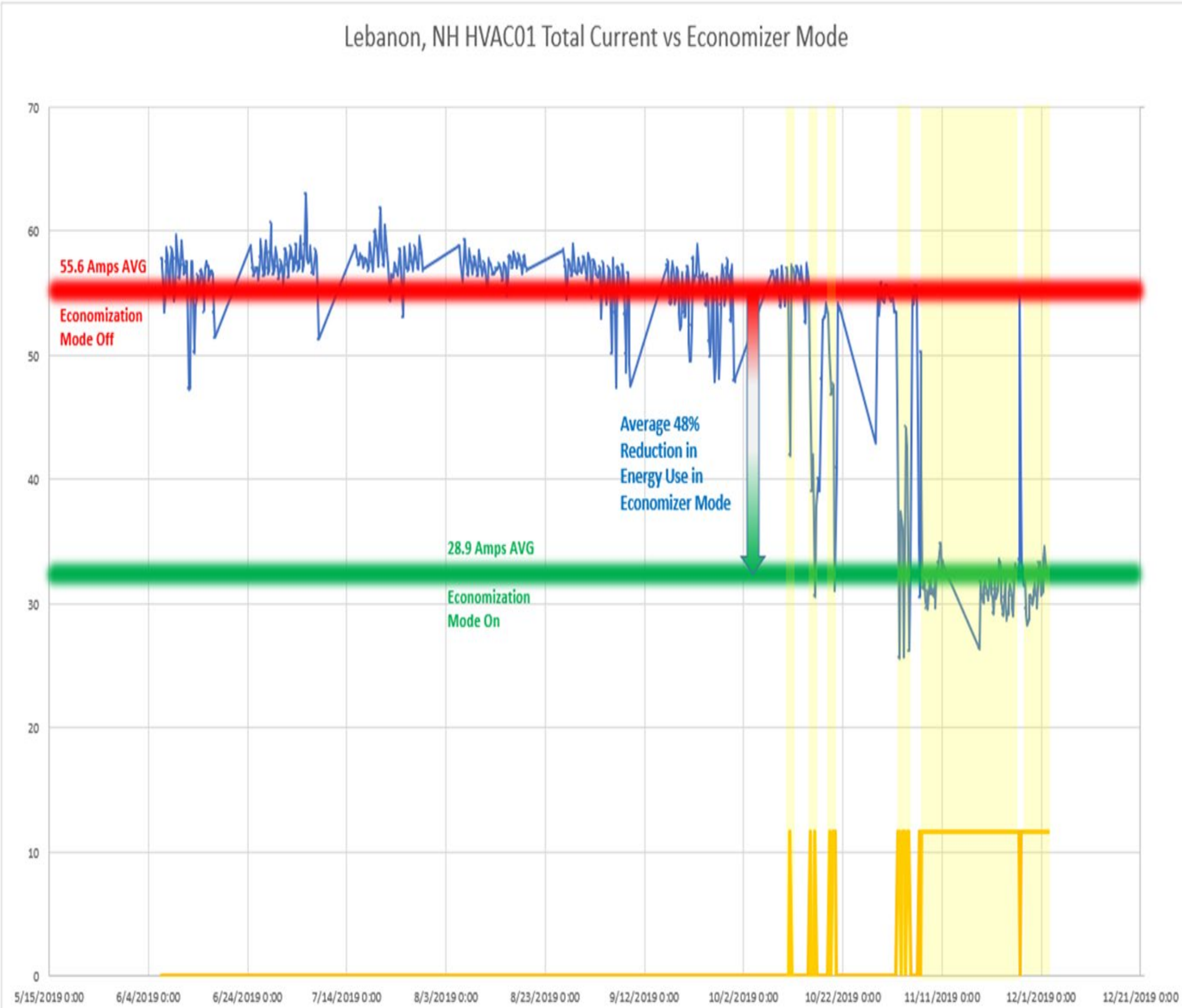
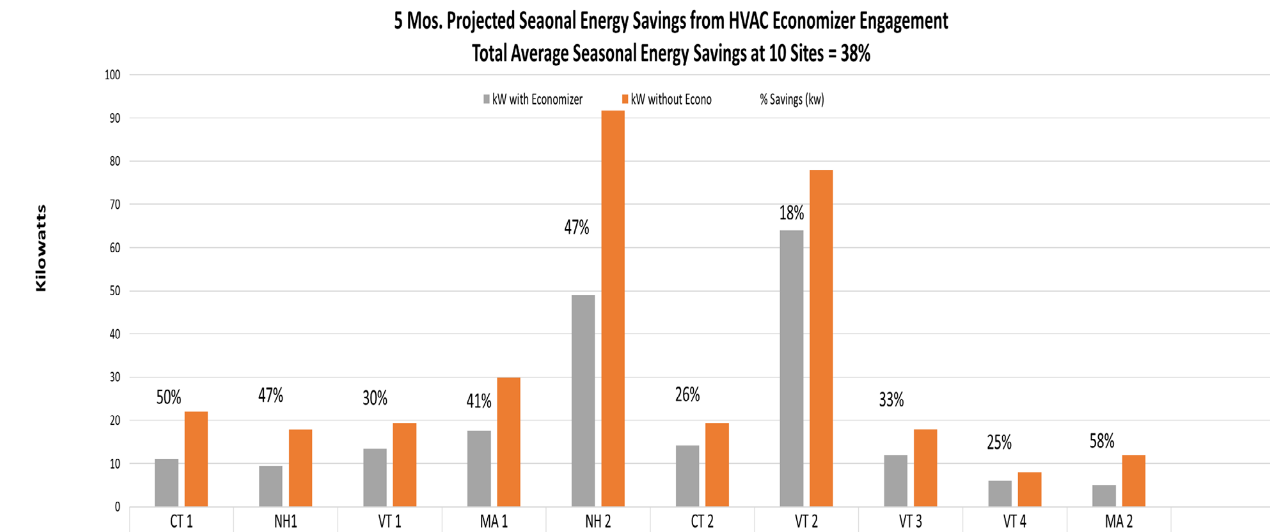


Figure 15 - Energy Use Comparison With And Without Economizer Activated

As shown in Table 3 the average energy savings projected across 10 sites is 38%. This figure can be increased by adjusting ambient room temperature control set points and the economizer set points. The MA 2 site indicated a reduction of 58%. These values seemed quite aggressive and with handheld meters and instruments our electrician confirmed the amp readings as correct.

Table 3 - 5 Month Projected Seasonal Energy Savings From Economizer Engagement



	CT 1	NH1	VT 1	MA 1	NH 2	CT 2	VT 2	VT 3	VT 4	MA 2
kW with Economizer	11	9.37	13.5	17.6	49	14.2	64	12	6	5
kW without Econo	22	17.8	19.3	29.8	91.7	19.3	78	18	8	12
% Savings (kw)	50%	47%	30%	41%	47%	26%	18%	33%	25%	58%

Summary:

- Most of North America is suitable for economization use
- Automated system controls require no manual intervention
- Significant energy reduction is achieved when economization is engaged
- Some state codes require economizer feature on HVAC

4. Conclusion

These three case studies have allowed us to identify substantial measured savings from multiple energy conservation measures. Although considered best practices blanking panels and many airflow efficiency measures often get overlooked or given low priority until an alarm indicates a thermal event. In many instances the network technicians who are “rack and stacking” their equipment in the space are not fully aware of the cost and impact of good airflow management resulting in limited compliance. On the other hand, those same technicians are keenly aware when a space is un-necessarily cold. It is not uncommon to see network or cabling tech’s wearing coats inside a headend with low set points and we can surmise that not only is that space wasting energy but the productivity of the workers are likely to be reduced as well. The economizer technology available today has become an outstanding energy saver and has not received the attention or accolades that should make it a requirement everywhere. Several states have adopted building codes and included HVAC economizers as mandatory, but the magnitude of savings should support inclusion regardless of codes. It is the intention of this paper to raise awareness to the potential for significant verifiable energy cost reductions and associated emissions that if deployed and measured across the cable industry would help achieve Energy 2020 goals quite easily. Susan JinDavis VP of Environmental Affairs and Chief Sustainability Officer of Comcast recently stated “Different energy strategies are needed for our various locations. We are choosing solutions based on what will make the biggest difference location by location, whether that‘s on-site solar, green tariffs, renewable energy supply contracts, or a combination. Across all of our operations, we want to find ways to not only power with renewables, *but to reduce our power needs overall*". As stated in the introduction the industry as a whole has been self-directed to maintain a commitment for efficiency and sustainability and the results of the measures presented here can provide financial justification for inclusion in long term planning and practices.

Abbreviations

AFO	Airflow Optimization
ASHRAE	American Society of Heating Refrigeration and Air-conditioning Engineers
CFM	Cubic feet per minute (airflow measurement)
Com Ed	Commonwealth Edison (Utility company)
CRAC	Computer room air conditioner
CI	Critical Infrastructure
Delta T	Difference in temperature
DF	Down Flow
DP	Dew point
ECM	Energy Conservation Measure
F	Fahrenheit
HVAC	Heating Ventilation and Air Conditioning
ISBE	International Society of Broadband Experts
OpEx	Operational Expense
RA	Return Air
RTU	Roof Top Unit
RH	Relative Humidity
SA	Supply Air
SCTE	Society of Cable Telecommunications Engineers
SNE	Small Network Equipment
STB	Set Top Boxes
TC	Technical Committee
VFD	Variable Speed Drive
VSD	Variable Frequency Drive

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