Energy Conservation Measure Recommendations for Cable Edge Facilities

Energy Audits and Analysis of Ten Cable Headends

A Technical Paper prepared for SCTE/ISBE by

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1. Introduction and Executive Summary

Comcast contracted Hitachi Consulting to explore energy conservation measures (ECMs) at five headend sites in the West Division and five in the Central Division. The task involved an on-site energy assessment, development of computational fluid dynamic (CFD) models of existing airflow conditions, and recommendations of ECMs for each headend. The effort resulted in identification of three key measures that apply broadly to Comcast headends and hubs: airflow optimization, advanced HVAC controls, and replacement of older, less efficient and ozone-depleting refrigerants. Implementing these three measures would provide a 5-year energy savings opportunity for the ten sites of just over $1.5 million, with the annual savings being just over $300,000. Hitachi Consulting also assessed LED lighting opportunities at the ten headends. Implementation of LED lighting and controls would provide a 5-year energy savings opportunity for the ten sites of just over $300,000, with the annual savings being just over $60,000.

The motivation for the effort is the fact that cable headends and hubs often do not employ the most modern cooling practices such as contained equipment aisles with hot/cold aisle discipline, which is now common in most data centers. These headends and hubs consequently have far more cooling capacity that would otherwise be needed. The challenge is to explore what could cost-effectively be done in these facilities to achieve significant energy savings in a reasonable payback period.

Detailed cost proposals from a multitude of subcontractors across all sites was not feasible for the present effort. However initial estimates indicate that payback periods on the order of 3 years or under are feasible for most sites and with sites in states with higher utility rates paying back even sooner. The estimated range of implementation costs varies from approximately $40k to $160k, depending mainly on the size of the site. The true cost of implementation and payback period can only be determined from piloting the ECM implementations and measuring the actual energy savings obtained in the pilots.

In addition to potential energy consumption and cost savings benefits, there are also significant performance and customer satisfaction improvements that come from having more efficient, robust, and redundant cooling in headends and hubs. The benefits of the airflow optimization, advanced HVAC controls and refrigerant replacement also improves:

- power margin
- site resiliency towards R-22 phase-out by 2020
- normalizing inconsistent temperatures across the inlet side of the equipment
- reduces overheating equipment situations with no alarms
- adds HVAC redundancy
- and extends the useful life of the HVAC technology.

All of this leads to significant operating expense (OpEx) cost reductions and improved customer satisfaction via reduced IT equipment downtime.

More optimized cooling technology can also reduce the cost of future capital investments by lowering the tonnage of cooling required in replacement projects. The reduction of total energy consumption at headends and hubs can also enable more sites to be viable for alternate energy projects that seek to reduce Comcast's dependence on the electrical grid and reduce the carbon footprint overall.

The specific energy conservation measures recommended in this effort include:

Air Flow Optimization (AFO):

- Increase utilization of blanking panels in all racks to limit the hot and cold air to a specific space and limit infiltration within the racks
- Increase utilization of top of aisle containment to limit hot air recirculation and infiltration over the top of the racks
- Increase utilization of end aisle containment (strip curtains or end panels/doors) to contain cold aisles and prevent infiltration of cold air
- Redirect and/or add additional supply ducting to deliver cold air directly into contained cold aisles
- Reposition and/or add additional return ducting to facilitate hot air return to CRAC units

HVAC Controls:

- Add advanced HVAC controls to optimize key components of the HVAC system to reduce HVAC energy consumption by 15-25%

Refrigerant Replacement:

- Install nextgen replacement refrigerants that extend the life of existing HVAC systems and can also increase efficiency and capacity over R-22 and R-407C by as much as 20%
- As part of refrigerant replacement and/or installation of advanced controls, "true-up" the HVAC equipment to address any performance issues and bring it back to nominal operation.

In this report, the results of detailed site visits, modeling and recommendations for each of the ten headend sites will be presented, followed by an analysis of the portfolio overall as well as conclusions and recommendations from the effort.

The ten Comcast headends covered by this report are:

West Division Sites
- Roseville, MN
- Hayward, CA
- Santa Clara, CA
- Beaverton, OR
- Burien, WA

Central Division Sites
- Stone Mountain, GA
- Atlanta, GA
- Jonesboro, GA
- Woodstock, GA
- Augusta, GA

The potential energy savings associated with implementation of these three ECMs at the 10 headend facilities is summarized in Table 1 below. The average utility rate for these 10 sites was $0.081, and as stated in the introduction, when all sites are considered, the total energy cost savings over 5 years was estimated to be $1.5M.

Table 1 - Energy Savings Analysis for ECM Implementation at All Ten Headend Sites

Facility	Size / Max IT Load (provided by Comcast)	Energy Savings (kWh)	% HVAC Energy Reduction
Roseville, MN	24,175 ft2 / 470 kW	311,133	22%
Hayward, CA	33,000 ft2 / 330 kW	213,206	26%
Santa Clara, CA	28,800 ft2 / 460 kW	284,735	17%
Beaverton, OR	13,737 ft2 / 1,100 kW	479,090	23%
Burien, WA	6,561 ft2 / 530 kW	306,214	19%
Stone Mountain, GA	25,596 ft2 / 960 kW	704,865	19%
Atlanta, GA	24,626 ft2 / 1,000 kW	751,019	19%
Jonesboro, GA	6,467 ft2 / 220 kW	170,482	36%
Woodstock, GA	6,720 ft2 / 430 kW	384,536	38%
Augusta, GA	10,245 ft2 / 210 kW	142,933	24%
All Facilities	179,927 ft2 / 5,710 kW	3,748,213	22%

Table 2 below shows statistically how the rack inlet temperature changed before and after AFO implementation for all ten headend sites. Note that 383 racks with max inlet temperatures of 80°F or more have been fixed, and if the desired maximum inlet temperature is 75°F or less, then implementing the airflow optimization ECMs brings 466 racks into the standard, even after the set point is raised in the facilities with airflow optimization.

Table 2 - AFO statistical impact on rack inlet temperature distribution after set point increase for all 10 headend sites.

Range of Max Inlet Temperature	Number of Racks *		
	Baseline	After AFO ECMs	After AFO ECMs and Set Point Increase
Above 80°F	384	1	1
Between 75°F and 80°F	222	47	139
Between 70°F and 75°F	329	246	714
Below 70°F	781	1,422	862
Total	**1,716**	**1,716**	**1,716**

* Number of racks for all three scenarios does not include Beaverton, OR – Phase 2 headend, Stone Mountain, GA – VPC2 and Atlanta, GA – IT Room as these rooms were not recommended for AFO due to discontinuities in hot/cold aisle layouts and therefore raising the set point temperatures would achieve

significant energy and cost savings. The table also does not include 304 empty racks from some of the sites that did not have any installed IT equipment at the time of the audit.

2. Site Audits and Analysis

2.1. Procedure

For each site, a detailed site assessment was performed, involving tasks prior to the site visit, the actual site visit, CFD modeling of the airflow in the critical spaces within the site, analysis of the results, recommendations for ECMs and finally estimation of the energy savings which would result from each ECM individually as well as the combined impact of all recommended ECMs. The following tasks were performed for each site:

- HVAC equipment: Assessments of the following units, if applicable.
    - Packaged rooftop units (RTUs)
    - Computer room air conditioning (CRAC) units
    - Wall-packaged units
    - HVAC control system, or building automation system (BAS), where applicable
- Datacom Equipment
    - Equipment racks and rows of racks that may be candidates for aisle containment
- Assessment tasks
    - HVAC
        - Review and document as-programmed controls sequences of operations for the HVAC systems and equipment;
        - Document nameplate data and physical condition of the installed HVAC equipment;
        - Review and document building automation system (BAS) user interface, graphics access, and overall system capabilities (if applicable);
        - Document location of supply and return air diffusers;
        - Document identified solutions for analysis and consideration.
    - IT Equipment
        - Statistically sample and verify rack electronics to help quantify CFD model confidence.
        - Verify floor plan and rack layout on-site against existing equipment lists and site diagrams;
        - Document blanking panels utilized on-site (via pictures/on site estimates);
        - Capture thermal images to document/verify hot zones with larger critical equipment;
            - Document CFM and temperature differential for these equipment types for CFD modeling; and
        - Measure the CFM, temperature, velocity of each mass inlet and outlet locations such as perforated tiles, return and other supply vents.
        - Measurement of the vent dimensions and the calculation of vent free-area.
        - Locations of the thermostats and other external temperature sensors.

For the CFD modeling, analysis and airflow optimization recommendations, the pre-audit data such as floor plans and equipment lists from Comcast databases were verified and corrected if needed during the site audits. Additional information on the HVAC units and supply and return temperatures/CFM were collected while on site. All this information was input into a commercial CFD modeling tool. Next, thermal images captured at the site were used to calibrate the CFD model. The thermal images were used to adjust the power consumption (heat load) of the IT equipment as recorded in the Comcast databases to better match the conditions at the site. In addition, annual kWh existing in the form of utility bills were cross referenced as a sanity check on the overall calibrated IT load for each site. Next, several models with various AFO ECMs were created. The most viable model for optimally producing energy savings while maintaining performance was selected for each of the sites. Finally, a scenario with increased set point temperature was created such that all rack inlet temperatures are still within the ASHRAE recommended range (64°F-80°F) for realizing the energy savings resulting from airflow optimization. The following flow chart summarizes the procedure:

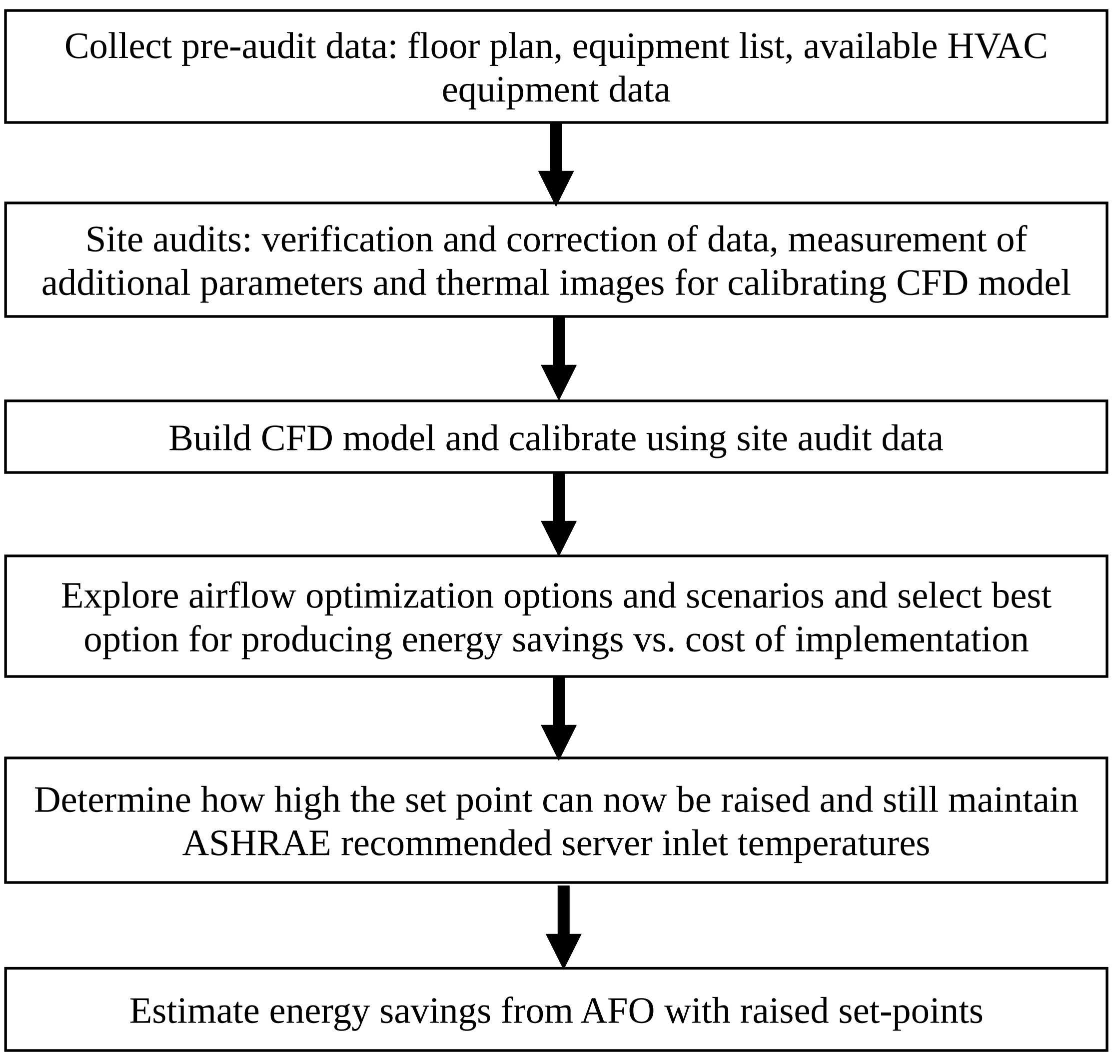

Figure 1 - Process flow chart for airflow optimization and energy savings estimation.

2.2. Example Site Assessment for Beaverton, OR

In the interest of space, only one example of a detailed site assessments and ECM recommendations will be provided here. The Beaverton facility is a one-story building located just west of Portland, OR with two headend rooms (Phase 1 and Phase 2) and an administration/office space. The building is typically occupied by Comcast staff and contractors at least 12 hours a day during weekdays with marginal occupancy on weekends.

The headend space has two (2) zones with critical equipment: “Phase 1” and “Phase 2”.

1. Phase 1 headend is comprised of 36 racks of local market equipment and is cooled by two (2) 16.5 ton Liebert CRAC units. The space has both hot-cold and mixed aisle configurations. Currently neither end-of-aisle containment nor rack containment is in place. The Phase 1 headend is cooled by two (2) – 16.5 ton Liebert CRAC up-flow units. There is no ducting; the air is simply directed from the Liebert units towards the equipment aisles.
2. Phase 2 headend is comprised of 328 racks of local market and regional data center equipment and is cooled by eight (8) 31.5 ton up-flow Liebert CRAC units. The space has limited hot/cold aisles with most of the aisles being mixed aisles where exhaust from one rack row can flow into the front of the inlet side of the adjacent rack row. There is no end of aisle containment and limited use of blanking panels. All the CRAC units have supply ducting, however there is still a lot of heat buildup, primarily due to the long distance from the sources of the heat to the returns of the Liebert CRACs. Heat also builds up since all the returns to the CRACs are at floor level and not necessarily lined up with any specific hot aisle.

The administration/office space is cooled with four roof top units (RTUs).

Figure 2 and Figure 3 below shows the current layout of the Phase 1 and 2 spaces utilized for CFD modeling, respectively, with labels depicting hot, cold and mixed aisles.

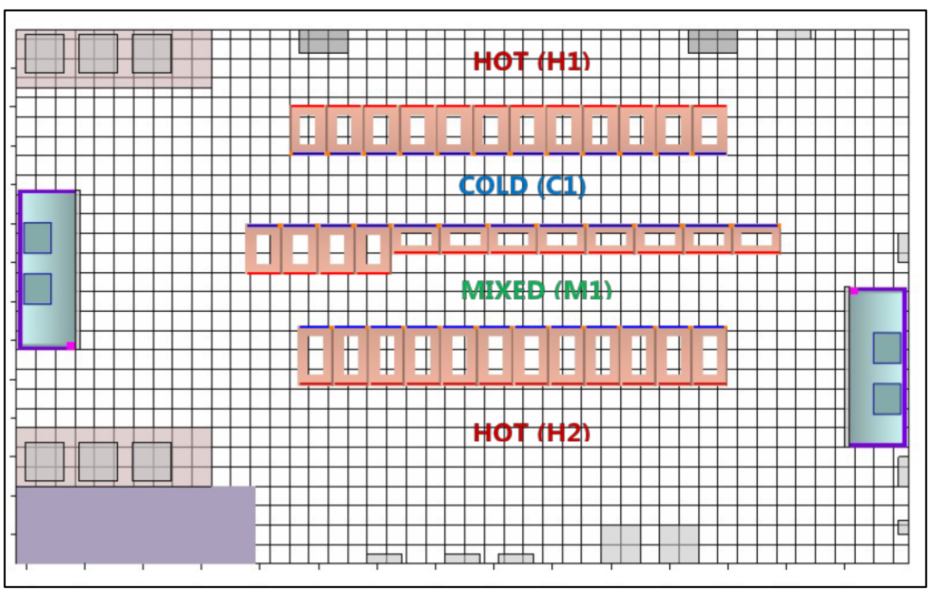

Figure 2 - Layout of the Beaverton headend – Phase 1 headend room.

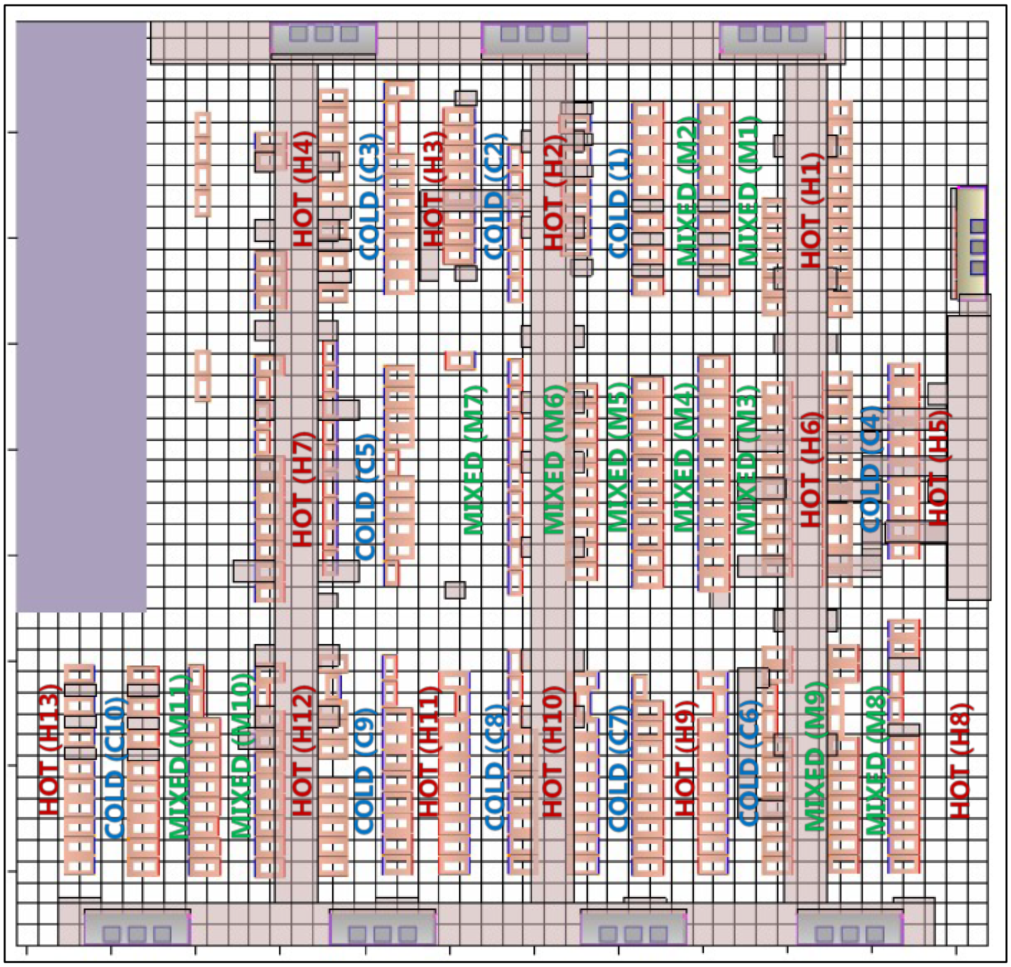

Figure 3 - Layout of the Beaverton headend – Phase 2 headend room.

It should be noted that it is extremely common to find mixed aisles in telecommunications edge facilities. The fact that hot/cold aisle discipline is beginning to be established in this example facility puts it ahead of the curve and enables the kind of energy savings that are sought in these edge facilities.

Table 3 below summarizes the overall facility specifications for the Beaverton headend facility. Note that the stated IT load in Table 3 is based on summing the equipment power consumption values from the Comcast database prior to the onsite audit. Since many of the chasses of the larger IT devices are only partially populated and actual power consumption is typically less than the nameplate value, the database power value is generally higher, and can often be significantly higher than the actual IT load. For this facility the calibrated IT load determined after the site audit was calculated to be 446 kW instead of 1,100 kW. It is not uncommon for actual site IT loads to be on the order of half the nameplate/stated IT loads, however exceptions do occur, thus a methodical procedure should be used for each site modeled.

Table 3 - General facility summary for Beaverton, OR.

Gross Building Size	13,737 ft^2
Spaces/Zones	• Headend: Phase 1 (local market) and Phase 2 (local market and regional datacenter) • AC and DC power rooms • HVAC utility room • Administrative (office, storage, restrooms, technical workspace)
Critical Net Floor Area	Phase 1: 1,083 ft^2 Phase 2: 7,040 ft^2 **Total: 8,123 ft^2**
Stated IT Load	1,100 kW (Phase 1 and 2)
Calibrated IT Load	Phase 1: 33 kW Phase 2: 413 kW **Total: 446 kW**

2.2.1. Site Findings

2.2.1.1. HVAC Systems

The Phase I headend space uses hot aisle/cold aisle configuration in many areas, however the Phase II headend space has a significant number of mixed and non-contiguous aisles that creates challenges for AFO-based energy savings that have acceptable payback periods. This is because of the large number of blanking panels needed, plus the end aisle containment required. Further, even in well-defined hot and cold aisles, the CFD modeling revealed that hot exhaust can still pass through large rack openings to get into the cold aisle and mix with the supply air, thereby raising the intake temperatures. Blanking panels would definitely help but would reduce mixing much more effectively if coupled with a more consistent hot/cold aisle configuration, which may require either moving equipment and/or racks in the near term, or alternating waiting to add blanking panels until the existing process of decommissioning IT equipment and adding new equipment in proper hot/cold aisle manner plays out sufficiently to ensure the blanking panels accomplish the AFO goals.

All the CRAC units use either of type R-22 or R-407C refrigerants in their direct expansion (“DX”) cooling circuits, which allows the opportunity to improve both energy efficiency as well as eliminate ozone-depleting older refrigerants via replacement of these refrigerants with next generation types.

The site HVAC system types and conditions are summarized in Table 4 below.

Table 4 - HVAC system type and conditions for Beaverton, OR.

Primary Cooling Systems	• Headend – Phase 1 room is cooled with two (2) Computer Room Air Conditioner (CRAC) units. • Headend – Phase 2 room is cooled with eight (8) Computer Room Air Conditioner (CRAC) units. • Admin space is cooled with four roof top units (RTUs).				
Primary Heating Systems	2 - Trane heat pumps and 2 - Trane gas-fired RTUs				
Air Distribution	Phase 1 room: no ducting; Phase 2 room: Single integrated ducting system tied into all CRAC units				
HVAC Redundancy	Phase 1 room: numerical only; Phase 2 room: yes				
Controls	No advanced HVAC controls in use				
HVAC Equipment	**Unit**	**Date**	**Age (years)**	**Tons**	**Refrigerant**
	CRU-1	Aug-99	18	16.50	R-22
	CRU-2	Sep-99	18	16.50	R-22
	CRU-3	Sep-00	17	31.50	R-22
	CRU-4	Sep-00	17	31.50	R-22
	CRU-5	Sep-00	17	31.50	R-22
	CRU-6	Sep-00	17	31.50	R-22
	CRU-7	Sep-00	17	31.50	R-22
	CRU-8	Sep-00	17	31.50	R-22
	CRU-9	Sep-00	17	31.50	R22
	CRU-10	Apr-10	7	30.00	R-407C
	HPU-SR1	May-01	16	7.50	R-22
	HPU-SR2	May-01	16	7.50	R-22
	RTU-PWR2	Mar-01	16	10.00	R-22
	RTU-PWR1	Mar-01	16	10.00	R-22
Total Air Flow Demand*	Phase 1: ~10,679 CFM (CRAC Units) Phase 2: ~59,708 CFM (CRAC Units)				
Total Air Flow Supply	Phase 1: ~16,800 CFM (Based on CRAC unit nominal capacity) Phase 2: ~113,450 CFM (Based on CRAC unit nominal capacity)				

*Approximate calculation based on the IT load and an average increase of 20ºF across the IT equipment

2.2.1.2. HVAC Findings

An energy audit of the site to support CFD modeling and develop ECM recommendations was performed on January 23-25, 2017. In addition to verifying the HVAC and IT equipment in use, as well as presence and location of ducting and thermostats, the condition and performance of the HVAC systems were measured and observed. Infrared thermal images of hotspots and other strong sources of heat, and supply air temperatures and flow measurements at the diffusers were also gathered to help calibrate the CFD models.

The following summarizes observations from the site audit on current site conditions and opportunities for improvement:

1. The headend rooms (Phase 1 and Phase 2) both have considerably more tons of cooling than the IT equipment load would mandate yet are challenged in maintaining a uniform cool temperature across the room. The Phase 1 room has over three times the cooling tonnage needed for the IT heat load, while the Phase 2 room has over twice the cooling tonnage required for the IT heat load and with its ducting configuration does have redundancy. The overcooling is common in edge facilities due to the significant amount of mixing of hot and cold air in these facilities.
2. There appears to be a mismatch between the rack airflow demand and supply in certain areas, which is resulting in hotter inlet temperatures in those areas (as captured by thermal images).
3. A reoccurring inefficiency is external hot to cold aisle rack recirculation, i.e., the removal or transport of heat produced back to the return intakes of the CRAC units. In many cases, the heat appears to spill over the top of the racks, or goes through and around them into the next aisle, compounding the problem.
4. The inefficiency in removing heat from the room is also demonstrated by the temperature of the return air to the CRAC units which has a range of 66^0 F to 75^0 F with an average of 71.5^0 F.
5. The headend space contains some hot/cold aisle configuration, but still has many mixed aisles with racks aligned in the same direction and often right next to a hot/cold aisle.
6. The Phase 1 room lacks true HVAC redundancy; if one of the CRAC units fail or lose power, equipment in certain zones will not get the sufficient cooling they need to avoid overheating. This is also common in telecommunications edge facilities.
7. The Phase 2 room has true HVAC redundancy, but still lacks ducting to every aisle, thereby reducing the effectiveness of the HVAC redundancy.
8. Both headend rooms lack sufficient blanking panels and other measures to contain all racks.

2.2.1.3. Energy Profile

Table 5 shows a summary of the Beaverton headend energy profile collected from utility data, equipment data from the Comcast database and later calibrated, and information collected on-site.

Table 5 - Summary of energy supply/demand at Beaverton, OR.

Energy Sources	Electricity (Grid)
Calibrated IT Load	Phase 1: 33 kW Phase 2: 413 kW **Total: 446 kW**
Sub-Meter Data Availability	None available
Energy Utility Provider(s)	Portland General Electric
Baseline Annual Electricity Consumption (kWh)	6,404,800
Utility Rate ($/kWh)	$0.074
Annual Electricity Cost	$474,319
Baseline Annual Natural Gas Consumption (therms)	N/A
Utility Rate ($/therm)	N/A
Annual Natural Gas Cost	N/A
Estimated PUE*	1.73
***PUE listed is an estimate based on utility bills and calibrated IT load. To calculate actual PUE, sub-metering of IT and headend space is required.**	

Hitachi Consulting and Comcast compiled monthly energy utility consumption and cost through past bill requests from utility providers. The chart in Figure 4 below illustrates the trend of electric use and demand for 24 recent months. There is an overall upward trend in energy consumption over the two years shown in the chart: the average daily kWh per month in January-March 2017 is about 18% higher than the values in January-March 2015.

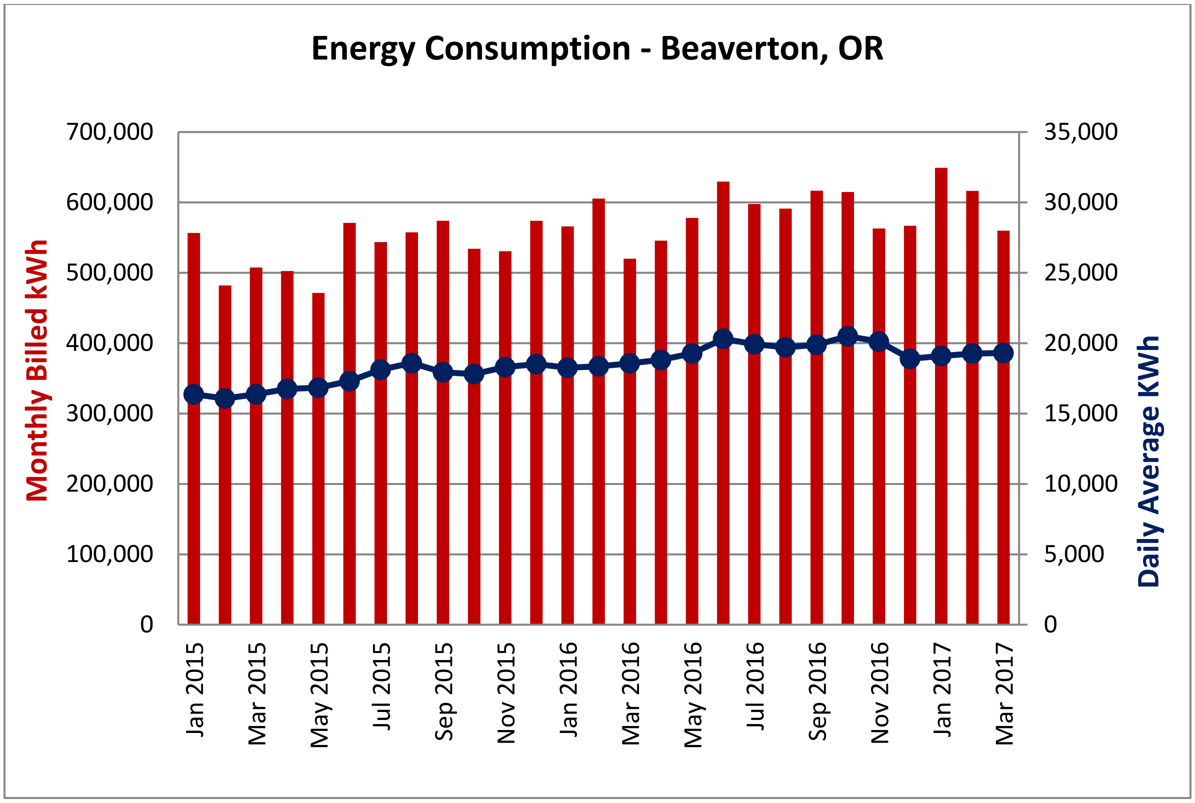

Figure 4 - Historical monthly utility consumption for Beaverton, OR.

Table 6 below summarizes the measured and estimated values for electrical load types found in the facility and Figure 5 depicts the relative consumption amounts. The critical IT load accounts for most of and the electricity demand and consumption at the facility. This load was calculated utilizing equipment data for the site, calibrated by thermal images through the CFD model.

Table 6 - Energy load and consumption by building system for Beaverton, OR.

Baseline Electrical Load	Load (kW)	kWh
Critical IT	446	3,907,000
HVAC (compressors, fans, etc.)	240	2,104,000
Lighting	8	74,000
Other Load (UPS losses, Plug Load)	37	320,000
Total	**731**	**6,405,000**

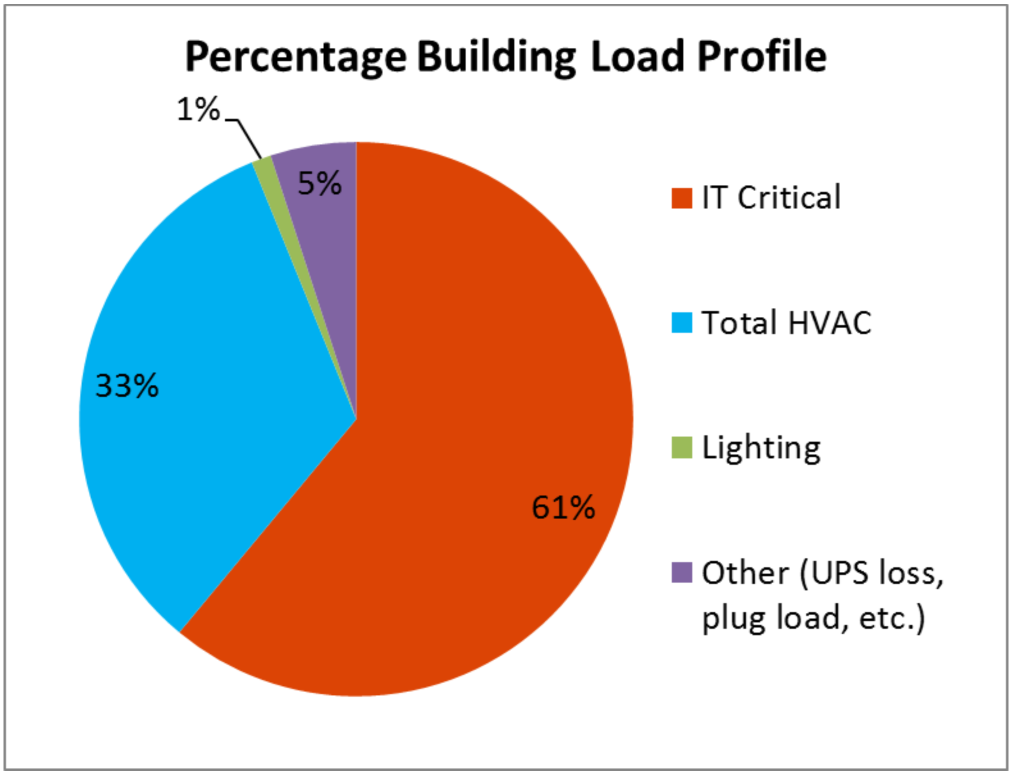

Figure 5 - Energy load percentage by building system for Beaverton, OR.

Note that since the IT and/or HVAC energy consumption is not currently monitored at the facility, it is only possible to estimate the current PUE of the facility using the calibrated IT heat load of 446 kW and a total average load of the headend space of 731 kW. These numbers result in an estimated annualized PUE of 1.73, which means the facility presents a solid opportunity for energy efficiency improvements. The recommended installation of ECMs could help reduce the PUE value. Making use of its metering capabilities, the installation of advanced HVAC controls on all HVAC systems at the facility would also permit an accurate PUE to be determined not just as an annual average, but throughout the year. The sensitivity of the facility energy efficiency to many factors such outdoor temperature as well as IT load changes could be accurately monitored, as could also the health of the HVAC systems and the impact of the energy efficiency improvements.

2.2.2. Computational Fluid Dynamics (CFD) Modeling Results

2.2.2.1. Baseline CFD Model: Phase 1 Headend

Figure 6 below shows the CFD model results for existing airflow conditions in the Phase 1 headend room at Beaverton, OR. The baseline model was calibrated based on the thermal images captured at the site. A wide range of temperatures across rack inlets were observed due to the lack of containment and lack of hot/cold aisle discipline. The mixed aisle M1 between rows 16 and 17 contains several CMTS devices, the intakes of which are exposed to the hot exhaust of the equipment in aisle 17. Fortunately, since the CMTS devices are located at the bottom of the racks in row 16, they are still getting relatively cool air, as can be seen in the thermal image below in Figure 7. However, if additional devices are added to these racks towards the top of the rack, they will be exposed to the hot exhaust more directly. Alternately, if additional equipment is added to row 17 such that additional hot air exhaust is fed into aisle M1 and no airflow optimization is deployed, it is possible that the CMTS devices would have significantly increased intake temperatures.

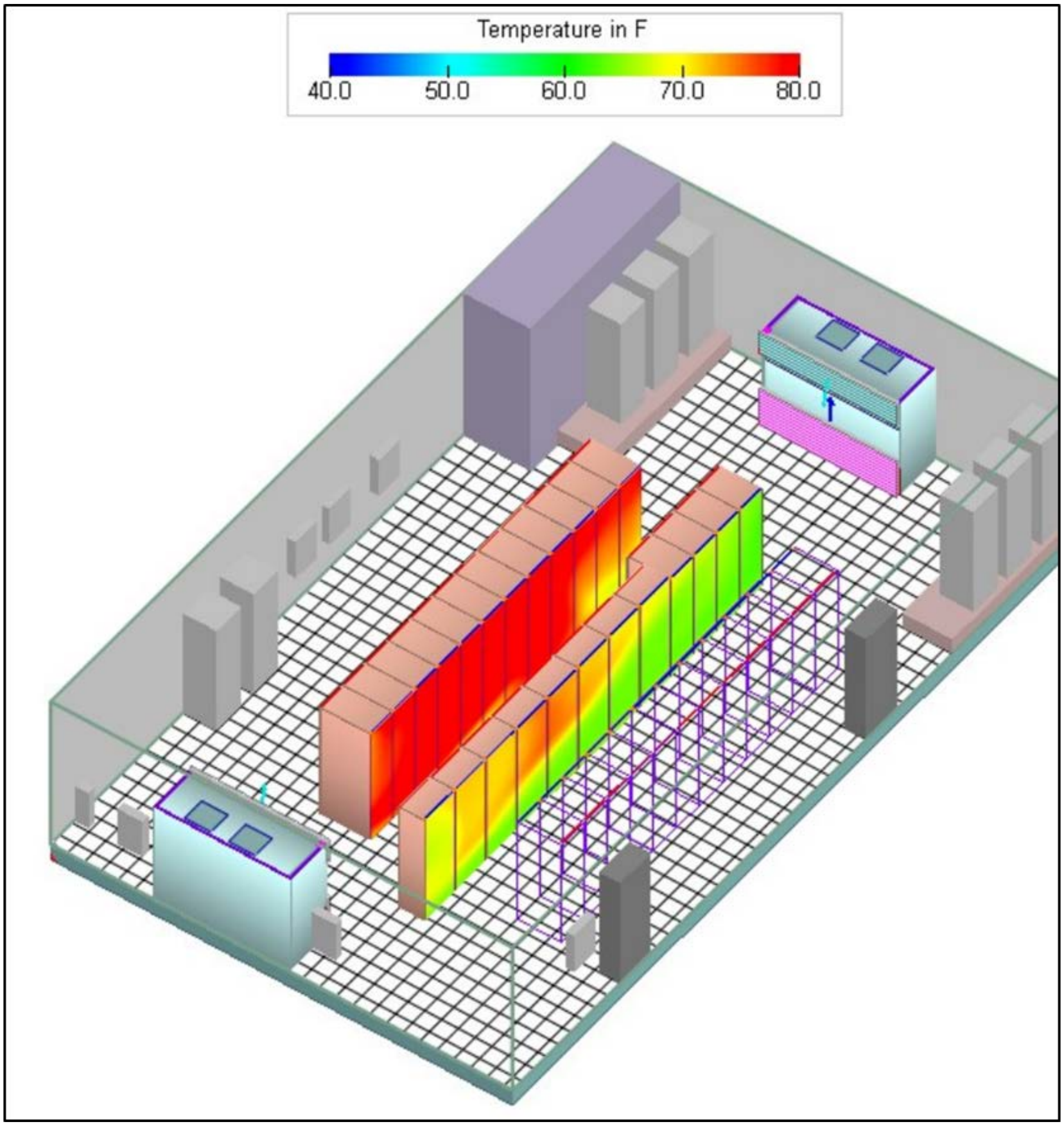

Figure 6 - 3-D model of rack inlet temperature distribution for Beaverton, OR – Phase 1 headend room.

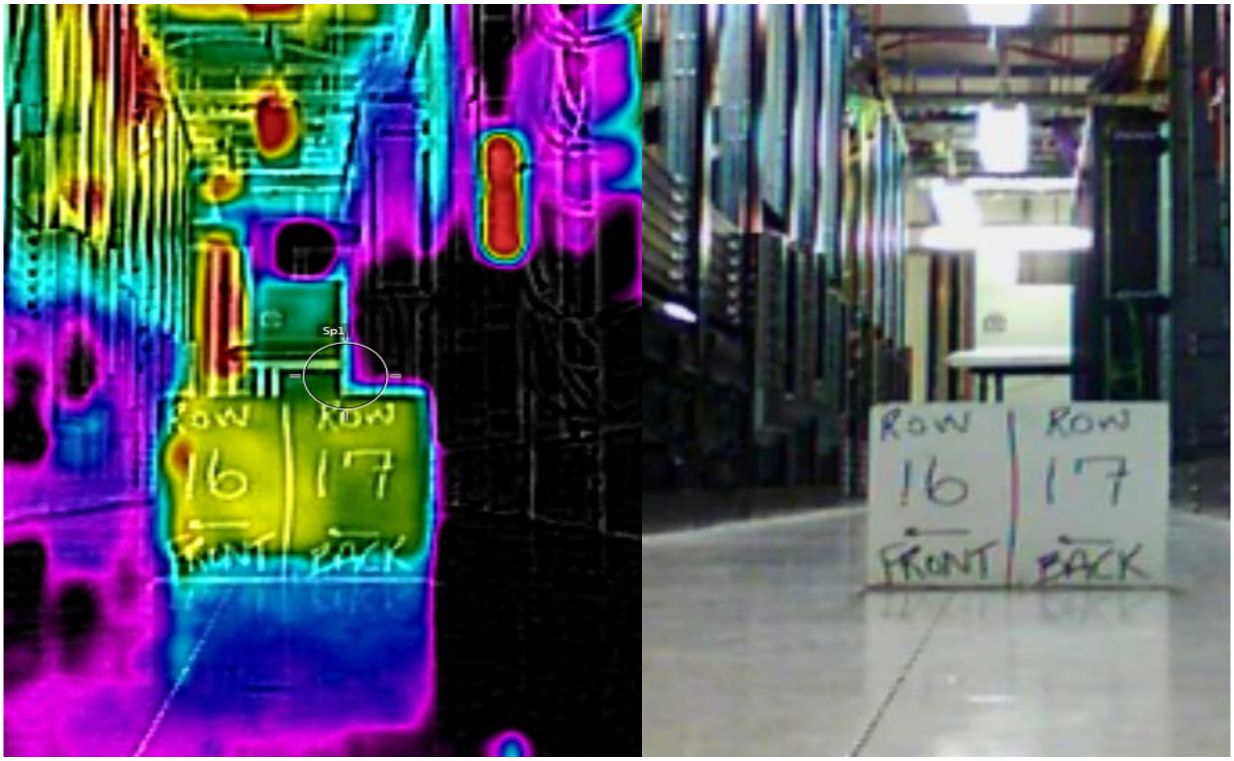

Figure 7 - Thermal (left) and standard (right) images of rack rows 16 and 17 in the Phase 1 headend room.

2.2.2.2. Air Flow Optimization ECM Recommendations: Phase 1 Headend

Hitachi Consulting utilized CFD modeling to design and optimize the airflow by iteratively building in various efficiency measures which allowed for the channeling of hot air more efficiently toward CRAC unit return vents and away from equipment inlets. Better cooling for critical equipment and elimination of hot spots was the overarching goal and once the areas exhibiting these issues were corrected and considerably improved, set points could be raised. For the Beaverton Phase 1 headend, Hitachi Consulting recommended the following AFO measures:

- Top and side containment of both the cold aisle C1 and the mixed aisle M1 via:
  - Addition of blanking panels;
  - Addition of top rack containment panels.

Figure 8 below shows a CFD model screen capture of the improvement in the rack inlet temperature across the Phase 1 headend facility after the AFO recommendations are implemented. The main aspect to note is the decrease in recirculation of hot-air over the tops of racks back into the cold (C1) and mixed (M1) aisles. These AFO recommendations result in uniform rack inlet temperatures across all racks and better containment of cold and mixed aisles to eliminate hot spots.

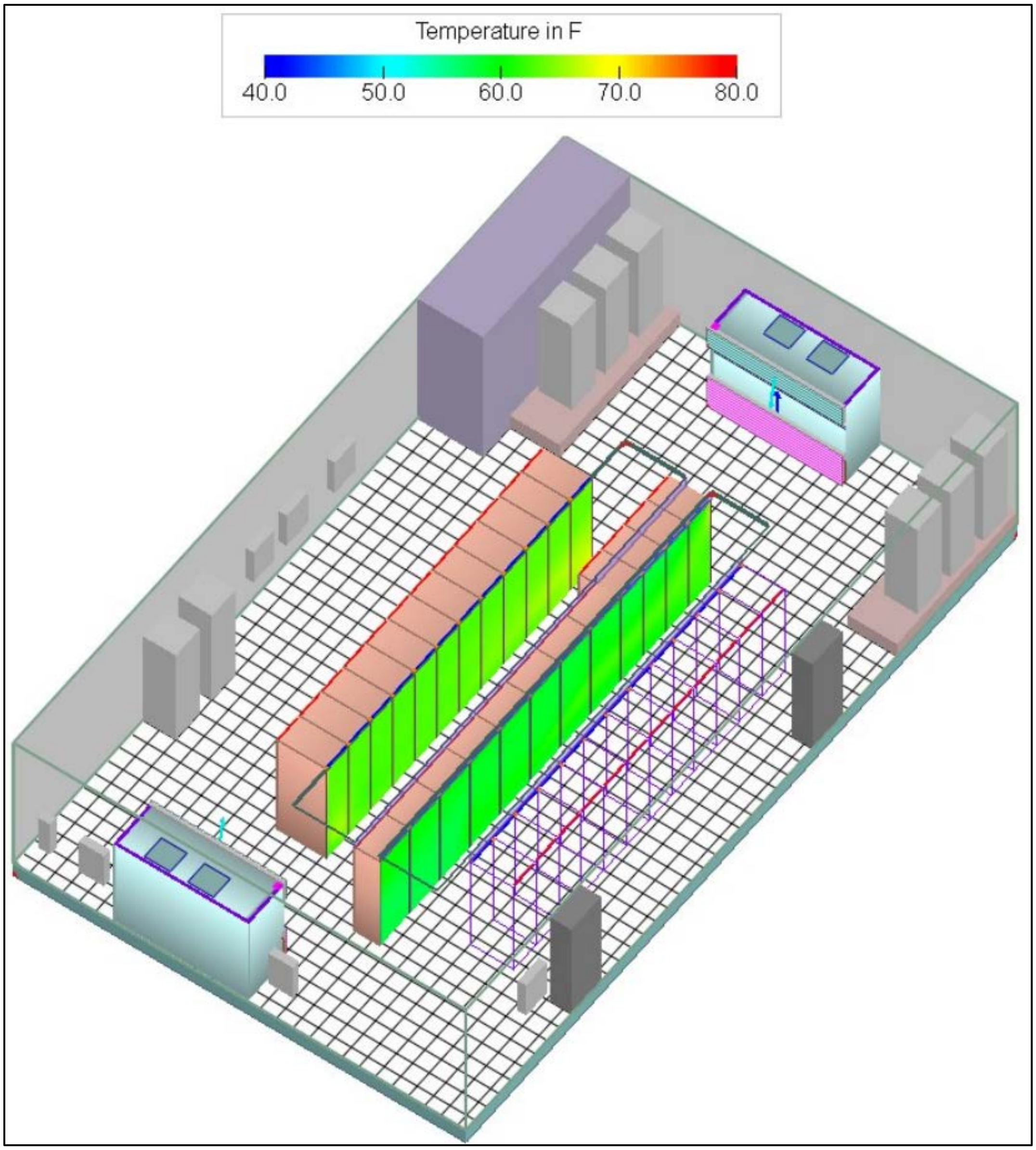

Figure 8 - 3-D model of rack inlet temperature distribution with AFO recommendations for Beaverton, OR – Phase 1 headend room.

2.2.2.3. Achieving AFO Energy Savings: Phase 1 Headend

With hot spot elimination and uniform distribution of rack inlet temperatures based on Hitachi Consulting's AFO ECM recommendations, the set point temperature can now be raised 6°F to achieve energy savings. Figure 9 below shows the CFD modeling results of raising the set point temperatures after the recommended AFO ECMs are implemented. Note that the recommendations include movement of the thermostats to the aisles. As shown in Figure 9 below, the temperatures of the hot aisles have increased. However, the cold and mixed aisles are still maintained, the rack inlet temperature distribution is uniform and all rack inlet temperatures are still within the ASHRAE recommended range for class A1 to A4 data center spaces (64°F-80°F). Hitachi recommends that set point be raised gradually (1-2°F per day) to avoid any alarms to the equipment.

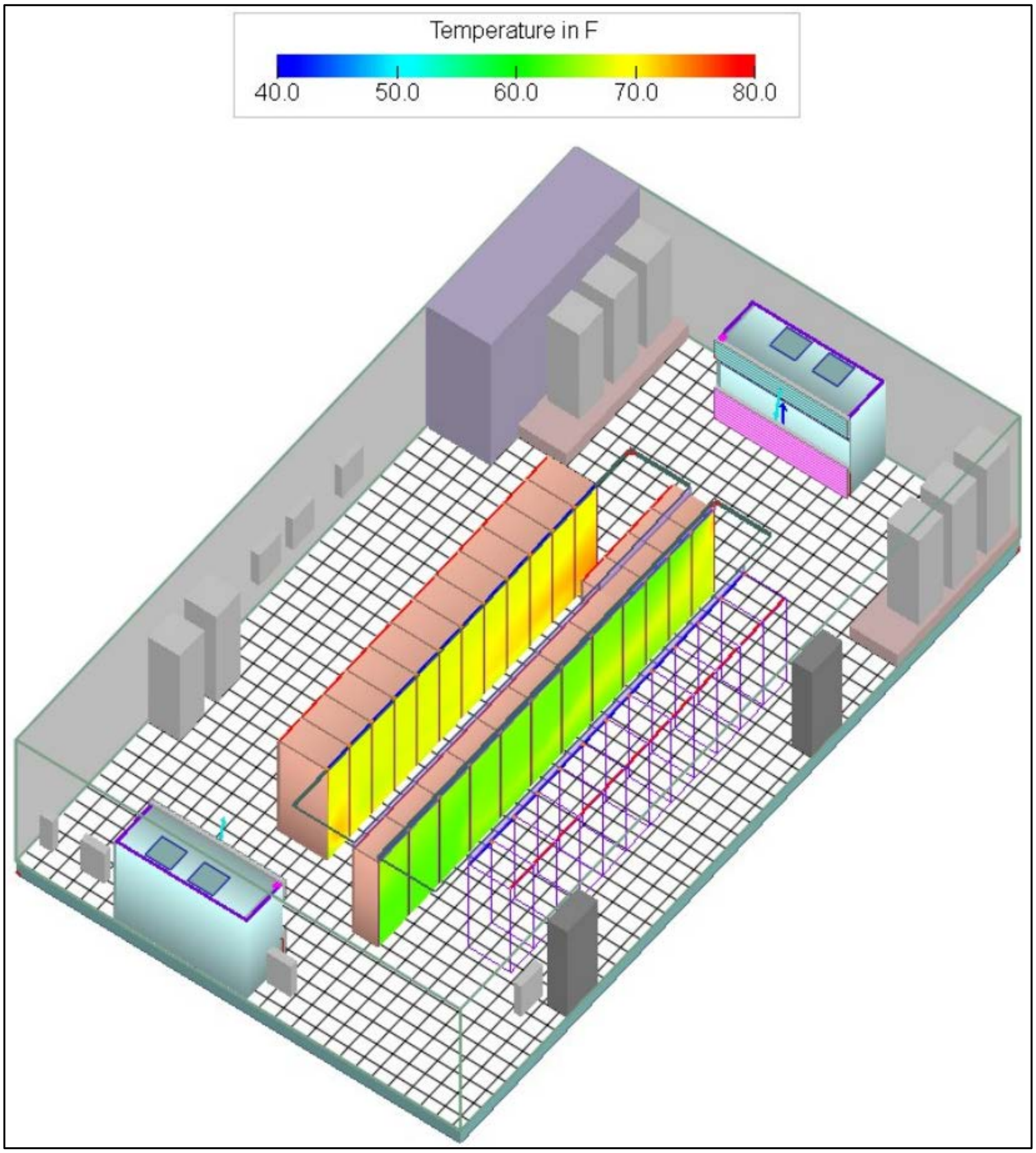

Figure 9 - 3-D model of rack inlet temperature distribution with AFO recommendations and after raising set point 6 °F for Beaverton, OR – Phase 1 headend room.

2.2.2.4. Summary of AFO Impact: Phase 1 Headend

Figure 10 below shows a summary view of Beaverton Phase 1 airflow: (1) at current airflow baseline, (2) optimized after AFO implementation, and (3) optimized after AFO implementation with an increased set point by 6°F (while maintaining inlet temperatures under 75°F throughout the racks). Table 9 shows statistically how the rack inlet temperature changed before and after AFO implementation.

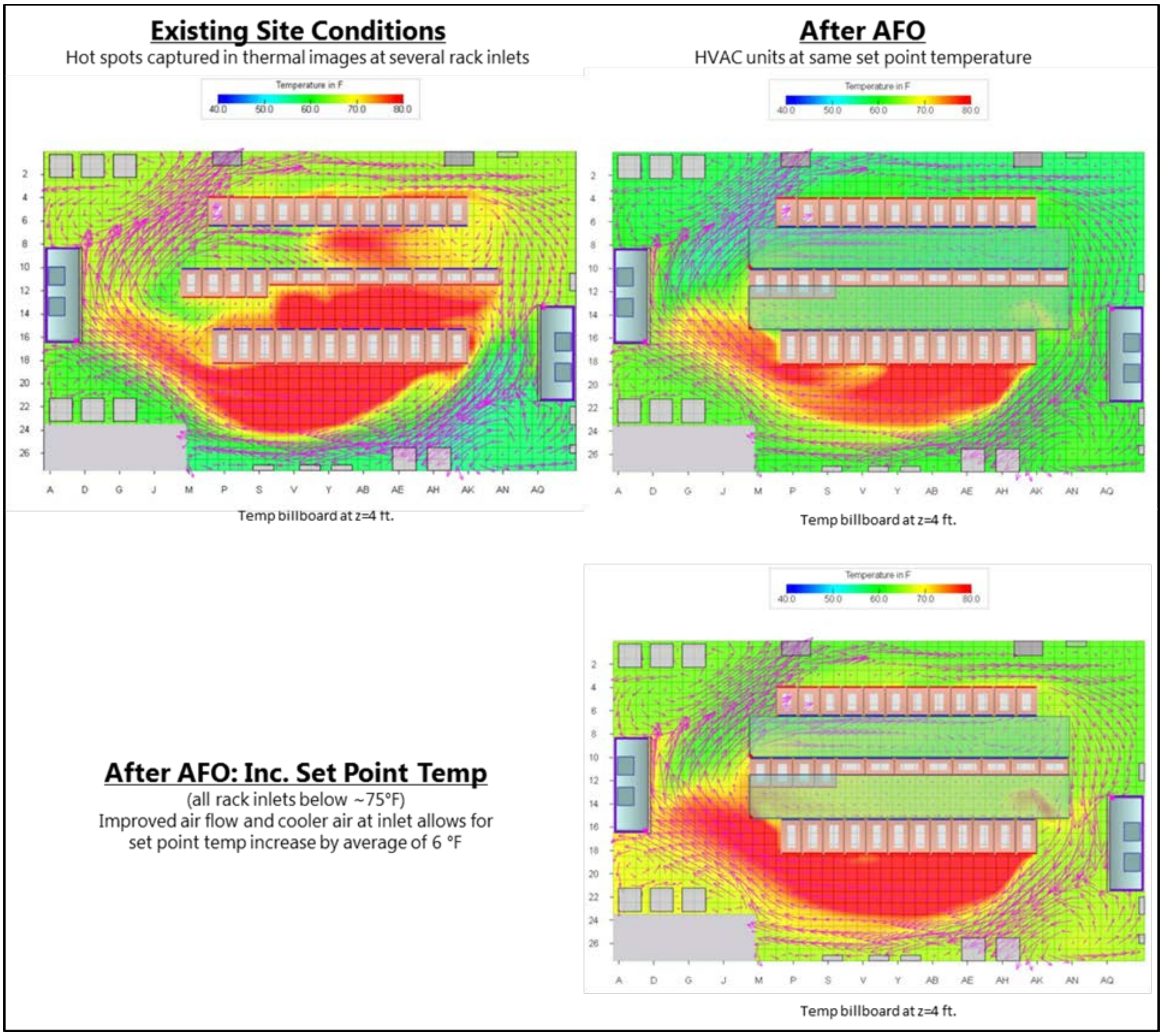

Figure 10 - Temperature distribution at 4 feet for Beaverton Phase 1 headend room, including (1) baseline, (2) + AFO recommendations, and (3) + AFO recommendations and raised temperature set point.

Table 7 - AFO statistical impact on rack inlet temperature distribution after 6°F set point increase for Beaverton Phase 1 headend room.

Range of Max Inlet Temperature	Number of Racks*		
	Baseline	After AFO ECMs	After AFO ECMs and 6°F Set Point Increase
Above 80°F	9	0	0
Between 75°F and 80°F	6	0	0
Between 70°F and 75°F	9	0	7
Below 70°F	6	30	23
Total	**30**	**30**	**30**

*Does not include 6 empty racks that do not have any equipment (total 36 racks).

2.2.2.5. Baseline CFD Model: Phase 2 Headend

Figure 11 below shows the CFD model results for existing airflow conditions at Beaverton, OR – Phase 2 headend. The baseline model was calibrated based on the thermal images and CFM measurements captured at the site. A few hot spots can be seen in the figure, as well as a few racks with significantly lower inlet temperatures than most of the racks in the room.

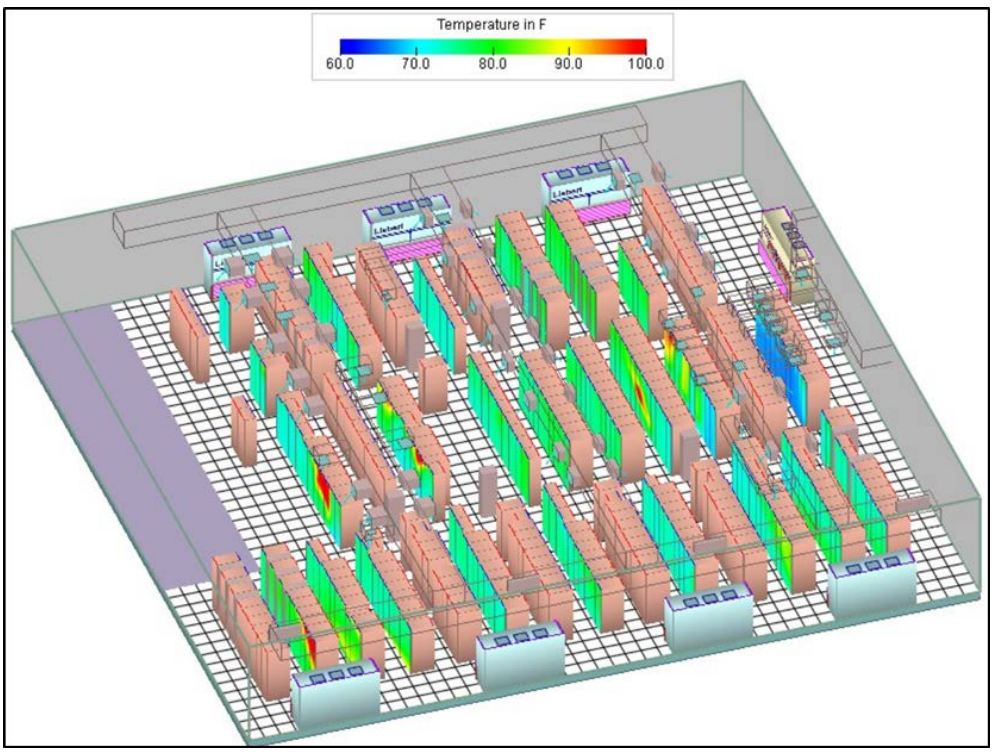

Figure 11 - 3-D model of rack inlet temperature distribution for Beaverton, OR – Phase 2 headend room.

2.2.2.6. Air Flow Optimization ECM Recommendations: Phase 2 Headend

Hitachi Consulting utilized CFD modeling to design and optimizes the airflow by iteratively building in various efficiency measures which should allow for the channeling of hot air more efficiently toward CRAC unit return vents and away from equipment inlets. Better cooling for critical equipment and elimination of hot spots was the overarching design goal. This site exhibited some challenging hot spots that would require some row and rack reconfiguration, combined with AFO measures to be fully effective. For the Beaverton Phase 2 headend, Hitachi Consulting recommends the following AFO measures:

- Full containment of all racks via blanking panels to prevent recirculation of heat within racks
- Top containment over areas of high heat production to reduce its effect on adjacent aisles

Figure 12 below shows CFD model capture of the improvement in the rack inlet temperature across Phase 2 headend room after the AFO recommendations are implemented. AFO recommendations result in more uniform rack inlet temperatures across all racks and better containment of cold aisles to eliminate hot spots.

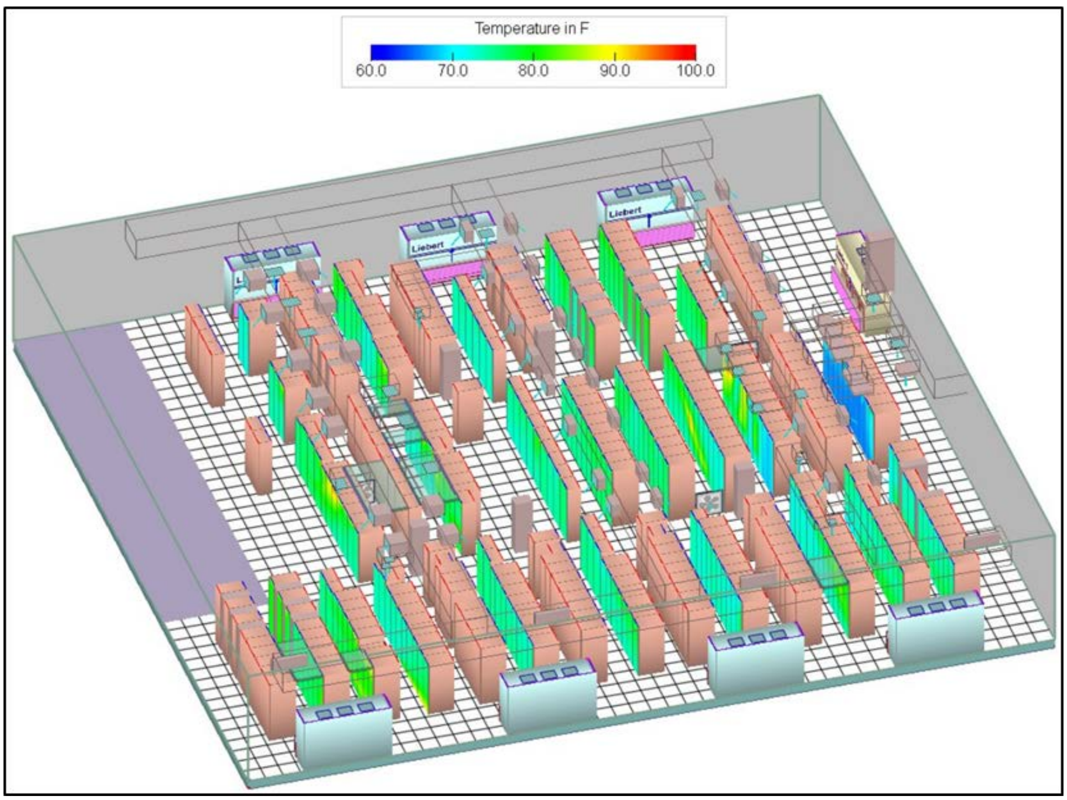

Figure 12 - 3-D model of rack inlet temperature distribution with AFO recommendations for Beaverton, OR – Phase 2 headend room.

2.2.2.7. Achieving AFO Energy Savings: Phase 2 Headend

Achieving energy savings and an acceptable payback of AFO ECM implementation was challenging for the Beaverton Phase 2 headend room due to the significant investment required in blanking panels and containment and the fact that there are only one out of eleven contiguous rows with a hot and cold aisle configuration. While extreme hotspots were indeed eliminated by the AFO ECMs, analysis of the modeling results showed that there were still a significant number of racks with inlet temperatures above 80 °F. Consequently, it was not recommended to raise the set points in this headend, and that means there will be no energy savings from the airflow optimization, rather only performance improvements.

The suspected causes for the AFO ECMs being insufficient to permit raising the set points in this situation are:

1. The depth or length of the aisles is roughly 88 feet and while the supply is ducted to bring cold air to the areas, there is no medium or return ducting to remove the heat or bring it back to the returns of the CRACs.
    a. This is evidenced by the average return temperature of 70°F, with a range of 66°F to 75°F
2. Insufficient hot/cold aisle configuration with mixed aisles interspersed throughout the headend.
3. The Liebert CRAC units are designed to have the return air inlets at floor level which makes it difficult to remove the heat. Often, due to the nature of thermal stratification, the low return grilles pull in the cool air meant for the IT equipment.
4. The heat produced from the equipment in the center of rows either stagnates or recirculates over the tops of racks, creating hot air that cannot easily move back to the CRAC return vents.

The performance improvements from adding blanking panels throughout the facility nonetheless significant since they create channels and effectively block exhaust air from recirculating within the racks which helps the overall cooling. Should Comcast decide to install the blanking panels and top containment, it was recommended that a more detailed equipment and HVAC audit and review of this site be performed to confirm that the conditions of this room are such that achieving significant energy savings and further airflow optimization may require redesign and renovation of the room. A second examination would be required if a large increase in the IT heat load is planned. Such redesign and renovation was outside the scope of the present effort.

2.2.2.8. Summary of AFO Impact: Phase 2 Headend

Implementing the recommended AFO ECMs eliminates severe hot spots and makes the temperature distributions and rack inlet temperatures more uniform. Figure 13 below shows a summary view of the Phase 2 room air flow: (1) at current airflow baseline and (2) optimized after AFO implementation. Table 8 shows statistically how the rack inlet temperature changed before and after AFO implementation.

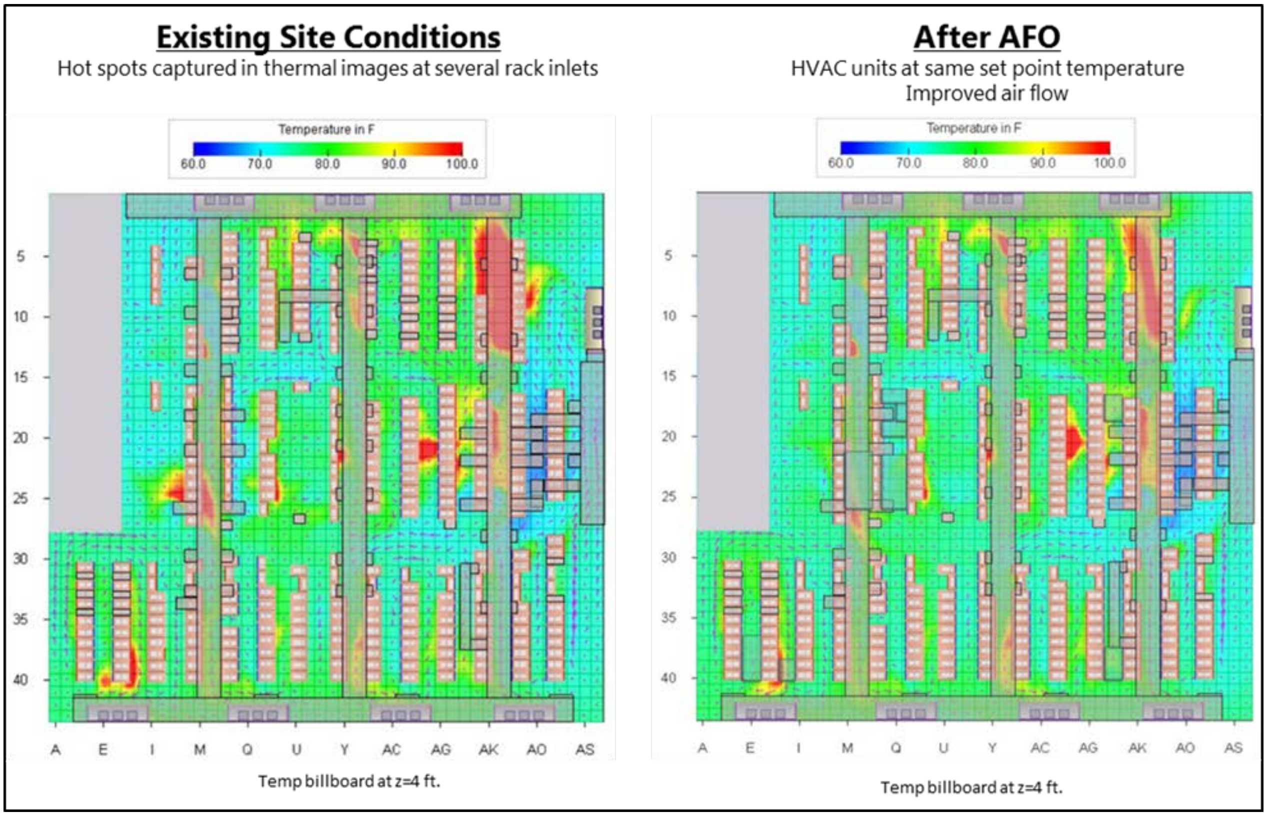

Figure 13 - Temperature distribution at 4 feet for Beaverton Phase 2 headend room, including (1) baseline and (2) + AFO recommendations.

Table 8 - AFO statistical impact on rack inlet temperature distribution after AFO ECM implementation for Beaverton Phase 2 headend.

Range of Max Inlet Temperature	Number of Racks*	
	Baseline	After AFO ECMs
Above 80°F	62	58
Between 75°F and 80°F	89	84
Between 70°F and 75°F	65	72
Below 70°F	16	18
Total	**232**	**232**

*Does not include 96 empty racks that do not have any equipment (total 328 racks)

2.2.3. HVAC Energy Conservation Measure Recommendations

In addition to the AFO ECMs just presented, the following additional energy conservation measures are recommended as a result of the site visit and energy audit.

2.2.3.1. Addition of Advanced HVAC Controls

Advanced HVAC controls are recommended for all ten (10) CRAC and four (4) RTU units in the facility to provide complete HVAC monitoring/health checks, and to increase energy efficiency of the affected CRACs. HVAC controls are installed by licensed mechanical contractors, usually recommended by Comcast and local to the site. The installation is simple and the local mechanical contractors are trained for about an hour and then overseen by the subject matter expert (SME) on the first one or two installs. The install takes about an hour for the first one, but thereafter, the process should only take about 30 minutes. The controller node has power connections and a clamp for the energy monitoring. Temperature probes are put in the supply air, return air, and by the furnace exhaust.

The advanced HVAC controls work by optimizing key components of the HVAC system to reduce HVAC energy consumption by 15-25%. Since the controls measure the supply air, return air, and energy usage, the unit can also tell when the equipment begins to fail to provide the cooling necessary or is not operating at 100% of its nominal capability. Thus, advanced HVAC controls also provide a health-check functionality.

2.2.3.2. Refrigerant Replacement

A nextgen, more efficient refrigerant is recommended to replace all R-22 and R-407C refrigerants currently in use at the facility. The new refrigerant in each of the units will improve their lifespan, effectively increase the capacity of each unit and will increase energy efficiency and thereby provide energy savings. In addition, this ECM also eliminates ozone-depleting refrigerants at the facility making the facility compliant to upcoming regulations.

The R-22 and R407C refrigerant is reclaimed and replaced by licensed mechanical contractors, usually one recommended by the cable operator and local to the site. The refrigerant replacement process entails reclaiming the R-22 or R-407C refrigerant by vacuuming the coolant lines until the R-22 or R-407C reaches approximately 500 microns. The system is then charged with the nextgen refrigerant per the nextgen pressure temperature chart.

2.2.4. Summary of ECM Recommendations

Table 9 provides a summary of the recommended ECMs for the Beaverton headend facility.

Table 9 - Summary of ECM recommendations for Beaverton, OR.

Space	Air Flow Optimization	Advanced HVAC Controls	Refrigerant Replacement
Phase 1 Headend	• Containment: add ceiling panels and blanking panels • Raise set point 6 degrees.	• Add HVAC controls to both CRAC units	• Replace refrigerant in both CRAC units
Phase 2 Headend	• Containment: add ceiling panels and blanking panels • Raise of set point temperature not recommended, resulting in no predicted savings from AFO for the site.	• Add HVAC controls to all 8 CRAC units	• Replace refrigerant in all 8 CRAC units
Power Room	N/A	• Add HVAC controls to (2) Trane RTU Units: RTU-PWR1-2	• Replace refrigerant in (2) Trane RTU Units: RTU-PWR1-2
Administrative Areas	N/A	• Add HVAC controls to (2) Trane RTU Units: HPU-SR1-2	• Replace refrigerant in (2) Trane RTU Units: HPU-SR1-2

2.2.5. Summary for Beaverton, OR Headend

Deployment of the three recommended ECMs would provide a total annual HVAC energy reduction of over 479,000 kWh, thereby reducing the HVAC energy consumption by 23% and improving the power margin for the facility. Other benefits of the recommended ECMs are summarized in the next section of this report.

3. Portfolio Analysis and Recommendations

The Hitachi Consulting team completed an on-site energy and equipment audit of each of the ten headend sites similarly to the one described above for Beaverton, OR. In this section, an analysis of the entire portfolio will be presented, with trends and conclusions based on examining all ten sites.

3.1. Airflow Optimization Issues Across the Portfolio

The Hitachi Consulting team developed CFD models for each site depicting baseline air flow conditions at the facility, and identified technically and financially feasible ECMs for Comcast's consideration. The CFD modeling along with the site visits showed inconsistency in the aisle temperatures, limited hot/cold aisle discipline and generally that the spaces were overcooled to try and compensate for mixing and areas of heat. Even with this general overcooling, the CFD modeling results across the portfolio identified inlet side areas of the racks with temperatures of up to 95°F with no alarms being triggered. The following are common issues that were identified at the headends across the portfolio of ten sites covered in this effort.

3.1.1. Insufficient Use of Blanking Panels

Substantial portion of the empty rack units (RUs) in most of the head ends were un-blanked. Un-blanked RU spaces in the racks lead to recirculation of hot air inside of the racks. The red circle in the Figure 14 below shows this recirculation of hot air in a rack at a head end that was audited during the site visits.

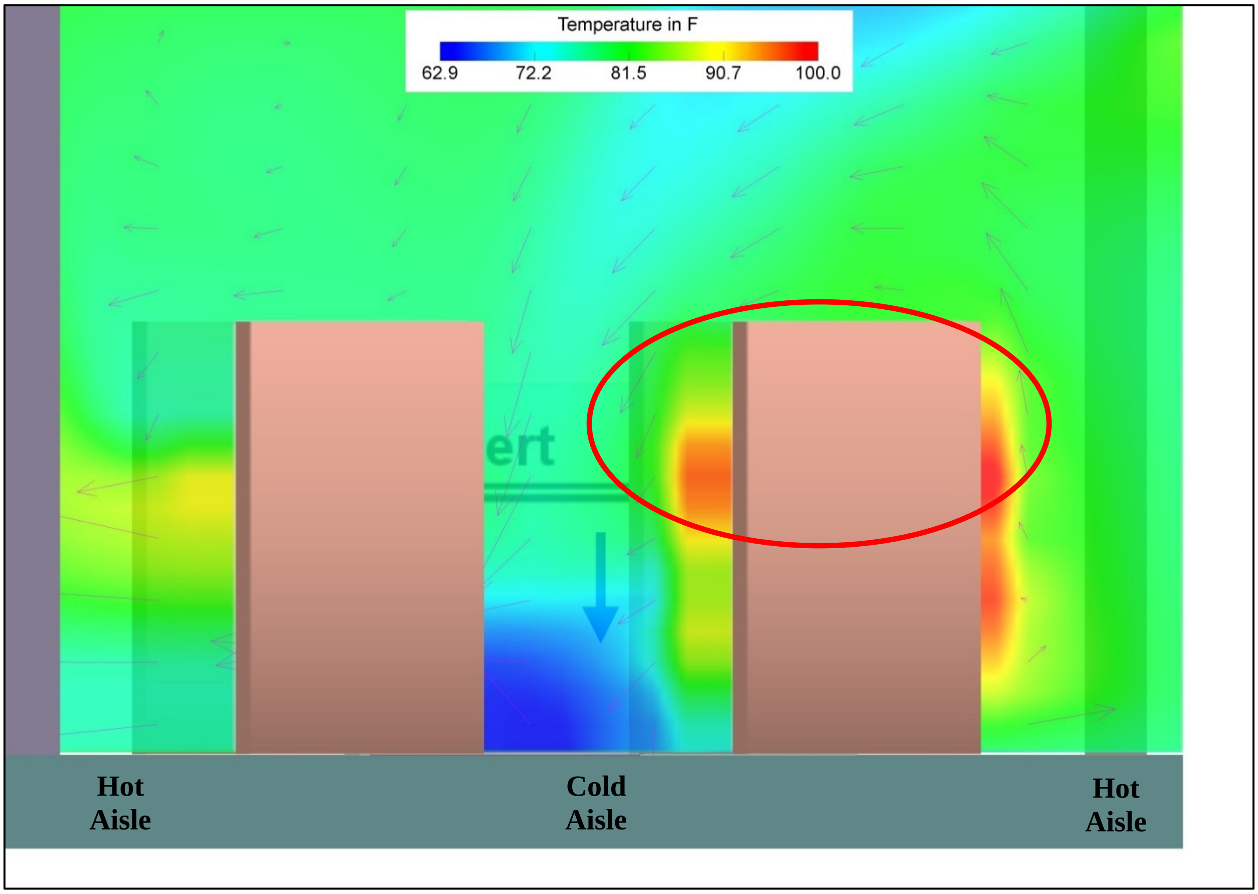

Figure 14 - Recirculation of Hot Air within the Racks – in Absence of Blanking Panels (x-z plane)

3.1.2. No Hot- Cold Aisle Configuration

Very few facilities that were audited had complete hot/cold aisle configurations which results in mixing of hot exhaust air with the cold air being supplied to the racks. Figure 15 below shows the typical configuration noticed at the audited head end sites. The exhaust of one rack row faces the inlets of an adjacent rack row, leading to hot spots on the inlet side of those racks.

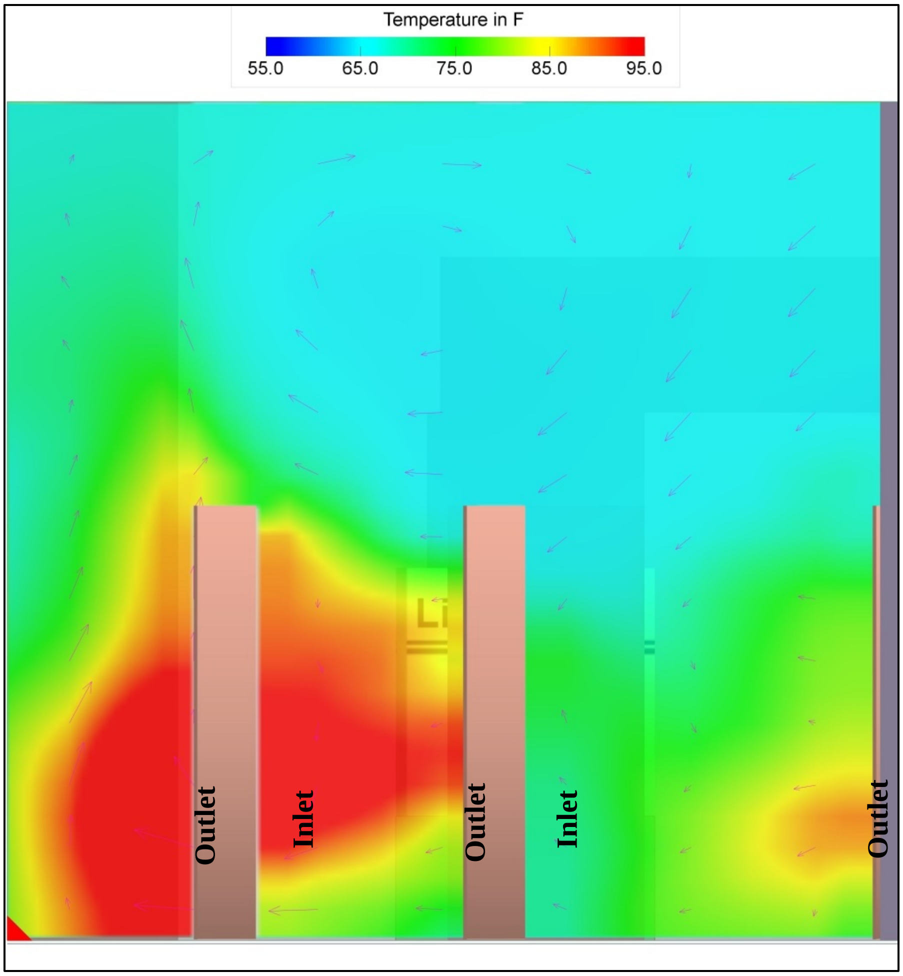

Figure 15 - Hot Exhaust Air Blowing onto the Inlet of the Racks (x-z plane)

3.1.3. Absence of Aisle Containment

Most cold aisles at the audited head end sites were not contained. Absence of side containment lets hot air infiltrate around the sides of the racks into the cold aisle. Absence of top aisle containment leads to hot air looping into the cold aisle from the top of the racks. Adding top and end aisle containment can significantly reduce the mixing of hot exhaust air with the cold air being supplied to the servers. Figure 16 (a) is a plan view capture of rows showing infiltration of hot air looping around the side of the aisles. The red circle highlights this hot air looping in. The red circle in the Figure 16 (b) below shows the infiltration of hot exhaust air into the cold aisle from the top of the racks. This infiltration is commonly seen in telecommunications edge facilities.

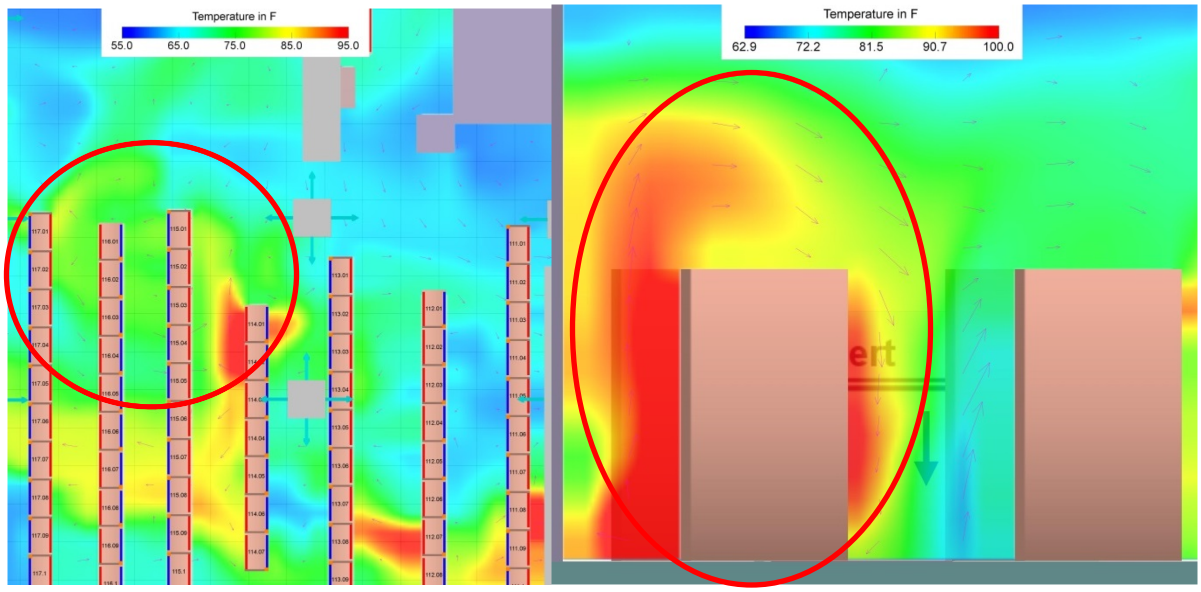

Figure 16 - (a) Plan view of racks showing hot air infiltration from the sides (x-y plane) (b) Infiltration of hot air from the top of racks (x-z plane)

3.1.4. Summary of AFO Recommendations

Considering all ten sites covered by this effort, the following airflow optimization recommendations apply in some manner to all ten sites:

- Increased utilization of blanking panels in all racks to limit the hot and cold air to a specific space and limit infiltration within and without the racks
- Addition of top containment where needed to limit infiltration of hot air from over the top of the aisles
- Addition of end aisle containment in form of strip curtains or end panels/doors to contain cold aisles and prevent infiltration of hot air
- Addition and/or redirection of supply ducting to focus cold supply air directly into the aisles
- Addition and/or repositioning of return grilles to facilitate hot air return to CRAC units.

It should also be stated that the airflow optimization recommendations presented in this report were developed such that they are resilient to equipment changes at each site, whether to increase or decrease the overall heat load. Further, since the recommendations include placing thermostats in the aisles, this allows controlling any decommissioned space independently and/or closing of diffusers, thereby minimizing the cooling provided to the decommissioned space as a site evolves.

3.2. Presence of R-22 Refrigerant

All sites contained at least one of either R-22, R-407C, R-134A refrigerants, and for many of the sites most HVAC units have older, outdated refrigerants that should be replaced with nextgen refrigerants. Nextgen refrigerants should be a direct drop-in replacement for refrigerants of type R-22, R-407C, and R-134A and improve performance while meeting the DOE standards as acceptable refrigerants. These nextgen refrigerants can increase the HVAC energy efficiency over R-22 and R-407C by as much as 20%, and further give the HVAC system an increased capacity that can also extend the life of the HVAC units because the compressor does not run as much. Note, most importantly, as of 2020 it will no longer be possible to buy R-22 or install it into HVAC systems.

The number of HVAC units for each site that are recommended to have their refrigerant replaced are listed in Table 12 below.

Table 10 - Number of HVAC units with outdated refrigerants by site.

Facility	Number of HVAC Units with Outdated Refrigerants
Roseville, MN	9
Hayward, CA	16
Santa Clara, CA	10
Beaverton, OR	14
Burien, WA	13
Stone Mountain, GA	7
Atlanta, GA	6
Jonesboro, GA	4
Woodstock, GA	4
Augusta, GA	5
All Facilities	**88**

While the larger sites generally have more HVAC systems that would benefit from refrigerant replacement, there is no rule of thumb for converting site size or site IT load into a predictable number of HVAC units that require replacement refrigerants. A detailed audit by subject matter experts should be performed to determine precisely which units require, or could benefit from nextgen refrigerants.

As part of replacing the refrigerant, it is good practice to "true-up" the equipment, meaning the mechanical technician will go through the equipment, replacing simple pieces where needed, like contacts, belts (tension or replace), and also check for refrigerant leaks. If there is anything that cannot be fixed or replaced in 15 minutes with parts normally found on the mechanical technician's truck, it is brought to the attention of the site property manager and scheduled to be fixed immediately such that the deployment of the new technology is not impaired.

3.3. Lack of Efficient Controls

All sites visited had HVAC systems that would benefit from advanced HVAC controls to improve energy efficiency, extend the life of the system, and provide additional sub-metering of HVAC consumption data. Advanced HVAC control units use an algorithm to optimize key HVAC components and consequently the HVAC system uses about 80% of the original HVAC energy consumed. Advanced HVAC controls can also extend the life of the HVAC system.

An added benefit to advanced HVAC controls is when the equipment is replaced, the advanced control units can be reinstalled on the new equipment to provide continued savings and longevity.

Table 11 lists the number of HVAC units for each site that are recommended to have advanced controllers installed.

Table 11 - Number of HVAC units recommended for advanced controllers by site.

Facility	Number of HVAC Units with Outdated Refrigerants
Roseville, MN	12
Hayward, CA	23
Santa Clara, CA	17
Beaverton, OR	14
Burien, WA	13
Stone Mountain, GA	51
Atlanta, GA	12
Jonesboro, GA	6
Woodstock, GA	11
Augusta, GA	10
All Facilities	**169**

Similarly, to nextgen refrigerants, as part of installing the advanced HVAC controls, it is good practice to have the equipment "trued-up". Since both refrigerant replacement and the installation of advanced controllers should have a system "true-up," one of the benefits of doing both ECMs at the same time is to reduce the total number of "true-ups" required.

Also, as with refrigerant replacement, while the larger sites generally have more HVAC systems that would benefit from advanced controls, there is no rule of thumb for converting site size or site IT load into a predictable number of HVAC units that should have advanced controllers installed. Again, a site audit by SMEs is the best way to accurately determine how many units would benefit from HVAC advanced controls.

3.4. General Age Issues for HVAC Units

The last two recommendations for installation of nextgen refrigerants and advanced HVAC controls should be tempered by the following considerations for individual sites: history of critical HVAC mechanical issues, history of not attaining set points, general reliability of manufacturer (for example Liebert units often exhibit up to 25 year lifespans), preventive maintenance practices at the site, incentives by state and federal governments for HVAC replacements, and whether a particular site is slated for complete overhaul, expansion, or decommission. For example, if a site is slated for complete decommissioning in the next two years, and the cost of the ECMs recommended results in a payback period that significantly exceeds two years, facility managers may prefer to hold off on the ECMs for that particular site.

However, it should also be noted that the system "true-up" procedure that should be done as part of either refrigerant replacement or advanced controller installation has the added benefit of detecting HVAC system issues in a process-controlled manner that is not service-impacting. Thus the "true-up" can prevent a subsequent HVAC system failure that might otherwise impact service delivery. Nonetheless, the three main ECMs recommended in this effort met the criteria of significant energy savings with a reasonable payback period.

3.5. Overstated IT heat loads

Since many of the sites lacked sub-metering of IT and HVAC power consumption, equipment lists from the Comcast database were used to estimate the IT equipment heat load for CFD modeling. Unfortunately, the lists for all the sites generally contained nameplate heat load value, and many of the larger energy-consuming devices were only partially populated and thus consume far less energy than their nameplate values. Therefore, the total IT heat load of the facility had to be adjusted or de-rated to match the actual heat load at the site. To accomplish this, thermal images of each row and rack were collected during site audit using a thermal camera, and the CFD model was then calibrated to the thermal images. The following Table 12 shows the resulting derating of IT equipment kW for each of the sites visited.

Table 12 - De-rating of the equipment/server

Site	Stated IT Load - Name Plate Heat Load (kW)	Calibrated IT Load (kW)	De-rating factor
Roseville, MN	470	253	53.8%
Hayward, CA	236	86	36.4%
Santa Clara, CA	460	129	28.0%
Beaverton, OR	1,100	446	40.5%
Burien, WA	531	195	36.7%
Stone Mountain, GA	1,031*	627	60.8%
Atlanta, GA	1,042*	448	43.0%
Jonesboro, GA	131*	68	51.9%
Woodstock, GA	352*	218	61.9%
Augusta, GA	182*	102	56.0%
Total (all sites)	**5,535**	**2,572**	**46.5%**

*Site IT load was corrected based on equipment seen on-site.

Thus, based on the ten sites covered in this effort, when examining the nameplate IT load of a facility that lacks sub-metering for true load measurement, a maximum of 62% of the nameplate IT load should be used for site analysis. It should be noted that the actual IT heat load could be as low as 28% of the nameplate value. This derating of stated IT load is important not only to HVAC optimization, but also to facility powering requirements and planning, and may prevent costly facility powering upgrades that could have been unnecessary.

3.6. Summary of Savings Resulting from the Recommended HVAC ECMs

The potential energy savings associated with implementation of the three ECMs at the ten headend facilities was summarized in Table 1 in Section 1 of this paper.

The benefits of the AFO, controls and refrigerant replacement go beyond energy reduction and cost savings; they also improve power margin, solve the problem of R22 phase-out by 2020 for the site, inconsistent temperatures across the inlet side of the equipment, overheating equipment with no alarms, redundancy and compressor/HVAC life extension. Table 13 below provides a more complete list of benefits from implementing the proposed ECMs at edge facilities.

Table 13 - Summary of proposed ECM benefits for Comcast critical facilities.

	Meeting New Standards for Facilities	Improving / Maintaining Customer Satisfaction	Lower OpEx Costs		Lower CapEx Costs
			Energy Reduction	Maintenance Reduction	
Airflow Optimization	**Move to hot/ cold aisle** discipline in all facilities	• **True HVAC redundancy** to prevent IT equipment overloads **Reduce alarms and outages**	• **Reduced cooling tonnage** / number of HVAC units • **Eliminates hotspots** **Permits increasing set point**	**Fewer HVAC units** to maintain	**Higher power margin**
Advanced Controls	**HVAC health check** monitoring	**Increased visibility of HVAC performance** – better able to predict failures and replace accordingly (reduce alarms and outages)	• **Optimized HVAC runtime** **Peak demand reduction**	• **Extends HVAC life** • **Reusable on replacement equipment** **Fewer truck rolls**	**Higher power margin**
Nextgen Refrigerant Replacement	**Regulatory compliance** for elimination of ozone-depleting refrigerants	**PR benefit for Comcast customers** who care about the environment	**Increased HVAC capacity** of existing systems (reducing compressor run time)	**Extends HVAC life** and reduces load on existing HVAC units	**Higher power margin**

Table 2 in Section 1 of this paper showed statistically how the rack inlet temperature changed before and after AFO implementation for all ten headend sites.

3.7. Energy consumption trends

As a final analysis of the entire portfolio, consider the energy consumption trends depicted in Figure 17 below for all ten sites. Note that the three largest sites, Atlanta, Stone Mountain, and Beaverton, all had significant energy consumption growth over the past two years and further the slope of the growth trend line for each is similar. Hayward and Santa Clara also had growth trends, and upon examination of the actual numbers, these two sites had the steepest growth curves from a percentage perspective, even though the absolute growth was overshadowed by the three largest sites. The five remaining sites either had no growth, or in the case of Woodstock, actually decreased energy consumption very slightly.

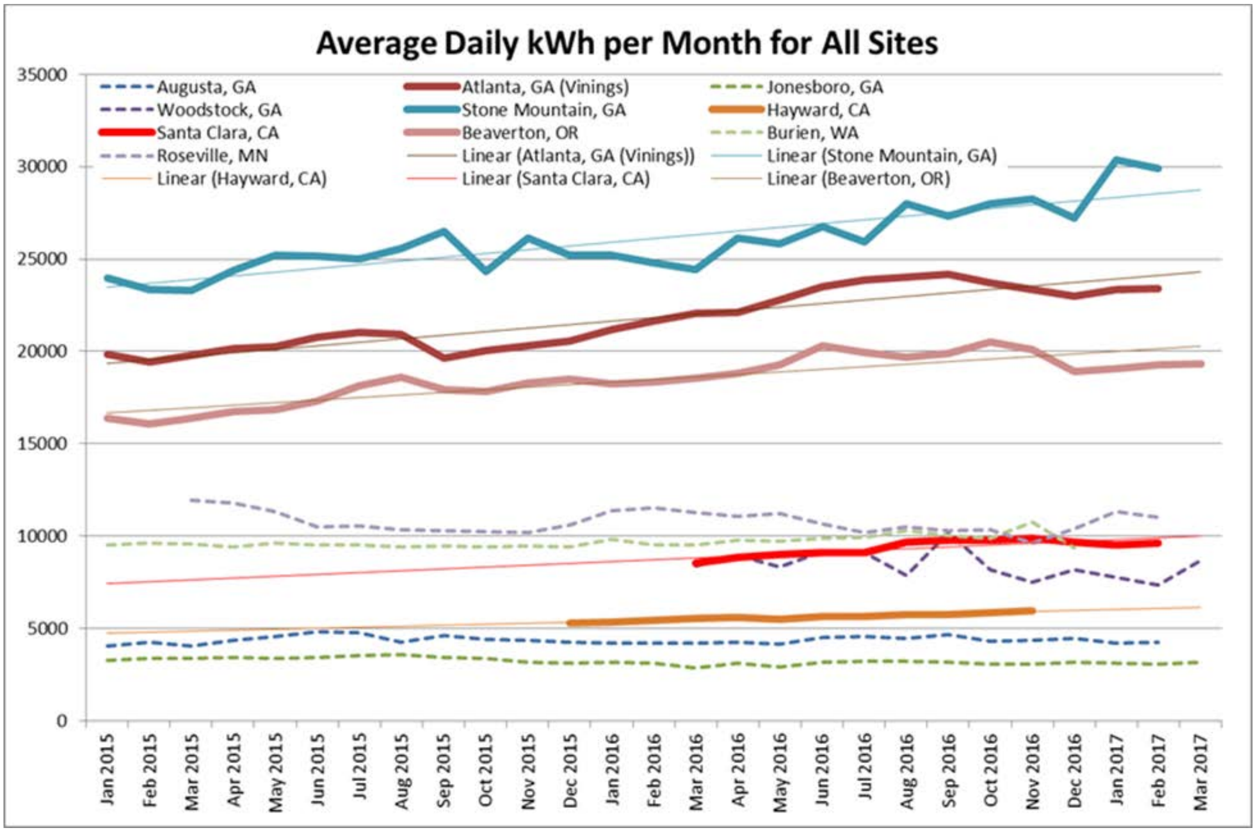

Figure 17 - Energy consumption trends across the portfolio of ten sites.

3.8. Lighting Opportunities

LED lighting opportunities were also assessed at the ten headends. Implementation of LED lighting and controls would provide a 5-year energy savings opportunity for the ten sites of just over $300,000, with the annual savings being just over $60,000. This is without incentives and with occupancy sensors. Incentives are generally available across all utilities, but were not investigated as part of this effort.

Table 14 below depicts the energy savings opportunity with LED lighting retrofit and controls at each of the ten headend sites.

Table 14 - Potential energy savings for LED lighting retrofit at all headend sites.

Facility	Annual Savings	
	Energy Savings (kWh)	**% Lighting Energy Reduction**
Roseville MN	68,145	76%
Hayward CA	107,265	63%
Santa Clara CA	73,381	71%
Beaverton OR	56,053	76%
Burien WA	29,295	75%
Stone Mountain, GA	137,335	75%
Atlanta, GA	119,977	74%
Jonesboro, GA	36,140	76%
Woodstock, GA	12,079	74%
Augusta, GA	12,947	80%
All Facilities	**652,617**	**72%**

4. Conclusion

Energy savings are possible for cable edge facilities, even given their diversity, historical development, and changing functionality. The headends analyzed in this study prove that with a methodical approach, these savings can be achieved across an entire portfolio. As demonstrated in the example case presented, this methodical approach means seeking not to impose modern standards at any cost, but rather applying solutions with a keen eye towards payback period, longer term site plans and more traditional benefits of energy conservation measures.

5. Abbreviations

Abbreviation	Definition
AFO	Air flow optimization
AHU	Air handling unit
ANSI	American National Standards Institute
APOP	Alternate point of presence
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
A1-A4	ASHRAE data center classes
ASR	Aggregation services routers
BAS	Building automation system
CapEx	Capital expenditures
CCAP	Converged cable access platform
CFD	Computational fluid dynamics
CFM	Cubic feet per minute
CMTS	Cable modem termination system
CO	Central office
CRAC	Computer room air conditioner
Cx	Cold aisle number
DC	Direct current
DOE	Department of Energy
DX	Direct expansion
ECM	Energy conservation measure
HVAC	Heating, ventilation, and air conditioning
Hx	Hot aisle number
IR	Infrared
IT	Information technology
kW	Kilowatt (unit of power)
kWh	Kilowatt-hour (unit of energy consumption)
LED	Light emitting diode
Mx	Mixed aisle number
NA	Not applicable
Nextgen	Next generation
OpEx	Operating expenses
PDU	Power distribution unit
PR	Public relations
PUE	Power usage effectiveness
RTU	Rooftop unit
RU	Rack unit
R 22, R410A, R 407 C, R134 A	Types of refrigerants
SCTE	Society for Cable Telecommunication Engineers
SME	Subject matter expert
SOW	Statement of work
Tons	HVAC tonnage (unit of HVAC capacity)- 1 ton = 12,000 Btu/hr.

UPS	Uninterruptable power supply
VHE	Video head end
VPC 1/2	Video processing center
XD C/O/R	XD-extreme heat density system C- chiller and pumping unit O- overhead cooling module R – rear cooling module

