Guidelines for Cable Facility Climate Technology Optimization

Cooling Optimization for Edge Facilities

An Operational Practice Prepared for SCTE/ISBE by

John Dolan
Senior Guideline Specialist
Rogers Communications Inc.
8200 Dixie Road, Brampton ON CA L6T 0C1
519-852-5666
john.dolan@rci.rogers.com

Daniel Howard
Director, Consulting Services
Hitachi Consulting
2512 Parkdale Place NE
404-625-1593
daniel.howard@hitachiconsulting.com

Arnold Murphy
President
SCTi
3476 Galetta Road,
Arnprior, ON CA K7S 3G7
613-558-4415
a.murphy@sct-inc.com

Ken Nickel
Executive Vice President
Quest Controls, Inc.
870 Emerald Bay Rd., Suite 307
South Lake Tahoe, CA 96150
530-600-4570
knickel@questcontrols.com

Dave Smargon
COO
AIRSYS North America
915 De La Vina Street,
Santa Barbara, CA 93101
805-312-7549
dave.smargon@air-sys.com

Table of Contents

Title **Page Number**

List of Figures

List of Tables

Introduction

The SCTE ISBE 2020 Program identifies Edge Facilities (Class D as defined by SCTE 226) as by far the largest contributor to an MSO's energy consumption. This is because they significantly outnumber Data Centers and Regional headends. See Figure 1.

The focus of this paper will be on the *edge facilities* and it will provide insight into creating an overall guideline for facility climate technology optimization.

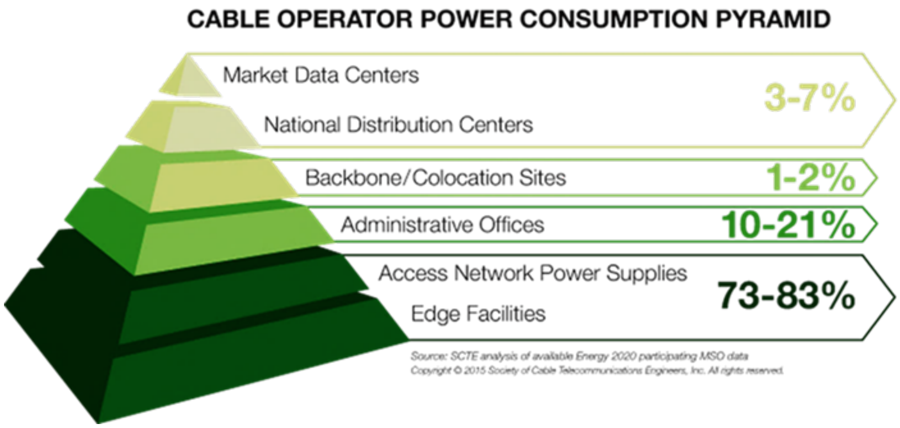

Figure 1 - Power at the Edge

The main elements to be discussed for a guideline are:

- How to manage air flow
- How to create an energy management plan and process
- What data to gather
- How to develop a baseline.
- How to consider the various cooling solutions
- How to perform measurement and validation
- How to pursue rebates
- How to evaluate the return on investment
- How to consider new or improved cooling technologies.

Following a guideline for *edge facilities* can reduce alarms and/or downtime, lower energy consumption and cost, improve energy efficiency, and improve the power margin. This is intended for cable operator local engineering and operations personnel, as well as corporate sustainability teams.

The paper was a team effort not only from the 5 principle authors but I would like to recognize the significant contributions from the following people:
Curtis Stiles, Time Warner Cable; **George Gosko**, Hitachi Consulting; **Supriya Dharkar**, Hitachi Consulting; **Jake Yu**, AIRSYS North America; and **Ed Kaye**, AIRSYS North America.

Guidelines

1. Developing a Cooling Energy Management Plan

A cooling energy management plan is a process with the final goal to reduce the cost to cool a watt of information technology (IT) equipment load. Under the assumption that many current edge facilities are overcooled and have undesirable mixing of hot air with cold air, a cooling energy management plan to reduce mixing, focus the cooling on the IT equipment, and enhance heating, ventilation and air conditioning (HVAC) equipment and controls can lead to significant energy and operational expenditure (Opex) savings as well as improvements in facility robustness.

Ultimately this plan should be applied to an entire portfolio of edge facilities to have the greatest impact on reducing the cost of cooling, and should involve common measures that can cost-effectively be applied at scale. Changes that improve the cooling effectiveness and efficiency at facilities in the portfolio should be identified in the plan, implemented, and measured to demonstrate energy consumption and cooling effectiveness before and after the implementation should be made. This will help validate the improvements and reductions of cooling costs, especially when energy incentives are sought.

At a minimum, the cooling energy management plan must:

- Categorize and characterize sites (*edge facilities*)
- Follow a standard methodology
- Clearly define metrics to evaluate solutions and validate them as successful
- Identify areas of concern
- Incorporate all rebates/incentives where available

The plan is essential in proving the changes improved energy efficiency in a manner that is compliant with both standards as well as the requirements of the energy incentives.

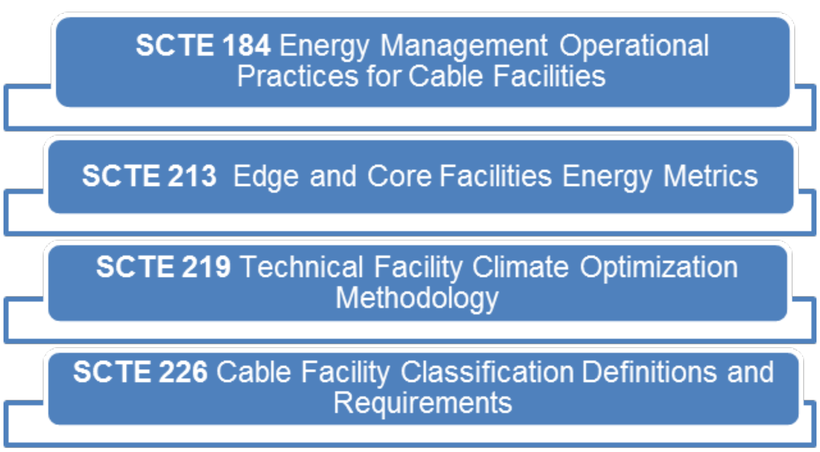

Figure 2 - Relevant SCTE Energy Standards for Facility Climate Technology Optimization

2. Process, Standard Methodology

An Energy Management Plan is a process. Figure 3 provides an example of a standard methodology to follow to implement a plan.

First, there is the overall **plan** for site or sites. The **baseline** data must be collected for each site so that there is clear data to compare any changes to. Then, the **measurement** of changes begins but a **remediation** point may be reached where there are issue occurring that are affecting the data, such as an IT refresh, that will skew results. This allows time for changes to be made to the plan. Once the site is stable the result on climate of the changes can be accurately measured and the **report** is made. Finally the analysis will determine if the changes were effective in meeting the climate goals.

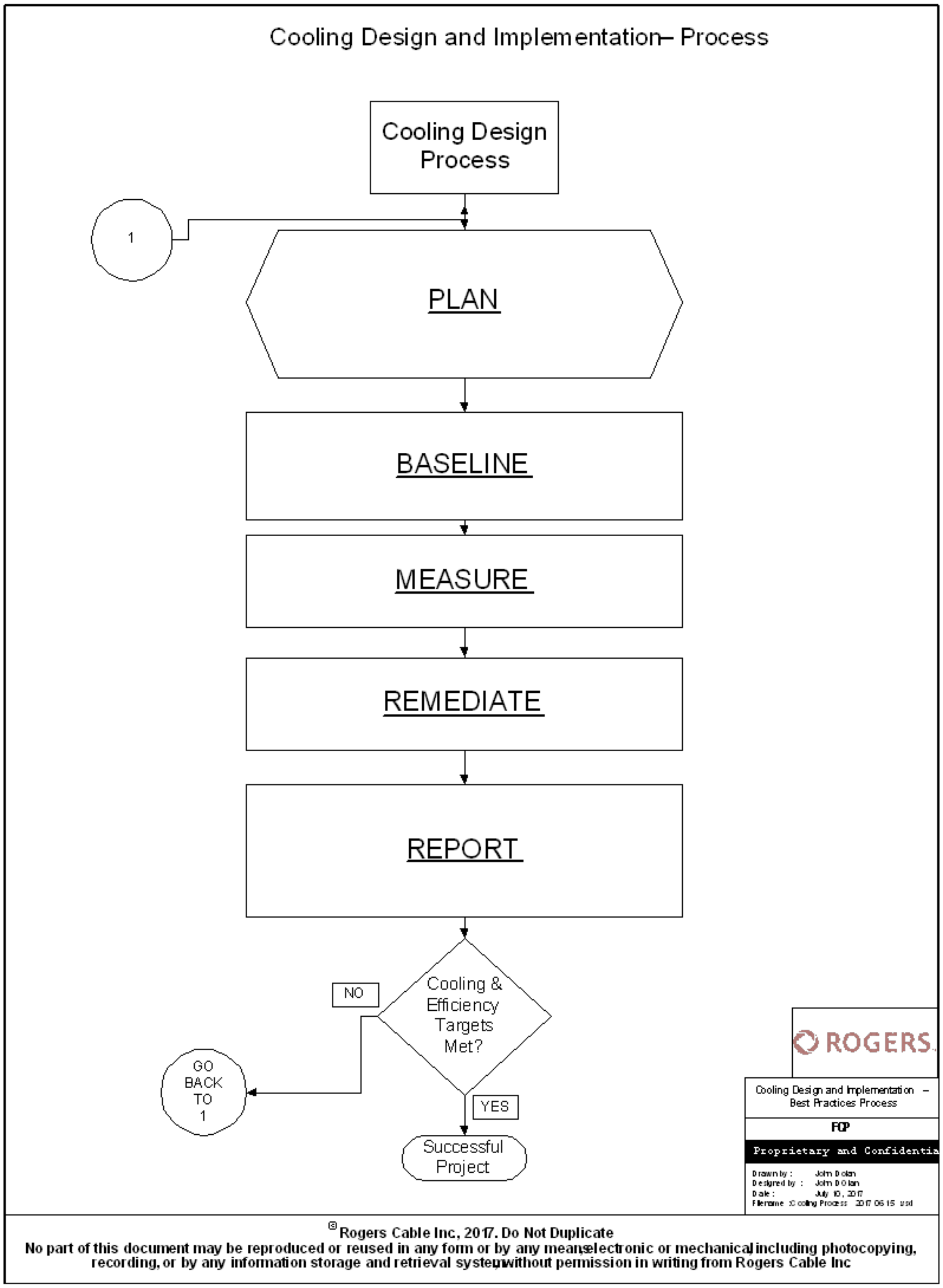

Figure 3 - Energy Plan Methodology (Used with Permission from Rogers)

3. Facility Climate Data Collection

It is extremely important to collect data both before and after implementing energy conservation measures to verify the achievement of the cooling energy management plan goals, confirm estimates of energy savings from vendors and modeling activities, and most importantly to ensure that the rack inlet temperatures are maintained at recommended levels while lowering the cost of cooling. Many improvements such as airflow optimization, refrigerant replacement, advanced controls, and newer, more efficient HVAC units will yield immediate improvements that can be seen within a month after implementation. Others such as HVAC economizers may require data collection over cooler months where the technology is most applicable to visibly yield savings.

Data collected on the facility climate is useful not only in measuring climate technology efficiency but they are also useful in:

- Reducing alarms
- Reducing hot spots and cold spots
- Reducing temperature variations across the facility
- Improving computer room air conditioner (CRAC) redundancy

Specific data recommended for capture as part of a cooling energy management plan and implementation are provided in this section.

3.1. Rack Inlet Temperatures

Rack inlet temperatures should be characterized, either via direct thermometer measurements, remotely monitored temperature sensors, or via infrared thermal imaging. The goal of airflow optimization is to create as uniform rack inlet temperature profile across the facility as possible and maximize the temperature difference between the HVAC supply and return. Measurement of the rack inlet temperatures, ideally at the top, middle and bottom of each rack, and subsequent characterization of the distribution of rack inlet temperatures across the facility, is preferable prior to, and after implementing airflow optimization measures.

After optimizing airflow, energy savings are realized by gradually raising the HVAC set points. Rack inlet temperatures must be tracked during this process to ensure that temperatures do not exceed recommended values as the set-point is raised. Exact values to be maintained are cable operator specific, but in general the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) TC 9.9 guidelines are used.

The following chart shows the ASHRAE temperature and humidity limits (recommended and allowable) on a psychometric chart. The red section area shows the ASHRAE recommended range for Class A1- A4 facilities.

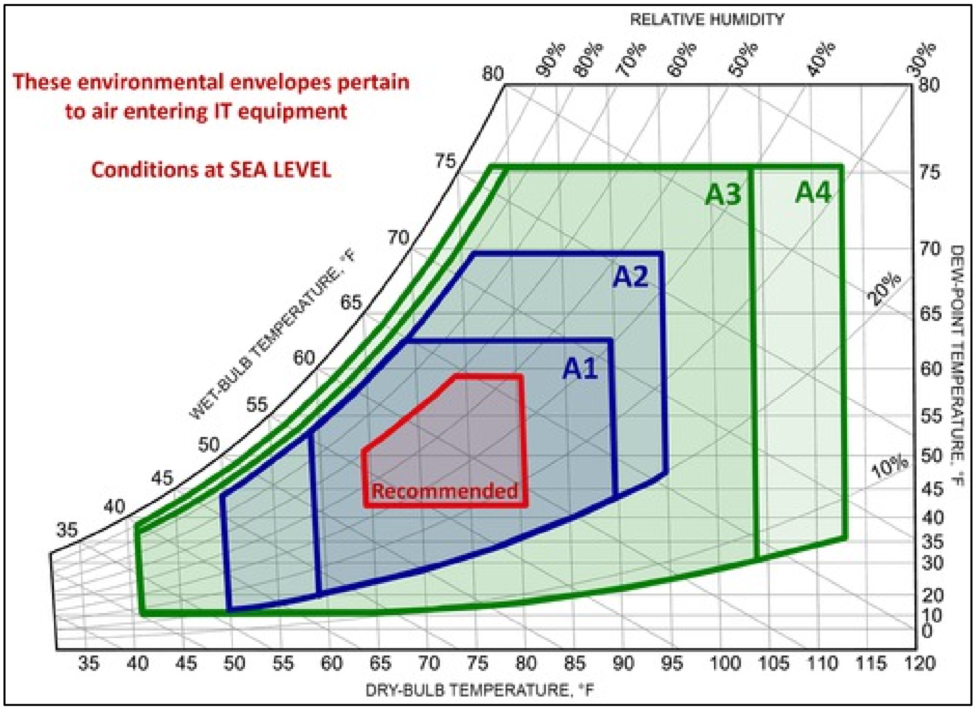

Figure 4 - Psychometric Chart showing ASHRAE Temperature and Humidity Levels

The following table shows the equipment environmental specifications for air cooling according to the ASHRAE 2015 Thermal Guidelines. ASHRAE recommends a dry bulb temperature for Class A1 to A4 facilities to be in the range of 64.4 °F to 80.6°F.

Table 1 - ASHRAE 2015 Thermal Guidelines

Table 1. Air-Cooled Data Center Classes (Product Operation)

Class	Dry Bulb, °F	Max. Dew Point, °F	Humidity
Recommended			
A1 to A4	64 to 81		42°F dp to 60% rh and 59°F dp
Allowable			
A1	59 to 90	62.6	20 to 80% rh
A2	50 to 95	69.8	20 to 80% rh
A3	41 to 104	75.2	10°F dp and 8 to 85% rh
A4	41 to 113	75.2	10°F dp and 8 to 90% rh

Table 2. Liquid-Cooled Datacom Facility Classes (Product Operation)

	Typical Infrastructure Design		
Class	Main Cooling Equipment	Supplemental Cooling Equipment	Facility Supply Water Temperature, °F
W1	Chiller/cooling tower		36 to 63
W2		Water-side economizer	36 to 81
W3	Cooling tower	Chiller	36 to 90
W4	Water-side economizer (with dry-cooler or cooling tower)	N/A	36 to 113
W5	Building heating system	Cooling tower	>113

Source: ASHRAE (2012a).

While the ASHRAE guidelines give a range of rack inlet temperatures that is acceptable, it should be noted that it is also desirable to minimize the variation in rack inlet temperatures, even if all are within the ASHRAE range. If there are many racks at the upper limit and many racks at the lower limit, the set point cannot be changed in either direction without causing some racks to get outside the recommended range. If instead, all racks are brought to the midrange temperature via AFO, it is then possible to raise the setpoint and achieve energy savings without any racks exceeding the recommended inlet temperature range. A process of continuous improvement in cooling quality would thus involve identifying racks that are at the upper and lower extremes of range, taking AFO measures to bring those racks closer to the same temperature as the other racks and thus providing more uniform cooling to all racks, and then raising the setpoint of the HVAC system to achieve further energy savings.

There are several methods for collecting rack inlet temperature data: some modern IT devices provide both inlet and exhaust temperature measurements. If such measurements are available, they should be captured. If, as more typical, such data from the IT equipment is not ubiquitously available, then rack inlet temperatures should be measured either directly with a handheld fast response digital thermometer or via strip thermometers that are placed at the top, middle and bottom of each rack, or using a thermal imaging camera. The latter is often the most convenient since both rack inlet and exhaust temperatures can be quickly measured and used to calibrate computational fluid dynamics (CFD) models subsequently. Infrared cameras can now be had for under $1000. The other use of such data is to identify any hotspots at rack inlets that should be addressed via airflow optimization, and for quick visual verification of CFD model output graphics with actual thermal images

If the set points are to be raised following airflow optimization, the inlet temperatures should be characterized daily as the set-points are incrementally increased by one to two °F at a time to insure the facility reaches a steady state temperature distribution and is still within ASHRAE recommendations. For facilities that are poorly insulated and thus more sensitive to outside air temperatures (as can be seen from daily HVAC energy consumption vs. outside air temperature), it is also recommended to characterize the rack inlet temperatures again during the hottest months following implementation of airflow optimization and raising of HVAC set-points to ensure that sufficient cooling continues to be provided to the IT equipment.

Figure 5 depicts an example of rack inlet air temperature characterization as a baseline prior to implementing airflow optimization measures. In this example, airflow direction is not shown, but an important discovery was that the cooling problem turned out to be not as was originally thought. Many of the blue cold racks have inlet temperatures well below the AHSRAE limit of around 80 °F. In fact, only one rack appeared to have a hot spot, and the problem turned out to be an issue of how CRACs were initially installed. As is typical in cable *edge facilities*, even if there are alarms from hotspots at individual pieces of IT equipment, this facility was over cooled, raising the cost of cooling per watt as well as creating issues with forecasted capacity. Solving the hotspot issue subsequently eliminated the hotspot and permitted the addition of IT load without requiring additional cooling.

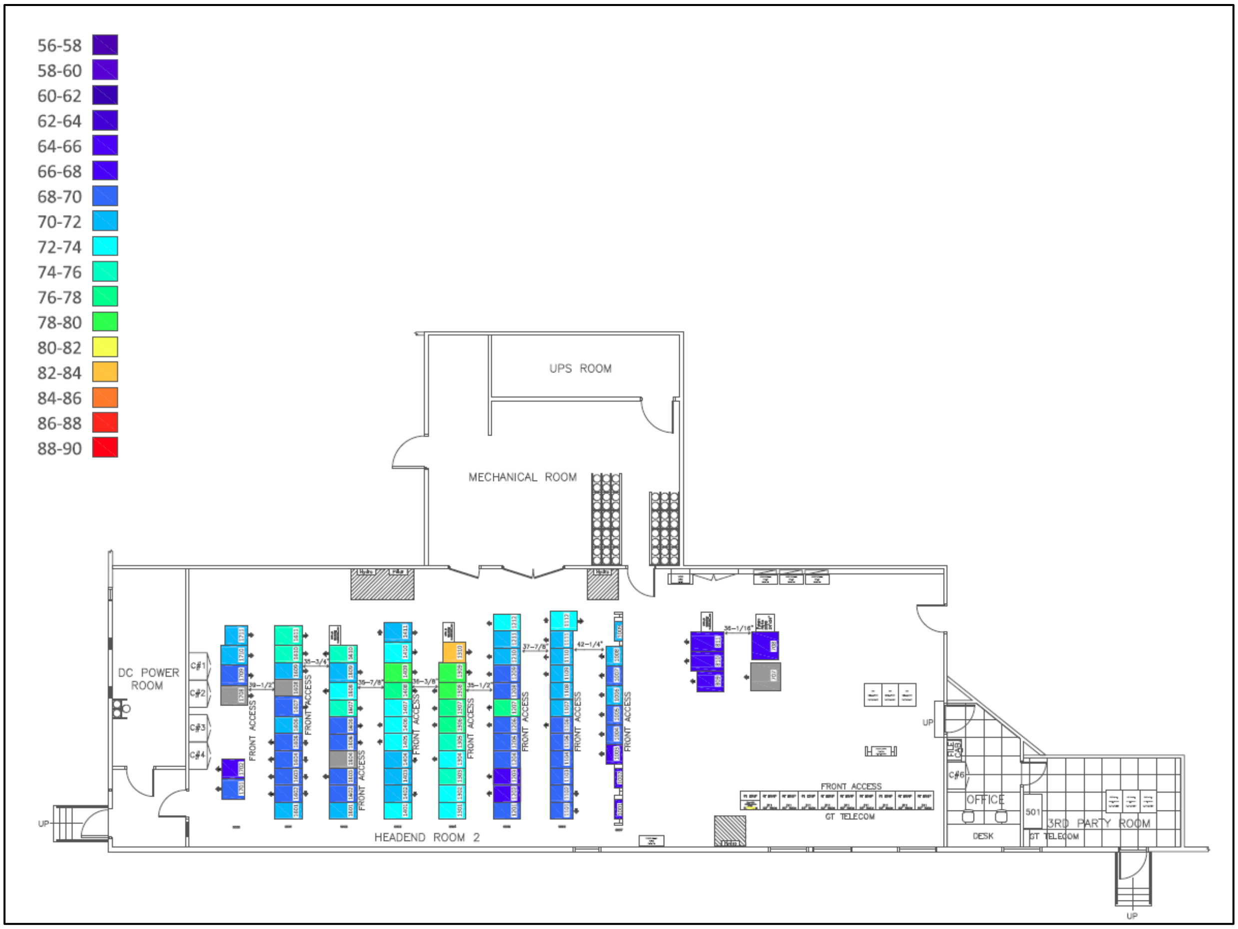

Figure 5 - Example of Rack Inlet Air Temperature Baseline Characterization

3.2. Energy Consumption of HVAC and IT Equipment

Sub-metering to separately characterize both HVAC and IT energy consumption, along with the total facility energy consumption allows calculation of the power usage effectiveness (PUE) per SCTE 213 [S213] as described in the section on PUE below, and ultimately confirms that the cooling cost per watt of IT equipment has indeed been reduced, even if the total wattage of IT equipment to be cooled has changed.

If the IT equipment load as well as other non-HVAC loads are constant and will continue to be constant for several months after implementation of the cooling energy management plan, then it is possible to use the facility utility bill to see the impact of energy conservation measures on reducing the HVAC energy consumption. Unfortunately, due to the consistent growth of services this is seldom the case in cable *edge facilities*; new equipment is constantly being added, or at a minimum, additional cards are added to existing equipment chasses, and ideally older equipment is being decommissioned and removed. The result is that the IT equipment heat load in cable *edge facilities* changes rapidly enough that sub-metering of HVAC equipment is usually required, in addition to sub-metering of the total IT equipment load.

Sub-metering of HVAC equipment can be accomplished with a variety of commercially available devices, with the addition of certain types of HVAC controllers that also monitor energy consumption, or with monitoring options that can be included when new HVAC systems are installed. Sub-metering may be as simple as sub-metering the direct current (DC) plant (if all IT equipment is fed from the DC plant), or by installing individual sub-metering devices if both DC and alternating current (AC) plants are used to power IT equipment. If the lighting and plug loads in the facility are minimal, or easily characterized/estimated, then it is also possible to use the sub-metering of all HVAC systems to subtract that contribution from the total facility energy consumption along with estimates of the lighting and plug loads to estimate the IT equipment load and track changes that will affect the cost per watt to cool the IT equipment.

SCTE 213 recommends measuring energy consumption of two of the three values of (total building, IT load, and HVAC load) and calculating PUE at least every 15 minutes. If seeking reductions in peak demand costs, which can be a significant component of the total energy bill, it is recommended to measure these values more frequently, on the order of every minute, in order to observe the value and duration of peaks in energy usage that may be addressed by modern control algorithms and technology.

3.3. HVAC Performance

To characterize the performance of the HVAC/CRAC systems before and after implementing energy conservation measures and for performing CFD modeling, the following data should be captured:

- Complete nameplate specifications of all HVAC/CRAC units, including
    - System model and serial number
    - Date installed and date of any major upgrades or retrofits
    - Cooling tonnage provided
    - Refrigerant type and amount
- Physical condition of the HVAC units
- CRAC supply and return air temperatures
- Dimensions and type of supply diffusers and return vents
- Air flow direction (especially for directional diffusers/vents)
- Outdoor air temperature
- Cubic feet per minute (CFM) air flow
- Air pressure differential
- Humidity
- HVAC as-programmed controls and sequences of operations

A small temperature difference between supply and return temperatures often indicates significant mixing of hot and cold air is occurring in the facility, for example, or can indicate issues with the HVAC units themselves.

3.4. Facility Dimensions and Characteristics

If CFD modeling is anticipated as part of a cooling energy management plan then detailed locations and dimensions of racks, openings, HVAC unit location, supply and return details, ducting, large bundles of cabling, gaps in the floor and racks themselves, and so on are required for input into the model. Additional data will be required such as: what the heat load of each piece of equipment (or the entire rack) and HVAC unit specifications. The airflow direction of the IT equipment can also be important to characterize individually since occasionally some equipment vents differently from other equipment in the rack. It is also important to characterize the existing use or absence of containment such as blanking panels, plastic curtains/panels, and so on. While general layouts of facilities are available prior to implementing energy conservation measures, a site visit is often best for accurate and complete data capture. The lack of accuracy in facility layouts is due to either incomplete detail in the available layouts, or recent changes in IT equipment and installation or removal of entire racks, both of which can have a significant impact on airflow and cooling effectiveness, and thus the baseline characterization of the site.

4. Placement of Equipment

The placement of IT equipment in a facility has an enormous impact on the cooling cost per watt of IT equipment. Keeping cold supply air separate from hot return air is the key goal, and this can only be achieved via a rigid hot/cold aisle discipline of rack row orientations and IT equipment placement within the racks. Unfortunately, many cable *edge facilities* lack this kind of rigid hot/cold aisle discipline. While some cable operators are moving IT equipment to achieve a rigorous hot/cold aisle discipline in *edge facilities*, others are taking a more gradual approach and adding new equipment in hot/cold aisle manner while removing decommissioned equipment in mixed aisles and blanking openings to reduce mixing in the process. When dealing with legacy facilities even when hot/cold aisle discipline is implemented, it is often only partially implemented to avoid the service disruption that might result from moving IT equipment to achieve such discipline.

In cable *edge facilities*, an entire rack row is often exhausting into the inlets of an adjacent row, and in other cases, one or more pieces of IT equipment are exhausting into what would otherwise be a pure cold aisle with inlets of other IT equipment. Another common departure from a rigid hot/cold aisle discipline occurs when IT equipment that vents side to side is located in racks with front to back type airflow. In some cases, entire racks of IT equipment that vents side to side are exhausting hot air directly into the inlets of an adjacent rack. Luckily many IT manufacturers of these side to side flow devices also offer shrouds that can be installed to convert the airflow to front to back type flow, however these types of configurations should be done during initial equipment installation as modifications can be quite difficult to achieve in a crowded rack row.

Often IT equipment placement is done for the convenience of minimizing cabling efforts rather than optimizing cooling effectiveness. This can result in a new, higher powered (and often denser) piece of equipment heating an aisle that is already challenged for airflow. It can be preferable to place newer, higher powered devices in an aisle that is sparsely populated to distribute the heating load rather than one that is densely populated with other high-powered devices.

Given the increasing heat density of IT equipment and the impact equipment placement has on cooling efficiency, the following should be kept in mind as new equipment is installed:

- Instill hot/cold aisle discipline as new equipment is installed and old equipment is removed
- Consider and/or model the cooling impact of new high-powered equipment *before* it is installed
- Maintain proper setbacks for equipment racks and HVAC units
- Do not block either return or supply air flow with racks and cabling
- Use 100% of existing rack space in lieu of installing a new rack unless it is part of a move toward hot/cold aisle discipline
- Use blanking panels throughout the facility as well as other containment methods such as brushes and end strips/paneling.

Regarding setbacks, an example mandate would be a 2 foot minimum setback from equipment racks/rows to keep them free of cabling to improve airflow and so that ducting can be added/modified for better airflow if the aisle is later contained. Another example setback would be from HVAC supply and return vents so they are not blocked and airflow is maintained.

Ideally equipment deployment should be a joint effort between the facilities and IT workforces. The facilities workforce should be proactive in recommending new equipment locations based on the current state of cooling in the facility. As new equipment is added and old equipment removed, the facility should constantly be striving to achieve a hot/cold aisle discipline/standard to minimize the cooling cost per watt of IT equipment.

5. Airflow Management

Airflow management or specifically airflow optimization (AFO) involves taking measures to reduce mixing of hot and cold air, more effectively transport cooling to IT equipment inlets and heat from IT equipment exhausts to HVAC returns, eliminate hotspots at rack inlets, and make the distribution of rack inlet temperatures more uniform so that HVAC set-points can be raised without exceeding the upper limit at any particular rack or IT device in the facility.

Airflow optimization refers to finding ways to reduce the mixing of hot and cold air by better channeling the cold air to the rack inlets and ensure there is a balance between the air required to cool equipment and total air supplied. Excess supply air results in air bypass meaning the conditioned cold air does not achieve any cooling of IT equipment. Given the chaotic nature of airflow in many cable *edge facilities* and the fact that air patterns are not visible, it is recommended that CFD (air flow) modeling be used to visualize the air flow patterns and to identify problem areas.

5.1. Computational Fluid Dynamics Modeling Tools

A good commercial CFD modeling tool features a graphical user interface, an advanced solver, and powerful visualization and reporting capabilities. It solves the three-dimensional form of the fluid flow and energy equations to predict:

- The velocity, pressure, and temperature fields in the air space under the raised floor (under-floor plenum)
- The airflow rates through the perforated tiles
- The velocity, pressure, and temperature fields above the raised floor or slab, i.e., in the critical space of the facility with the IT equipment

The CFD tool outputs should have been validated against measurements from actual facilities. CFD modeling software can be very compute-intensive, so a high-performance laptop or desktop computer or alternately a cloud-based software solution should be used for the calculations. The package used should include good technical support, and it is recommended to explore several options before selecting a package. Software costs should be balanced against labor time required to set up and run simulations.

Most commercial CFD modeling packages will be able to handle both slab-type and raised floors, as well as ceiling plenum or non-plenum type airflow. Even if the raised floor space is not used for airflow, but instead is used for cabling (which occurs often in cable edge facilities), major openings in the raised floor can be modeled for their impact on airflow.

In the following subsections, an example will be presented of how CFD modeling can highlight airflow management issues and be used to test alternative solutions before making actual changes in airflow in a cable edge facility.

5.2. CFD Baseline Characterization

The baseline CFD model of an example cable edge facility was developed using facility layouts and dimensions along with locations and airflow directions of the following: racks, IT equipment, HVAC equipment, supplies and returns, ducting, and any major obstructions to airflow such as cabinets, shelves or cable bundles. Rack types and dimensions were also used, noting the absence of blanking panels, brushes or other means of covering gaps that can contribute to mixing. For racks with uniform distributions of similar equipment, the CFD modeler may choose to model the rack as a single entity with a given heat load, or may model the actual equipment in the rack with individual power consumption, airflow direction, and presence of lack of blanking panels on the rack. Since hot air can often flow over the tops of rack rows into cold aisles, it is important to capture the rack heights as well as other rack dimensions in the model.

Many cable operators have lists of equipment found within the facility along with the nameplate power consumption of the equipment that can be used to build rack models in CFD modeling packages. Caution in using this data must be exercised as nameplate power consumption levels of IT equipment are generally in excess, sometimes by over twice the actual power consumption of IT equipment and equipment lists can be out of date. Thus, the CFD modeler uses a combination of thermal images captured on site with previously determined de-rating factors known to be common for cable edge facility equipment. Finally, the CFD model parameters can be calibrated from the baseline CFD model of the facility to match measurements from the site itself and reproduces known issues at the site. Figure 6 depicts the baseline CFD model of this cable edge facility.

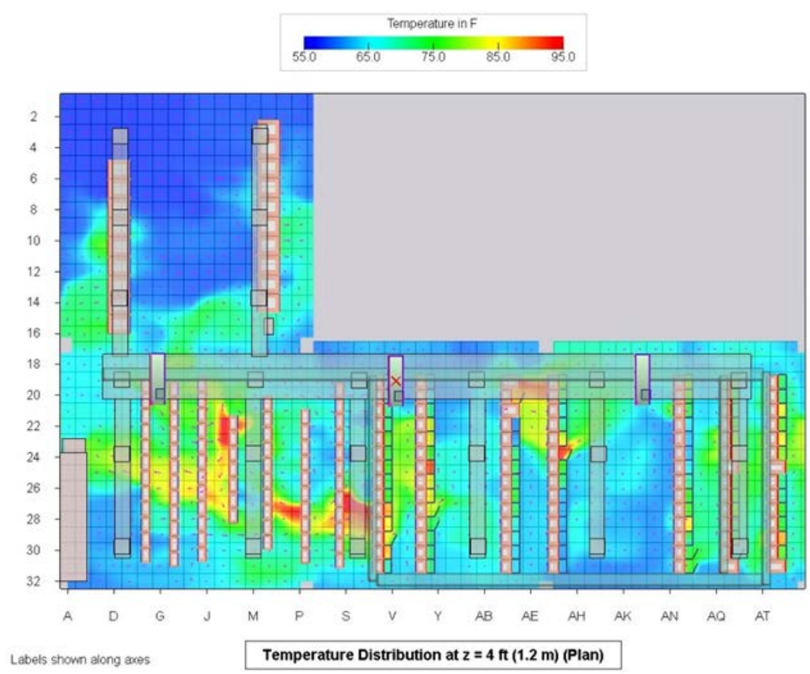

Figure 6 - Baseline CFD Model of a Cable Edge Facility

In Figure 7 hotspots are shown in red meaning the inlet temperatures are above ASHRAE maximum recommended level of 80.6°F. Dark blue areas represent spaces where air temperature is below the ASHRAE recommended minimum of 64.4°F. There are three return grids along the wall behind the header, one of which was inactive (see the three grey top ducts; the one with a red X was inactive).

The yellow and red regions in the figure indicate locations that are at the top of the ASHRAE standards for data center acceptable temperatures. There were no alarms from this high heat due to the high temp alarms being located far away on building walls and the lack of thermal sensors in the equipment in these racks. The red arrows in the figure indicate heat movement as it flows through the racks, which is happening due to the lack of blanking panels. Hot spots of up to 95 °F were seen, again with no alarms.

In this example, there was more than adequate cooling capacity: The 3 RTUs (roof top units) provide up to 264 kW of cooling, although only two were actually being used for cooling. The calibrated IT equipment load was determined to be 68 kW, which was far less than the nameplate values for this facility. Nonetheless, lack of good airflow management/distribution meant hot spots were present even given the over-cooling. Since the average total building load was 131 kW, the PUE was estimated at 1.93 for this facility for the baseline CFD model.

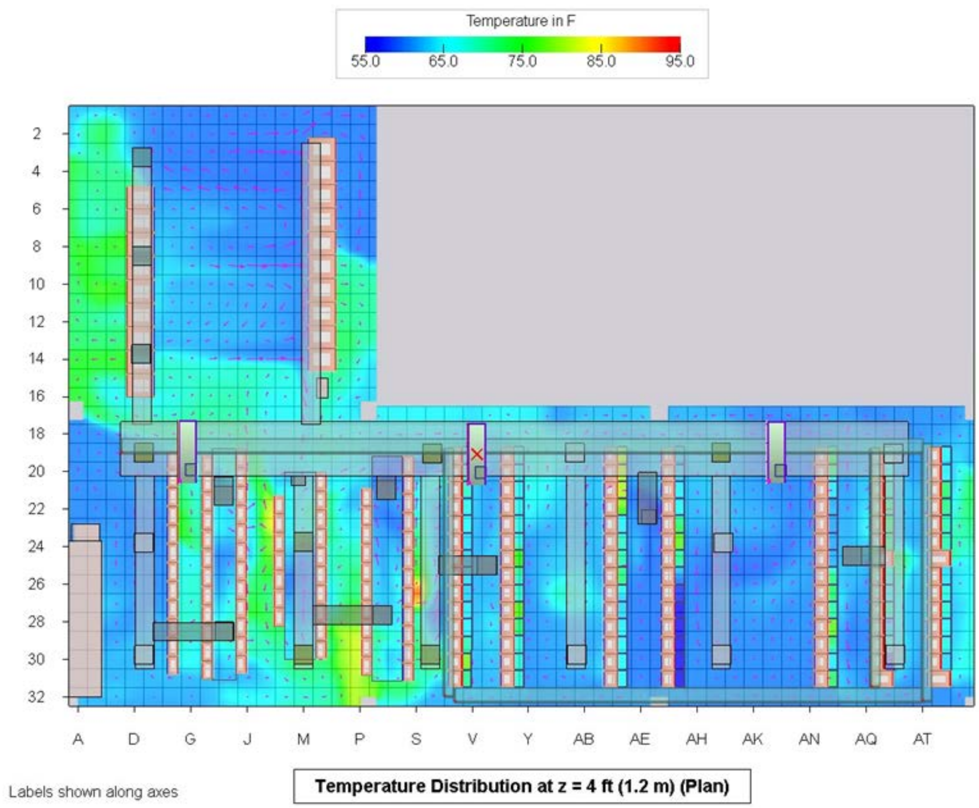

Figure 7 - CFD Model Results After Airflow Optimization

5.3. CFD Model After Airflow Optimization

As can be seen, there are several hotspots in rack inlets that should be mitigated, and further there is a lot of mixing of hot air from rack exhausts with cold air coming from the overhead ducting before it gets to the rack inlets. There is a very non-uniform distribution of rack inlet temperatures, which also results from the mixing of hot and cold air in the facility. Further, the thermostats were located on the walls of facility, in some cases far away from the inlets of key racks in the facility. These were the issues to address in airflow optimization for the facility using CFD modeling.

A variety of airflow optimization tactics were explored for this facility which resulted in a proposed design for airflow optimization involving the addition of new ducting, end aisle containment and blanking panels. Figure 8 shows the improvements in airflow management that resulted from the design. Hotspots have been eliminated, mixing of hot and cold air significantly reduced, and the range of rack inlet temperatures has been reduced so that the inlet temperatures in the facility are much more uniform. In essence, with the same cooling capacity, the facility has become much cooler, and the set-point can be raised to achieve energy savings and reduce the cost of cooling per watt of IT equipment.

5.4. CFD model after airflow optimization and after raising the set-points

In addition to the airflow management changes just described, the thermostats in the CFD model were moved to the cold aisles and additional thermostats were added so that the air temperature could be controlled where it matters most - at the rack inlets. Next the set-points of the HVAC systems were raised in the CFD model until just before the point where ASHRAE limits were exceeded on any particular rack. The results are shown in Figure 8.

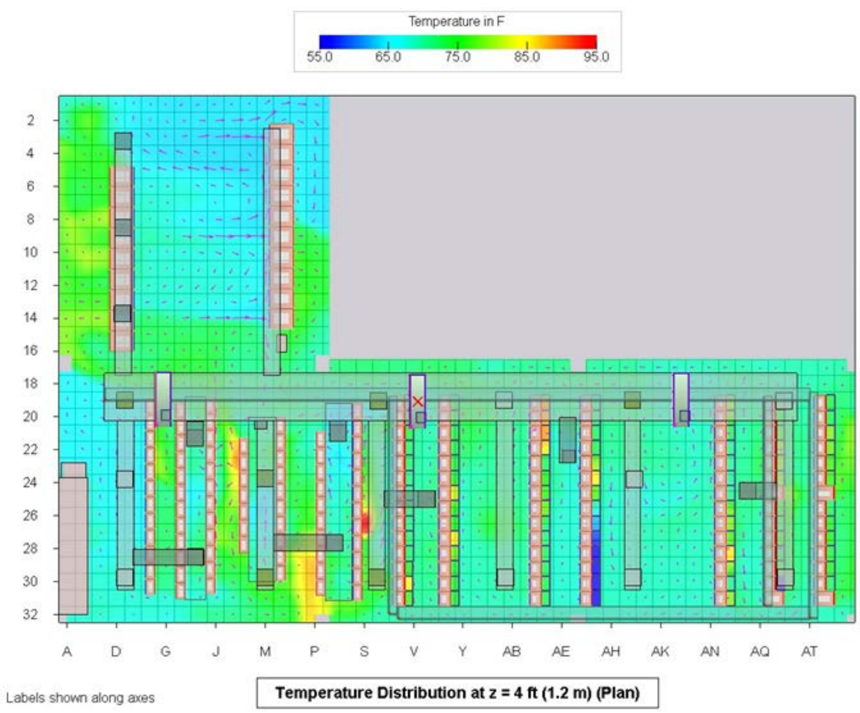

Figure 8 - CFD Model Results After Airflow Optimization and Raising the Set-Point

After raising the set-point by 6 °F, the inlet temperatures are slightly higher but still below ASHRAE upper limits, and some hotter areas at rack exhausts can be seen. Very hot exhaust aisles are normal and acceptable in modern facilities; it is the mixing of hot with cold air that is undesirable. With a 6 °F increase in set-point PUE was reduced from 1.9 to 1.7, the HVAC energy consumption was estimated to be approximately 17% lower, thereby significantly reducing the cooling cost per watt of IT equipment in the facility. Also, and importantly, elimination of equipment inlet hotspots avoiding any customer impact hours.

6. Beyond Airflow Management

Even if other energy conservation measures such as HVAC optimization, upgrades or replacements are planned, it is important to do airflow optimization first. This is because airflow optimization can reduce the tonnage of cooling capacity and thus the cost of HVAC upgrades or replacement, and can also enable true HVAC redundancy in the facility via ducting additions so that in the event one HVAC unit fails, cold air is still provided to the IT equipment. HVAC upgrades and replacements with more efficient technologies are covered in a later section. In this section, other optimizations of existing HVAC systems beyond airflow optimization will be covered.

Once the airflow has been optimized and HVAC set-points have been raised to achieve energy savings, the following additional optimizations of existing HVAC systems are possible and have been shown to reduce the current draw of existing HVAC systems and thereby lower the energy consumption of the HVAC systems, in addition to potentially extending the lifespan of existing HVAC units:

- Installation of add-on or stand-alone economizers to existing HVAC systems
- Deep cleaning of coils and other system maintenance items to 'true-up' the HVAC system back to its nominal operating condition
- Disabling or putting into lag mode any existing HVAC units that are deemed unnecessary after airflow optimization. (Lead-lag means that one HVAC unit activates first (the "lead" unit), then another activates after a "lag" only if necessary and may only activate if the first unit fails entirely. Alternately, the HVAC systems can be sequenced to distribute the runtime across the units while still reducing energy consumed since fewer units are simultaneously running.)
- Replacement of older refrigerants such as R22 and R407A with modern, more efficient refrigerants
- Installation of advanced HVAC controllers that can reduce the compressor on-time required to achieve the same level of cooling

Figure 9 below shows an example flow chart for exploring additional HVAC optimization measures that reduce the HVAC energy consumption following airflow optimization.

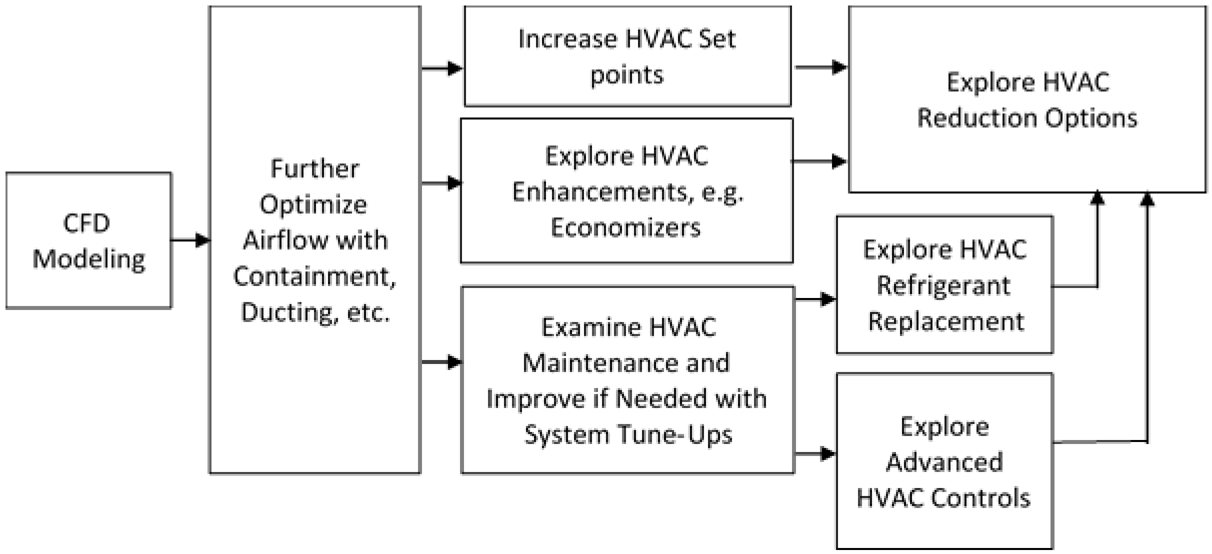

Figure 9 - Energy Conservation Measures Beyond Airflow Optimization

7. Power Usage Effectiveness

ANSI/SCTE 213 2015 [S213] describes how the power usage effectiveness (PUE) is to be measured in cable *edge facilities*. The PUE is defined as:

$$\textbf{Power Usage Effectiveness} = \frac{\textbf{Total Critical Facility Energy}}{\textbf{IT Equipment Energy}}$$

The above definition of PUE presumes the availability of detailed sub-metering data on the components of the facility energy consumption (IT, HVAC, lighting, plug load), or at least the availability of accurate IT and HVAC load sub-metering data. One would typically measure HVAC consumption at the CRAC units using sub-metering devices, and measure the IT load at panels of DC plants. Unfortunately, even these minimal measurements are often not available in current cable *edge facilities*, and the only data available is the total building energy consumption from the utility bill and the IT load from DC plant monitoring. Further, many cable *edge facilities* are either part of a larger facility, or have significant portions of the facility dedicated to office space that is separate from the critical equipment spaces, or have multiple zones that are independently cooled within the facility. These variations, along with the rapid changes in IT load often seen in cable *edge facilities* can significantly complicate the calculation of PUE. Nevertheless, those skilled in the art can accurately estimate the other components of energy consumption and compensate for non-critical spaces in the facility based on an energy audit of a site, detailed equipment lists, and so on. An example of this approach is shown in Figure 10 below for a cable headend. Whichever approach is used, it must be identically applied to all facilities, and preferably calibrated by actual detailed measurements from at least one facility.

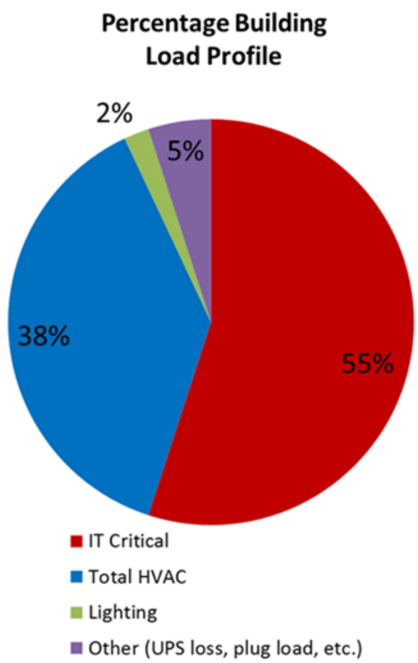

Figure 10 - Example of Energy Consumption by Percentage for a Cable Headend Facility

The distribution of energy consumption shown in Figure 11 is quite typical for cable edge facilities, but can vary greatly if the facility has the corner conditions just described or has already received the benefits of energy conservation measures to reduce the HVAC energy consumption as a percentage of overall facility consumption.

ANSI/SCTE 213 2015 [S213] describes how to convert from kWh to kW, provides examples of PUE calculations for cable *edge facilities* and describes how frequently to measure PUE. Especially for cable facilities that are not well insulated, the PUE can be quite sensitive to outdoor air temperature, as is seen in Figure 12. Higher outdoor air temperatures create an additional heat load on the facility that requires additional cooling for the same IT equipment load, thereby raising the PUE of the facility.

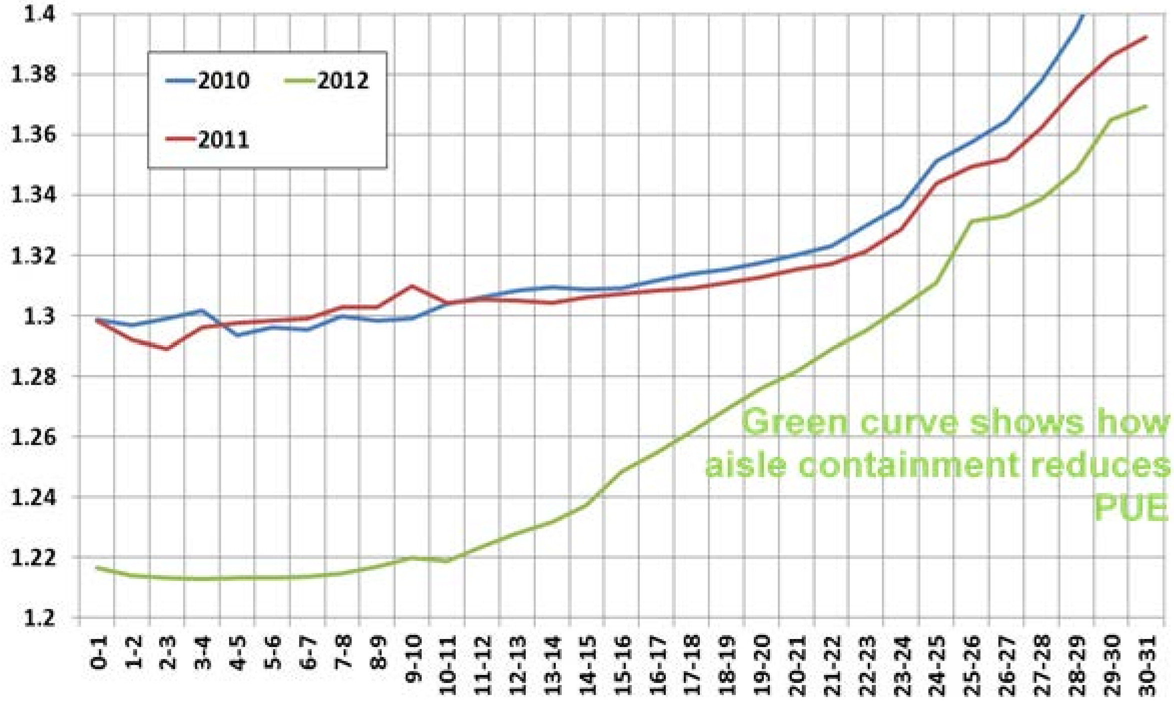

Figure 11 - PUE vs Outdoor Air Temperature in Degrees Celsius for a Facility Before and After Aisle Containment (see Bibliography & References)

In this case, the behavior of PUE vs. outdoor air temperature was plotted before and after implementing airflow optimization using aisle containment, and the effect on PUE is dramatic. Changes in outdoor air temperature and changes in the IT load and the HVAC load from drastic IT load increases can all skew the PUE measurement. Hence careful analysis of the actual data for a site is required to accurately determine the impact of energy conservation measures.

8. Incentives

Energy rebate incentives are available to help offset the cost of many energy efficiency projects for network facilities through state and provincial utility companies. A broad range of projects are considered eligible and include for example replacing lighting with LED’s, upgrading cooling units with variable speed fans, replacing energy inefficient cooling with more efficient units, installation of control systems, or replacing electrical equipment with natural gas powered. Each state has different programs and incentives so discussion with the local utility is necessary to determine project eligibility. In general incentives are available up to a maximum of 50% of the total project cost and are based on level of energy savings.

The key to successfully maneuvering the rebate process is to contact the local utility in advance of any work or commitment to purchase materials is made. Ensure there is a paper trail within your organization noting the intent to apply for incentive rebates and a paper trail with the utility companies. It is advisable to do this weeks in advance to have the opportunity to discuss the project, understand what the expectations are from the utility and agree on how the requirements such as energy metering, if required, will be done to satisfy the measurement and verification (M&V) plan requirements.

An application is submitted once agreement is reached on the project objectives, approach and M&V plan. Approval of the application can take a few weeks and may involve more discussion with the utility representatives. With most utilities once the application has been submitted work can begin on the project however if baseline measurements are required (and they often are) they must be taken before anything changes or work begins. Check with the local utility as some may require waiting until the application is approved before work can begin. Others prefer the baseline measures completed and submitted as part of the initial application.

Documentation required with the application filing generally includes:

- Description of base case and energy efficient case
- Technical specs on existing and new equipment
- Quotes, estimates or pricing from the vendor for the new equipment to show project cost
- Calculations showing the projected energy reductions (these are estimates as metering may not have been done at this point)
- A variety of forms to be signed by company representative

Costs internal to a company, such as manpower to install or remove equipment are not considered eligible project costs.

Upon completion of the project a second energy measure is required. The pre and post-measures are used to determine the value of the energy rebate. Documentation generally required for the final application submission includes:

- Invoices showing product and installation costs
- Metering results from pre and post measurements and the level of energy savings
- Disposal forms for old equipment
- Usually a variety of forms unique to the utility company to be signed by company representative

The utility company may request a site visit pre- and post-work to verify the equipment and work completed. This may be a utility representative or a third party. Requests to take pictures of old and new equipment may be made – if company policy does not allow pictures this should be pointed out the representatives during the initial application discussions.

After the final application material is submitted and the utility approves the energy rebate on average, 8-12 weeks is required for processing of payment. The company representative will be advised if any questions have arisen or if the final application has been approved. Utilities generally require the company to create an invoice to the utility for payment of the energy rebate.

9. Summary of Plan, Measurement and Verification

Energy consumption before and after climate technology optimization must be accurately characterized for internal budgeting and for external purposes such as energy rebates and incentives. Documented results will give confidence that the outcome could be replicated at other *edge facilities*.

9.1. Pilot

Pilot new technologies or approaches in representative and realistic conditions. If this is a technology that can be applied to multiple *edge facilities* then make sure you select a site that is a good representative and try to eliminate or at least account for anomalies that might impact energy savings such as any new equipment being added, unique equipment layout, etc.

Conduct your testing during a period when you expect to see the results of the technology improvement. Even though *edge facilities* have year-round cooling demands, the effect of outside air temperature will greatly impact your results.

9.2. Baseline

Establish baseline models to evaluate new technologies. Baseline measurement can be expensive for *edge facilities* but it is necessary to properly evaluate improvements. The cost of monitoring and measurement is coming down with new Internet of Things (IoT) technology which are lower cost and easier to install.

Gather baseline environmental data such as supply air temperature (SAT), return air temperature (RAT), supply air humidity (SAH), return air humidity (RAH) and rack inlet temperatures. Knowing how the facility is performing is important to understand what impact the new technology has on the operation. Network reliability cannot and must not be compromised for the sake of energy savings.

Install sub-metering on HVAC & IT equipment to measure consumption and calculate PUE. Depending on cost and how the facilities' electrical panels are configured, it might be more cost effective to meter the incoming power to the facility and sub meter the HVAC. This can be an acceptable alternative if the rest of the electrical load is inconsequential or somewhat static. The goal is to be able to measure the improvement by accurately assigning the reduction in energy to the technology being implemented.

9.3. Implement

Implement the energy conservation measures at the facility and monitor the performance. If the measures are multifaceted then consider implementing them in stages to analyze the performance of each one independently. Methodical implementation will help determine which measures have the "biggest bang for the buck" so priorities and budgets can be set accordingly.

9.4. Analyze

Gather post-implementation data and calculate energy and cost savings. Consider the following follow-on questions:

1. Did the new optimization technology perform as expected?
2. Is the return on investment (ROI) payback within company guidelines? Use the environmental data collected to evaluate the impact on the performance of the facility. I.e. was proper temperature maintained in the facility?
3. Are there any inlet hotspots that need to be addressed?

9.5. Refine

Is there confidence the results can be repeated in other *edge facilities*? What worked well, what didn't? What should be done next? Use the data gathered to refine goals and design larger programs for the entire footprint.

9.6. Ongoing

Continue to capture data for 'health checks', changing trends, and to explore new opportunities. Ongoing monitoring will help to ensure the new measures are operating properly and that changes in performance can quickly and accurately be evaluated to prevent degradation in savings over the long term. *Edge facilities* are surprisingly dynamic and require constant monitoring to keep them at optimum performance.

10. Cooling Technologies

In this section, we provide top level insight into choosing the primary method for cooling a facility containing electronic equipment as well as choosing an economizer technology that can be coupled with a primary cooling method. We provide the reader a definition of each primary method and each economization option as well as a decision guideline that steers the reader towards the best efficiency.

It is not always possible or practical to simply choose the most efficient cooling approach as there are a series of other trade-offs that must be considered. These tradeoffs are outlined in this section in a qualitative manner which looks at the following elements of each choice:

- **Efficiency** → which methods typically deliver cooling capacity while consuming least amount of electricity.
- **Modularity** → Do you have options for growing capacity that creates an advantage like space utilization or control & coordination over simply adding more HVAC systems
- **Installed Cost** → This includes both relative equipment and labor costs and compares each option's upfront implementations costs.
- **Limitations** → This is an attempt to focus some attention on less tangible items. Limitations refers to the requirements for implementing a technology and whether the equipment room can accommodate each technology. For example, some sites do not have access to running water. There are several cooling and economizer solutions that require running water to work so these choices
- **Maintenance** → This characteristic compares the effort/cost to maintain each system. The simpler and lower cost to maintain the more preferable.

10.1. Primary Cooling Options

One or a combination of the methods below is typically used as primary cooling method to offset heat load year-round

10.1.1. Direct Expansion

Direct expansion (DX) uses a compressor to drive a refrigeration cycle to cool a site. It is also known as mechanical cooling. It introduces no outside air and can cool the indoor temperature cooler than the outdoor temperature. It has the least limitations but is also the least efficient.

10.1.2. Chilled Water

Chilled water (CW) system provides cold water to cool the room. After absorbing heat from the room, the chilled water returns to the chiller where the chiller remotes the heat from the water using the refrigeration process. It has high efficiency but is often quite complex to implement and therefore most often cost effective for very large projects (> 100kW).

10.1.3. Adiabatic Cooling

Adiabatic (AD) cooling works by blowing the supply air through an evaporation pad. Water evaporates as the air passes through the pad, the air cools down much like the process of perspiration cools down your skin. It is very efficient and works best in dryer environments since the cooling capacity is limited when the environment has high relative humidity.

10.2. Economization Options

Note: not all economization options are compatible with each primary cooling option.

10.2.1. Direct Airside Economizer

Direct airside (DA) economizer uses fresh air to cool the room when the environmental conditions are favorable. DA is the most energy efficient way of cooling a site because it directly uses the outside air with no loss from heat exchange. In areas with lower air quality, filtration or other mitigating technology must be properly deployed.

10.2.2. Indirect Airside Economizer

Indirect airside (IDA) economizer uses some form of heat exchanger to transfer heat between inside and outside air. It has lower efficiency than direct airside economizer but does not introduce outside air into the room.

10.2.3. Pumped Refrigerant

Pumped refrigerant (PR) economizer uses an economizer pump in place of the compressor when the outside air is significantly colder than the room temperature. Similar to indirect airside economizer, it does not introduce outside air. Additionally, it does not require any large wall penetration but usually has higher upfront cost (equipment and installation).

10.2.4. Indirect Waterside Economizer

Indirect waterside (IDA) economizer typically uses one or more cooling towers and heat exchanger to offload all or parts of the chiller’s load. Freeze protection must be considered for colder regions.

10.3. HVAC System Selection Guide

The following flow chart provides a process to help select among the various cooling technologies available for *edge facilities*. It provides a basic guide but does not go into the detail of such items as compressor types, air flow management or filters.

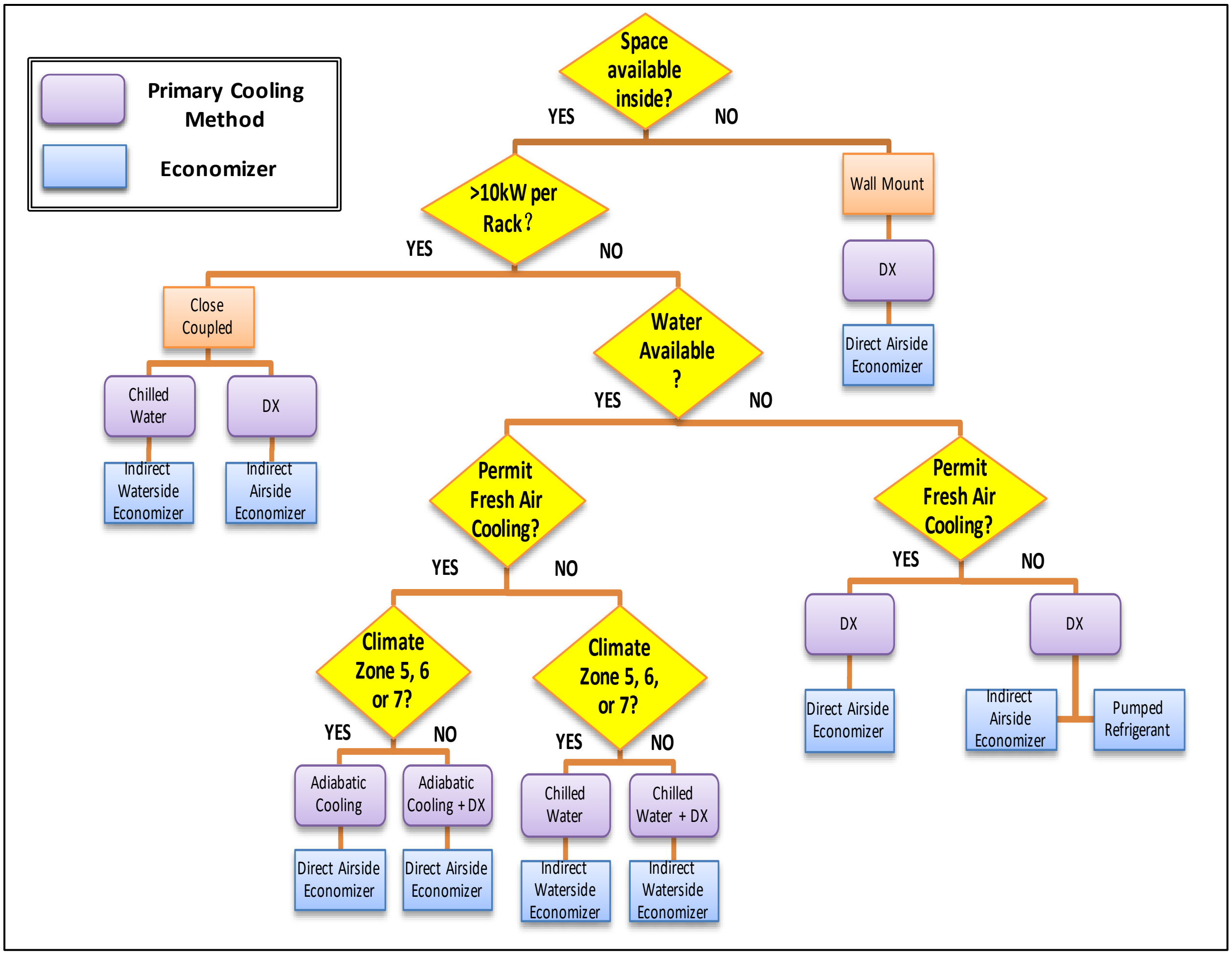

Figure 12 – HVAC System Selection Flow Chart

10.4. HVAC System Selection Guide

Figure 13 provides an overview of a qualitative analysis of the cooling technologies applicable to *edge facilities.* The scale provided is 1 to 100 with 1 being the lowest in a category and 100 being the highest in a category. For example, DX+PR cooling technology has a fairly high installed costs, but high efficiency, but also has limitations in size and is complex, modular to deploy (costs scale as you grow) but has a more parts to maintain.

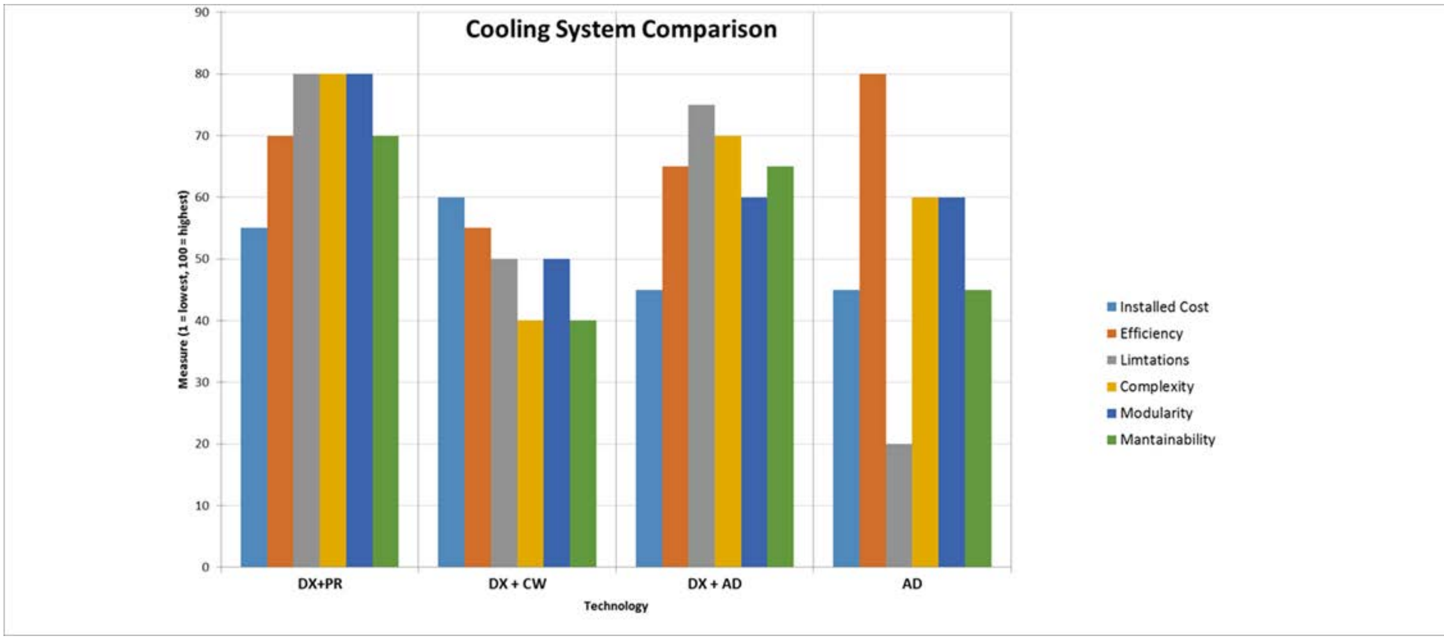

Figure 13 - Comparison of various HVAC system by category

11. Financial Analysis

Two viewpoints will be considered under financial analysis, actual financial analysis and non-financial analysis focusing on other factors such as customer outage hours.

11.1. Financial Payback

The focus of financial analysis is simple payback and compares 2 options. For example, continuing to use the existing cooling technology compared to adding in and economizer (free air cooling). Payback is generally acceptable under 3 years.

Analysis can be simple payback or more complex such as NPV (net present value), IRR (internal rate of return) and ROI (return on investment).

Simple payback is often used but ROI is more useful as it includes all factors for the life of the cooling technology including but not limited to: Initial costs, rebates, installation costs, cost of power, energy costs, maintenance costs, component replacement costs and end of life costs.

Simple Payback can be calculated as follows:

$$Payback\ Period = A + B/C$$

A = The last period with a negative cumulative cash flow.

B = The absolute value of cumulative cash flow at the end of the period A

C = Total cash flow during the period after A.

This will calculate when you 'break even' or get your money back. Normally less than 3 years is acceptable.

There are more detailed well know financial analysis that can be considered for large projects: NPV, IRR and ROI.

Net present value is another way of representing a ROI. It is the present value of the cash inflows and outflows at the required rate of return of your project compared to your initial investment. This is superior to Payback as it considers the time value of money over the life of the asset. The more positive the NPV the better this is for a project. Negative values indicate the initiative should be abandoned.

Analysis of the net present value (NPV) of two options is as follows.

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}$$

C_0 = Initial Investment
C = Cash Flow
r = Discount Rate (different from business to business)
T = Time

The Internal Rate of Return provides the rate at which a project breaks even. This does not provide actual amounts and should be used in conjunction with NPV. A high positive % is a good indication of a good investment. Of course, a solution with a negative % ROI should be abandoned.

Analysis of IRR of two options is as generally follows but it is recommended to use one of the tools available such as Excel.

$$0 = P_0 + \frac{P_1}{(1+IRR)} + \frac{P_2}{(1+IRR)^2} + \frac{P_3}{(1+IRR)^3} + \cdots + \frac{P_n}{(1+IRR)^n}$$

P_0, P_1,…P_n Cash flows in periods 1, 2, …n
IRR = Internal rate of return

Return on Investment, ROI, measures return on investment over time. A higher % indicates a good investment. Again, a very low or negative % ROI solution should be abandoned.

Analysis of ROI of two options is as follows:

$$ROI = \frac{Gains\ from\ investments - Cost\ of\ investment}{Cost\ of\ investment}$$

11.2. Example, Simple Payback and Operational Savings

An example of simple payback and operational savings is a study done by SCTi at a Rogers Facility to determine possible savings by raising the CRAC set point to reduce its energy consumption. Expectations in the industry appear to be modest at 1 – 2% savings per °F, although some have reported as high as 6% savings. This is highly dependent on initial conditions and other initiatives that may have been done a site to improve other aspects of cooling such as air flow. The results are shown in Table 2.

Table 2 - Savings by Increasing Set Point

ROGERS	Energy Reduction					
	Set Point		kW Average	% kW	% kW per	
Data Total for 4 CRAC	°C	°F			°C	°F
2016-10-30 Baseline	21	69.8	93			
10-Dec	25	77	86			
Δ	4	7	7	7.5	1.875	1.042
Per CRAC Annual		kWh	15,330			
		$ at $0.13 per kWh	$2,000			

The annualized savings per CRAC unit is $2,000 and simple Payback is 1.25 years for this initiative. Assuming 50 similar facilities the savings would be $1M in energy (operation) costs. Be aware that these types of studies can be complicated to plan and execute because of the number of variables affecting the energy efficiency results.

11.3. Other Non-Financial Considerations

For non-financial analysis, the Payback period is less important than improvement in other areas. It is more about increasing reliability, reducing churn, adding more customers, customer satisfaction or network uptime.

One general measure of this is customer impact hours of a cooling solution or technology. If the aim is to reduce customer impact hours as a result of cooling issues it may be prudent to, for example, invest in greater IT thermal resilience by installing more than N+1 in cooling, or add more sophisticated remote monitoring capabilities for remote sites to reduce truck rolls, maintenance costs, and provide a more predictive maintenance response.

12. Conclusion

This paper has provided the outline for an energy management plan for a process that will improve energy efficiency at edge facilities. Airflow is key and keeping supply and return air separate has the largest impact on the efficiency of the cooling system. A plan will ensure baselines are established before a project starts and that efficiencies and savings of the cooling technology solution can be clearly demonstrated. It ensures that appropriate data is gathered throughout the project to calculate the savings or payback. Finally, a plan can begin simply with airflow optimization but can evolve as required to use CFD and calculation of PUE to further improve efficiencies.

Abbreviations

AC	alternating current
AD	adiabatic cooling
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration and Air conditioning Engineers
CRAC	computer room air conditioner
CFD	computational fluid dynamics
CFM	cubic feed per minute
CW	chilled water
DA	direct airside economizer
DC	direct current
DX	direct expansion
HVAC	heating ventilation and air conditioning
IDA	Indirect Airside Economizer
IDW	Indirect Waterside Economizer
ISBE	International Society of Broadband Experts
IRR	internal rate of return
IT	information technology
IoT	Internet of things
PR	pumped refrigerant
PUE	power usage effectiveness
MSO	multiple system operator
NCTA	National Cable and Telecommunications Association
NPV	net present value
RAH	return air humidity
RAT	return air temperature
ROI	return on investment
SAH	supply air humidity
SAT	supply air temperature
SCTE	Society of Cable Telecommunications Engineers

Bibliography & References

ASHRAE TC 9.9 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance

SCTE 184 Energy Management Operational Practices for Cable Facilities

SCTE 213 Edge and Core Facilities Energy Metrics

SCTE 219 Operational Practice, Technical Facility Climate Optimization Methodology

SCTE 226 Cable Facility Classification Definitions and Requirements

WP49-PUE The Green Grid: PUE: A Comprehensive Examination of the Metric

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