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Adaptive Power Solutions for Cable

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
By

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1. Introduction

1.1. Executive Summary

Target Audience: Access network engineers, architects, and critical facility engineers

What is it? This operational practice covers the SCTE 216 standard, "Adaptive Power System Interface Specification (APSIS^{TM}), which enables cable operators to measure and control energy consumption associated with delivery of services.

What is the function of it? SCTE 216 defines software interfaces that allow energy measurement and optimization applications to command and control devices within a service delivery pipeline.

What are the immediate and long-term benefits of adopting it?

- Provides common definitions for all manner of electronic device to report energy consumption and accept commands in a uniform and comparable way
- Creates a framework in which devices may interoperate with energy measurement and optimization applications
- Energy consumption patterns can be more closely matched to service delivery demand

How does this operational practice impact the industry and fit into the SCTE Engineering Committee's and the Energy 2020 program's roadmaps?

- Provides the critical underpinnings for any number of energy measurement and optimization applications to be applied to a cable system
- Ensures consistent and reliable energy reporting metrics at the device level
- Enables operators to fine tune service delivery patterns to optimize reliability, customer experience, and energy consumption

What are some of the key points of this operational practice?

- Adopts international standards for device-level energy monitoring and controls, and is based on definitions provided by the IETF (Internet Engineering Task Force)
- Defines a high-level information model describing the energy-related data points and control functions supported by compliant devices
- Provides definitions for a growing number of protocol 'bindings' to the information model and allows device manufacturers to choose which specific software protocols (e.g. SNMP, IPDR, etc.) to use to implement the standard

What can you do to achieve maximum benefit from implementing this operational practice?

- Specify support for SCTE 216 as a requirement in future device purchases
- Consider strategies to buy or build energy measurement and optimization applications that utilize the SCTE 216 framework
- Support cross industry efforts to identify impactful energy optimization approaches based on device and systems level energy management

How can you learn more about this operational practice? Join the Energy Management Subcommittee (EMS) APSIS working group and assist in revisions and updates to this document. Visit http://www.scte.org/standards, or email: standards@scte.org for more information.

1.2. Scope

The cable network architecture described here provides context to segment devices into logical categories for the purpose of understanding software interfaces and interaction between components. The cable network is generally implemented in a hub-spoke topology, where network segments become more regionalized and numerous as we travel from left to right in the diagram. Network segments include:

- The Back Office Network includes Business Support Systems (BSS) used to run operations including billing, customer relationship management, trouble management, and new customer acquisition and Operational Support Systems (OSS) which include inventory, provisioning, configuration, performance and fault management. Adaptive Power Applications will typically be implemented within this logical network segment.
- The Backbone Network is comprised of content access and distribution systems, data centers, and other enterprise wide service delivery functions.
- The Transport Network provides video, voice, and data service to local markets and includes head-end and hub facilities.
- The Access Network serves the ‘last mile’ connecting the cable network to individual homes and businesses.
- The Customer Network demarcation point is at a single point of interface to a home or business or at a device or devices within a home or business at which the service termination point resides. Examples of such demarcation points are Set Top Boxes (STBs), Cable Modems (CMs), embedded Multimedia Terminal Adapters (eMTAs), Media Gateways (MGs), Private Branch Exchange (PBXs), Point of Sale (POS) or any other similar Network Interface Devices (NIDs). Requirements pertaining to equipment residing in the Customer Network are not within the scope of this document.

1.3. Background

This operational practice is in reference to the SCTE 216 standard for the Adaptive Power System Interface Specification (APSIS^{TM}).

Today’s cable systems include broadband telecommunications infrastructure, including high-speed data services, digital telephony and other applications, and multi-channel video program distribution systems composed of highly specialized television distribution technology. This document specifies software interfaces to cable systems to enable a broad set of energy monitoring and management applications. Interfaces *may* be defined at the level of individual devices, collections of devices including an entire facility, and networks spanning multiple facilities.

Applications that influence service delivery in order to attenuate energy consumption are called adaptive power applications. The set of device and system level interfaces that support such applications are Adaptive Power System Interfaces.

The focus of the specification is to define interfaces within the domain of cable service delivery networks, including the cable ‘plant’, data centers, digital voice platforms, wireless platforms, and other communications and distribution electronics. These interfaces are intended to complement definitions provided elsewhere that could allow a cable operator to obtain comprehensive visibility and control over their entire operations, including:

- The owned business enterprise networks (e.g., internal business networks, LANs, etc.)
- Operator facilities (e.g., HVAC, lighting, etc.)
- Interfaces to third parties (e.g., energy suppliers, other providers, demand-response managers, etc.)
- Interfaces to operator owned Customer Premises Equipment (CPE) (e.g., cable modem, set-top box, eMTA, etc.)
- Interfaces to energy consuming equipment owned by and located at a customer's and consumer's location (e.g., LCD TV, Wi-Fi Router, etc.)

Consumer Presence Equipment (CPE) are devices that deliver services within a customer's home or place of business and do not draw power from the service provider. APSIS does not directly address requirements of such equipment. However, a truly end-to-end energy management framework considers the impact of these devices on the service provider energy systems; for example, service provider applications on CPE can work in concert with logic within the network to optimize energy utilization within the network. Interface definitions between CPE and components within the service provider network *may* prove valuable in the future, although none are planned at this time.

The APSIS specification is also intended to enhance business continuity and disaster recovery by optimizing the performance, availability, and reliability of cable networks, optimize expenditure on energy, and improve the mean time between failures (MTBF) and extend the useful life of components and equipment.

2. Operational Practices

2.1. Overview

Energy management has become a strategic concern for the cable industry. Access to reliable and affordable local power sources, and increased energy efficiency are key enables for continued growth and improved customer experiences.

2.1.1. Power Limits

An apocryphal story that bears on our situation is that when rolling brown outs occurred in California energy grid in the early 2000's, they caused disruption of service for then nascent online service providers, such as Google. This provided a wake-up call to Silicon Valley that the existence of a utility power grid was not a guarantee of electrical service.

Those on the East Coast will recall Hurricane Sandy a few years ago. It revealed all too clearly the fragility of our electric infrastructure and many communities lost power for many days, and even several weeks.

These events highlight concerns over power availability as a potential limiter for cable's continuing growth. Internet traffic has increased spectacularly since its adoption, and shows little sign of slowing down. In order to ensure that increasing demand can be met, access to reliable and affordable power has become a topic of active research. Possible increases in power costs and concerns about reliability and availability of utility power have led to an examination of power management strategies, including energy management applications.

2.1.2. Internet Traffic Growth

As Internet traffic has grown, so has the deployment of large-scale data centers and networking infrastructure. The big internet application providers, such as Google, Amazon, Facebook, and related component manufacturers have made impressive strides in optimizing service delivery per unit power. Aggressive innovation in power generation, facilities design, and computing and software systems, has led to dramatic improvements in efficiency. Coupled with these improvements is the emergence of new software applications to monitor, measure, and control facilities and systems. Merging facilities control systems with IT device management systems are a new class of Data Center Management tools.

The portion of the cable infrastructure composed of commodity computing resources will naturally surf this wave of innovation. Every successive generation of compute, storage, and networking equipment becomes more energy dense due to the market forces brought to bear by the global computing market.

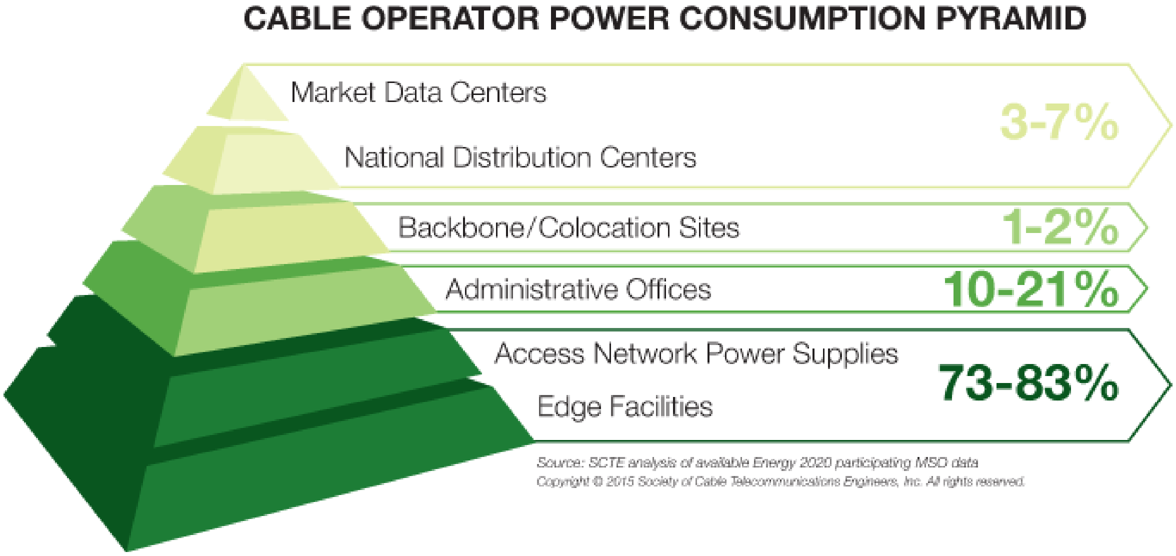
However, a significant portion of cable infrastructure does not automatically participate in this beneficent trend. Specialized gear such as encoders, modulators, receivers, fiber nodes, and so on is the topic of our current research.

2.1.3. Infrastructure

This infrastructure also differs from general computing resources in that it is necessarily distributed across a service provider’s geographic service footprint. While data centers can be located just about anywhere and optimize for energy availability and price, the cable plant is part of the neighborhood that it serves. While this dependence on local power has not to date been seen as a risk, ever increasing demand could impact the ability to reliably deliver service in some areas.

2.2. Cable Operator Consumption

Figure 1, taken from the published SCTE Energy 2020 material, illustrates the relative energy expenditure across various domains. This clearly shows that the area offering the most opportunity for improvement is the access network.



Source: SCTE analysis of available Energy 2020 participating MSO data
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Figure 1 - SCTE Energy Power Pyramid

Given these observations, the main areas under consideration for a smart energy future are power acquisition, facilities management, device and systems optimization, and measurement and control applications.

2.2.1. Power Acquisition

Power acquisition addresses that ways power is accessed by the cable plant. Facilities generally have diesel generators that serve to bridge temporary outages, but a number of interesting alternatives to the traditional grid, including on-sight power generation from solar, fuel cells, or other sources, micro-grids, and other solutions are being developed. For instance, Sterling engines are a type of power generator that could in time provide backup power or augment utility power. Given the inherent inefficiencies of transporting power over long distances, a general trend toward distributed power generation might generally occur.

2.2.2. Facilities Management

Facilities can be made ever more efficient through smart management of cooling resources, heat dispersion and sequestration, and other designs. While cable continues to invest in implementing best practices in this area, we have the benefit of following the leaders in this space, such as the largest data center designers. Where this topic becomes more interesting for us is in considering how to optimize the topology of our regional and local plant. The current facility layout is the result of many smaller systems haphazardly being built and deployed over a very long time and slowly becoming aggregated by ever-larger operators. Collapsing the number of nodes and closing older, less efficient facilities will lead to a reduction in power usage.

2.2.3. Device and Systems Optimizations

Device and systems optimizations include improved chipsets, density of signal processing pipelines, virtualization and cloud computing, and other design improvements.

2.2.4. Measurement and Control Applications

Finally, the adoption of monitoring and command/control interfaces and the introduction of mutable runtime properties, such as clock speeds, power levels, signal path clustering, and other knobs, will allow real-time system adaptations to improve energy utilization. To make use of these interfaces and controls, a software framework is needed to allow innovation to occur at the application layer to optimize energy usage by devices and collections of devices within a signal path.

Our software framework is described as a layered model. At the lowest layer are devices and the communications protocols they support, a middle layer establishes connections to a set of devices and aggregates measurement data, and finally, adaptive power applications utilize the middle layer to analyze and control the behavior of the connected devices.

3. Layered Adaptive Power Software

Figure 2 provides an illustration of our layered Adaptive Power software framework.

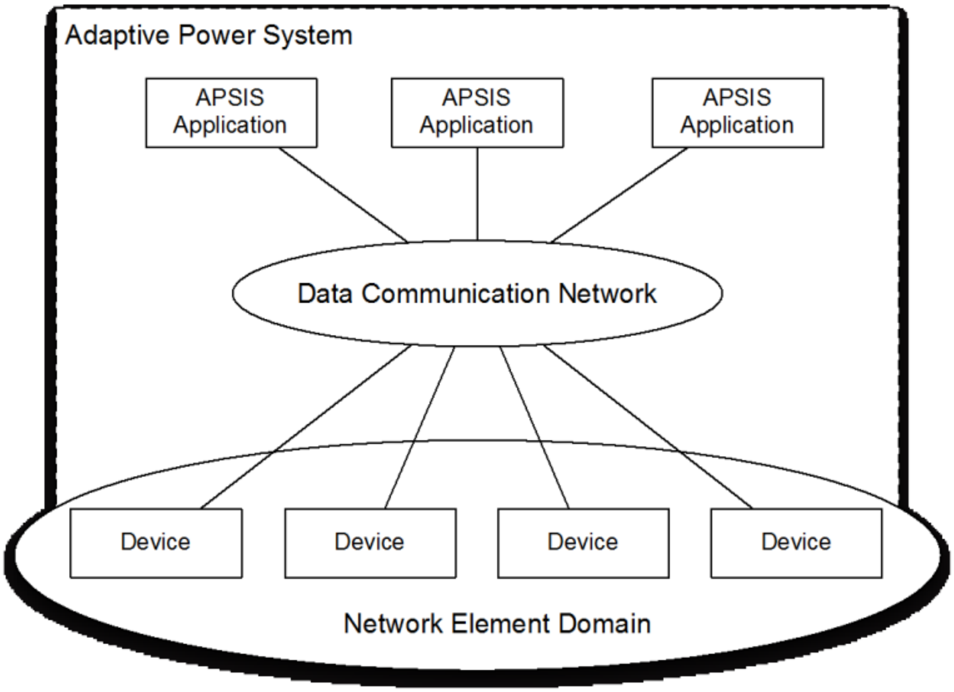

Figure 2 - Adaptive Power Software Framework

3.1. Physical Devices

At the lowest layer of our model are physical devices. The SCTE, along with the IETF and other forums, are actively defining interoperability definitions for devices. A Common Information Model is being developed that expresses the entities and relationships necessary to comprehensively monitor a device’s energy utilization, and to support command and control functions. An Information Model is a logical construct that simply describes data objects and their attributes. A protocol definition can define how these logical entities are encoded and transported on a software interface. Any number of encoding and transport protocols can support a logical model, and the logical model serves to unify differing representations of the model.

3.1.1. Protocol Specific Bindings

Protocol specific bindings are being defined to support the Information Model. For example, the IETF provides an SNMP MIB definition that conforms to the model. Since SNMP has certain disadvantages as a software interface in some environments, mappings between the Information Model and other protocols are planned, including NETCONF, IPDR, and TR-069.

This strategy allows devices and systems to implement the best transport and encoding solutions for given usage scenarios, while ensuring that at the application layer the data maintains known semantics. It's conceivable that one set of protocols might best serve to gather measurements, while others may be better suited as command and control interfaces.

3.1.2. Other Device-centric

Other device-centric definitions are also under development. For example, definitions of various power states may become useful to normalize the definitions of intermediate power states between fully powered and off.

3.1.3. Middle Layer

The middle layer of our model is necessary to provide connectivity to devices, gather measurements, and act as a control plane for applications. Software suites developed in the Data Center Management space mentioned above might adapt to fill this gap, or other solutions may arise. This layer allows applications to implement logic for measurement or control without having to be 'tightly-bound' to a specific device environment, thereby limiting its re-usability across multiple physical domains.

An Application Programming Interface (API) definition might be useful to promote interoperability between energy middleware systems and adaptive power applications. A REST style HTTP interface that represents the Information Model and supports command and control logic would decouple the application layer from the device layer, thereby allowing applications to interoperate with a number of middleware solutions and device installations. This could help foster innovation at the application layer by broadening the potential market for an application.

3.2. Adaptive Power Applications

Adaptive power applications may take many forms. First and foremost, sufficient measurement is the only way to establish a baseline against which to measure any remediation efforts. As Lord Kelvin famously said "If you cannot measure it, you cannot improve it." What is the impact of adding more servers, installing a better HVAC system, opening the doors during the winter? Only by measuring the system before and after the change can one calculate the cost-benefit ratio.

3.2.1. Collect Data

Collecting and analyzing data on the scale of a cable network is certainly a ‘Big Data’ problem, and will benefit from the tremendous innovation cycle we are currently in for data storage and collection, search, and visualization technologies.

3.2.2. Mine the Data

Simply mining energy data from a set of devices within a facility, or across multiple sites, could provide insights into system behavior that could aid decision-making and automated energy optimizations.

3.2.3. Details of the Data

Detailed measurement will allow operators to determine the energy coefficient associated with various services. What are the ratios for kilowatts/VOD stream, kilowatts/MB Internet access, and so on? Over time, these ratios should improve. As demand grows, the absolute energy usage may also grow, but hopefully at a lower rate.

3.2.4. Device Lifecycle

Device lifecycle management may be improved by comparing the energy utilization profile of devices against norms established across a large population. Rather than waiting for a scheduled mountainous or replacement, a deviation from an expected baseline could indicate service. This could help remediate problems before they occur, or allow devices to stay in the field longer than expected as long as they behave properly.

3.2.5. Applications

Applications might extrapolate the expected effects on a historical data set to model the cost-benefits of proposed changes to a system. Algorithms can be developed to analyze any number of potential solutions, such as collapsing the number of faculties within a region, or distributing edge caches.

3.2.6. Measurement and Command/Control Promises

Measurement combined with command/control promises to enable responsive systems that can modulate energy consumption as service delivery rates rise and fall. A completely non-adaptive system requires a fully powered system regardless of demand. An optimally responsive system would tightly correlate energy consumption with service demand.

For example, demand for video and data services spike in the morning and evening hours, and fall to very low levels during the nighttime hours. Applications that match consumption to the diurnal flow of demand could boost efficiency tremendously. Imagine a system than ‘breathes’ power along with surges in demand, and releases the energy as demand plunges.

3.2.7. Application Integration

Applications might also integrate into the power grid to implement demand response logic. As a local utility becomes burdened by other users, and therefore temporarily increases pricing, operators might be able to shave costs by attenuating their power consumption while maintaining acceptable levels of service.

3.2.8. Need for Research

Research is needed into specific algorithms for adaptive power systems. Some ideas that have been floated include clustering service flows onto a minimal set of devices, and powering down devices that are therefore unused. Treating different services, such as data, VOD, linear video, digital voice, and so on as individual special cases may be a good place to start.

3.2.9. Self-Adaptive Service

A self-adaptive service network shares many concepts with the emerging field of Software Defined Networks and leads us to imagine Adaptive Power Applications that seamlessly shuttle service flows to specific paths to optimize for any number of outcomes, including energy efficiency.

3.2.10. Adaptive Power Applications

Instrumenting and controlling cable infrastructure through Adaptive Power Applications presents opportunities to control energy costs and increase service reliability. A software framework to enable controller applications to grab measurements and issue commands to devices opens a new field of innovation. So-called Adaptive Power Applications might result in optimally efficient service delivery systems that match power consumption to demand.

4. Conclusions and Recommendations

4.1. Areas for Further Investigation or to be Added in Future Versions

Business use case scenarios can be taken into consideration for further investigation.

5. Abbreviations and Definitions

5.1. Abbreviations

APSIS	Adaptive Power System Interface Specification
BSS	Business Support Systems
CAPWAP	Control and Provisioning of Wireless Access Networks
CCAP	Converged Cable Access Platform
CDN	Content Delivery Network
CIM	Common Information Model
CM	Cable Modem
CMTS	Cable Modem Termination System
COS	Classification of Service
CPE	Customer Premises Equipment
DACS	Digital Access Control Systems
DCM	Data Center Management
DHCP	Dynamic Host Configuration Protocol
DNCS	Digital Network Control System
DOCSIS	Data Over Cable Service Interface Specification
DPI	Digital Program Insertion

DTA	Digital Terminal (or Transport) Adapter
DVR	Digital Video Recorder
EMS	Element Management System
EMS (SMS)	Energy Management Subcommittee
eMTA	Embedded multimedia terminal adapter
EPON	Ethernet Passive Optical Network
GigE/DWDM	Gigabit Ethernet
GW	Gateway
HBS	Home Security/automation Base Station
HDTV	High Definition Television
HFC	Hybrid Fiber Coax
HTTP	Hyper Text Transfer Protocol
HTTPS	HTTP Secure
HUB	Cable critical facility
IETF	Internet Engineering Task Force
IPDR	Internet Protocol Detail Record
IPTV	Internet Protocol television
IRD	Integrated Receive/Decoder
IRTs	Integrated Receiver Transcoders
IXPs	Internet Exchange Provider
L2TP	Layer 2 Tunneling Protocol
LDAP	Lightweight Directory Access Protocol
LTRP	Laser Transmitter/Receiver Pair
LWAPP	Lightweight access point protocol
MPEG	Moving Picture Experts Group
MTBF	Mean Time Between Failures
MUX	Multiplexer
NETCONF	Network Configuration Protocol
NIOS	Network Interface of Operator Supplied CPE
NMS	Network Management Systems
NOC	Network Operations Centers
OSI	Open Systems Interconnect
OSS	Operations Support Systems
OTT	Over The Top
PBX	Public Branch eXchange
POS	Point of Sale
PSTN	Public switched telephone network
QAM	Quadrature Amplitude Modulation
REST	representational state transfer
SAN	Storage Area Network
SCTE	Society of Cable Telecommunications Engineers

SDEM	Software Defined Energy Management
SMS	Sustainability Management Subcommittee
SNMP	Simple Network Management Protocol
STB	Set-top box
TBEC	Transaction Based Energy Control
TFTP	Trivial file transfer protocol
VLANS	Virtual Local Area Network
VOD	Video on Demand
VPN	Virtual Private Network
WAPs	Wireless access point(s)

5.2. Definitions

Access Network	The last portion of the network wherein telecommunications signals are transmitted to customers to provide broadband services. Typically the maximum distance of the access network is 15 miles.
Adaptive Power System Interface Specification	An end-to-end energy management standard and specification for cable telecommunications networks and associated interfaces to it.
Backbone	The portion of a cable network infrastructure that interconnects multiple portions of the network and networks in various locations. The backbone also connects facilities where the subtending networks exist.
Business Support Systems	Systems that telecommunications providers use to run the operations of their business from a customer's perspective. Typical support systems include product management, order management, revenue assurance and management as well as customer management.
Cable critical facility	Hub is a concept in network science which refers to a node with a huge number of links ("heavily linked")
Cable Modem	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system.
Cable Modem Termination System	An access-side networking element or set of elements that includes one or more MAC Domains and one or more Network System Interfaces. This unit is located at the cable television system Headend or distribution hub and provides data connectivity between a DOCSIS Radio Frequency Interface and a wide-area network.
Classification of Service	Classification of network traffic within network equipment based on packet inspection
Common Information Model	Is an extensible, object-oriented data model that contains information about different parts of an enterprise
Content Delivery Network	A system of computers on the Internet that delivers content transparently to end users

Control and Provisioning of Wireless Access Networks	Standard, interoperable networking protocol that enables a central wireless LAN Access Controller (AC) to manage a collection of Wireless Termination Points (WTPs), more commonly known as Wireless Access Points.
Converged Cable Access Platform	An access-side networking element or set of elements that combines the functionality of a CMTS with that of an Edge QAM, providing high-density services to cable subscribers.
Customer Premises Equipment	Any piece of equipment that is owned or provided by the cable telecommunications operator and is located in a customer’s home or business.
Data Center	Facilities that house telecommunications, computer and storage systems in support of the broadband telecommunications network.
Data Over Cable Service Interface Specification	An international telecommunications standard that permits the addition of high-bandwidth data transfer to an existing cable TV (CATV) system.
Digital Access Control Systems	A piece of circuit-switched network equipment used to control access to content in telecommunications networks
Digital Network Control System	A piece of circuit-switched network equipment used to control access to content in telecommunications networks
Digital Program Insertion	Allows cable headends and broadcast affiliates to insert locally generated commercials and short programs into remotely distributed regional programs before they are delivered to home viewers
Digital Terminal (or Transport) Adapter	Digital television adapter (DTA), or digital-to-analog converter [set-top box], or commonly known as a converter box, is a television tuner that receives a digital television (DTV) transmission, and converts the digital signal into an analog signal that can be received and displayed on an analog television set.
Digital Video Recorder	Device or application software that records video in a digital format to a disk drive, USB flash drive, SD memory card, SSD or other local or networked mass storage device.
Dynamic Host Configuration Protocol	Standardized network protocol used on Internet Protocol (IP) networks for dynamically distributing network configuration parameters, such as IP addresses for interfaces and services.
Edge QAM	A headend or hub device that receives packets of digital video or data. It re-packetizes the video or data into an MPEG transport stream and digitally modulates the digital transport stream onto a downstream RF carrier using quadrature amplitude modulation (QAM).
Element Management System	An element based system interface for monitoring and control of features and functions of a network.
Embedded multimedia terminal adapter	Embedded Multimedia Terminal Adapter, a combination cable modem and telephone adapter

Energy Management Subcommittee	SCTE subcommittee tasked with the development of standards and operational practices impacting cable operator energy consumption.
Energy management	The coordination of processes and technologies implemented to reduce or optimize energy end-use, operate efficiently, ensure the availability and quality of energy, and identify environmentally responsible, cost effective, efficient and sustainable energy sources with an emphasis on maximizing facility and/or system output.
Ethernet Passive Optical Network	The use of a passive optical network is a common example of fiber to the home relying on less amplifiers commonly found in a coax plant.
Gateway	A network node equipped for interfacing with another network that uses different protocols or on a different segment of the network
Gigabit Ethernet	GigE = term describing various technologies for transmitting Ethernet frames at a rate of a gigabit per second. (DWDM) = Dense wavelength division multiplexing of a variety of optical signals
Headend	A facility for receiving voice, video, data and other telecommunications signals for processing and distribution over the network. Typically these facilities distribute signals out to end customers or smaller hubs. A smaller, more regionally focused facility providing similar functions as a Master Headend but serving smaller populations of customers and network locations.
High Definition Television	A physical device and service that provides a resolution and quality of picture that is substantially higher than that of standard definition televisions.
Home Security/automation Base Station	Central controlling device that enables manipulation of all the connected devices such as lights, thermostats, locks etc.
HTTP Secure	HTTP over secure socket layer (typically port 443)
Hybrid Fiber Coax	A broadband bidirectional shared-media transmission system using optical fiber trunks between the headend and the fiber nodes, and coaxial cable distribution from the fiber nodes to the customer locations.
Hyper Text Transfer Protocol	An application protocol for distributed, collaborative, hypermedia information systems
Integrated Receive/Decoder	Integrated receiver/decoder (IRD) is an electronic device used to pick up a radio-frequency signal and convert digital information transmitted in it.
Integrated Receiver Transcoders	Provides MPEG-4 HD to MPEG-2 HD transcoding in a compact rack based unit.
Internet Engineering Task Force	A body responsible for, among other things, developing standards used in the Internet.

Internet Exchange Provider	An Internet exchange point (IX or IXP) is a physical infrastructure through which Internet service providers (ISPs) and Content Delivery Networks (CDNs) exchange Internet traffic between their networks (autonomous systems).[1
Internet Protocol Detail Record	Provides information about Internet Protocol (IP)-based service usage and other activities that can be used by Operational Support Systems (OSS) and Business Support Systems (BSS).
Internet Protocol television	A system through which television services are delivered using the Internet protocol suite over a packet-switched network such as a LAN or the Internet, instead of being delivered through traditional terrestrial, satellite signal, and cable television formats.
Laser Transmitter/Receiver Pair	Lightweight Access Point Protocol or LWAPP is the name of a protocol that can control multiple Wi-Fi wireless access points at once. It looks like there *may* be a mix-up on this line: LVI is not another name for LWAPP
Layer 2 Tunneling Protocol	L2TP is a tunneling protocol used to support virtual private networks (VPNs) or as part of the delivery of services by ISPs.
Lightweight access point protocol	Lightweight Access Point Protocol or LWAPP is the name of a protocol that can control multiple Wi-Fi wireless access points at once. It looks like there *may* be a mix-up on this line: LVI is not another name for LWAPP
Lightweight Directory Access Protocol	Lightweight Directory Access Protocol (LDAP; /ˈɛldæp/) is an open, vendor-neutral, industry standard application protocol for accessing and maintaining distributed directory information services over an Internet Protocol (IP) network
Master Headend	A master facility for receiving voice, video, data and other telecommunications signals for processing and distribution over the network. Typically these facilities are centrally located in a region and distribute signals out to smaller Headends.
Mean Time Between Failures	A measure that predicts the time between inherent failures of a system, equipment and/or component during its operational lifetime. Typically this is measured by the average time between failures.
Moving Picture Experts Group	Coding of moving pictures and associated audio for digital storage media.
Multiplexer	MUX, an abbreviation for multiplexer in circuit design or Mux, another name for Multiplex (TV).
National Distribution Centers	Locations in a broadband telecommunications network where centralized content and service origination occurs for the purpose of distributing and making such content available to customers throughout the network.
Network Configuration Protocol	OSI Model is a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard of their underlying internal structure and technology

Network Interface of Operator Supplied CPE	The customer side (northbound interface) demarcation point on the access network. In general, this is the connection point between the network cable (coaxial, Ethernet, etc.) and the CPE (set top box, cable modem, eMTA, etc.). The other demarcation point of the access network is the laser transmitter/receiver pair in the hub or Headend.
Network Management Systems	A combination of hardware and software used in conjunction to monitor and administer broadband telecommunications networks. Typical a NMS will interface with multiple Element Management Systems (EMS) that are focused on individual network elements or groups of related elements.
Network Operations Centers	A centralized location where the management and control of broadband telecommunications networks is exercised. NOCs can be centralized national centers or regionally focused points.
Open Systems Interconnect	OSI Model is a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard of their underlying internal structure and technology
Operations Support Systems	Typically network systems used by telecommunications providers to aid in the operation of networks including systems for inventory management, provisioning, configuration, performance and fault management.
Over The Top	Typically referred to as on-line delivery of audio and video without an Internet service provider being involved in the distribution, management or control of the content itself.
Point of Sale	A terminal composed of hardware and software that is used as an electronic cash register and serves as the device that records and transacts a sale.
Public Branch eXchange	A telephone exchange for a business or office that makes connections from internal telephones of a private organization with the public switched telephone network.
Public switched telephone network	Aggregate of the world's circuit-switched telephone networks that are operated by national, regional, or local telephony operators, providing infrastructure and services for public telecommunication.
Quadrature Amplitude Modulation	The format by which digital cable channels are encoded and transmitted via cable television providers.
Set-top box	An information appliance device that generally contains a TV-tuner input and displays output connections to a television set and an external source of signal, turning the source signal into content in a form that can then be displayed on the television screen or other display device.
Simple Network Management Protocol	A network management protocol of the IETF.

Society of Cable Telecommunications Engineers	The technical and applied science leader for the cable telecommunications industry focused on providing technical solutions, programs and benefits for every level professional in the industry.
Software Defined Energy Management	An element based management system with the expressed purpose of controlling the features and functions of network elements to monitor and control energy consumption, heat dissipation or other states.
Storage Area Network	A dedicated network that provides access to consolidated, block level data storage.
Sustainability Management Subcommittee	The legacy subcommittee within the SCTE standards program that was responsible for identifying standards and best practices for reducing power consumption and costs, increasing operating efficiency and minimizing disposal effects of outdated equipment. Replaced by Energy Management Subcommittee in 2014.
Transaction Based Energy Control	A systems based dynamic model to reduce energy consumption on and through elements provisioned throughout a telecommunications network that is correlated to predicted or real-time traffic demand.
Transport Network	A portion of the broadband telecommunications network that connects a backbone to the access network. Multiple facilities *may* reside on the transport network.
Trivial file transfer protocol	A simple, lock-step, File Transfer Protocol which allows a Client (computing) to get from or put a file onto a remote Host (network).
Video on Demand	Systems which allow users to select and watch/listen to video or audio content when they choose to, rather than having to watch at a specific broadcast time. IPTV technology is often used to bring video on demand to televisions and personal computers.
Virtual Local Area Network	A single layer-2 network partitioned to create multiple distinct broadcast domains, which are mutually isolated so that packets can only pass between them via one or more routers. A VLAN has the same attributes as a physical local area network (LAN), but it allows for end stations to be grouped together more easily even if they are not on the same network switch
Virtual Private Network	Virtual private network extends a private network across a public network, such as the Internet. It enables a computer or network-enabled device to send and receive data across shared or public networks as if it were directly connected to the private network, while benefiting from the functionality, security and management policies of the private network.
Wi-Fi	A data communications technology (based on IEEE 802.11 standards) that allows an electronic device to exchange data wirelessly over a computer network, today usually over a broadband high-speed Internet connection.

Wireless access point(s)	Wireless access point, a device that allows wireless devices to connect to a wired network.
YANG	A data modeling language for the NETCONF network configuration protocol

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Using Efficiency and Productivity Based Metrics to Characterize and Improve Access Network and Facility Energy Efficiency

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
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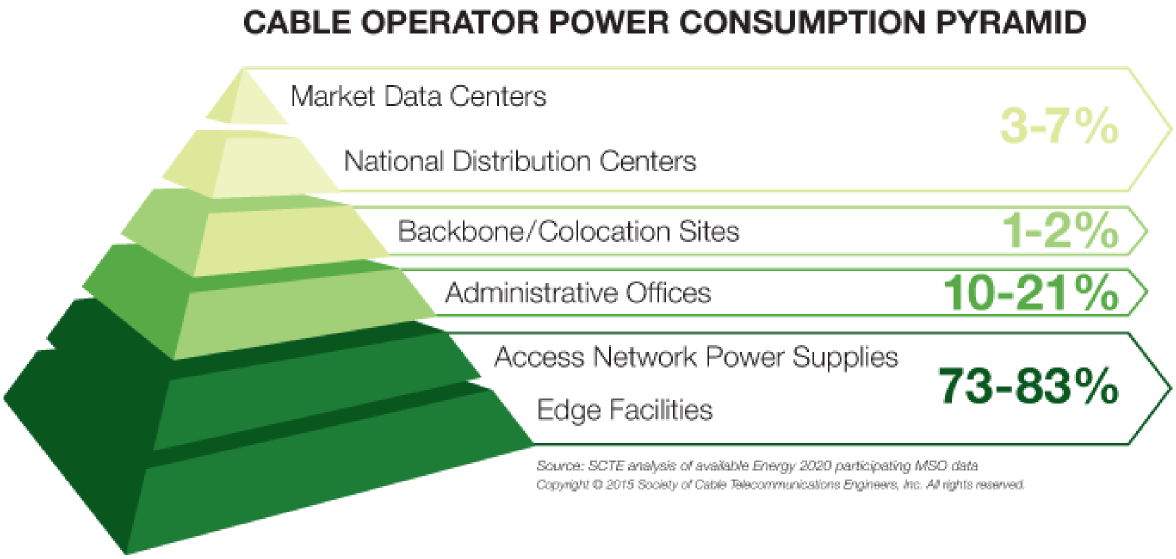
Table of Contents

1. Introduction

1.1. Executive Summary

The SCTE in its Energy 2020 program has set ambitious and important goals for the industry with respect to energy efficiency in the coming years. An important part of that work is in establishing metrics with which to set baselines for energy usage today, and then measure against those baselines to judge future improvements. The power pyramid shown in Figure 1 shows how power is used in a typical MSO.



Source: SCTE analysis of available Energy 2020 participating MSO data

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Figure 1 - Power Pyramid

The pyramid shows access networks and edge and core facilities together constitute the majority of energy used in a typical MSO. Because of that, Energy 2020 put particular emphasis on creating standards associated with these areas of energy usage.

With-in Energy 2020, three separate standards have been created guiding operators with respect to energy efficiency metrics for access networks and edge and core facilities

- SCTE 212 provides guidance to operators on how to create initial baseline power measurements for access networks and edge and core facilities.
- SCTE 211 provides guidance in using the baseline power measurements detailed in SCTE 212 to create metrics for access networks. These metrics are to be used in setting a solid baseline measurement, guiding energy efficiency improvement work, as well as judging progress towards better energy efficiency
- SCTE 213 provides guidance with respect to metrics similar to SCTE 211, but for edge and core facilities as opposed to access network.

These standards have been published and are available now for operators to use in their work. The intent of this document s to provide relevant cable operator's employees with guides as to how to use the metrics contained in SCTE 211 and SCTE 213 to improve energy efficiency in their networks and plant. A companion document, operationalizing SCTE 212, titled "Energy 2020 Baseline – Setting the Stage", is to be delivered as part of SCTE EXPO 2015 Technical Program in October 2015, by Dr. Rene Spee, Consultant from Coppervale Enterprises Inc.

1.2. Scope

This paper discusses how operators might use the energy productivity metrics for facilities and access networks laid out in the standards, in conjunction with other efficiency oriented metrics, to improve the performance of their infrastructure with respect to energy efficiency. The combination of efficiency and productivity metrics form the basis of a credible characterization of both facilities and networks with respect to energy efficiency. The paper will focus on how operators might use the metrics to characterize network infrastructure, prioritize project and improvement work across access networks as appropriate, as well as track progress over time. Included will be mention of typical energy efficiency and productivity fixes and improvements operators might want to implement, including reference to Energy 2020 Energy Management Subcommittee standards containing those recommendations as appropriate.

This paper is meant to be used in conjunction with the SCTE 211 and SCTE 213 standards documents, providing an operational practice to be used to make the standards more understandable and useable by network and technical staff. Operators using this document should also have available SCTE 212 standard document, as well as Dr. Spee's paper operationalizing SCTE 212 noted above, as they both are used and referred to in this document.

1.3. Benefits

Metrics associated with energy efficiency in critical facilities and access networks are fairly new to the cable industry. As such, in delivering these metrics to the industry, it is important to not just define the metrics themselves, but also to guide the cable operator community as to how they might start to use the metrics to improve energy efficiency in their facilities and plant. This document provides a starting point to guide cable operators in use of the metrics. Use of this document will start operators down the path of comparing facilities and access networks in a consistent and common way with respect to energy usage and performance. Such comparisons allow cable operators to separate and rank networks and facilities with respect to energy performance, and prioritize action and resource to the locations most in need.

In the long term, use of the standards in the manner outlined in this document should help operators understand fully energy performance in their facilities and access networks, and assist in improving that performance over time by understanding and spreading across their footprints good energy efficiency practices, as well as focusing scarce resources and capital spend to improve energy efficiency in the areas where return on that investment would be greatest.

1.4. Intended Audience

This document is focused specifically at regional and local engineering and operations cable operator personnel.

1.5. Areas for Further Investigation or to be Added in Future Versions

No area for further investigation has been identified as of the initial writing of this document.

2. Metrics for Characterizing Energy in Access Networks

Access Networks (AN) constitute layer one cabling, passives, and active transport electronics that transport signals to and from the IT equipment serving customers to the customer premise location itself.

The power pyramid shown in Figure 1 provides a view as to how power is consumed in an MSO. As shown in the pyramid, 73-83% is used in the combination of the access network and the edge and core facilities. Of that 73-83%, roughly 2/3rds to 3/4ths is utilized by the AN infrastructure. As it is such a high proportion, understanding the energy characteristics of AN's is important, as any improvement in this area, however small, can have a proportionally significant impact on overall energy usage at an MSO. AN efficiency and productivity metrics allow MSO's to create a proper baseline for individual AN's, compare and categorize AN's with respect to performance, focus resource and investment where it can have the greatest impact, as well as monitor on-going improvement related to that investment.

2.1. Access Network Energy Productivity

SCTE 211 details Energy per consumed Byte ($EPCB_{AN}$) as the metric operators should use to characterize the energy consumption of access network on a per unit basis. $EPCB_{AN}$ is defined in the standard as the total amount of Energy over a period of time, divided by total number of bytes transported, or mathematically

$$\boldsymbol{EPCB_{AN}} = \frac{\boldsymbol{Total\ Amount\ of\ Energy\ in\ an\ AN\ in\ a\ Month}}{\boldsymbol{Total\ Data\ Thruput\ in\ the\ AN\ for\ the\ same\ Month}} = \frac{\boldsymbol{kWh}}{\boldsymbol{TB}} \qquad \textbf{Equation 1}$$

$EPCB_{AN}$ measures the productivity of the energy used in the AN. Lowering $EPCB_{AN}$ means an operator is using less energy to produce the same data throughput. From a comparison basis, AN's that have lower $EPCB_{AN}$ are producing a TB of throughput with less energy than those with higher $EPCB_{AN}$. The lower $EPCB_{AN}$, the more productive the AN is in producing TB's of data throughput with the energy being used.

It is fairly straight-forward to understand $EPCB_{AN}$ as a concept – the lower the number, the more productive the energy is being used in an AN. It is also fairly straight-forward to calculate $EPCB_{AN}$ for an AN, as it is simple ratio of two numbers. The challenge centers around defining what constitutes an AN on which the $EPCB_{AN}$ metric should be measured, and finding the TB throughput data and kWh energy usage data for that metric so the calculation can be made.

2.1.1. What Constitutes Energy Consumed in an AN

SCTE 211 provides discussion and detail around exactly what an AN is, how it is structured, and how it is powered. Figure 1 from SCTE 211, shown as Figure 2 in this document, shows common AN structure for an HFC network.

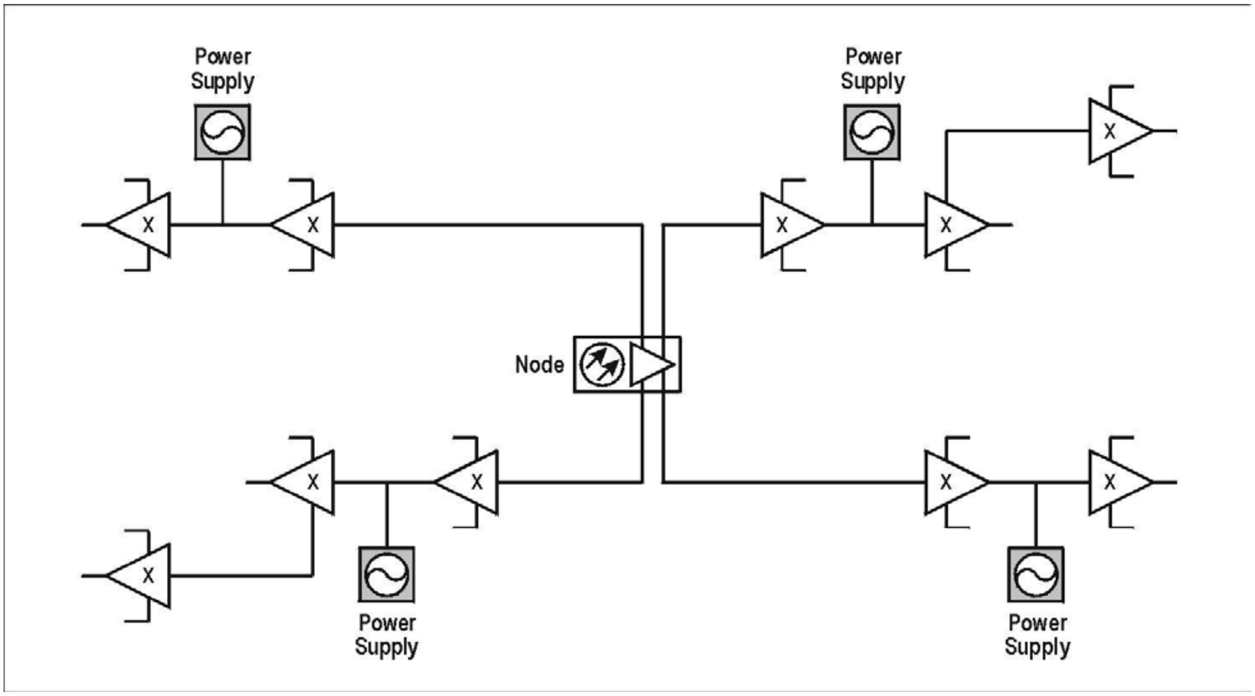


Figure 2 – Typical AN Structure

As noted in SCTE 211, "the AN contains devices such as nodes, amplifiers and Wi-Fi access points (AP) that require electrical power to operate. The electrical power is provided to the AN byline power supplies (LPS), which convert electrical power from the power grid to a quasi-square wave 60V or 90V AC voltage to power the AN equipment."

The challenge always with this particular energy productivity metrics is how to make the measurement. In the AN, the simplest and easiest point to measure energy consumed is at the outside plant power supply (OSP PS) location. All of the power consumed in an AN is ultimately delivered through the OSP PS, so if one wants to calculate the total power consumed in an AN, adding up the power consumed by each of the OSP PS in the AN will provide that calculation. Mathematically, this would be

$$\textit{Total Power Consumed in AN} = \sum_{1}^{n} \textit{Power consumed OSP } PS_n \textit{ in AN} \qquad \textbf{Equation 2}$$

For example, if one looks as Figure 1 as a sample AN, total power consumed for that AN would be the sum of the power in each of the four OSP PS's shown.

2.1.2. Sizing the Access Network for Energy Efficiency Metrics

Although in theory it is possible to calculate $EPCB_{AN}$ for any portion of an AN, from a practical perspective, the smaller and more granular one makes the AN being evaluated, the more difficult it is to make the measurement of the data throughput needed to make the calculation.

Because the groups of homes and subscribers served in an AN by a cable modem termination system (CMTS) service groups, video on demand (VOD) service groups, and OSP PS all differ in size, and are not necessarily structured to be easily grouped together, it can be problematic and quite difficult for an operator to calculate $EPCB_{AN}$ for any portion of an AN connected to a facility and/or head-end. It would only be by chance that any group of homes served by a CMTS and/or VOD service group would actually be the same as the group of homes served by an OSP PS (or an exact multiple of OSP PS's). As such, creating an $EPCB_{AN}$ measurement for any subset of an AN connected to a head-end would certainly require allocation of consumed bytes and/or power so as to make the bytes and energy consumed come from the same physical AN serving area.

As such, by far the best and most appropriate sizing of an AN for calculating $EPCB_{AN}$ is to calculate $EPCB_{AN}$ for the whole AN being fed by a head-end/edge/core router facility. The key attributes of the facility used to define the AN size is that it is the AN connected to a facility with CMTS and VOD/broadcast QAM equipment. If a facility has that equipment inside it, then ALL of the AN connected to that facility should be grouped into a single AN for the purpose of making the $EPCB_{AN}$ calculation. Figure 3 shows diagrammatically what this means.

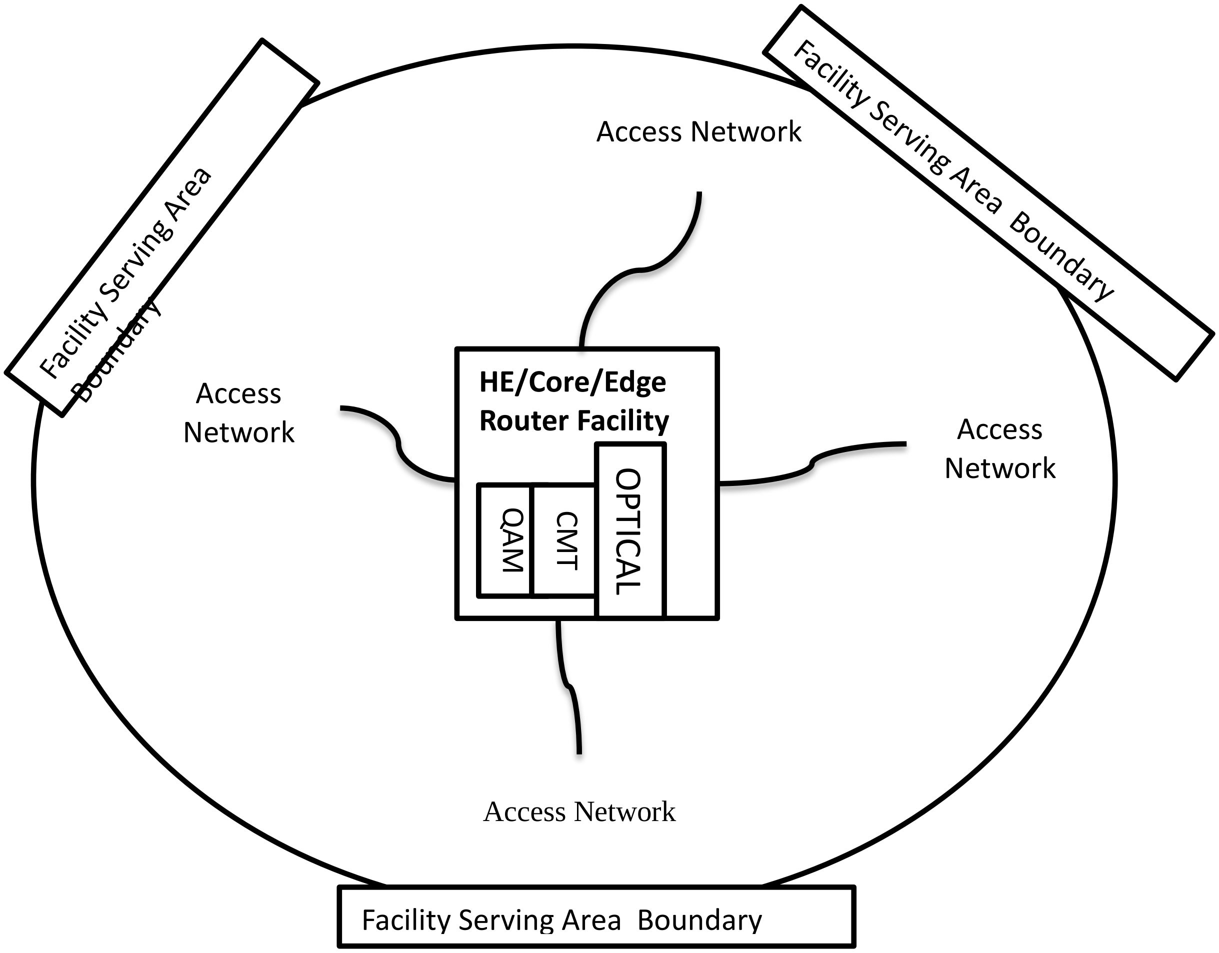


Figure 3 - AN Connected to Edge and Core Facility

For the purpose of calculating energy metrics, the size of access network used should be the total access network connected to an individual head-end and/or core/edge routing facility containing CMTS/QAM equipment feeding the AN. By doing this, as noted above, an operator can greatly simplify the gathering of CMTS, and VOD average bit rates by pulling the aggregate information from the routers the equipment is connected to. Gathering of energy consumed data is also made more straight-forward, as it is just the sum of the power of all the OSP PS's serving the AN connected to the facility.

2.1.3. Finding Energy Consumed for OSP PS's in an AN

As OSP PS's are connected to the grid, the natural and simplest place to look for consumed energy data is the electric bill for the OSP PS provided to the operator by the utility company provider of the grid connection. For metered OSP PS's, the utility billing information should provide power supply input power (kWh and days in bill). A typical utility bill for a metered OSP PS would detail how many kWh were consumed by the OSP PS, as well as the period in which the consumption occurred (typically around 30 days +/- a day or two depending on the billing month). This is exactly the information required for calculation of energy consumed for the OSP PS's in an AN.

In a perfect world, all OSP PS's would be metered, and every bill received for metered OSP PS's in the AN would be for the same calendar month. In practice, a high proportion of the OSP PS's are un-metered, and for those that are metered, we have found that utility bills produced in any given calendar month use different start and end dates, and differing number of days in the billing period. As such, for metered supplies, we recommend calculating a daily kWh average from any utility bill. The daily average can be used as detailed in following sections to equalize time-periods across all the OSP PS's in an AN, as well as in aiding in the process of estimating usage for unmetered supplies as and when required.

Attaining energy consumption data from un-metered supplies can be done, but is more difficult. By definition, they have no metering on them, so the utility bill for them will not provide information on kWh consumed. If an operator has un-metered OSP PS's in an AN, there are ways to estimate kWh consumed. These include:

- Physical measurement of AC input power at the PS itself. Using an appropriate measurement device an operator can measure grid input power to the OSP PS in kW. Although this doesn't provide kWh over a period of time similar to what a utility meter might provide, because the load of an OSP PS in an AN is fairly constant, this instantaneous kW measurement can be converted to kWh with reasonable accuracy just by multiplying the instantaneous kW measurement times the number of hours. The pro's of using this method is that it will provide the best and most accurate estimate of grid power short of having a continuous meter on the OSP PS. Additionally, because the load on an OSP PS is fairly constant over time, this is not a measurement that one would need to repeat with great frequency. For operators with OSP PS preventative maintenance (PM) programs, making this measurement one of the actions done at least once a year as a part of the PM would generally suffice in keeping the data current. The con of this method is that it can be resource and time consuming, as it requires visit to all unmetered PS's to make the measurement initially, as well as periodic re-visits in the event load dynamics change over time.
- If the AN has a mixture of metered and un-metered OSP PS's, and the metered supply is large enough, data from the metered supplies can be used to estimate un-metered usage. If an average kWh usage per OSP PS from the metered supplies is calculated, that same average figure for usage can be assumed for all un-metered supplies. Refer to Dr. Spee's paper in section 2.2.3 for sampling approach to metered versus unmetered supplies in an AN.

- Additionally, if the resources don't exist to visit all un-metered OSP PS's, but not enough metered supplies are available to be statistically significant, an operator can choose to visit and measure input power at a subset of the unmetered OSP PS's in the access network to try and provide enough data with which to extrapolate OSP PS energy consumed for the remaining supplies. Combination of metered and measured OSP PS's can be used to provide the appropriate sample size to calculate average OSP PS power, and that average can be used as estimate for un-metered and unmeasured OSP PS's.
- A number of OSP PS's (both metered and un-metered) contain some sort of transponder device. Transponders provide significant functions for operators to use in operating and maintaining OSP PS's, including typically output voltage and current of the OSP PS facing the AN load. Power calculated from this information constitutes power consumed in the AN itself, but does not equal input power from the grid, as effects such as power factor and power supply efficiency cause the power delivered to the load to be less than the input power to the power supply. As power supply efficiency varies with % load in a non-linear fashion, and power factor varies based on a number of factors, it is difficult with existing data to provide a general algorithm for operators to use to reliably convert transponder data to energy input data. If operators would want to use the transponder information to estimate input power, they would need to work with their OSP PS supplier to develop an algorithm for them that provides efficiency at different loads for the PS's used, as well as some estimation of power factor confirmed through appropriate testing and field verification. With these caveats, use of transponder data provides another way to attain energy consumed by an OSP PS. Pro's of this approach is where an operator has transponders in place, the OSP PS output voltage and current is available and can be polled in real time remotely. The Con's of this approach is the need to convert the data to input consumption data, and the inherent inaccuracies associated with that conversion.

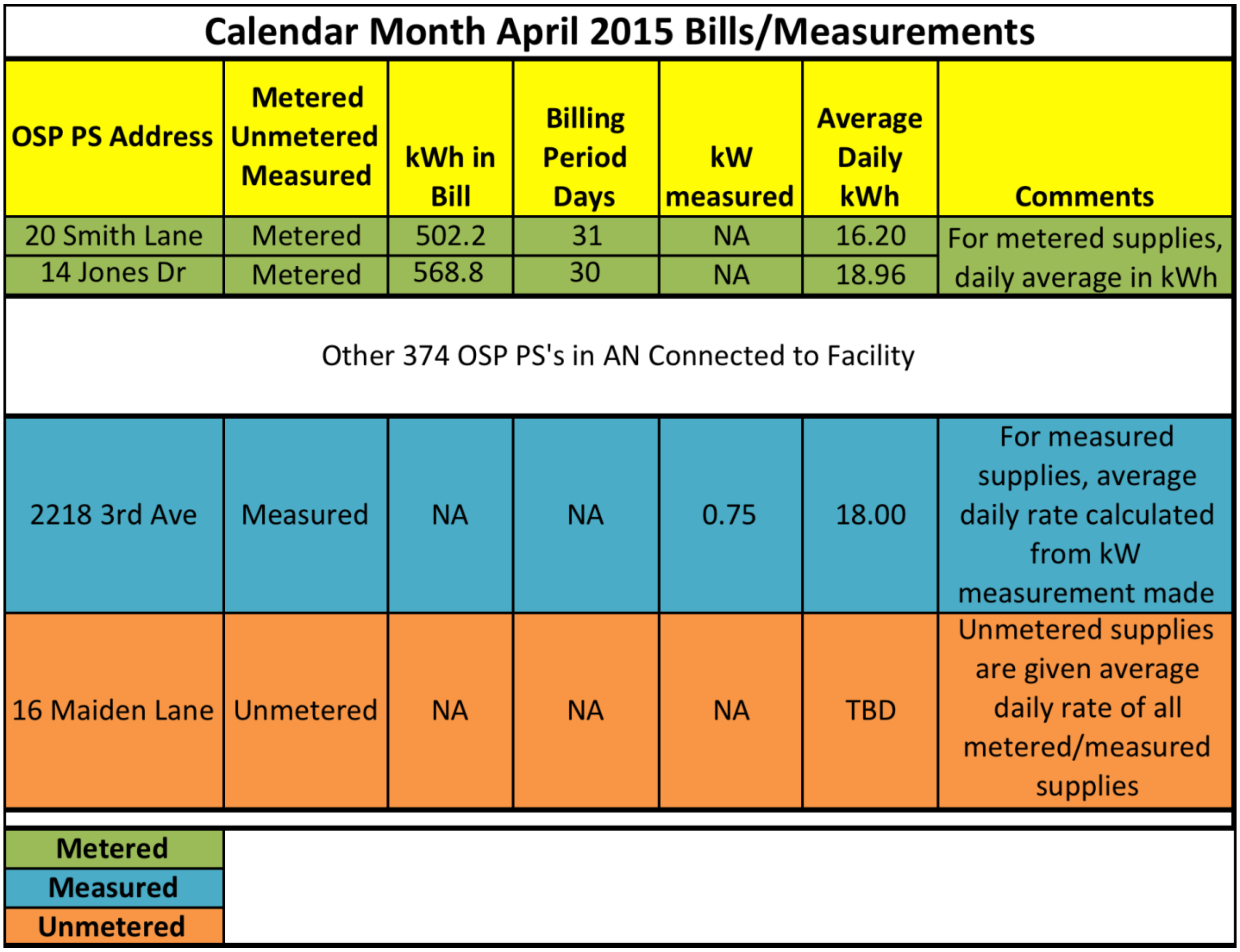
Although as a document, its specific function is to help operators create baseline power measurements for AN's, Section 6 of SCTE 212, along with its companion operational document from Dr. Spee written for EXPO 2015, provide detail on ways to attain energy consumed for OSP PS. Operators should refer to these documents for guidance related to attaining OSP PS information.

As noted above in section 2.1.2, ***the AN for which $EPCB_{AN}$ should be calculated is for the total AN connected to an Edge and Core Facility containing CMTS/VOD/Broadcast equipment***. One way for an operator can do this is to:

- List all the OSP PS in the AN connected to the facility
- Using the techniques discussed above in section 2.1.2 determine the average kWh consumed in a day by each OSP PS. For metered and measured supplies, put the exact number. For unmetered OSP PS's that are estimated, put the average daily kWh rate calculated from the metered and measured OSP PS's as noted above.
- Add together the daily average kWh calculations for all the OSP PS's in the AN connected to the E&CF. This provides the average DAILY consumption in the AN connected to the E&CF
- Energy consumed for the measurement period (i.e. a calendar month) would be the daily average in kWh multiplied by the number of days in the measurement period.

As an example, if the totality of the AN connected to a HE/edge/core Router facility contains 378 OSP PS's, to find the consumed power of that AN in the calendar month of April 2015, one would create a table that looks something like the Table 1.

Table 1 - AN Energy Consumption Table



Calendar Month April 2015 Bills/Measurements

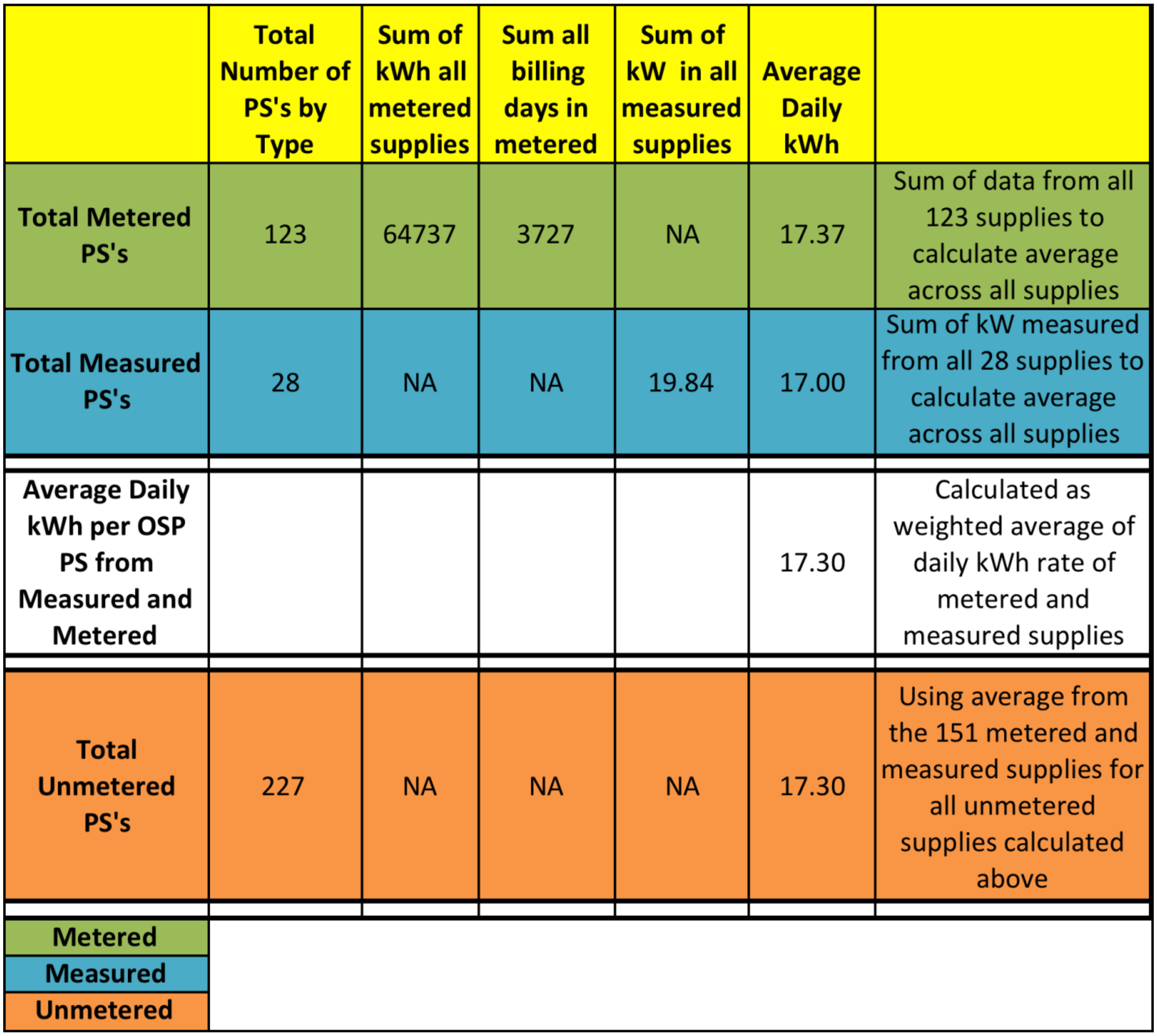
OSP PS Address	Metered Unmetered Measured	kWh in Bill	Billing Period Days	kW measured	Average Daily kWh	Comments
20 Smith Lane	Metered	502.2	31	NA	16.20	For metered supplies, daily average in kWh
14 Jones Dr	Metered	568.8	30	NA	18.96	
Other 374 OSP PS's in AN Connected to Facility						
2218 3rd Ave	Measured	NA	NA	0.75	18.00	For measured supplies, average daily rate calculated from kW measurement made
16 Maiden Lane	Unmetered	NA	NA	NA	TBD	Unmetered supplies are given average daily rate of all metered/measured supplies

🟩	**Metered**
🟦	**Measured**
🟧	**Unmetered**

For metered supplies, simply taking the total number of kWh in the billing period, and dividing by the days in the billing period, provides a daily average rate of kWh as the individual OSP PS's. The first two lines in green in Table 1 show this. For measured supplies, the average daily rate is calculated from the kW measurement made on the supply. This is shown in the blue line in Table 1.

I have showed the unmetered supply on this list (orange line) as being "TBD". As noted in previous section, it will be estimated using an average daily rate calculated from the metered and measured supplies Table 2 shows this process for our sample AN.

Table 2 - Calculating average daily kWh from metered/measured for use in unmetered



	Total Number of PS's by Type	Sum of kWh all metered supplies	Sum all billing days in metered	Sum of kW in all measured supplies	Average Daily kWh	
Total Metered PS's	123	64737	3727	NA	17.37	Sum of data from all 123 supplies to calculate average across all supplies
Total Measured PS's	28	NA	NA	19.84	17.00	Sum of kW measured from all 28 supplies to calculate average across all supplies
Average Daily kWh per OSP PS from Measured and Metered					17.30	Calculated as weighted average of daily kWh rate of metered and measured supplies
Total Unmetered PS's	227	NA	NA	NA	17.30	Using average from the 151 metered and measured supplies for all unmetered supplies calculated above
Metered						
Measured						
Unmetered						

If in the sample AN shown in Table 1, 123 of the OSP PS's have metered data, and 28 have been measured sometime in the month, then the data from those 151 OSP PS's can be used to create an average daily kWh usage for an OSP PS in the AN. That average would be used as estimated usage for all OSP PS's (including unmetered) in the AN.

This is how the "TBD" slot in Table 1 is filled with a number, which in the case of this example is 17.30 kWh per day. In this example, then, the 17.30 kWh per day becomes the average daily kWh rate per OSP PS for all 378 OSP PS's in the AN, including the 227 unmetered supplies. As noted earlier, section 2.2.3 of Dr. Spee's paper provides guidelines for appropriate data sample sizes to guide operators as to how many metered/measured supplies would be required to produce a meaningful estimate for the unmetered supplies in and AN. Please refer to that paper for more detail on the process associated with this.

Once a daily rate for all OSP PS's in the AN is established for the period, one just needs to take that daily rate, multiply it by the total number of OSP PS's in the network (378 in the example above) and the number of days in the month for the calculation (30) and the energy consumed by the AN needed for the EPCB calculation can be made. In the example above, that is

$$Energy\ Consumed = 17.30\ \frac{kWh}{day} *\ 30\ days\ in\ month\ of\ April * 378\ OSP\ PS's$$

$$Energy\ Consumed = 196{,}206\ kWh\ in\ Month\ of\ April\ 2015$$

2.1.4. Finding Consumed Bytes for an Access Network

SCTE 211, in Section 7 defines what constitutes a consumed bit in an AN, and how to calculate consumed bytes from that information. That definition includes:

- All data or telephony bits delivered to a user or device are defined as consumed.
- All video on demand (VOD) or switched digital video (SDV) bits are defined as consumed.
- Broadcast (BC) video bits
- Data overhead bits such as bits used in packet headers are considered to be consumed bits, because they are part of the information that is delivered to the user or device.

These bytes consumed in an access network typically come from the following sources:

- CMTS Equipment
- Broadcast QAM Modulators
- VOD QAM Modulators
- Switches, routers, PON, etc. used to service commercial customers

As design and build of the data and bit transport networks vary from operator to operator, it is difficult to provide specific guidance on how exactly to attain this data in individual networks. In general though, dependent on their own set-up, operators should focus on getting the following information:

- Data ingress and egress information from CMTS equipment. This should be gathered as an average bit-rate US and DS over a period of time. As the CMTS's typically connect to a core router of some type in the facility, throughput information for the CMTS equipment can be gathered from there.
- Data ingress/egress information for VOD equipment. As with CMTS's, QAM modulators use typically use gigabit ethernet on the backside to connect to the edge/core router, so it is likely that average bit-rate information can be attained from this device.

Assuming the AN for which consumed bytes is being measured is for the total AN connected to an E&CF as per section 2.1.2, operators can focus on measuring average bit rate throughput from routers in a facility, as the CMTS and VOD equipment in the facility will generally all go through some sort of router network to get to the backbone. Whether this is as simple as pulling information from a single router or multiple routers depends on operator network implementation, but it is in the routing devices that this information will typically be found.

With respect to the broadcast elements of the data throughput:

- To calculate consumed bytes for broadcast, SCTE 211 asks for the total number of broadcast transport streams feeding the AN, as well as the QAM modulation used. From that, SCTE 211 guides one through calculating the average bit rate per broadcast transport stream to be used.

- SCTE 211 also contains assumptions to be used for converting analog broadcast channels to their digital equivalent bitrate for the purpose of calculating consumed bytes for analog channels.

It should be noted SCTE 211 instructs operators to multiply the broadcast bit rates by percentage viewing from customer statistics to attain bytes consumed. Because the AN is now defined as being across the whole facility, it would be recommended for this calculation that the assumption be that all broadcast is consumed 100% of the time.

Calculating the bytes consumed is a similar exercise of adding together all CMTS, VOD, and Broadcast sources of bits transported to the AN from the facility, over a time period similar to the time period used to calculate the energy consumed. For avoidance of doubt, ***THE TIMEFRAME USED TO CALCULATE CONSUMED BYTES MUST BE EXACTLY THE SAME AS THE TIMEFRAME USED TO CALCULATE ENERGY CONSUMED.***

As noted earlier, and discussed in SCTE 211, it is typical that for CMTS and VOD equipment, the data available is an average bit rate across a period of time from routers in the facility. This average bit rate will generally be in either megabits per second (Mbps) or gigabits per second (Gbps) for each of the routers on which CMTS, VOD, and equipment to service commercial customers are connected. Table 3 details how and MSO might collect data and make calculation for US/DS traffic running through routers.

Table 3 - Traffic from Core Routers in a Facility

Sum of Traffic from Facility Core Routers			
Gbps INGRESS (US Traffic)	Gbps EGRESS (DS Traffic)	Total Gbps	TB Consumed (month)
3.065	39.570	42.635	13,813.74
Ave Gbps for the month for all Residential Ports, data taken from the Residential Routers		Gbps IN + Gbps OUT to give TOTAL Gbps	TOTAL Gbps divided by 1000 to convert to Tbps, then multiplied by 30*24*60*60 (number of seconds in month) divided by 8 bits per byte

First step is to total all the ingress and egress traffic from the routers connected to the equipment facing the AN in the E&CF. This needs to include throughput from CMTS, VOD, and any Commercial equipment connected to routers in the E&CF. As noted above, the equipment in most E&CF's would go through a router in the facility where the information can be found, and totaled into egress and ingress data rates. As can be seen from the Table 3, if the average Gbps rate across the month for the router(s) can be found, by simply multiplying those rates by the number of seconds in the time period desired, and making appropriate conversion from gigabytes to terabytes, the total number of TB's consumed by the ingress and egress portions of the network can be found.

With respect to broadcast traffic transported through the AN, it to can be easily turned into a Mbps bit rate delivered number for use in calculating bytes consumed. To do this, an operator need only know the number of digital transport streams the E&CF is using to provide broadcast services to the AN where the calculation is being made. Table 4 shows an example of how such a calculation can be made.

Table 4 - Calculating Broadcast Bytes

Broadcast			
QAM Mbps	# of Transport Streams	Fixed Gbps from Broadcast	Broadcast Terabytes in Month
42.88	73	3.06	967.2
Bitrate for QAM transport on Transport Streams (256 QAM assumed)	Total Number of Broadcast TS's	TOTAL Gbps for all Broadcast TS's	Same calculation to convert TOTAL Gbps to TB Consumed in month as for Residential Traffic

Again, total TB's consumed can be calculated from the Mbps and Gbps rates using the same simple math of multiplying by the time period in seconds, dividing by 8, and converting units as noted in ingress/egress section previous.

To calculate total consumed bytes for the AN, then, one must just add together the consumed bytes for the month from the residential, commercial, and broadcast elements. Complete the example using the tables above.

$$\begin{aligned} &Total\ TB\ Consumed\ in\ the\ Month \\ &\qquad = Total\ Residential\ Router\ TB + Total\ Commercial\ Router\ TB + Broadcast\ TB \\ &\qquad = 12956.8 + 533.1 + 967.2 = \ 14457.2\ TB \end{aligned}$$

2.1.5. Making the $EPCB_{AN}$ Calculation

Once energy consumed and bytes consumed is calculated for an AN, calculation of $EPCB_{AN}$ is fairly straight-forward for that AN. If the bytes consumed in the above sample calculation in section 2.1.4 are assumed to be for the month of April 2015 for the AN connected to the facility for which power consumption example was shown in section 2.1.3, using equation 1, $EPCB_{AN}$ for that facility for the month of April 2015 would be:

$$EPCB_{AN} = \frac{Total\ Amount\ of\ Energy\ in\ an\ AN\ in\ a\ Month}{Total\ Data\ Thruput\ in\ the\ AN\ for\ the\ same\ Month} = \frac{196206}{14457} = 13.57\frac{kWh}{TB}$$

2.1.6. Determining Frequency of $EPCB_{AN}$ Measurement

$EPCB_{AN}$ can be calculated for the AN for each facility where energy and bytes consumed data is available. With respect to organizing the data and frequency of collecting data

- The first $EPCB_{AN}$ measurement taken for an AN connected to a facility should be considered the baseline measurement for that facility. SCTE 212 details the reasons and importance in setting a baseline, as it provides a base figure on which tracking of future performance (either better or worse) can be judged. Because of lack of real experience with this metric, it may prudent for operators to see a few months of initial tracking before setting and absolute baseline for an AN. In keeping with the practice of setting a good baseline to help with future work associated with the metric, it would be suggested that the baseline be set with data from the first 6-12 months of tracking.
- Frequency of updating $EPCB_{AN}$ for AN's is still an open item. As noted earlier in this section, energy consumed in an AN is generally fairly stable, changing little from month-to-month unless there is a known significant event that occurs. Consumed byte information, however, will in theory have the potential to change in a more significant way month-to-month depending on subscriber packages and usage patterns. Initially, until rate of change of $EPCB_{AN}$ is better understood, operators should update $EPCB_{AN}$ at a minimum quarterly, and monthly if practicable. Because energy consumed, particularly for unmetered accounts in the AN is fairly stable but can be difficult to get if it needs to be measured, it would seem sensible that for unmetered accounts, the instantaneous power measurement used to calculate energy consumed is only re-done yearly as a part of PM work as suggested earlier, and that only the bytes consumed updated more frequently.
- As this metric is still in its infancy stage, not enough data exists on actual AN's for $EPCB_{AN}$ to say categorically what is a good measurement and what is a bad measurement. As such, at least initially until enough data is collected to allow operators to make such a determination, $EPCB_{AN}$ is to be used by operators to compare energy productivity between AN's in their footprint.
- Assuming $EPCB_{AN}$ information is produced by individual facility as detailed above, continual tracking and reporting of $EPCB_{AN}$ data for each individual facility should be part of an Operator's on-going energy efficiency program.

2.1.7. Organizing $EPCB_{AN}$ Data for Use

Although the industry is still in the very early stages of understanding how the data might be used, as noted above, it would be suggested that operators collect and track this data for each AN connected to a E&CF where CMTS/VOD/Broadcast capability exists. Having the information in this form will allow operators to make comparison of AN's with respect to $EPCB_{AN}$ performance. Table 5 shows an example as to how operators might potentially organize information to compare $EPCB_{AN}$ performance between AN's across a service region.

Table 5 - Calculating $EPCB_{AN}$ by Facility for Quarter

Region 1 Access Networks EPCB Performance - 2nd Quarter 2015								
		Energy/Power			Traffic			Metric
Region 1 Access Networks		Total kWh in Quarter	Total Billing Days		Total TB Traffic in Quarter	Total TB Traffic Days		EPCB
Facility "A" AN		588619	91		43371	91		13.57
Facility "B" AN		331186	91		28914	91		11.45
Facility "C" AN		309582	91		20800	91		14.88
Other Facilities in Region 1								
Facility "X" AN		191646	91		13147	91		14.58
Total Region		28420660	91		2124640	91		13.38

Another important element to track is performance over time. This too can be done in a simple table as well as shown in Table 6.

Table 6 - Tracking $EPCB_{AN}$ for Facilities in a Region

Region 1 AN EPCB Comparison						
Region 1 Access Networks	**Baseline (1Q2014)**	**Q1 2015**	**Q2 2015**	**Q3 2015**	**Q4 2015**	**CY2015**
Facility "A" AN	14.5	13.7	13.6			13.6
Facility "B" AN	12.0	11.8	11.5			11.6
Facility "C" AN	16.9	14.8	14.9			14.8
Other Facilities in Region 1						
Facility "X" AN	15.9	14.5	14.6			14.5
Regional Average	13.8	13.4	13.4			13.4

By tracking individual AN's in this manner, operators can monitor changes to the measurements for the AN's connected to facilities over time. Having the ability to compare AN's allows operators to easily see poor performers and accordingly target any corrective action to the places where it is needed most. Seeing the trend of the metric over time helps operators see any sudden changes and/or anomalies in performance, and react to them quickly.

Additionally, with the base data for each individual AN, operators can choose to group the facility information by geography. This would allow comparison of higher-level regional averages and performance, allowing comparison at groupings of AN's to potentially spot poor performers and trends on a wider scale. Availability of this data also allows operators to develop energy related KPI's at the network, region, or enterprise levels of the business.

2.1.8. An Alternate Approach – Using Subscribers instead of Bytes to measure productivity

For some operators, finding data throughput may prove difficult and/or problematic. If that is the case, an alternative approach would be to use subscribers in the metric as opposed to bytes of data, under the assumption that attaining subscriber data for the AN connected to a facility would be easier than attaining the data throughput information. Use of subscribers as a unit of productivity is not specifically defined in SCTE 211, but as it is defined as a productivity unit in SCTE 213 for E&CF's, operators should be aware that using subscribers for productivity is an acceptable substitute in the absence of throughput data, and should be considered an option for operators in the event throughput data cannot be found as a way to get started with an AN energy productivity metric.

If this were the case, the metric used would be "Subscribers per kW", and would be calculated in a manner similar to that shown for "SPkW" calculation for E&CF's in section 3.1, equation 6 of this document. Use of SPkW for AN's would be similar to use of SPkW in E&CF's as detailed in section 3, if an operator chooses this approach. Operators should refer to the SPkW portions of this document in section 3, as well as the SPkW portions of SCTE 213 as reference for adapting SPkW energy productivity metric to AN's.

It should be noted that use of throughput data and EPCB will ALWAYS be the preferred energy productivity metric. But in the event data throughput is difficult to attain, even though it is not specifically detailed in SCTE 211, SPkW can be used as a substitute energy productivity metric in AN's similar to E&CF's as defined in SCTE 213.

2.2. Access Network Energy Efficiency

For data centers/critical facilities, the concept of power usage effectiveness (PUE) is a well understood and widely used metric for measuring energy efficiency. PUE is a pure energy efficiency metric, measuring solely ratio of total energy in the facility to the energy needed by the equipment performing productive work. PUE in and of itself, however, provides no insight as to how productive the energy being used is – that is left to the $EPCB_{FAC}$ metric for critical facilities (defined and discussed later in this document).

Although not as well known or understood in the industry, AN's similarly have a pure efficiency metric that can be used to judge just pure energy efficiency in the AN, regardless of the productivity of the energy. That metric is "Watts/Mile of Plant", or WPM. Mathematically, this would be

$$(\boldsymbol{WPM})\ \boldsymbol{Watts\ per\ Mile\ of\ Plant\ for\ an\ AN} = \frac{\boldsymbol{Total\ Watts\ in\ the\ AN}}{\boldsymbol{Miles\ of\ Coax\ Plant\ in\ the\ AN}} \quad \textbf{Equation 3}$$

Although not specifically defined in an SCTE document to date (it is slated for inclusion in future version of SCTE 211), we have enough tracking and history of the metric exists from past access network audit work done to indicate this metric provides a good view as to the pure energy efficiency of an AN.

2.2.1. Finding the Data needed to calculate WPM for an Access Network

To calculate WPM for an AN, an operator needs two pieces of information for the AN for which the metric is being calculated:

- Total watts for the AN
- Total linear miles of coax plant for the AN

Finding total watts for an AN is a simple extension of the work detailed above to find kWh for the AN for the $EPCB_{AN}$ metric. If one has found the energy consumed over a period of time for the $EPCB_{AN}$ metric in kWh, to convert that measurement to kW, one only needs to divide by the number of hours in the time period, or mathematically

$$\mathbf{kW} = \frac{\mathbf{kWh}}{\mathbf{hours\ contained\ in\ the\ time\ period\ kWh\ are\ measured\ in}} \qquad \textbf{Equation 4}$$

To convert to watts, just multiply the kW figure by 1000.

Miles of linear coax plant in an access network has been a commonly used term in United States cable television (kilometers per mile for other parts of the world). The measurement is typically used in conjunction with network homes passed to indicate relative density of AN’s in HP’s/Mile of plant. As such, it is likely that operators today have some form of the measurement already in place.

In the event an operator does not have a measurement of miles of plant, then there are common sources where the information needed to calculate it are contained. These would be

- Network GIS/Mapping systems. If an operator has their plant in a GIS/Electronic Mapping system, depending on the system, it is possible all cable type and length could be summed up for an AN such as to produce this measurement.
- If only flat records of the plant data exist (either in electronic or paper form), then the calculation for miles of coax for an AN can be done manually

2.2.2. Using the Data to calculate WPM for an Access Network

If an operator is measuring and tracking $EPCB_{AN}$ for an AN connected to an E&CF, WPM should be similarly calculated for that same AN. Doing this simplifies data collection as it allows AN energy consumption data for both the metrics to come from the same data collection process. Keeping the AN consistent between the metrics also aids in the use of the metrics. With the common AN definition between the metrics, analytics can be developed using the metrics together for AN’s. A later section of this document talks through how this might be done.

As with $EPCB_{AN}$, the initial WPM measurement made on an AN should be considered the baseline measurement for that AN. Once the baseline is set, as with $EPCB_{AN}$, continued monitoring and updating of WPM for each of the AN's the metric is calculated for should occur. Because the coax plant miles and AN wattage are fairly stable over time, frequency of updates to WPM for an AN certainly don't need to be monthly. As noted in section 3, the kWh measurement from which the kW measurement for this metric is derived stays fairly stable. Updating that part of the WPM metric in a manner consistent with the frequency that kWh's are updated for $EPCB_{AN}$ would be sufficient.

With respect to miles of coax plant, as noted, plant mile data is fairly stable. Changes in plant miles are generally a function of planned capital events such as plant extensions. As in today's mature cable industry these events are less frequent, and operators know precisely when they will happen, one would recommend that once the baseline is set for an AN's plant miles for the WPM metric, that updates of the plant mile information in this metric be updated once a year. Only exception to this would be if an operator is aware of plant extension activity. As plant extension generally implies additional OSP PS's are placed, when the power for those additional OSP PS's in included in the kW part of the metric, the operator should also look to include the additional plant miles at that time, as well.

As an example of this calculation, using the data from the sample energy consumed calculation made in section 2.1.3 for an AN in the month of April 2015, there we found the total energy consumed was calculated to be 196,206 kWh for the month. If we further assume that the number of coax miles in the plant is 1400 miles, then the WPM calculation is made in the following manner

- First, the total kWh in the month must be converted to a kW number, as for the WPM metric, we use the average instantaneous load for the month in watts, not the consumed energy for the month. We calculate this using Equation 4:

$$kW = \frac{kWh}{hours\ contained\ in\ the\ time\ period\ kWh\ are\ measured\ in}$$

$$kW = \frac{196206}{30\ days * 24\frac{hours}{day}} = \frac{196206}{720} = 272.5\ kW$$

- As WPM uses watts, not kilowatts, we multiply the kW number by 1000 to attain watts. This simple calculation yields 272,500W
- We then apply Equation 3 to make the calculation

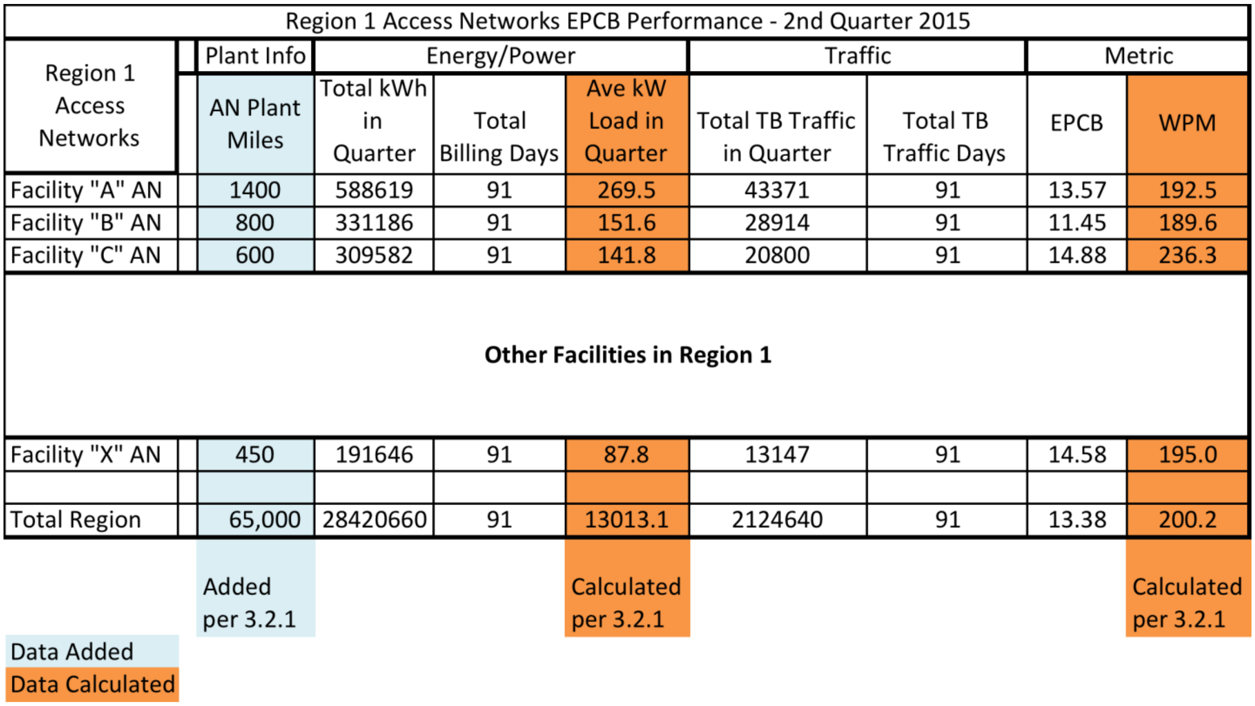
$$\boldsymbol{WPM}\ of\ Plant\ for\ an\ AN = \frac{Total\ Watts\ in\ the\ AN}{Miles\ of\ Coax\ Plant\ in\ the\ AN}$$

$$\boldsymbol{WPM}\ of\ Plant\ for\ an\ AN = \frac{272{,}500}{1400} = 194.6\ WPM$$

2.2.3. Organizing WPM Data with $EPCB_{AN}$ for AN's

Assuming the data for both WPM and $EPCB_{AN}$ for AN's are taken for the AN connected to an individual E&CF as suggested above, organizing the data for reporting purposes can be straight-forward. Table 7 shows how Table 5 in section 2.1.7 can be adapted to include WPM information for AN's.

Table 7 - Sample Summary Table Regional AN Performance in Quarter



Region 1 Access Networks EPCB Performance - 2nd Quarter 2015

Region 1 Access Networks		Plant Info	Energy/Power			Traffic		Metric	
		AN Plant Miles	Total kWh in Quarter	Total Billing Days	Ave kW Load in Quarter	Total TB Traffic in Quarter	Total TB Traffic Days	EPCB	WPM
Facility "A" AN		1400	588619	91	269.5	43371	91	13.57	192.5
Facility "B" AN		800	331186	91	151.6	28914	91	11.45	189.6
Facility "C" AN		600	309582	91	141.8	20800	91	14.88	236.3
Other Facilities in Region 1									
Facility "X" AN		450	191646	91	87.8	13147	91	14.58	195.0
Total Region		65,000	28420660	91	13013.1	2124640	91	13.38	200.2
		Added per 3.2.1			Calculated per 3.2.1				Calculated per 3.2.1

Data Added
Data Calculated

As can be seen in Table 7, with the addition of the plant mile data, and calculation of the kW load from the kWh information, the WPM calculation can be added. WPM can also be added to as a part of the continuous tracking, if desired. Addition of WPM information to the continuous tracking Table 6 in 2.1.7 is in Table 8.

Table 8 - Adding WPM to Quarterly Reporting

	Baseline (1Q2014)		Q12015		Q22015		Q32015		Q42015		CY2015	
Region 1 Access Networks	EPCB	WPM	EPCB	WPM	EPCB	WPM	EPCB	WPM	EPCB	WPM	EPCB	WPM
Facility "1" AN	14.5	192.1	13.9	191.3	13.6	192.5					13.61	191.9
Facility "2" AN	12.0	256.3	11.3	255.9	11.5	253.5					11.62	254.7
Facility "3" AN	16.9	176.8	16.5	177.3	14.9	177.2					14.82	177.2
All Facilities in Region 1												
Facility "X" AN	15.9	195.3	15.1	194.4	14.6	195.1					14.52	194.8
Regional Average			13.44	204.7	13.38	200.2					13.40	

Because in theory WPM for an AN is fairly stable, to simplify recording, an operator may choose to show only that quarter's results and the running average. If in a given quarter the WPM measurement differs in a significant way from on-going running average, then investigation as to what may have caused the change can occur.

As with the $EPCB_{AN}$ metric, with this base data for each individual AN, the information can be grouped and averaged to allow higher-level comparison from region to region.

2.3. Using WPM and $EPCB_{AN}$ together to characterize Access Network

Once WPM and $EPCB_{AN}$ are base-lined and tracked, the next question is how does an operator use them? With respect to energy usage, metrics allow an operator to:

- Properly develop a baseline measurement with respect to energy for each access network
- Compare access networks with respect to energy characteristics, and separate out poor performing access networks for appropriately targeted resource and attention, as well as find top performers who can be used to develop potential best practices with respect to attaining good energy performance.
- Evaluate changes in energy performance as a result of investment in improvements and/or changes to operational practices aimed at improving energy performance.

By their own rights, both WPM and $EPCB_{AN}$ provide important information with respect to the energy efficiency of an access network. WPM provides operators with the raw energy efficiency of the network. Regardless of what the energy is used for, the lower your WPM measurement is, the more energy efficient the access network is. If one has a network is at 200 WPM, and another at 175 WPM, the network with the lower number is more efficient. The reasons why it is more efficient can be many

- Better design (i.e. fewer actives per mile)
- More efficient active components deployed (actives, passives, and cables)
- More efficient OSP PS's

- OSP PS's running closer to full load
- 90V instead of 60V powering for active network powering

$EPCB_{AN}$ on the other hand, provides important information on the productivity of the energy used in the access network. The lower the $EPCB_{AN}$, the more productive the access network is in producing real work/output for the business. An access network with an $EPCB_{AN}$ of 10 kWh/TB is making better use of energy than one operating at 15 kWh/TB. In producing what is in effect the same service capability for customers connected to the network, the network with the higher $EPCB_{AN}$ is doing it using 50% more energy. Although certainly all of the reasons that create a higher WPM can contribute to a higher $EPCB_{AN}$, other factors specifically associated with production of TB throughput on the network will have impact on the energy productivity performance.

This largely centers on two key attributes of an access network, subscriber penetration, and more importantly data usage of those subscribers. The reason why what subscribers do in using the network can have such an impact on the $EPCB_{AN}$ metric is that the raw power required to run an access network to the same number of homes passed for a lightly loaded low penetration/low data usage network is in theory not that much different from the power required to run a highly penetrated/high data usage network. In other words, HFC networks built to a common architecture and a general subscriber penetration and data usage expectation, will need about the same amount of power whether they have a 5% penetration or a 75% penetration. So although the energy required for the AN would be the same, the productivity of the energy as measured in $EPCB_{AN}$ will be very different in each case. The network with higher penetration would presumably have higher data thru-put, and hence be getting much better productivity from the energy it uses then the network with the lower penetration/lower data usage.

Because energy efficiency metrics are so new, little history exists with respect to WPM and $EPCB_{AN}$ for the industry to know what constitutes a good number and what is a bad number. We will only be able to determine that once we have gathered enough metric data to look at and make that judgment. What we can do with the metrics, though, is use them to make comparison between AN's to help in determining good and poor performers. As an example, if for a group of AN's in a region the baseline $EPCB_{AN}$ was plotted on the y-axis, and baseline WPM on x-axis, it might look something like in Figure 4.

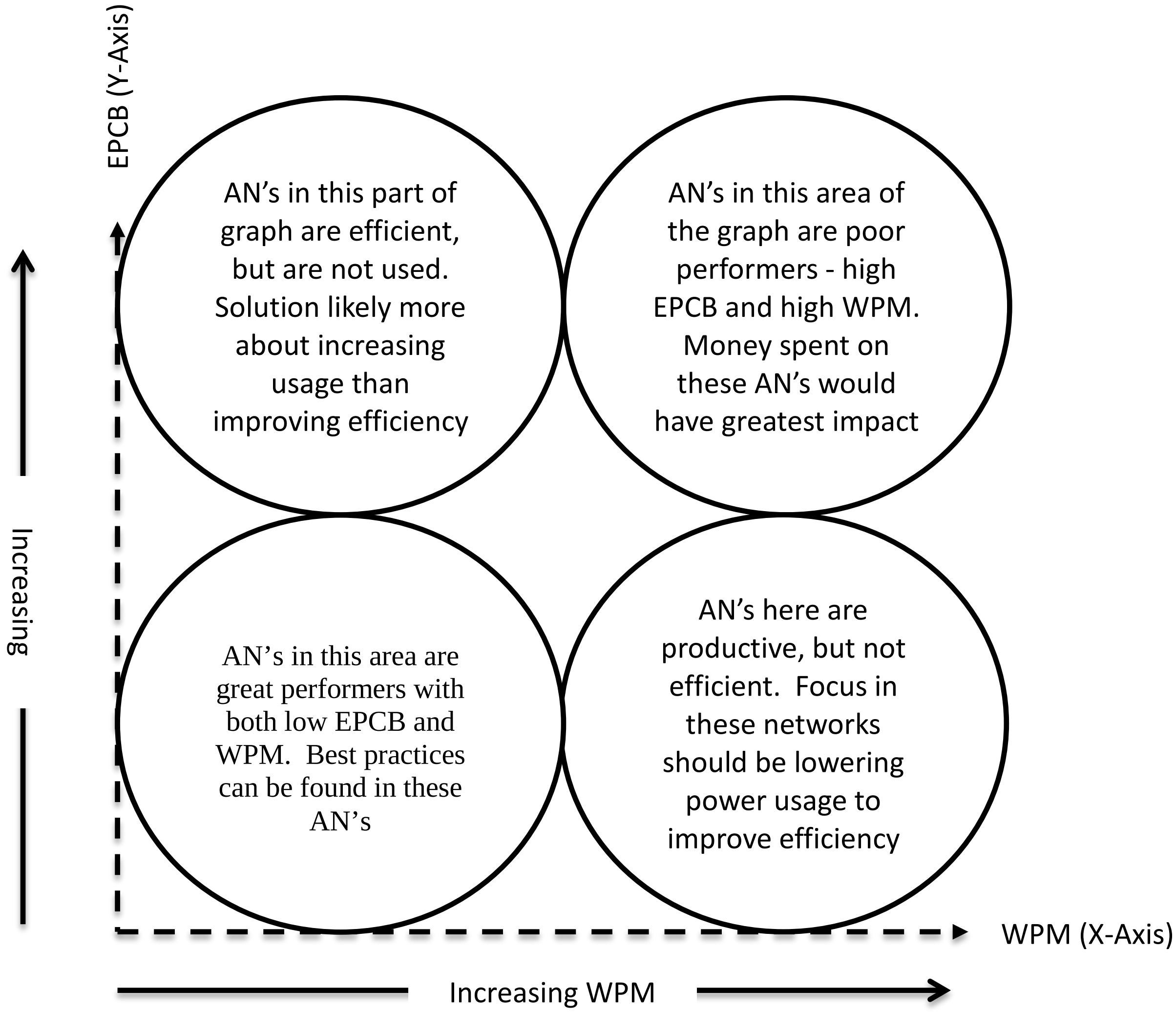


Figure 4 - Baseline $EPCB_{AN}$ vs. WPM Graph for AN's

As can be seen, plotting all AN's on a graph like this helps operators see relative comparison of AN's with respect to their energy efficiency and productivity of that energy. Knowing where an AN lands in this graph with respect to others helps an operator determine potential course of action (if any) for access networks. In the above example, if an AN is in the area of low $EPCB_{AN}$ and low WPM, it is a good performer – this is a place where operators can look for best practices with respect to energy performance. Conversely, if the AN falls in the area of the graph with high $EPCB_{AN}$ and high WPM, these are the worst performing AN's for the operator. These presumably are the AN's where the most opportunity for improvement that might have real impact for the company might be, and are AN's network operators should pay attention to first. Facilities with high $EPCB_{AN}$ and low WPM are efficient, but not very productive – one would be limited in these network to lower power to improve performance – it would be more useful to focus on how to drive penetration and usage of the network. Conversely, AN’s that have low $EPCB_{AN}$ and high WPM are being well used, but need efficiency improvement.

Continual plotting of ECPB and WPM for access networks over time can help operators see changes in performance. Over time, operators should see changes in line with arrows shown in Figure 5.

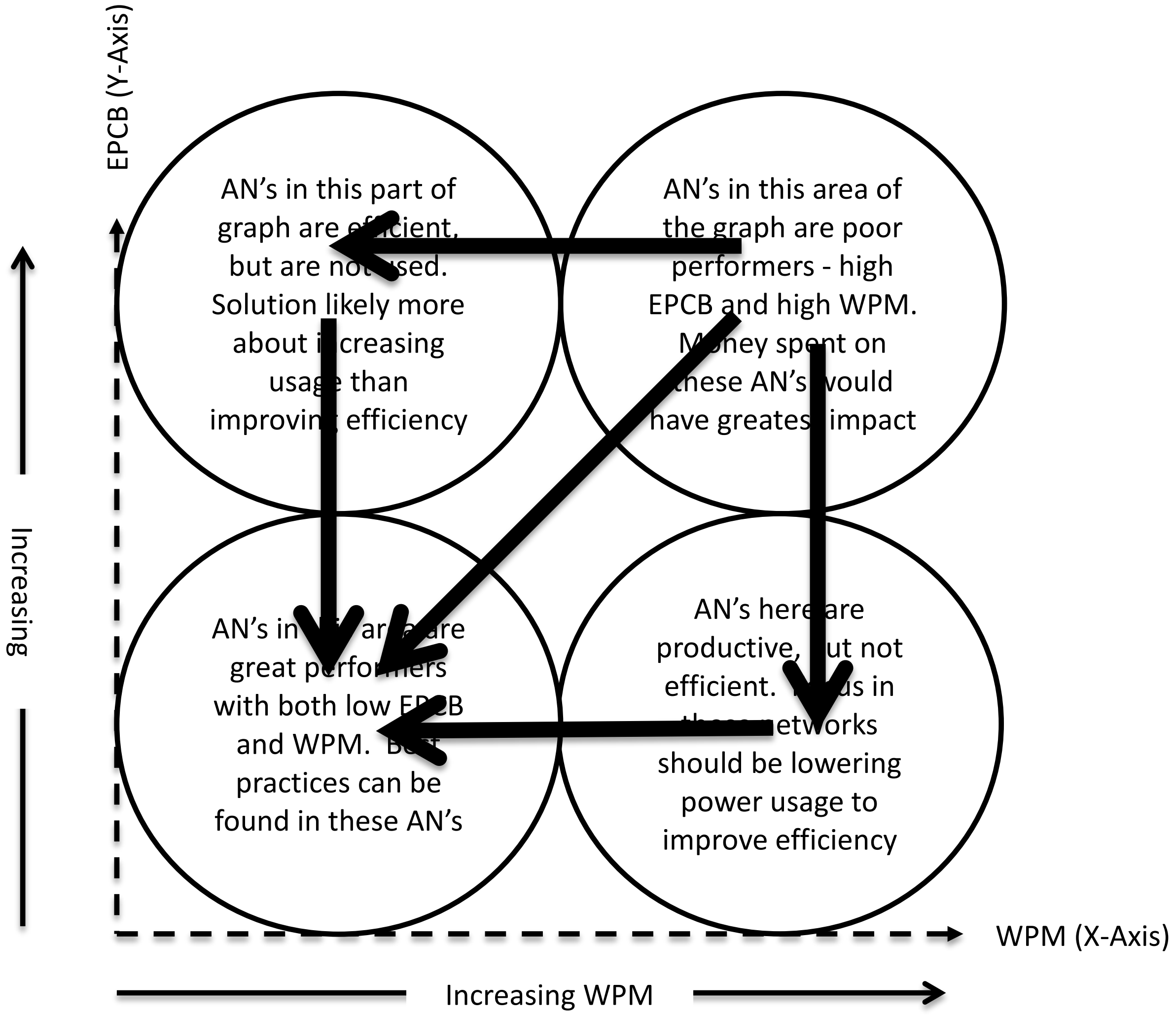


Figure 5 - $EPCB_{AN}$ vs. WPM Graph with AN Movements

After using the initial baseline to separate and categorize AN’s to best target resource and capital, continual monitoring of the WPM and $EPCB_{AN}$ in this manner can help operators see movements in energy efficiency and energy productivity of their AN’s, track success (or not) of improvement work and/or projects, as well as generally keep track of energy performance of AN’s.

It should be noted that it is well understood that improvement of AN energy efficiency and productivity is neither simple nor inexpensive. They typical projects that improve energy efficiency in an AN, things like:

- More efficient network design
- Conversion of 60V plant to 90V
- More efficient network equipment and OSP PS's
- Running OSP PS's at higher load

All are costly and capital intensive to do, and typically on their own cannot be justified on energy improvements alone. Still, it is important for operators to take the step to baseline and continually monitor access network with respect to energy efficiency and productivity, so that as the need for upgrades and/or evolutions to new architectures in the AN do occur, energy can be factored into the decision making process as well.

3. Metrics for Characterizing Energy in Edge and Core Facilities

The SCTE in Energy 2020 recognizes that MSO's in their networks and businesses have a large number of facilities, and that the nature and use of those facilities can be quite varied. As a result of the relative large number of varied types of facilities in an MSO, the SCTE is developing SCTE EMS-025 "Cable Facility Classification Definitions and Criteria" to provide categorization and definition of MSO facilities. The intent of the document is to provide clear separation of facilities by type and function, so that Energy 2020 facilities work and solutions are not generalized to all facilities, but instead properly targeted by facility classification.

In most MSO's the facility classification typically with the greatest number of facilities, and more than likely the classification wit the most energy usage, is called the Edge and Core Facilities (E&CF's) . E&CF's are responsible for the housing of the equipment required to deliver triple-play residential and commercial products to MSO subscribers. Equipment is typically staged in racks. Equipment requires proper power, airflow management, and backup power to support everyday operations.

Location of E&CF's in MSO networks is typically a function of the practical reach of HFC optical transport equipment. Because of those limitations, and the need to house equipment with-in the low 10's of km's distance from a customer, MSO's have an E&CF anywhere from every few thousands of homes passed for less dense network to high 10K to low 100K HP for more dense areas.

Of the 73-83% of energy shown in the power pyramid, Figure 1 as used by the typical MSO in the AN and E&CF infrastructure, about 1/3rd to 1/4th of it is utilized by the E&CF portion. As such, any move to reduce energy in an MSO will include understanding the energy characteristics of E&CF's, targeting poor performing facilities, as well as monitoring progress and improvement in E&CF performance. E&CF efficiency and productivity metrics allow MSO's to create a proper baseline for each facility, compare and categorize facilities with respect to performance, focus resource and investment where it can have the greatest impact, as well as monitor on-going improvement related to that investment.

3.1. Critical Facility Energy Productivity Metric

SCTE 213 provides two alternatives for detailing energy productivity in an E&CF. The preferred metric is Energy per consumed Byte ($EPCB_{FAC}$). Similar to its AN equivalent, $EPCB_{FAC}$ as it relates to E&CF's

is defined in the standard as the total amount of Energy over a period of time, divided by total number of bytes transported over that same time period, or mathematically

$$\boldsymbol{EPCB_{FAC}} = \frac{\textbf{Total Amount of Energy in an EC\&F in a Month}}{\textbf{Total Data Thruput in the E\&CF for the same Month}} = \frac{\boldsymbol{kWh}}{\boldsymbol{TB}} \qquad \textbf{Equation 5}$$

Because for some operators, attaining subscriber count fed by an E&CF facility may be simpler than getting TB throughput information, SCTE 213 provides an alternate productivity metric using subscribers as opposed to data throughput as the measure of productivity. The alternative metric for energy productivity in E&CF's detailed in SCTE 213 is Subscribers per kW (SPkW), and is equal to the total number of subscribers fed by the E&CF divided by the total kW load of the facility. Mathematically, this would be

$$\boldsymbol{SPkW} = \frac{\textbf{Average Subscribers fed by the E\&CF in the Period}}{\textbf{Average E\&CF Load in the Same period}} = \frac{\boldsymbol{Subs}}{\boldsymbol{kW}} \qquad \textbf{Equation 6}$$

Both $EPCB_{FAC}$ and SPkW measure the productivity of the energy used in the E&CF. Improving $EPCB_{FAC}$ and/or SPkW means an operator is using less energy to produce the same data throughput. From a comparison basis, E&CF's that have lower $EPCB_{FAC}$ are producing a TB of throughput with less energy than those with higher $EPCB_{FAC}$. The lower $EPCB_{FAC}$, the more productive in producing TB's of data throughput the energy being used in the E&CF is. With respect to SPkW, E&CF's with a higher SPkW are more productive, as they are serving a greater number of subs for each kW of load in the facility.

It is fairly straight-forward to understand $EPCB_{FAC}$ and SPkW as concepts – the lower the $EPCB_{FAC}$ and/or the higher the SPkW, the more productive the energy is being used in an E&CF. It is also fairly straight-forward to calculate both these metrics for an E&CF, as each is simple ratio of two numbers. The challenge centers on finding the TB throughput data, subscriber data, and kWh energy usage data for that metric so the calculation can be made.

It should be noted before leaving this section, that if an operator has a choice, $EPCB_{FAC}$ would be the preferred metric. Although the metrics are still in their infant stages, and data and reporting of this metrics is quite small and limited as of Fall 2015, from an intuitive standpoint, it is believed data throughput represents a truer view of "productive work" than just pure subscribers. As more data becomes available, and more definitive and real analysis can be done on the metrics, this could alter and/or change. But for now, the recommendation would be to use $EPCB_{FAC}$ over SPkW if it can be done.

3.1.1. What Constitutes Energy Consumed in an Edge and Core Facility

Total edge and core facility energy is defined as the energy dedicated solely to the facility (e.g., the energy measured at the utility meter of a dedicated facility or at the meter for a facility or equipment room in a mixed-use facility). Total facility energy includes all IT equipment energy, plus everything that supports the IT equipment-using energy, such as the following:

- Power-delivery components, including UPS systems, switchgear, generators, power-distribution units (PDUs), batteries, and distribution losses external to the IT equipment
- Cooling system components, such as chillers, cooling towers, pumps, computer room air-handling units (CRAHs), computer room air-conditioning units (CRACs), and direct expansion air-handler (DX) units

- Other miscellaneous component loads, such as data center lighting

SCTE 213 in section 6 defines Total Facility Power ($\boldsymbol{P_{TF}}$) as the energy provided to the critical facility by all sources is consumed by all the elements of a critical facility. Mathematically, SCTE 213 shows $\boldsymbol{P_{TF}}$ as

$$\boldsymbol{P_{TF} = P_{IT} + P_{HVAC} + P_L + P_{Dist}} \qquad \textbf{Equation 7}$$

Where
$P_{IT} = Power\ consumed\ by\ IT\ Equipment$

$P_{HVAC} = Power\ consumed\ by\ HVAC\ and\ Cooling\ of\ facility$

$P_L = \ Power\ consumed\ by\ Lighting\ and\ Convenience\ outlets\ in\ facility$

$P_{Dist} = Power\ consumed\ for\ IR^2\ losses\ ,rectifier/UPS\ ineffiencies, etc.$

For the purposes of making the $EPCB_{FAC}$ calculation for an individual E&CF, SCTE 213 advocates use of total facility power $\boldsymbol{P_{TF}}$ for energy consumed. It should be noted that SCTE 213 also provides the option to use $\boldsymbol{P_{IT}}$ for energy consumed in the EPCB and SPkW calculations, providing definition of $EPCB_{IT}$ and $SPkW_{IT}$ as alternate metrics for energy productivity in E&CF's. $\boldsymbol{P_{IT}}$ is discussed later in section 3.2.1 of this document in relation to PUE, and extensively in section 12 of SCTE 213 as it relates to its use as an alternate to $\boldsymbol{P_{TF}}$ for energy productivity metrics.

There are advantages using $\boldsymbol{P_{IT}}$ for EPCB calculations. One important one is that $\boldsymbol{P_{IT}}$ constitutes the real equipment energy in the facility only. As such, it is the "pure" energy just producing bytes (excluding cooling, lights, etc.), and as such,, should in theory be the consumed energy used if EPCB is to be purely about productivity, and not contain any facility efficiency elements in the calculation.

For simplicity sake, this paper will use $\boldsymbol{P_{TF}}$ for energy consumed, and $EPCB_{FAC}$ for sample calculations for facilities, but would recommend the reader refer to section 12 of SCTE 213 before making their own decisions on use of $EPCB_{FAC}$ versus use of $EPCB_{IT}$ tracking, to understand better pro's and con's of using $\boldsymbol{P_{IT}}$ over $\boldsymbol{P_{TF}}$ for energy consumed, so that an informed decision as to direction can be made.

3.1.2. Finding Energy Consumed in an Edge & Core Facility

Section 6.2 of SCTE 213 shows how an operator might attack finding $\boldsymbol{P_{TF}}$ for an E&CF. To summarize:

- Use of utility bill information from grid/source provider. This is the simplest and most practical way for an operator to attain P_{TF}. Output of this measurement would be in kWh, and time period Δt_p as extracted from the utility bill. The real advantage of using this method to get the data is its simplicity. Unlike OSP PS, all E&CF's would typically be metered and have an utility bill associated with them.
- Should the utility bill not be available for some reason, another option would be to have technicians take periodic readings of utility meters placed at the E&CF by the grid/source supplier, should they be available and accessible. As utility meters typically measure in kWh, meter readings must be taken over a period of time. Output of this measurement would be in kWh, and time period Δt_p for the measurement should be noted as the measurements are taken.

> This method addresses how to gather utility information if for some reason the billing data is not available. The negative of doing this is that it requires technician resource to read the meters for all the E&CF's where measurements are taken.

SCTE 213 also discusses use of automated power monitoring systems in the facility to gather the information. As noted in the document, these systems place power monitoring/measurement capability in the appropriate location in the critical facility, storing and/or transporting power data automatically as instructed by the operator. Although there are many great reasons for deploying an automated power monitoring system in an E&CF, including the fact that measurement is under full control of the operator and can be tracked in real time, automated power monitoring systems are not absolutely required for making the $EPCB_{FAC}$ measurement. The monthly billing data is more than adequate determining $\boldsymbol{P_{TF}}$ for the $EPCB_{FAC}$ calculation as a starting point for the E&CF $EPCB_{FAC}$ metric.

It should be noted that in the event a facility is fed by multiple sources, $\boldsymbol{P_{TF}}$ is the sum of the measurement from all the sources feeding the critical facility. If there are multiple energy sources and/or multiple energy meters, $\boldsymbol{P_{TF}}$ would be the sum of the energy from all the sources for the period. In the event a facility is a shared facility (i.e. E&CF + Administrative space), preference would be for the E&CF space to have a separate utility meter and/or separate monitoring to provide a "clean" energy consumed measurement from the utility bill and/or meter for that space. If the E&CF space is not separately metered, a number of approaches can be taken, but all require some sort of physical measurement of the power connections feeding E&CF facility portion of the building. Best approach would be to have power monitoring in place such that continuous measurement of the load could be made, and a real kWh figure obtained. Taking the measurement as an instantaneous power measurement on the load periodically could also be done, to try and approximate the percentage of the total power related to the E&CF portion. But this approach is less than ideal, as the load in both the admin portion and the E&CF portion vary by time of year and time of day. SCTE 213 provides more detail on the various methods for finding $\boldsymbol{P_{TF}}$.

3.1.3. Finding Consumed Bytes for an Edge and Core facility

By making the $EPCB_{FAC}$ consumed byte calculation for AN's done for the complete network connected to a facility, finding consumed bytes for the $EPCB_{FAC}$ calculation for the facility itself is in most cases a simple task. The consumed bytes for the facility $EPCB_{FAC}$ calculation are by and large exactly the same as the consumed bytes calculated for the AN network connected to the facility. ***If the calculation is made for the AN as laid out in section 2.1.4, in the vast majority of E&CF's, that same consumed byte calculation can be used for the facility calculation of*** $\boldsymbol{EPCB_{FAC}}$**.**

The only exceptions operators need to look out for are E&CF's which serve multiple purposes, and may have other sinks and sources of data throughput. As an example, if an E&CF is used to house server/storage equipment for internal or customer applications, then throughput associated with ingress and egress from that equipment would be added. If by chance routers are contained in the facility outside of those used to connect the access equipment, throughput for those should be added to the consumed byte calculation. But in most cases, the consumed bytes measurements and calculation used for AN $EPCB_{FAC}$ should be the same as the consumed bytes number used for E&CF $EPCB_{FAC}$.

The important takeaway for the reader with respect to this section is that by finding bytes consumed for the AN connected to a facility for the AN metrics as described in section 2 of this document, an operator already has in hand one of the two pieces of data needed to calculate $EPCB_{FAC}$ for the E&CF. All that remains is attaining the total facility power to match.

3.1.4. Making the $EPCB_{FAC}$ calculation for an Edge and Core Facility

Once energy consumed and bytes consumed is known for an E&CF, as with the AN, calculation of $EPCB_{FAC}$ is fairly straight-forward for that facility. SCTE 213 provides a more detailed sample calculation for $EPCB_{FAC}$ specific to the facility. For example, if the bytes consumed in the above sample calculation in section 2.1.4 is assumed to be for the month of April 2015 for the facility itself, and the power consumption for that facility itself for the same month is assumed to be 108029 kWh, then $EPCB_{FAC}$ for that facility for the month of April 2015 would be

$$EPCB_{FAC} = \frac{Total\ Amount\ of\ Energy\ in\ the\ Facility\ in\ a\ Month}{Total\ Data\ Thruput\ in\ the\ Facility\ for\ the\ same\ Month} = \frac{108029}{14457} = 7.47\frac{kWh}{TB}$$

For further reference and instructions, SCTE 213 provides a more detailed sample calculation for $EPCB_{FAC}$ specific to the facility.

3.1.5. Frequency of $EPCB_{FAC}$ calculation for an Edge and Core Facility

$EPCB_{FAC}$ can be calculated for each E&CF where energy and bytes consumed data is available. With respect to organizing the data, frequency of collecting data, etc.,

- The first $EPCB_{FAC}$ measurement taken for and E&CF should be considered the baseline measurement for that facility. As noted in the AN portion of this document in section 2, SCTE 212 details the reasons and importance in setting a baseline, as it provides a base figure on which tracking of future performance (either better or worse) can be judged. Because of the of lack of real experience with this metric, it may prudent for operators to see a few months of initial tracking before setting and absolute baseline for a E&CF. But in keeping with the practice of setting a good baseline to help with future work associated with the metric, it would be suggested that the baseline be set with data from the first 6-12 months of tracking.
- Ideally, as this metric will vary over time, and understanding those variances could be important in knowing where to focus efficiency projects, as well as judging the benefits of those projects, it would be recommended this metric be tracked for each E&CF on a monthly basis. Understanding resources may not be available for that sort of frequency, even recording the metric for E&CF's on a less frequent (i.e. quarterly) basis would useful, with a target to evolve to monthly when/if possible.
- As this metric is still in its infancy stage, not enough data exists on actual E&CF's for $EPCB_{FAC}$ to actually say categorically what is a good performance and what is a bad performance with respect to this metric. As such, at least initially until enough data is collected to allow operators to make such a determination, $EPCB_{FAC}$ is to be used by operators to compare energy productivity between E&CF's in their footprint.

Assuming $EPCB_{FAC}$ information is produced by individual facility as detailed above, continual tracking and reporting of $EPCB_{FAC}$ data for each individual facility should be part of an Operator's on-going energy efficiency program.

3.1.6. Organizing $EPCB_{FAC}$ Data for Use

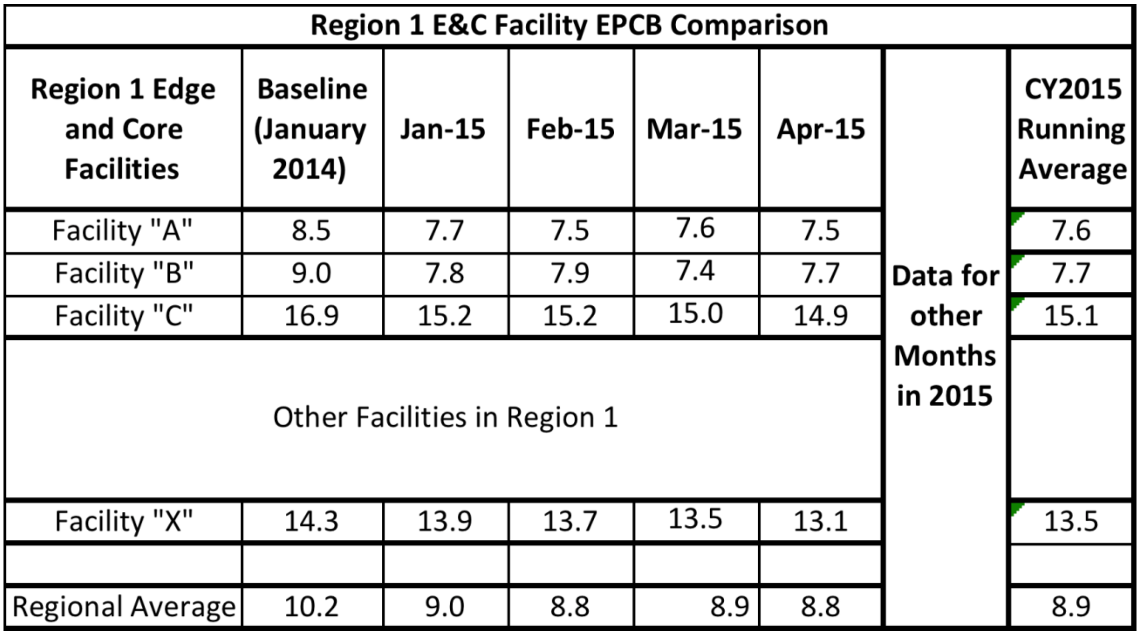
As with AN's, organization of the data with respect to E&CF's is a function of how an operator might want to use the data. Although the industry is still in the very early stages of understanding how the data might be used, as noted above, it would be suggested that operators collect and track this data for each facility. The good news with respect to organizing the data for MSO's is that because the $EPCB_{AN}$ metric is directly tied to a specific E&CF, in many cases the TB data calculated for the AN can also be used for the calculation of $EPCB_{FAC}$. Because the TB data can be re-used for the same set of facilities, adapting what is shown for Table 5 for AN's, the corresponding table summary for $EPCB_{FAC}$ calculations for facilities in a region for a month is shown in Table 9.

Table 9 - Sample Summary $EPCB_{FAC}$ Data for E&CF's in a Region

Region 1 Edge and Core Facilities EPCB Performance - April 2015						
	Facility Energy/Power			Traffic		Metric
Region 1 E&C Facilities	Total kWh in Quarter	Total Billing Days	Average kW load	Total TB Traffic in Quarter	Total TB Traffic Days	Facility EPCB
Facility "A"	108029	30		14457	30	7.47
Facility "B"	76566	30		9638	30	7.94
Facility "C"	70851	30		6933	30	10.22
Other Facilities in Region 1						
Facility "X"	57362	30		4382	30	13.09
Total Region	6256160	30		708213	30	8.83
Typical Tool	BMS, Utility Data, or manual measurements as per 4.1.2			Bandwidth Utilization Tool + Conversion to Terabytes from Gbps as per 3.1.4 and 4.1.3.		Calculated per Equation 5

As with AN's, seeing the trend of the metric over time helps operators see any sudden changes and/or anomalies in performance, and react to them quickly. Table 10 is the E&CF version of the AN trend table for shown in Table 6 earlier.

Table 10 - Sample E&C Facility Trend Table for $EPCB_{FAC}$ Metric



Region 1 E&C Facility EPCB Comparison							
Region 1 Edge and Core Facilities	**Baseline (January 2014)**	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**		**CY2015 Running Average**
Facility "A"	8.5	7.7	7.5	7.6	7.5	**Data for other Months in 2015**	7.6
Facility "B"	9.0	7.8	7.9	7.4	7.7		7.7
Facility "C"	16.9	15.2	15.2	15.0	14.9		15.1
Other Facilities in Region 1							
Facility "X"	14.3	13.9	13.7	13.5	13.1		13.5
Regional Average	10.2	9.0	8.8	8.9	8.8		8.9

3.1.7. An Alternative Productivity Metric – SPkW

For some operators, finding TB throughput for an E&CF may be difficult and/or problematic. Typically operators do keep track of subscriber count per E&CF for disaster recovery purposes, SCTE 213 also defines Subscribers per kW in a E&CF as an energy productivity metric. As with $EPCB_{FAC}$, SPkW should be calculated monthly. Section 7 of SCTE 213 provides operators with a simple approach to attaining average subscribers in a month, essentially by adding together the beginning and ending subscriber counts in the month and dividing by two. With the average subscriber count for the month, an operator can calculate SPkW using equation 6 from above. It should be noted that for this metric, the average facility load in kW is used, so the facility energy for a given month in kWh needs to be converted to average kW load per equation 4.

For the purpose of completeness, Table 11 shows use of SPkW instead of $EPCB_{FAC}$ in the Sample Summary Facility Data Table (SPkW equivalent of Table 9 above).

Table 11 - Sample E&C Facility Trend Table for SPkW Metric

Region 1 Edge and Core Facilities SPkW Performance - April 2015					
	Facility Energy/Power			Subscribers	Metric
Region 1 E&C Facilities	Total kWh in Quarter	Total Billing Days	Average kW Load in Qtr	Average Subscribers in the Month	Facility SPkW
Facility "A"	108029	30	150.0	80594	537.1
Facility "B"	76566	30	106.3	67128	631.2
Facility "C"	70851	30	98.4	34430	349.9
Other Facilities in Region 1					
Facility "X"	57362	30	79.7	20583	258.4
Total Region	6256160	30	8689.1	4054690	466.6
Typical Tool	BMS, Utility Data, or manual measurements as per 4.1.2		Calculated using Equation 4	Typically from Billing Data	Calculated per Equation 6

The same thing as is done for $EPCB_{FAC}$ to compare the SPkW measurement over time for facilities can be done as shown in Table 10. As noted at the start of this section, SPkW as a metric shows improvement as the number gets higher, not lower as with $EPCB_{FAC}$. So for instance, in the above table, Facility “B” with and SPkW of 631.2 is a much better performer with respect to energy productivity then Facility “C” with SPkW of 349.9.

3.2. Edge and Core Facility Energy Efficiency

While $EPCB_{FAC}$ provides a good measure of energy productivity for an E&CF, the corresponding energy efficiency metric is Power Usage Effectiveness (PUE). PUE is an internationally recognized efficiency metric for data centers and critical facilities. As noted in SCTE 213, PUE provides a useful tool for evaluating and measuring the energy usage and efficiency of the infrastructure equipment that supports the IT equipment within a critical facility. SCTE 184 specifically mentions PUE as a metric operators track for critical facilities. Operators can use PUE results to address and reduce the energy usage related to the supporting infrastructure within their critical facilities.

Mathematically, PUE is defined as the ratio of total critical facility energy to IT equipment energy.

$$\boldsymbol{PUE = \frac{Total\ Critical\ Facility\ Energy}{IT\ Equipment\ Energy} = \frac{P_{TF}}{P_{IT}}}$$ **Equation 8**

PUE can be used to illustrate a data center's energy allocation. A PUE of 3.0 indicates that the critical facility's total-energy usage is three times greater than the energy usage for the IT equipment alone. Or alternatively, that 1/3rd of the facility energy is used for the IT equipment, and 2/3rd of the energy is used for items in the facility other than that IT equipment providing service. PUE is a number that is always greater than 1, and the closer to 1, the more energy efficient the critical facility. PUE as a metric has been measured and reported by a number of different data center and critical facility owners across the world over the years. In general, best in class data centers perform with PUE <1.5 and approaching 1.15-1.2. Typical data center/critical facility PUE performance is in the 1.8-1.9 range.

PUE as a metric is best applied when looking at trends in an individual facility over time and measuring the effects of different design and operational decisions within a specific facility. Assuming consistency in the measurement of PUE with-in their own company, operators can use PUE measurements from the facilities with-in their own footprint to compare facilities for the purpose of targeting investment in energy efficiency properly. PUE *should not* be used to compare facilities across operator, or to compare to facilities of companies in other industries, as such comparisons are meaningless and potentially misleading and harmful.

3.2.1. Finding the Data needed to calculate PUE for E&CF Facilities

Making the PUE calculation requires two pieces of data, total facility power ($\boldsymbol{P_{TF}}$) and IT equipment power ($\boldsymbol{P_{IT}}$)**.** The total facility power used for PUE is measured/calculated in a similar manner to the total facility power for the $EPCB_{FAC}$ metric detailed in section 3.1.1. As such, if the $EPCB_{FAC}$ calculation has been made using total facility power $\boldsymbol{P_{TF}}$**,** then total power for the

IT Equipment power **(**$\boldsymbol{P_{IT}}$**)** for a facility is the power required for just network equipment needed to service customers. With respect to the cable industry, this would include power for equipment that delivers voice, video, and data services (i.e. CMTS, QAM modulators, routers, data switches, soft-switches, etc.) in the E&CF.

$\boldsymbol{P_{IT}}$ itself has no third party measurement device like the utility meter, and must be measured by operators either directly or with automated monitoring equipment. Typically the IT equipment in an E&CF is either DC powered and battery backed up, or battery backed through UPS. As such, the simplest way to measure IT equipment power is to sum power from all UPS and/or DC rectifier sources in the head-end. A more precise measurement can be made by directly measuring power at PDU's at the row, rack, or equipment level, but for the purpose of making a PUE calculation for the facility, measurement at the UPS/DC rectifier level is considered acceptable.

Unlike total facility power $\boldsymbol{P_{TF}}$, where the power typically comes in kWh over time, $\boldsymbol{P_{IT}}$ is typically an instantaneous measurement of the load in kW at the time the measurement is taken. This means if one has the total facility power in kWh for a given month, that figure will need to be converted to an average kW load for the month to make the PUE calculation. In general, the instantaneous load measurement of $\boldsymbol{P_{IT}}$ works for calculating PUE in a given month unless there is some known event, equipment add, etc. in the month, the IT equipment load stays fairly stable.

Section 10.2 of SCTE 213 provides a very detailed view as to what IT equipment power is and how to find it for an E&CF.

3.2.2. Frequency of PUE Measurement

Frequency of measurement of PUE ultimately is governed by what is possible with respect to frequency of measurement of P_{TF} and P_{IT}. SCTE 213 recommends operators measure PUE consistent with the frequency of measuring P_{TF} and P_{IT}, defining the different levels of measurement frequency as

- Monthly – this is the most basic PUE measurement, providing a snapshot of PUE at the time in the month P_{IT} is measured
- Daily – can be done manually, but typically more practical using automated monitoring equipment. This is a better way to track PUE, as it will be provide tracking of weather/environment changes across the month.
- Continuously (i.e. every 15 minutes) - requires automated monitoring equipment. This is best way to view PUE, as it provides full view of variations across the whole of each day due to weather/environment.

As continuous measurement of PUE requires automated power monitoring capability, it may not be practical for operators in all facilities initially. SCTE 213 indicates monthly snapshot for PUE is an acceptable starting point for operators to work from, until such time as the equipment needed to measure continuously is available.

It should be noted that PUE as a metric is greatly advantaged if it is measured on a continuous basis. This is because P_{TF}in particular is impacted by the outdoor environment surrounding the facility, and as such can fluctuate in a statistically meaningful way through-out a day and through-out a year. The graph in Figure 6 shows how PUE can vary over a one-year period.

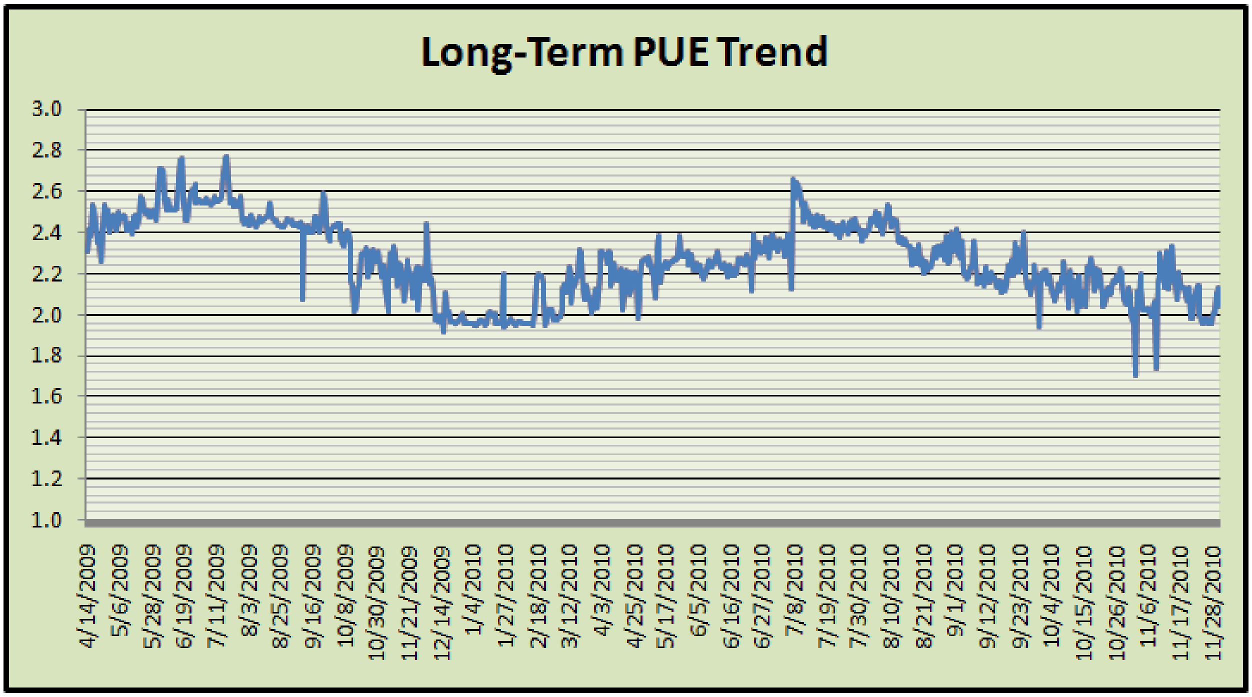


Figure 6 - Long Term PUE Trend Example Graph

As can be seen in Figure 6, PUE for a facility tends to trend with temperature, going higher in the summer months, and lower in the winter months. This is largely driven by the differences in HVAC and cooling needs due to the environment surrounding a facility. These variations in PUE due to external factors are why continuous monitoring of PUE is desired, and a PUE baseline typically needs to be over a year, and not just a one month snapshot.

Even in a given month, PUE can vary from the average in a meaningful way. Table 12 is real data that has been adjusted to make anonymous.

Table 12 - Daily PUE Reading Example for Month

Facility G - Month of January 2015			
Date	Total Facility kW	IT Equipment kW	PUE
1/1/15	83.1	25.8	3.23
1/2/15	81.3	25.8	3.16
1/3/15	80.5	25.8	3.13
1/4/15	82.4	25.8	3.20
1/5/15	83.6	25.7	3.25
1/6/15	83.2	25.7	3.23
1/7/15	82.8	25.7	3.21
1/8/15	83.5	25.8	3.24

1/9/15	82.8	25.8	3.22
1/10/15	81.0	25.7	3.14
1/11/15	81.9	25.7	3.18
1/12/15	88.7	25.7	3.45
1/13/15	85.6	25.8	3.32
1/14/15	85.8	25.7	3.33
1/15/15	85.9	25.8	3.33
1/16/15	84.2	25.7	3.27
1/17/15	82.8	25.7	3.22
1/18/15	81.6	25.7	3.17
1/19/15	83.3	25.7	3.24
1/20/15	84.6	25.7	3.29
1/21/15	85.5	25.7	3.32
1/22/15	83.6	25.7	3.25
1/23/15	82.9	25.7	3.22
1/24/15	82.9	25.7	3.22
1/25/15	85.1	25.7	3.31
1/26/15	86.8	25.7	3.37
1/27/15	85.1	25.7	3.30
1/28/15	86.4	25.7	3.35
1/29/15	87.3	25.8	3.39
1/30/15	85.8	25.8	3.33
1/31/15	83.6	25.8	3.25
Average	84.0	25.7	3.26
Max	88.7	25.8	3.45
Min	80.5	25.7	3.13

As can be seen from the table, daily measurement of PUE can reveal variance from the monthly average in the +/- 5% range. Continuously measuring P_{TF} is the only way to insure full capture of these variations in the PUE measurement. Although this is a good start, and certainly better then no PUE readings at all, moving to automated measurement systems like those provided by BMS will aid in making PUE data more useful. SCTE 213 recommends operators move as quickly as practical to continuous measurement of PUE for this very reason.

3.2.3. Using the Data to calculate PUE for Facilities

Once the data is available, calculating PUE is a fairly simple process. As noted in the equation, it is a ratio of two separate, total facility power and IT equipment power, with the calculation being simply dividing one number by the other. The only challenge is insuring the two components used are of the same dimensions (i.e. either both in kW, or both in kWh). If both are in kWh, then Δt_P is used for each measurement and must be the same, as well.

For example, if in the sample facility shown above for the $EPCB_{FAC}$ example in 4.1.4, the IT equipment power is measured at the DC rectifiers, and instantaneous DC IT equipment load is found to be 70.3 kW, calculating PUE would be a two-step process

- As noted in section 3.2.1, the first step to calculate a monthly average of PUE with the kWh data would be to take the kWh number from 4.1.4 of 108029 kWh for the month, and convert it to kW load. Using equation 4

$$kW = \frac{kWh}{hours\ contained\ in\ the\ time\ period\ kWh\ are\ measured\ in} = \frac{108029}{30 * 24}$$

$$= 150.0\ kW$$

- With that, average PUE can be calculated for the month using equation 8

$$\boldsymbol{PUE} = \frac{\boldsymbol{Total\ Critical\ Facility\ Energy}}{\boldsymbol{IT\ Equipment\ Energy}} = \frac{\boldsymbol{P_{TF}}}{\boldsymbol{P_{IT}}} = \frac{\mathbf{150.0}}{\mathbf{70.3}} = 2.13$$

3.2.4. Using PUE to improve Energy Efficiency in Facilities

Much has been written about the use of the PUE metric in helping operators to improve critical facility energy efficiency. The Green Grid (TGG), in particular, has written extensively on use of PUE for such purposes as noted in [i3] and [i4]. As with any metric, PUE is only useful if it is properly used. The PUE metric is associated with the critical facility infrastructure. PUE is not a data center productivity (DCeP) metric, nor is it a stand-alone, comprehensive efficiency metric. PUE measures the relationship between the total facility energy consumed and the IT equipment energy consumed. When viewed in the proper context, PUE provides strong guidance for and useful insight into the design of efficient power and cooling infrastructure architectures, the deployment of equipment within those architectures, and the day-to-day operation of that equipment.

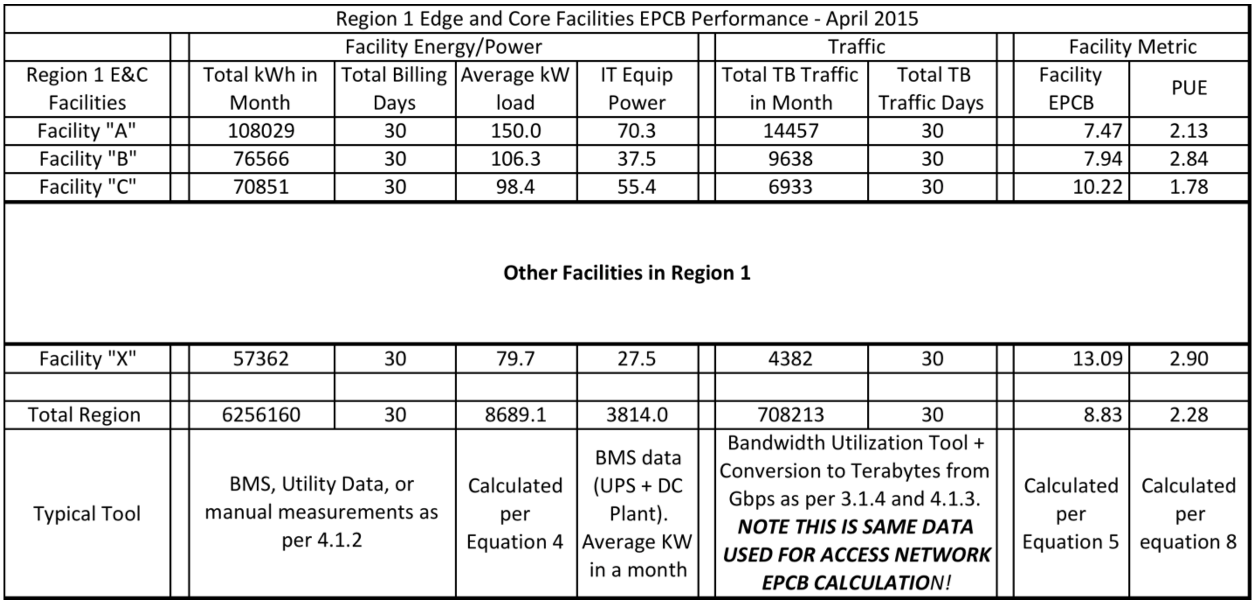
Proper use of PUE to improve energy efficiency in a critical facility is accomplished through a process of measurement of the metric performed for each facility. This includes:

- Taking initial snapshot PUE measurement of all critical facilities in an operator’s geographic footprint. Whilst not constituting a full baseline PUE profile, an initial snapshot PUE can identify obvious outliers with respect to energy efficiency, for immediate attention.
- Creating an initial baseline profile of a facility with respect to PUE. For a critical facility, SCTE 213 recommends that a critical facility baseline be created using a full years’ worth of PUE measurements, so that facility variations due to weather/environment can be included in the baseline. Such data can aid operators in targeting energy efficiency improvement appropriately to critical facilities
- Continuing measurement of PUE as energy efficiency improvements are implemented, so that the impact of those improvements can be judged against the baseline.
- Continuing measurement of PUE also allows operators to quickly see anomalies in energy efficiency that might occur, and to deal with them quickly.

3.2.5. Organizing PUE Data with $EPCB_{FAC}$ for Edge and Core Facilities

Assuming the data for both PUE and $EPCB_{FAC}$ for edge and core facilities are measured and recorded as indicated above, organizing the data for reporting purposes can be straight-forward. From a data organization and viewing standpoint, it is very simple to add PUE measurements to the tables with $EPCB_{FAC}$ and/or SPkW information for facilities in it. Table 13 shows what is needed to add PUE to the $EPCB_{FAC}$ summary table from above Table 9.

Table 13 - Example Summary $EPCB_{FAC}$ and PUE Data for Regional Facilities



Region 1 Edge and Core Facilities EPCB Performance - April 2015								
	Facility Energy/Power				Traffic		Facility Metric	
Region 1 E&C Facilities	Total kWh in Month	Total Billing Days	Average kW load	IT Equip Power	Total TB Traffic in Month	Total TB Traffic Days	Facility EPCB	PUE
Facility "A"	108029	30	150.0	70.3	14457	30	7.47	2.13
Facility "B"	76566	30	106.3	37.5	9638	30	7.94	2.84
Facility "C"	70851	30	98.4	55.4	6933	30	10.22	1.78
Other Facilities in Region 1								
Facility "X"	57362	30	79.7	27.5	4382	30	13.09	2.90
Total Region	6256160	30	8689.1	3814.0	708213	30	8.83	2.28
Typical Tool	BMS, Utility Data, or manual measurements as per 4.1.2		Calculated per Equation 4	BMS data (UPS + DC Plant). Average KW in a month	Bandwidth Utilization Tool + Conversion to Terabytes from Gbps as per 3.1.4 and 4.1.3. ***NOTE THIS IS SAME DATA USED FOR ACCESS NETWORK EPCB CALCULATION!***		Calculated per Equation 5	Calculated per equation 8

Adding PUE data to the monthly tracking matrix and tables yields something that looks like Table 14.

Table 14 - Example Summary $EPCB_{FAC}$ and PUE Data Trending Regional Facilities

Region 1 E&C Facility EPCB and PUE Comparison													
Region 1 Edge and Core Facilities	Baseline (April 2014)		Jan-15		Feb-15		Mar-15		Apr-15		Data for other Months in 2015	CY2015 Running Average	
	EPCB	PUE	EPCB	PUE	EPCB	PUE	EPCB	PUE	EPCB	PUE		EPCB	PUE
Facility "A"	8.5	2.11	7.7	2.04	7.5	2.06	7.6	2.09	7.5	2.13		5.2	2.08
Facility "B"	9.0	2.56	7.8	2.65	7.9	2.71	7.4	2.85	7.7	2.84		5.6	2.76
Facility "C"	16.9	1.92	15.2	1.68	15.2	1.76	15.0	1.76	14.9	1.78		9.3	1.75
Other Facilities in Region 1													
Facility "X"	14.3	3.02	13.9	2.65	13.7	2.68	13.5	2.78	13.1	2.90		8.9	2.75
Regional Average	10.2	2.28	9.0	2.13	8.8	2.17	8.9	2.24	8.8	2.28		8.9	2.21

These tables provide the reader a sample idea as to how to organize the data metric data so that facility metrics can be tracked and compared.

3.3. Using PUE and $EPCB_{FAC}$ together to characterize facilities

Just as WPM and $EPCB_{FAC}$/SPkW characterize energy efficiency and productivity for access networks, PUE and $EPCB_{FAC}$/SPkW for edge and core facilities provide similar characterization for an operator's edge and core facility infrastructure. As noted in earlier section, the two metrics provide different but complimentary information with respect to the performance of the facility. PUE as a metric specifically focuses on the efficiency of the facility itself. It is a measure how energy efficient the facility is with respect to maintaining the environment the IT equipment uses to produce capabilities and service needs of the business. $EPCB_{FAC}$/SPkW on the other hand, focuses on how efficiently the energy is used to produce the capabilities and service needs of the business. Improvements in PUE generally manifest themselves in making HVAC and other support systems in the facility more energy efficient. Improvements in $EPCB_{FAC}$/SPkW come from making the energy used better at producing real work output from the facility per unit energy.

Once PUE and $EPCB_{FAC}$/SPkW are base-lined and tracked as described above, as with their AN metric brethren, the key question is how does an operator use them? As noted previously but worth repeating, with respect to energy usage, metrics allow an operator to

- Properly develop a baseline measurement with respect to energy for each E&CF. As noted earlier, SCTE 212 details setting energy consumption baseline for a facility. Additionally, total facility base-lining is covered as a part of SCTE EMS-024 document "Facility Climate Optimization Operational Practice" currently under development as part of the SCTE Energy 2020 initiative.
- Compare facilities with respect to energy characteristics, and separate out poor performing access networks for appropriately targeted resource and attention, as well as find top performers who can be used to develop potential best practices with respect to attaining good energy performance.

- Evaluate changes in energy performance as a result of investment in improvements and/or changes to operational practices aimed at improving energy performance.

PUE and $EPCB_{FAC}$/SPkW provide important information with respect to the energy efficiency of an edge and core facilities. PUE provides operators with the raw energy efficiency of the network. Regardless of what the energy is used for, the lower your PUE measurement is, the more energy efficient the facility is. If one has a facility with PUE of 2.5, and another at 2.0 PUE, the facility with the lower number is more efficient. The reasons why it is more efficient can be many

- More efficient HVAC/Cooling design (typically top reason)
- Physical location (cooler weather aids energy efficiency)
- More efficient UPS/Rectifiers

SCTE EMS-024 document, when published, should provide operators with guidance on ways to improve PUE and energy efficiency with-in an edge and core facility.

As with $EPCB_{FAC}$ for AN's, $EPCB_{FAC}$/SPkW, provide important information on the productivity of the energy used in the access network. The lower the $EPCB_{FAC}$ (or higher the SPkW), the more productive the access network is in producing real work/output for the business. The key drivers of $EPCB_{FAC}$ for E&CF's centers around number of subscribers connected to the facility, and probably most importantly, the amount of data those subscribers use for their services.

The reason why what subscribers do in using the network can have such an impact on the $EPCB_{FAC}$ metric is that equipment power in a facility is not generally linear to subscriber or data throughput load. Equipment tends to load significant portions of the power on with the provisioning of the first subscriber or byte, with only small increments of power as throughput and/or subscriber connections grow. As such, a poor $EPCB_{FAC}$ could be an indication of issues of underutilized and/or over-provisioned facility locations. Solutions to poor $EPCB_{FAC}$ tend to center around ways to improve utilization of equipment in facilities, up to and including full consolidation of facilities if technically and/or economically viable. Facilities performing poorly on $EPCB_{FAC}$ tend to be good initial candidates for consolidation assuming other factors associated with consolidation make sense.

Unlike any of the other metrics discussed in this paper, PUE is a reasonably well understood metric for facilities, with a long history, and enough data to generally set and apply targets. It is expected that EMS-024 when it is published will provide guidance on use of PUE for such purposes by operators. So although real targets can be set for PUE, as with AN $EPCB_{FAC}$, E&CF $EPCB_{FAC}$ for the industry is still a relatively new metric. As an industry, we haven't enough information to say what constitutes a good number and what is a bad number. We will only be able to determine that once we have gathered enough metric data to look at and make that judgment.

As with the WPM and $EPCB_{FAC}$ in AN's , though, what we can do with the metrics is use them to make comparison between access network, to help in determining good and poor performers. One can characterize facilities by plotting these two metrics for facilities a quadrant grid as shown in Figure 7, using operator target PUE and $EPCB_{FAC}$ to set the center points on the graph for splitting into quadrants.

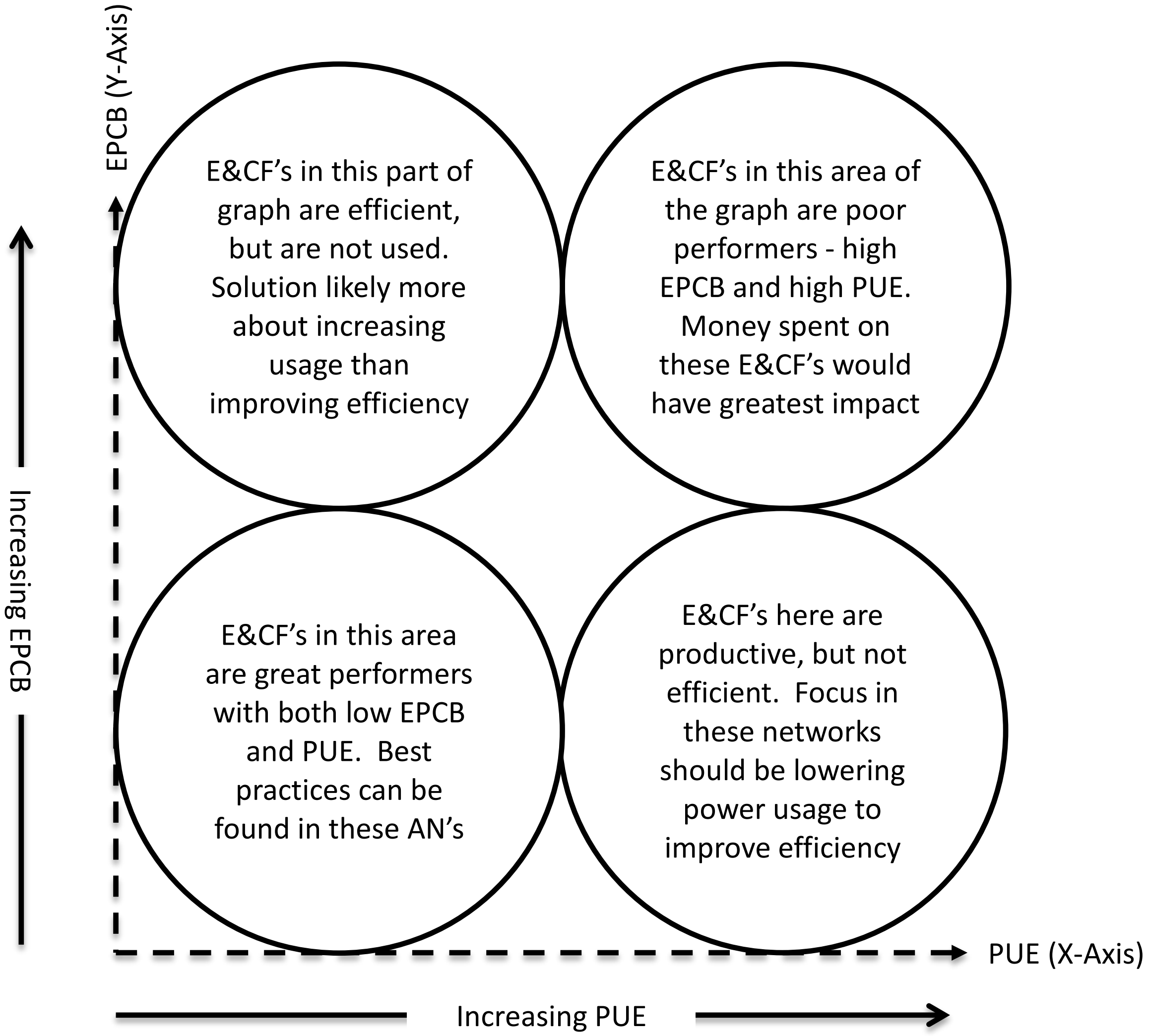


Figure 7 - $EPCB_{FAC}$ vs. PUE for Edge and Core Facilities

Placement of the facilities in this grid based on their performance in these two metrics allows an operator to quickly characterize facilities with respect to energy efficiency and energy productivity. Facilities landing in the lower left-hand (low PUE and low $EPCB_{FAC}$) are performing well– these facilities are the operators best in class with respect to energy performance. These are facilities from which best practices for facility operation *should* be taken. And if consolidation in the area around these facilities is to be done, from an energy perspective, these are the facilities that *should* be consolidated into, not consolidated away.

Facilities landing in the bottom right-hand portion of the graph are making productive use of the energy (low $EPCB_{FAC}$), but are not efficient as facilities themselves (high PUE). Depending on how poor the PUE is, operators would want to look at facilities in this quadrant for potential energy efficiency/HVAC/cooling improvements first over other facilities, as doing that could potentially move them in the direction of the best practice quadrant. Facilities in top left-hand part of the graph are performing efficiently as facilities (low PUE), but are not productive (high ECPB). As they are efficient, facilities in this quadrant may be candidates for being consolidated into, as in theory they have available capacity for adding work units to better use the energy that is there. The low PUE means that any power added to support the new work units would be added efficiently.

Facilities in the top right-hand portion of the graph represent an operator’s worst performers. Not only are they energy inefficient in their ability to create the proper environment for the IT equipment (high PUE), the energy they are using is not productive (high ECPB). From purely an energy efficiency and productivity perspective, facilities in this quadrant *should* be looked at first for potential consolidation and/or elimination. Failing that, these are the facilities where presumably the most opportunity exists for improvement work.

As with AN’s, continual plotting of ECPB and WPM for access networks over time can help operators see changes in performance. Over time, operators should see changes in line with arrows shown in Figure 8.

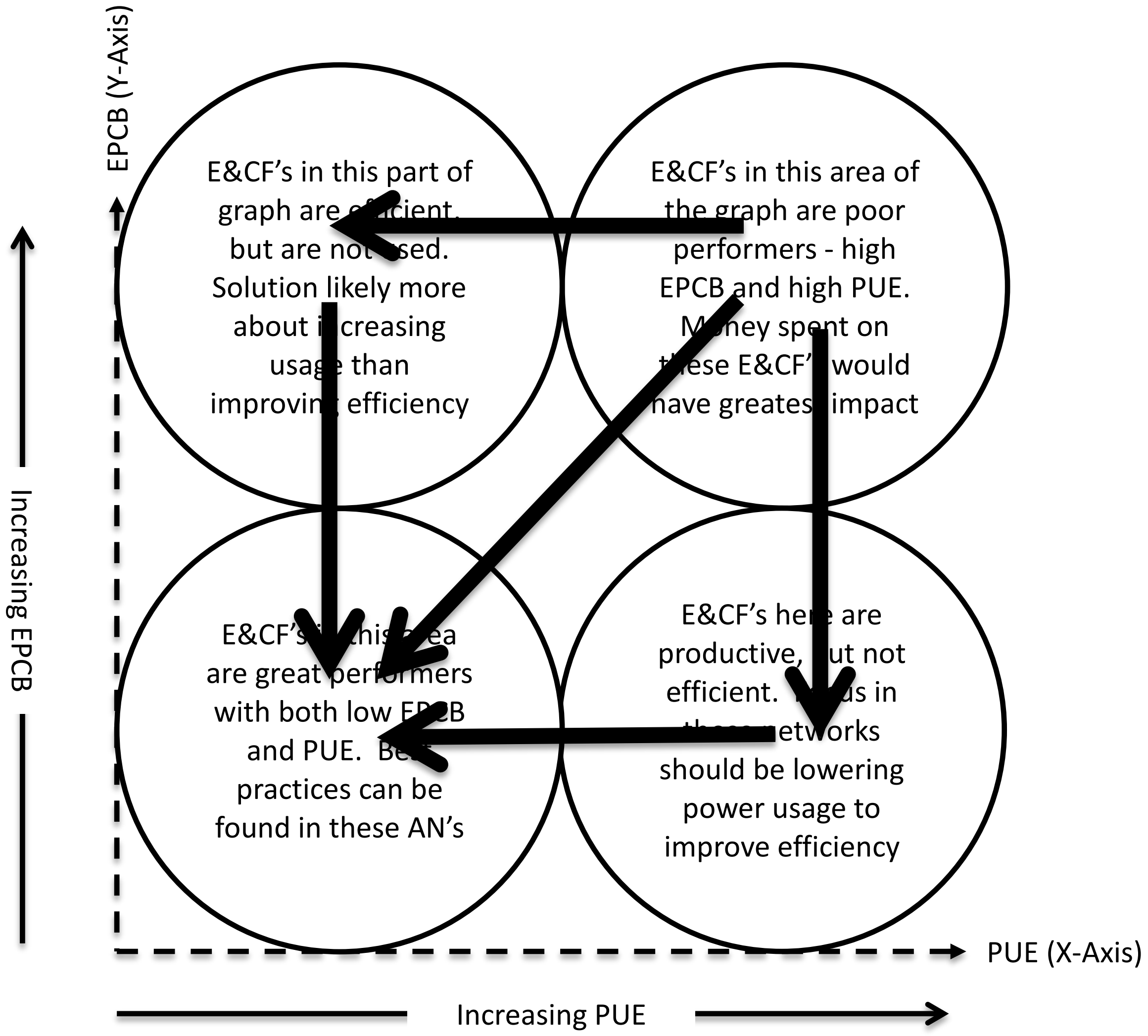


Figure 8 – $EPCB_{FAC}$ vs. PUE for Edge and Core Facilities Movement Diagram

Characterizing facilities in this manner gives operators the ability to quickly and easily categorize and track facilities with respect to energy performance, as well as to integrate energy performance into the equations used to determine facility consolidation as well as facility improvement projects.

4. Summary and Conclusion

An important part of any energy efficiency program is metrics. As noted in this and many Energy 2020 documents, use of the proper energy metrics allow an operator

- Set a proper baseline with respect to the metric
- Prioritize actions in accordance with comparisons based on the metric

- Monitor progress in the metric from actions taken
- See and react to on-going performance with respect to the metric

As access networks and edge and core facilities constitute in the range of 73-83% of an MSO's electricity usage according to the power pyramid, prioritizing the development and deployment of energy metrics in these two areas makes good business sense

Using SCTE 211 and SCTE 213 as a guide, this paper has attempted to lay out an approach operators can take to understand the energy characteristics of their access networks and edge and core facility infrastructures using the metrics described in those two SCTE documents. In laying out the approach, the paper has sought keep the process as simple as possible, to encourage operators to begin as quickly.

Summary of the metrics desired, how they are calculated, and where they come from is in Table 15.

Table 15 - Summary Metrics Table

	Access Networks				**E&CF Facilities**			
Metric Name	EPCB		WPM		EPCB		PUE	
Metric Formula	kWh/TB		Watts/Mile		kWh/TB		kW/kW (Dimensionless)	
Calculation Unit	Total Access Network connected to a E&CF		Total Access Network connected to a E&CF		Per Edge and Core Facility		Per Edge and Core Facility	
Metric Reporting Frequency	Monthly if possible, but quarterly OK		Quarterly, but yearly OK		Monthly		Monthly, with target to move to continous	
Data Required	AN kWh	AN Terabytes	AN Watts	Miles of AN Plant	Facility kWh	Facility Terabytes	Facility Total kW	Facility IT Equip kW
Data Source	Billing Data, Direct Measurement	Measured Router Traffic + Broadcast estimation	Calculated from kWh data for AN	GIS, Plant Maps	BMS, Utility Data, or manual measurements	Measured Router Traffic + Broadcast estimation. Same as TB calculation for AN	Calculated from Facility kWh for monthly, BMS for continuous	BMS, or manual measurements
Document Reference Section	3.1.3	3.1.4	3.2.1, Equation 4	3.2.1	4.1.1, 4.1.2	3.1.4, 4.1.3	4.1.2	4.2.1
Other SCTE Docment Reference	SCTE 212 Section 6	SCTE 211 Section 7	NA	NA	SCTE 213 Section 6.2	SCTE 213 Section 8.2	SCTE 213 Section 6.2	SCTE 213 Section 10.2

Mathematically, the metrics themselves are quite simple. All are simple ratios, requiring only division to compute. Calculation of the metrics is also quite easy as well, requiring little more than simple addition, subtraction, multiplication, and division. Once you have gathered the data for the metrics, the most difficult part of creating the metrics is associated with the conversions needed to insure that metrics are created using the correct version of the numerator and denominator. Probably the most important skills associated with being able to calculate the metrics correctly is to understand the differences between, and knowing how to convert between

- kW, kWh over time, and average kW over time – kW is an instantaneous load measured at a specific time. kWh is kW usage measured over a period of time. Average kW over time is calculated from kWh and kW by dividing the kWh number by the number of hours in the time period.

- Bits per second (Gbps), bytes (TB), and average bits per second over time - As with kW, any bits-per-second measurement is an instantaneous measurement done at a particular point in time. Average bits per second over time are just that - the average bit rate as measured by equipment over a period of time. And much like kWh is to kW, bytes are the total number of bits measured over a period of time, divided by 8 (8 bits/byte). Bytes are typically converted from average bit rates by multiplying the average bit rate by the number of seconds in the time period, and dividing by 8.
- Tera-, Giga-, Mega-, and Kilo- - data for the metrics arrives using varying metric standard prefixes. To properly calculate and use the metrics in this document, one must be competent in making the different metric system conversions

So although the math may not be difficult, the important aspect of the math is to make sure when doing the metric, the correct versions of the data are being used. If the metric is kWh/TB, then they are both the time based measurement and calculations, and the time period kW and bits are measured across need to be the same.

Past the math, the real issues most operators will face are in gathering the data. Table 15 also shows information on data required and data source for measuring and/or calculating the metrics. In keeping with the them of "staying simple", metrics are produced for both AN's and E&CF's at an individual E&CF location. Required data **per facility** to produce all the metrics is

- Monthly kWh information for the facility (from utility billing information)
- Monthly IT Equipment Power for the facility (measured UPS or DC load)
- Monthly Terabyte throughput information for the facility (obtained from router data with broadcast assumption added)
- Quarterly sum of kWh data for each OSP PS in the access network connected to the facility (from billing info, or measured)
- Linear miles of access network plant, updated yearly (from GIS, maps, etc.)

With just this information, operators can get started with an initial baseline of these metrics, and continually track their metrics for their access network and edge and core facility infrastructure. And with that baseline, as noted above, an operator can start the process of understanding energy performance in AN's and E&CF's. Once initial baselines are set, and AN's and E&CF's ranked with respect to performance, operators can properly target and prioritize resource and capital in line with the access network and facility energy improvement techniques being developed within Energy 2020.

5. Abbreviations and Definitions

5.1. Abbreviations

AN	Access Network
DCeP	Data Center Energy Productivity
E&CF	Edge and Core Facility
$\mathrm{EPCB}_{\mathrm{AN}}$	Access Network Energy per Consumed Byte
$\mathrm{EPCB}_{\mathrm{FAC}}$	Edge and Core Facility Energy per Consumed Byte
Gbps/Tbps	Gigabits per second/Terabits per second
HD	High Definition

HFC	Hybrid Fiber Coax
kWh	kilowatt hour
Mbps	Megabits per second
MSO	Multiple System operators (cable operator)
OSP PS	Outside Plant Power Supply
PM	Preventative Maintenance
PON	Passive Optical Network
PUE	Power Usage Effectiveness
SCTE	Society of Cable Telecommunications Engineers
TB	Terabytes
UPS	Uninterruptable Power Supply
TGG	The Green Grid
W	Watt
WPM	Watts/Mile of Coax Plant

5.2. Definitions

Core Facility	Structures responsible for backbone traffic and edge to edge connectivity of services to large pools of customers
Critical Facility	Any structure that if non-functional, impacts customer experience and would generate greater than 250 calls to call centers
Critical Load	Equipment, if turned off or not operable, greatly impacting customer experience
Customer	Invoiced/complimentary consumer of network service(s)
DC Power Plant	Batteries, rectifiers, charge controllers, power bays, primary and secondary distribution equipment (BDFB/fuses), converters and inverters supporting load.
Downstream	Information flowing from the hub to the user
Edge Facility	Structures servicing neighborhoods where an outage would be contained to a specific pool of customers and not impact greater customer base
Meter	Equipment able to measure amount of power consumed over time
Metric	Mathematical calculation aiding in the intelligent decision making process
Outside Plant	Section of the cable network responsible for connecting facilities to customers as well as facilities to facilities
People Space	Building with primary function enabling people to perform activities such as meetings, calls, computer work, and other non-critical facility activities
Power Distribution	Moving of power in a controlled manner from utility service entry to load
Uninterruptable Power Supply (UPS)	Power protection device helping to prevent equipment power down during primary source of power failure
Upstream	Information flowing from the user to the hub

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Recommended Evaluation Process for Critical Facility Solutions

Determining the Best Solution for Your Needs

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
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1. Introduction

1.1. Executive Summary

In the past few years, there has been a shift in the design and implementation of critical facilities from the traditional “stick-built” or “brick and mortar” approach to alternative methods that include “containerized” or “prefabricated” solutions.

The increasing number of options and choices has created an environment where it is confusing for end-users to decide what is best for their short-term and long-term needs. It is therefore imperative that the definitions mentioned within this document are used in a consistent manner to establish a reliable framework against which end-users can evaluate each option.

This article provides a recommended approach to determining the appropriate needs-based solution and outlines which factors and data should go into making that decision.

1.2. Scope

This document focuses on the decision making process of evaluating solutions for your critical facility’s needs.

The information contained in this article includes:

- Justifications for prefabricated solutions
- Market trend and current product choices in the prefabricated market
- Evaluation process to determine the best solution for your needs
- Guidance on how to make the decision that is right for you

1.3. Benefits

For most customers, planning future growth can be difficult and trying to align the space and infrastructure needs to support that growth can be even more challenging. Unfortunately there is no simple solution that addresses all needs, but there is value in developing a detailed plan, even if it changes.

Each end user must go through the analysis to determine what delivery model best meets their business needs and provides maximum flexibility to respond to changes. There are many benefits of going through a thorough evaluation early in the process.

Proper planning can:

- Avoid unnecessary capital spend on a solution that doesn’t meet the need,
- Allow end-users to develop a realistic strategy for scalable solutions that fit the business,
- Allow for the evaluation and consideration of a broader list of options and solutions,
- Prevent end-users from being swayed by marketing and products that only meet part of their needs.

1.4. Intended Audience

The process and decision criteria for selecting appropriate critical facilities solutions as outlined in this article should be used by owners, operators, service providers, real estate professionals, owner's representatives, and other consultants or professions that analyze or evaluate facility solutions.

1.5. Areas for Further Investigation or to be Added in Future Versions

Financial Analysis of options, scaling, etc.

2. Overview

In the past few years, there has been a shift in the design and implementation of critical facilities from the traditional "stick-built" or "brick and mortar" approach to alternative methods that include "containerized" or "prefabricated" solutions. Part of this shift in the industry is the introduction of various terms – modular, containerized, prefabricated, off-site construction, stick-built – that create confusion in the industry.

To prevent misinterpretation, it is important to consistently use the definitions noted above, and understand that "modular" does not mean "containerized." The terminology can be confusing, and understanding the definitions above will help maintain consistency in the development and evaluation of options.

This demand has been created as the result of changing business requirements, capital planning, and the constant desire for "just in time" delivery. These options are very appealing for some of the following reasons:

- Small scale deployments (500kW and below)
- Compact, High Density Deployments (24kW per rack+)
- Needs for individual components (Racks, Power, or Cooling)
- Quick Deployment

Since the initial introduction of these applications to the market, the increased demand has led to several vendors developing a variety of product offerings. In the past two to three years, these offerings have improved in quality as a result of increased competition and through incorporating lessons learned from early deployments.

During this time, potential buyers have also become more informed and are mandating more stringent building requirements (wind loading, seismic, redundancy, energy efficiency, etc.). Several product offerings have responded to this with products designed and constructed in compliance with international standards, which comply with BSI, ISO, NEC, and IEC, amongst others.

When going through this process the terminology can confuse things, but so can the various product offerings in the market. These alternative construction options have the capability to be a complete solution or only a partial solution to the overall critical facility and our goal is to inform the decision makers.

3. Current Market Offerings

Within the market, there are a variety of product offerings that come in various shapes and sizes. When taking the holistic view of the market, the options for prefabricated, containerized, and modular products typically fall into one of the following categories:

IT or Rack Space Solution: A customized product to address the IT / Rack Space solution.
These are typically modified containers that can be pre-populated with cabinets and sometimes with pre-populated rack-mounted equipment. These options offer a "plug and play" rack space solution that require power and cooling connections from a different source.

Cooling Solution: A customized product containing the HVAC solution.
The cooling solutions could vary, but the typical offering promotes low power usage effectiveness (PUE) through some form of free cooling. Several of these products also include a direct expansion (DX) or chilled water solution for when ambient conditions do not support free cooling.

Power Solution: A customized product containing the electrical infrastructure.
These solutions are not as common as the other products on the market, but this offering may include a pre-fabricated UPS, DC Plant, or electrical distribution offering that can support the critical facility. These offerings can be customized through an end user's specification and require all components to be installed, wired, and tested prior to shipping from the vendor's factory to the end user's site.

Combined Solution: A customized product containing some combination of the above.
These solutions are a combination of the above items. The most typical seem to be a Cooling Solution coupled with some rack space, but no power offering. Other offerings include a complete facility solution, through either an "off-the-shelf" product or a customized solution.

4. How to evaluate what works for you

The most important consideration for any project is ***evaluating an option or solution against your requirements***. The first step is identifying, confirming, and documenting your requirements. Without knowing what you need, you cannot confidently decide what solution works best.

Every end user needs to go through the process of documenting and confirming the internal requirements (location, size, density, life of the facility, growth plans, reliability objectives, efficiency goals, etc.) and then evaluate the options available to meet those requirements. For some customers, this is as simple as a quantity of racks and total IT load, while for others, it may include restrictions on Capital funding over a given time period.

These drivers are the key factors that should be weighed when looking at all of the delivery options — and should, at a minimum, include the following:

- Alignment with the corporate business plan
- Geographic location(s)
- Load Growth Profile
- Day 1 Critical Load
- Master Plan / Scalability (Facility & Capacity Growth Plan)
- Density (W per SF or kW / rack)

- Facility Reliability / Tier Rating
- MEP System Topology
- Schedule / Delivery Timing
- Sustainability
- Energy Efficiency Considerations

Once the requirements are known, the next step is evaluating the solutions that are available - colocation, lease v. own, new development, prefabricated, etc. There are usually several solutions for every project / problem, which is why it's important to define the need before the solutions are considered.

The typical evaluation assesses several key criteria for each solution. Below is an example of the metrics that should be weighed when considering the options:

- Adherence to Requirements
- Ability to support initial needs and long term growth
- Initial Capital Expense (CAPEX)
- Operating Expenses (OPEX)
- Total Cost of Ownership (TCO)
- Project Delivery Schedule
- Project Risks
- Local Market and Market Labor Experience

During this evaluation, the consideration of utilizing a prefabricated solution as compared to a traditional stick-built solution should occur. As you consider options, do not be fooled by terms like "modular" or "scalable." These terms are frequently mistaken for a "containerized" or "prefabricated" solution, which is a misnomer.

Modular and scalable attributes can be incorporated into ANY facility. Both traditional brick and mortar facilities as well as prefabricated solutions can be designed to support modular or scalable growth. The key decision for each customer is how that scalable growth is achieved.

Scalable growth can be within the facility, e.g. adding critical infrastructure components to existing rooms as growth occurs (i.e. UPS modules), OR scalable growth can be a physical expansion of the building shell/footprint. Both are modular and scalable growth attributes. As long as this evaluation is part of the initial requirements gathering process and master plan development, it can be achieved using any of these solutions.

It is important to note that the options analysis should happen prior to any detailed design efforts. It may be advantageous to have your owner's rep/project manager, design team, and engineers engaged for parts of this evaluation, but a decision needs to be made prior to design because the solution will impact the overall delivery method, timing, and contract values for the delivery of the project.

5. Where is the industry going?

The industry is continuously evolving by way of improvements in hardware technology. With each improvement, computing power, equipment efficiency, and required rack space are changing. These changes seem to fuel the ongoing rack density debate and whether 4kW, 6kW, 8kW, 12kW or 24kW per rack is the "right" density for the future data center. It seems like this debate has been underway for over a decade, and the only consistent answer is "it depends;" it depends on your business need.

Over the past 15 years, delivering millions of square feet and hundreds of megawatts of critical facilities both large (20MW) and small (50kW), we have seen that every client needs to find the balance between the cost of building additional space and higher power density based on your defined business needs and growth plans.

In short, the question should be, "where is the dollar threshold when it becomes more economical to build more space and spread the load, versus the cost of high density space?"

The best advice we can give is to remain flexible and plan for flexibility within your facility.

When designing a new facility or selecting an option, plan for changes in density or technology to be feasible in future phases. This approach will allow you to adapt to changes as the industry evolves. The adoption of "containerized" and "prefabricated" solutions can play a role in this long term flexibility approach, but remember the key selection criteria – ***the solution needs to align with your requirements***.

Regardless of the construction method, we are seeing clients trend towards smaller Day 1 facilities that allow scalable growth through additional buildings or building expansions.

As the industry has become more familiar with construction processes and methodologies, the idea of frequent construction initiatives to support the need for capacity growth is no longer the deterrent it may have been ten years ago.

6. How do you choose?

With all of these options and available solutions, how do you choose the best model for your company?

While the industry can't always agree on everything, the one thing it can agree on is that ***your facility solution needs to be scalable and flexible to meet your current needs and long term growth***.

For most customers, planning the future growth can be difficult or impossible, so in these cases the best plan for growth is the ability to add or expand the facility. Be smart with your site selection and design to ensure this future growth can be achieved with minimal impact to the online systems. The industry is getting more comfortable with construction methodologies, so the process of going through building expansions and upgrades should not be a deterrent, but these expansions do need to be carefully considered during the "Day 1" design.

Unfortunately, there is no simple solution. ***Each end user needs to go through the analysis and evaluation process to determine what the right model is for their company's business need.***

When going through the evaluation, do not be fooled by good marketing. The vendors providing offerings in the prefabricated markets are pushing schedule and improved "speed to market" as a key benefit. While these solutions can be fabricated in 16 to 20 weeks (depending on size), these lead times are based on a pre-engineered product. ***This is not a customized solution.***

Any custom solution will require a design phase in advance of fabrication or construction which should be accounted for in the evaluation. Customization requires the design and development of shop drawings to ensure that the proposed product meets your specifications and requirements.

7. Guidance

The decision on type of facility and delivery approach is a complicated one, and there isn't a single answer for the entire industry or for a given company. Each decision must be based on the requirements and needs of that specific scenario.

> ***Products v. Custom Solutions* -** Too often the focus is on speed to market, which forces a specific solution for a client when proper planning could have expanded the list of available options. If you take the time to plan for growth (new buildings, building expansions, facility / site master plans, capital planning processes, due diligence, site assessments, etc.), the ability to react and execute projects using any methodology becomes much easier and you won't need to "settle" for something less than your business needs require.
>
> ***Know what you want*** – Don't look for the vendors to define your need. Take the time upfront with your internal stakeholders to define your requirements. The format doesn't matter as much as the fact that it's documented to support the evaluation process and to support any RFPs necessary to engage vendors.
>
> ***Alignment to your requirements*** – Know the difference between a pre-made product being offered by a vendor and a customized solution. If you are buying something that is "off the shelf" and "readily available" then it will likely not be customized to your request or meet all of your specific business requirements. Make sure you understand and agree that meeting some of your requirements (not all) is acceptable and make an informed decision before compromising.
>
> ***Know what you're getting* –** Another key step in this process is know what you are getting. The prefabricated solutions are most often not complete solutions. These packages or products do not include site work, permitting, utility coordination, etc. and in some cases could exclude other components of the complete facility. It's important to understand what scope is being procured with a product and what you will need to procure through other means. This can be a planned "plug and play" solution, but you need to plan for, and articulate, the complete solution.
>
> ***Delivery Schedules & Critical Path*** – While most products offer fast speed to market solutions, it is important to understand what the critical path is for the project. This will vary if all you need is a container with racks v. a complete new facility. If you are delivering a complete facility don't forget permitting, utility requirements, and equipment lead times. All of these items will likely take longer than a prefabricated solution, so make sure you understand what the critical path is and whether or not those speed to market offerings are really helping you.
>
> ***Ask for help*** – There are plenty of operators across the industry that have gone through this process, and don't be afraid to ask around the industry or engage professional services (owner's representative, project management, MEP engineering, etc.) to assist with the evaluation. Whether this is part of the upfront due diligence on a major project or a short term engagement to focus on your solution, there are resources available to help.

While we wish there was a single solution for all our needs and problems, there clearly is not. Every opportunity has a variety of solutions that can work, and deciding which one is the "right" solution is always a process and sometimes a negotiation.

Know what you want and need, and don't settle for less. Be skeptical and ask the tough questions. As a general rule, any solution that is expected to be customized to your needs will require a design phase to allow for that customization.

Be diligent in your evaluations. Establish your strategy considering location, size, density, growth plans, flexibility needs, reliability objectives and efficiency goals. Align yourself with a good partners and consider all options before making a decision.

8. Abbreviations and Definitions

8.1. Abbreviations

AHJ	Authority Having Jurisdiction
BMS	Building Management System
BSI	British Standards Institute
DC	direct current
DX	direct expansion
EPMS	Electrical Power Monitoring Systems
HVAC	Heating, Ventilation, Air Conditioning
IEC	International Electro-technical Commission
ISO	International Organization for Standardization
IT	information technology
kW	kilowatt
NEC	National Electric Code
PUE	power usage effectiveness
SCTE	Society of Cable Telecommunications Engineers
SF	Square feet
UPS	uninterrupted power supply

8.2. Definitions

Critical Facilities	Any structure, equipment or system whose failure or disruption will cause a failure in business operations
containerized	Applies to a critical system or facility built offsite within a container (ISO or non ISO)
modular	The design approach to allow for a site or facility to be constructed in multiple, predefined assemblies. This approach may apply to either traditional construction methods or any of the alternate methods mentioned herein
Off-site	Applies to the construction process done entirely or largely within a manufacturing facility independent from the location of deployment or use
prefabricated	applies to the construction process done entirely or largely off-site; that is, built off-site and then reassembled on-site
PUE	the ratio of total amount of energy used by a computer data center facility to the energy delivered to computing equipment
scalable	Refers to the ability of a design to easily flex (expand or contract) in physical size

	or capacity
stick-built	applies to the construction process where components are erected and installed onsite

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New A/C System Architecture Promises Significant ROI in Data Centers

Floating Head Pressure Technology Reduces Energy Costs and Consumption

A Technical Paper Prepared for
the Society of Cable Telecommunications Engineers
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Table of Contents

1. Introduction

1.1. Executive Summary

This paper explores the energy savings data centers can achieve by switching their air conditioning system architecture from fixed head pressure to floating head pressure technology. Included is an explanation of why floating head pressure technology is more economically and environmentally feasible, and a case study focused on a full-service electrical contractor in Ontario, Canada, that specializes in mission-critical applications such as data centers.

1.2. Scope

Applies to high-density computing environments where precise air temperature, circulation and humidity is critical to daily operations.

1.3. Benefits

Floating head pressure is a more modern, sophisticated climate-control technology that reduces energy consumption in air conditioning system architectures. This technology offers long-term savings benefits as well more operational reliability because of its ability to adapt to ambient temperatures and regulate condensing temperatures accordingly. This would have tremendous impact on energy savings and efficiency in data centers.

1.4. Intended Audience

Data center facility managers and operators.

1.5. Areas for Further Investigation or to be Added in Future Versions

After changing to floating head pressure technology, how much energy savings took place after one year, three years, etc. as well as how few compressors need replaced.

2. New A/C System Architecture Promises Significant ROI In Data Centers

Computer room air conditioning (CRAC) units play an invaluable role in data centers, maintaining precise air temperature, circulation and humidity in high-density computing environments. While these CRAC units have evolved with ever more sophisticated climate control techniques, most legacy units rely on a relatively unsophisticated air conditioning (A/C) strategy of operating at a high fixed condensing pressure.

Fixed condensing refers to the practice of maintaining condensing pressures corresponding to 105 °F at all times. Also referred to as *fixed head pressure* in refrigeration and A/C systems, this common configuration sizes the system to maintain refrigeration on the hottest days of the year. Because of this, fixing the head pressure forces the compressor to run at high horsepower, even when the ambient temperature is well below design conditions for the majority of the year. For a quick mechanical analogy, the concept is similar to revving your car to 7,000 RPMs at all times, even when idling or when not necessary.

But with recent advances in refrigeration and A/C system technologies, data center operators now have an alternative cooling technology for their CRAC units — move from a fixed head pressure system to one that's capable of modulating (or "floating") its head pressures in unison with the changing ambient temperature. Because condensing temperatures are allowed to float down with the ambient temperatures — as low as 70–80 °F – this technique is also referred to as *low condensing operation* or *floating the head pressure*.

In industrial and commercial refrigeration systems, the practice of floating the head pressure has been widely adopted — even regulated in certain environmentally conscious regions in North America — to help reduce energy consumption. For these facility managers, reduced energy consumption translates directly into energy savings, typically as much as 20 percent — sometimes even more.

By using a floating head A/C system, this savings potential is now well within the typical data center operator's reach. And with utility and regulatory incentives to help offset first costs, ROI can be achieved in surprisingly short order.

Bob and Ryann Burton, mechanical systems manager and field service manager, respectively, at EA Group in Ontario, Canada, have seen firsthand how floating head pressures can provide significant energy savings in data centers. EA Group is a full-service electrical contractor that specializes in mission-critical applications such as data centers. When Ryann recently headed up a team that piloted a floating head system in a large data center in Ontario, the results were undeniable.

"By meeting our proposed 20 percent energy reduction objective, we qualified our customer for a 50 percent rebate on the cost of the installation," explained Burton. "With the incentive program funded by the Ontario Power Authority and the energy savings, the customer achieved system payback in less than one year," he said. Burton added that carbon footprint reduction and improvements in power usage effectiveness (PUE) were also significant additional benefits. For complete details of the installation, see the *Data Center Case Study* section of this article.

Aside from this being a completely new technology in data centers, another possible reason for floating head pressure's slow adoption rate is the perceived potential for A/C system failure and related consequences. There's a lot at stake for data center operators, namely millions of dollars in computing equipment and sensitive end user data that's even more difficult to put a dollar value on. For floating head pressure A/C systems to be a viable option in data centers, ensuring reliable operation will be extremely important.

But by relying on the expertise of technicians who are now specializing in this technology, some data center operators are seeing the value in transitioning their CRAC units to a floating head pressure configuration. What may make this even more appealing to operators is the fact that their existing systems can be retrofitted to exploit this new technology, thereby lowering the barrier to entry.

2.1. Floating Head Pressure - Definitions and History

Floating head pressure operation refers to the practice of varying the condensing pressure (or floating the head) in unison with fluctuations in ambient temperatures. In a modern floating head system, head pressure is controlled by varying the speed of the condenser fan motors in an effort to operate at the minimum condensing pressure for as long as ambient will permit. The second key component is an electronic expansion (EX) valve that manages the state of the refrigerant at the evaporator.

Technicians designate a minimum saturated condensing temperature (SCT) to establish the lowest point at which the system is able to operate effectively. For example, in data center CRAC units, the SCT is typically 80 °F. As the ambient temperature falls in a floating head system, the head pressure will float down with it until it reaches the 80 °F minimum SCT. From a retrofit point of view, any time a system is permitted to operate below its traditional 105 °F SCT set point, energy savings will result.

Traditional refrigeration and A/C systems were designed to artificially keep fixed head pressures high all year long, usually at 105 °F condensing temperature. The architecture of these systems is based in large part on the use of mechanical thermostatic expansion (TX) valves that control the refrigerant flow into the evaporator.

Decades ago, the concept of low condensing operation was introduced using TX valves and the technology of the day. Due to the limitations of the TX valve, these first floating head systems were fraught with issues. As ambient temperatures and head pressure floated lower, the system struggled to maintain capacity and digest the flash gas (bubbles) that formed in the refrigerant. The flash gas ultimately choked the TX valve, and it was unable to produce the necessary volume.

As a workaround to these limitations, technicians added mechanical heat exchangers, liquid pressure amplification pumps and sub-cooling loops to help control flash gas. Since these systems were difficult to maintain, most operators saw these measures as excessive and opted to bring the head pressures back up to a fixed set point.

To this day, the majority of refrigeration and A/C systems in North America rely on high fixed head pressures near 105 °F. Until very recently, technology did not exist that would enable operators to float their system head pressures down to a much lower condensing temperature (70 °F in refrigeration, 80 °F in A/C systems) without sacrificing reliability.

2.2. Technological Evolution Enables Wider Adoption and Real Energy Savings

Today’s emphasis on energy efficiency has prompted refrigeration and A/C equipment manufacturers to develop EX valves and system technology that supports a wider range of condensing pressures. This option is available not only for new systems, but also for retrofits into existing systems with fixed, variable speed or digital compressors.

Unlike the mechanical TX valves used in fixed head pressure architecture, EX valves enable low condensing systems to digest flash gas as the head pressure floats with falling ambient temperatures. Certain EX valves can easily transition through capacity ranges by modulating from 10 to 100 percent in a linear, stepped fashion.

When the condensing head pressure drops with the falling ambient temperature, compressor wattage decreases, and compressor capacity (BTU/hr) increases. Because of the increased capacity, compressor runtime hours are significantly reduced, and compressor lifecycle and reliability are greatly improved.

As the ambient temperatures drop, operators will find an increasing opportunity for energy savings. Typical systems can achieve 15–20 percent energy efficiency ratio (EER) improvements on the compressor for every 10 °F decrease in head pressures.

Below 50 °F ambient typically represents the temperature at which the maximum savings from low condensing operation can be achieved. However, since traditional fixed head pressure systems run at a condensing temperature of 105 °F, the savings potential for low condensing systems exists whenever the ambient temperature is 75 °F (see Figure 1).

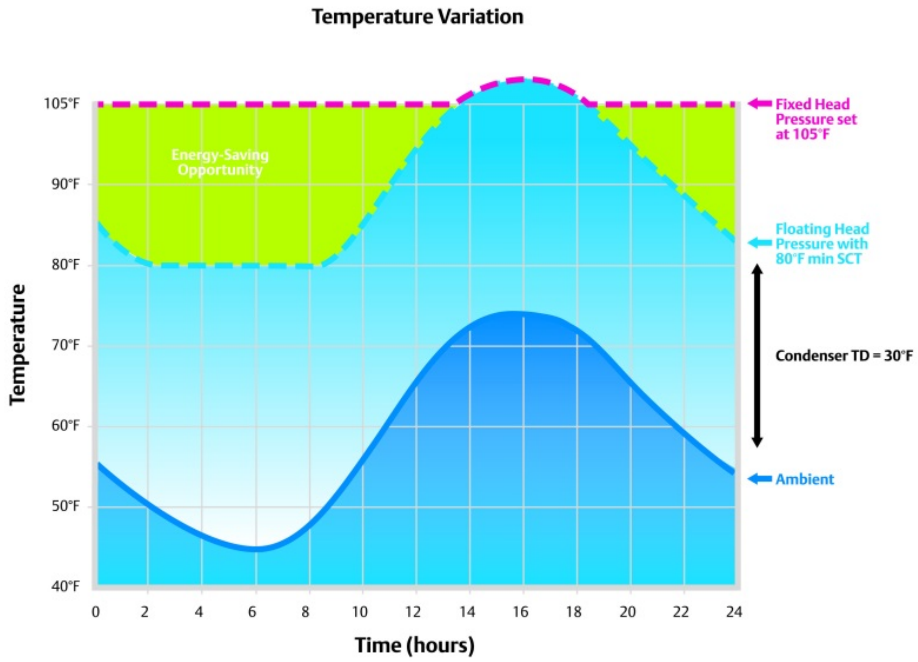


Figure 1 - Comparing fixed head pressure operation (dotted red line) with floating head pressures (dotted blue line); the area shaded green shows the energy-saving opportunity in a 24-hour period.

In Canada and parts of the northern U.S., the ambient temperature is 50 °F or below for 63 percent of the year. In the central part of the U.S., the temperature is below 50 °F for 50 percent of the calendar year. Even in the southern tip of Florida, the ambient temperature is below 50 °F for 10 percent of the year. This means that North American data center operators who would allow their system head pressures to float have opportunities to achieve real savings (see Figure 2).

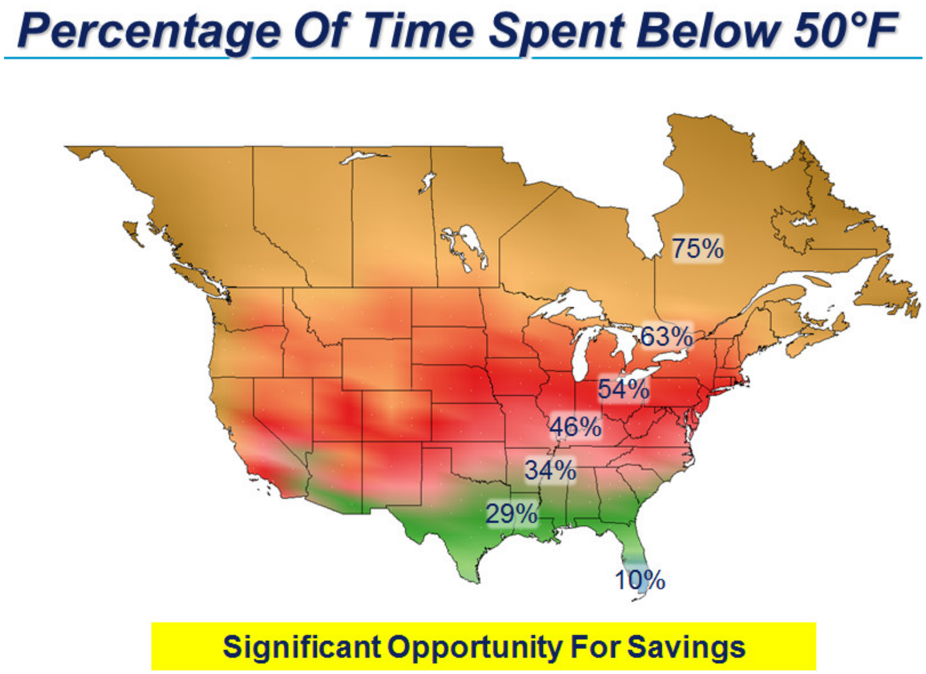


Figure 2 - When temperatures are at or below 50 °F, A/C systems can capitalize on floating the head pressure. There are significant savings opportunities in North America.

2.3. Sidebar: Data Center Case Study

In recent years, EA Group and Emerson Climate Technologies partnered to develop a floating head pressure strategy for a large co-location data center site in Ontario, Canada. Relying on Emerson's EX valve technology and EA Group's expertise in data center climate control, the team evaluated the site's existing CRAC units and went to work on devising an energy-efficient retrofit solution.

According to EA Group's project leader, Ryann Burton, the retrofit strategy utilized the data center's existing 30-ton, air-cooled CRAC units that were configured to run at a fixed head pressure control set at a minimum SCT of 105 °F. And even though floating head pressure had been used effectively in refrigeration, Burton knew that the data center environment was less forgiving.

"It's a very critical environment, more so than in refrigeration, because of the intense heat load in these large data centers," said Burton. "In this very high-density computing scenario, it's not unusual to have 150 tons of cooling running in 5,000 square feet. This leaves little to no room for error."

The team started with a software analysis that calculated the existing and potential energy efficiency of the data center's CRAC units. They factored in the unit compressor type and current energy cost per kW hours, and then developed a business case that proposed 20 percent annualized energy savings.

The co-location site agreed to a pilot test on one of the CRAC units. First, Burton's team measured and verified two identical units side by side for one month to establish baseline power consumption. Then, they retrofitted one of the units with a floating head system, dropping the head pressure from 105 °F condensing to a minimum SCT of 80 °F. Burton said that after one year of pilot testing, where both units ran side by side at the same workload, the results were verified by a third party — and were conclusive.

"While we forecasted 20 percent energy efficiency savings on the floating head retrofit system, we actually saw 23 percent savings after the first year," said Burton, adding, "On these 30-ton CRAC units, the savings equated to a more than 1,000 kW/hr per week reduction."

The verified results made the data center eligible for an incentive program from the Ontario Power Authority (OPA), which offered a 50 percent rebate on the cost of all new floating head equipment and installation costs.

For the data center's operators, the combination of the successful pilot and the funding made available by the OPA's incentive program made a convincing business case for floating head pressure systems. Soon after, they began the process of converting additional CRAC units, 30 at a time. To date, the data center has converted more than 100 CRAC units, and has received nearly $400,000 in governmental incentives. And, they're achieving ROI on each unit in just one year based on utility rates in Ontario.

Burton said that another unexpected benefit to the conversion was extending the lifecycle of the compressors in the retrofitted systems.

"Because they run at lower head pressures, there's less wear and tear on the machines," said Burton. "We're actually retrofitting 15 to 20 year old machines, but because now these machines are running so efficiently and reliably, they're going to be in use for five to ten more years," he added.

In addition to extended compressor life, compressor capacity is also increased. Each 30-ton machine picked up 10 percent more capacity when operating at 80 °F minimum condensing, (63 percent of the year or 5,524 hours, in the Toronto area) as the result of the retrofit, essentially improving from 30 tons to 33 tons of capacity. "What this means in a computer room, is that in a block of 10 CRACs, you've just picked up another 30-ton machine," said Burton. The increased capacity is a direct result of the floating head system's ability to improve the net refrigeration effect. "When we bring liquid back from the condenser at 80 °F condensing temperature, we actually pick up more refrigeration effect," said Burton.

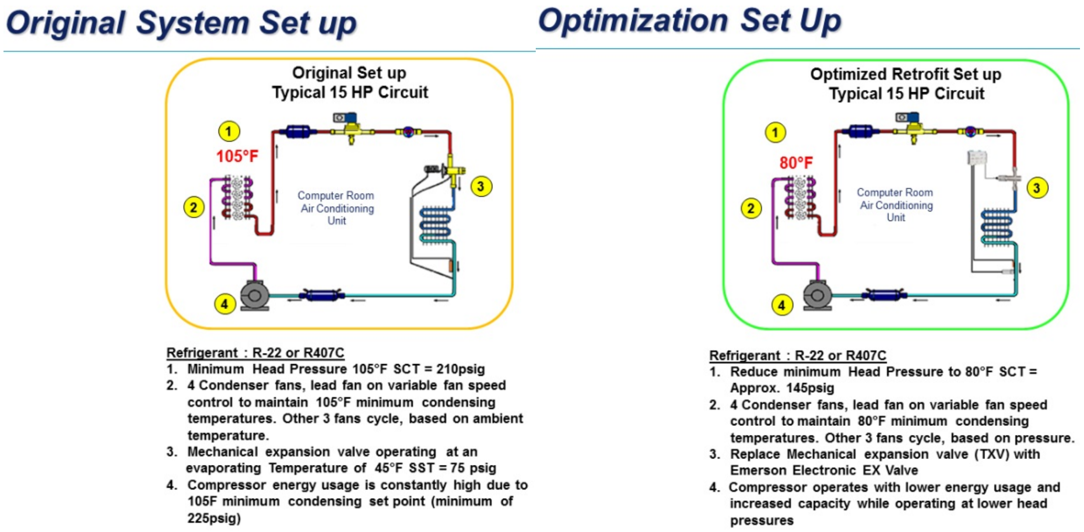
2.4. At a Glance: Floating Head Pressure Benefits

- Lowers energy consumption and costs
- Increases compressor A/C tonnage capacity
- Extends compressor and system life through reduction in compression ratios and cycles
- Improves sustainability (refrigerant reduction and lower energy consumption)
- Improves facility PUE
- Maintenance cost reduction due to reduced wear
- Prevents compressor failure due to flooding
- Utility incentives/rebates to upgrade system

2.5. The Mechanics of an Electronic Retrofit

To convert legacy A/C systems from fixed condensing to floating head pressure operation, field technicians had to follow a very specific set of procedures. The floating head retrofit is a standalone solution that doesn't interfere with the legacy system's controls, programs or safety measures.

- *EX valve* — Legacy mechanical expansion valves were replaced by Emerson's EX valve. This allows the head to float safely through precise control of superheat and prevents liquid refrigerant flood-back to the compressor.
- *Electronic controller* — Installed on the A/C unit, the controller communicates only with the EX valve and not the unit itself.
- *Variable speed drive fan* — At the condenser, fan cycling is reconfigured with a variable speed drive fan and other fans (as well as a pressure transducer and temperature sensors) to control 80 °F condensing.
- See Figure 3.



Refrigerant : R-22 or R407C
1. Minimum Head Pressure 105°F SCT = 210psig
2. 4 Condenser fans, lead fan on variable fan speed control to maintain 105°F minimum condensing temperatures. Other 3 fans cycle, based on ambient temperature.
3. Mechanical expansion valve operating at an evaporating Temperature of 45°F SST = 75 psig
4. Compressor energy usage is constantly high due to 105F minimum condensing set point (minimum of 225psig)

Refrigerant : R-22 or R407C
1. Reduce minimum Head Pressure to 80°F SCT = Approx. 145psig
2. 4 Condenser fans, lead fan on variable fan speed control to maintain 80°F minimum condensing temperatures. Other 3 fans cycle, based on pressure.
3. Replace Mechanical expansion valve (TXV) with Emerson Electronic EX Valve
4. Compressor operates with lower energy usage and increased capacity while operating at lower head pressures

Figure 3 - Comparison of system configurations based on a typical 15 HP circuit on a 30-ton CRAC. Savings with floating head retrofit was $6,497 per CRAC per year.

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2.6. Caveat: Data Center Expertise Required

Maintaining equipment and information integrity in high-density data center environments requires considerable expertise. While the idea of introducing a floating head configuration on legacy A/C systems to save on energy costs is appealing, changes of this magnitude should not be attempted without careful, deliberate consideration and extensive research. Since this a relatively new technology in data centers, operators should only consult with contractors who have done their homework on floating head pressure and its implications to data center applications.

But in the hands of skilled technicians, floating the head pressure in data center A/C units represents a tremendous opportunity to cut energy costs, extend equipment lifecycles and improve compressor capacity. And if utility incentives can also help shorten the return on investment, then the prospect of moving to a floating head system configuration will only become more appealing.

3. Conclusions

Floating head pressure technology has been widely adopted across a variety of industries, and has the potential to modernize A/C system architecture in data centers. However, since this technology is relatively new to data center applications, operators need skilled contractors for consultation and implementation. This technology offers great benefits to the end user: energy costs can be reduced; equipment lifecycles can be prolonged; compressor capacity can be improved; and users may be eligible for government and/or utility incentives to help accelerate ROI.

4. Abbreviations

CRAC	computer room air conditioning
A/C	air conditioning
PUE	power usage effectiveness
EX	electronic expansion
SCT	saturated condensing temperature
TX	thermostatic expansion
EER	energy efficiency ratio
OPA	Ontario Power Authority

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Greenfield 380VDC Deployment in a Broadband Service Provider Critical Facility: Cost Study

An Operational Practice Prepared for
the Society of Cable Telecommunications Engineers
By

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Title **Page Number**

1. Introduction

Target audience:

Critical infrastructure engineering, power distribution planning and operations teams, design and construction teams, energy and sustainability teams, network engineering, business management, financial managers, budget coordinators, technical operations, and corporate real-estate.

What is this cost study?

This document is a study identifying the benefits (impact) of deploying 380VDC vs 48VDC in a Broadband Service Provider critical facility. The methodology was to identify a sample site and compare pricing of the 48VDC and 380VDC solutions based on quotes obtained from equipment suppliers and installation contractors.

What is the function of this cost study?

This document is a cost study focused only on new Greenfield deployments, not existing sites. This is a basic comparative cost study and is not a full business case. It is intended to provide guidance in creating a business case for a particular site.

What are the immediate and long-term benefits of adopting 380VDC?

- This study is a document that outlines what higher voltage is, (380VDC to be specific) and how green field application can address growing space and costs challenges
- Cable operator facility planners, managers and engineers can use this cost study as a basic reference when considering greenfield or brownfield expansion utilizing 380VDC deployments.
- 380VDC is globally recognized as the primary facility distributed voltage, and many alternative energy and energy storage system supporting 380 V direct current as a deployed viable and available cost saver in other industries such as data center and telecommunications.

How does 380VDC impact the industry and fit into Cable's Energy 2020 roadmap?

- Onsite local generation for critical facilities based on efficient distribution models such as the proposed 380VDC helps to facilitate the new distributed energy generation models such as solar, fuel cell and micro turbine.
- Increased energy savings & return on investment, and operational efficiency.
- Simplify and expedite the selection process when evaluating installation options at greenfield and validate the deployment of 380VDC for broadband service provider's critical facilities.

What are some of the key provisions of this cost study?

- 380VDC operates with several benefits over 48VDC including: significant reduction of copper leading to simpler connectivity, and reduction in distribution losses thus improves cooling, and improved energy efficiency.
- Another advantage of the 380 approach is its ability to facilitate integration of non-grid power sources such as fuel cells and solar photovoltaic systems.
- Fairly compare and contrast the build of materials and costs associated with both 380 and 48VDC.

What can you do to achieve maximum benefit from implementing 380VDC?

- Make impactful decisions on what power distribution infrastructure design to implement and what type of facility is most applicable in order to meet SCTE Energy 2020 goals.
- Justify the deployment of 380VDC in greenfield broadband critical facilities.
- Cost avoidance in selecting the best model based on improved connectivity and ease of expansion for a broadband service provider's critical facility power distribution system.

1.1. Executive Summary

Energy 2020 has established various goals in response to the changing energy climate and cable industry trends. Within SCTE documents there have been estimates of the cable industry electric spend growing from approximately one billion dollars per year to as much as four billion. Energy 2020 goals include reducing grid dependency by 10%. Additional information shows that between 73 and 83% of the power consumed is at the edge in hubs and headends and the access network power supplies. To meet these aggressive and necessary goals will require efficiency optimization and the inclusion of onsite generation, in our 24x7 mode of operation. With these goals in mind the role of direct current, especially 380 V is well suited in local generation. 380 V must be seriously considered as a distribution voltage in cable facilities.

Cable operator's technology has changed greatly in the last ten years. The lines are lines that continue to blur between what has been traditional cable TV service facility and a modern day data center. With this evolution comes opportunity for new engineering for the foundation of all service: power and its distribution. This study is a document that outlines what is 380VDC and how green field application can address growing space and costs challenges.

With recent history demonstrating new challenges such as regulation by the EPA and climate demands, the amount of available utility power may be a challenge. Onsite local generation for critical facilities based on efficient distribution models such as the proposed 380VDC helps expedite the new distributed energy generation models such as solar, fuel cell and micro turbine.

When distributed generation and its application are considered we should look at Europe and Asia since they are years ahead of the US implementation of microgrids. 380VDC operates with several benefits over 48VDC including: significant reduction of copper leading to simpler connectivity, and reduction in distribution losses thus improves cooling. 380VDC is globally recognized as the primary facility distributed voltage, and many alternative energy and energy storage system support 380 V direct current. Many alternate energy systems such as solar, fuel cells and micro turbines support 380VDC.

Those industries that consider their operations as mission critical, such as communication companies, need to look not only at efficiency gains but also need to look at the reliability of the power source/s and interconnectivity of local sources of power.

Economic cost comparisons will vary widely because of network topologies that drive the equipment deployment in headends, hub sites and data centers. However, there are some basic cost comparisons that can be performed as simple paper analysis to highlight physical differences in power distribution infrastructure for a -48VDC plant versus -380VDC deployment. The initial analysis is the significant differences in the required copper cable content and much higher scalability and connectivity of 380VDC distribution. Cable operator headend planners, managers and engineers can use this cost study as a reference when considering utilizing 380VDC deployment.

1.2. Scope and Methodology

A typical site layout was utilized for comparison purposes (refer to load Table 1- and general layout Figure 2). This or similar type of site was and is being deployed today by some cable providers. 48VDC and 380VDC infrastructure costs were derived from quotations obtained for this cost study and are based industry standards. To simplify comparison, 380VDC equipment was selected to closely emulate 48VDC quoted components rather than optimizing for site geography. Busway was selected as the means of 380VDC distribution in lieu of discrete wiring as it is simpler to install and provides for easy, no added labor cost extension to full capacity in the future.

Power requirements were determined by evaluating a site's typical -48VDC equipment loads. The figure below illustrates the quantity and number of devices along with their circuit requirements and characteristic load. Utilizing the known -48VDC equipment and site power requirement, an equivalent profile was estimated for a 380VDC site.

While 380VDC power supplies availability is increasing, not all devices are currently available with this option. This comparison is based on the assumption that 380VDC power supplies are available for all devices. In current application, converters may be required which could alter the sites overall power efficiency and increase cost. See Table 1.

Table 1 - Equipment Load Calculation

Equipment Load Calculation

Device	Qty	Circuit Size	Circuit Qty		Equipment Load (W)	Total Load (W)
			(A)	(B)		
Edge Router	2	60A	4	4	3600	7200
Multiservice Optical Network	1	30A	1	1	960	960
Network Switch	1	60A	8	8	9360	9360
Service Aggregation Router	2	60A	8	8	1680	3360
Broadband Router	2	60A	1	1	2160	4320
RF Gateway	2	60A	2	2	1680	3360

Site Load	**28.56 kW**

1.3. Benefits

Awareness of the application of 380VDC and how green field application can address growing space and cost challenges are highlighted in this cost study. The study will also aid in the expediting of the process to evaluate power distribution options when constructing new facilities. Finally, a baseline of a sample build of materials can be used as a reference point when constructing or planning a new critical facility.

1.4. Intended Audience

Critical infrastructure engineering, power distribution planning and operations teams, design and construction teams, energy and sustainability teams, network engineering, business management, financial managers, budget coordinators, technical operations, and corporate real-estate can all benefit from reviewing this study.

1.5. Areas for Further Investigation or to be Added in Future Versions

The following list of exclusions in this study can serve as a reference for future publications. This cost study will only apply to new Greenfield deployments, not existing sites. It will not include any building costs such as roof reinforcing or costs related to cooling equipment. It does not consider equipment that is not rated at 380Volts DC. The costs of the coordination study and arc flash study is not included as these will vary by the AC/DC design details. This is a comparative cost study and is not a full business case. It is intended to provide guidance in creating a business case for a particular site. Detailed comparison is recommended for each specific deployment case due to high sensitivity of the results to site geography, type of the powered equipment, scalability and connectivity requirements. Energy incentives and rebates are not included because these will vary locally.

2. 380VDC Introduction

Cable facility power distribution models over the past several years have evolved to include AC as well as DC power. The equipment that cable operators deploy depend on DC power at the silicon level to enable our products and services. New thinking in DC power distribution, namely 380VDC has become an excellent resource for data center architects to simplify power distribution architecture. End to end power distribution in a traditional AC based facility is typically the following: 1. AC utility power converted to DC within the DC plant to interface with batteries, 2. Converted back to AC for distribution to racks (often including an additional step down to a lower voltage), and finally 3. Converted back to DC by equipment power supplies. In comparison, a DC distribution architecture converts AC power to DC power within the DC plant, and distributes DC to the equipment loads. The 380VDC distribution approach keeps the power in a state closer to what the equipment needs to complete its given function. See Figure 1.

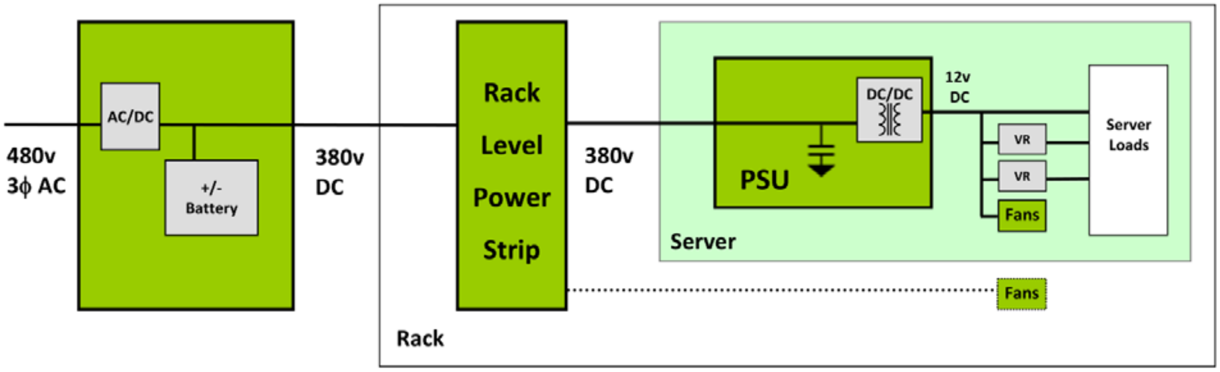


Figure 1 - 380VDC Architecture

3. Financials

The following paper study was conducted to demonstrate the possible financial implications of selecting 380VDC power distribution.

3.1. MODEL: 380VDC Greenfield Statement/Scope of Work

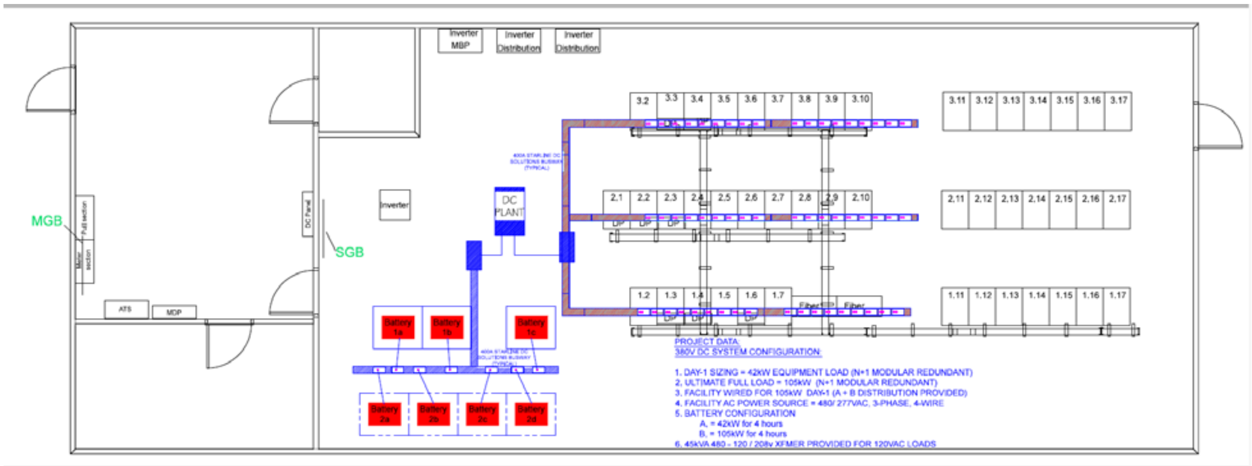
Research and pricing has been conducted that outlines what a 380 volt infrastructure build would include:

- Install a new 380VDC power plant.
- Install 3-cabinets of batteries each with 100 amp battery disconnect provided internal to battery cabinet. Each cabinet is equipped with 28 strings of front terminal batteries.
- Install busway (rated 400a up to 600v dc) – (2 busway runs; battery plant busway and distribution busway)
- Install cables/feeders from battery busway to DC power plant and from DC power plant to distribution busway; rated 400a each; 3-wire feeders (+ , - , Ground) (2 – 500 kcmil + #3awg ground cables)
- Install 1- ¼” X 4” X 48” copper bar for a SGB in the DC power area.
- Install support brackets between the MGB to the SGB for 750mcm cable.
- Install 1- 750mcm green cable from the MGB to the SGB. (25’)
- Install 1- 750mcm green cable from the SGB to the DC power plant for a reference ground. (18’)
- Install 1- 2/0mcm green cable from the SGB to above the DC power plant, Batteries.
- Install busway plug-in circuit drops, in-rack pdu’s and jumper cords to each load.

The sample provided labor cost was $35,440 and materials $8,085 to complete the job that totaled $43,525.

3.2. Engineering Description: 380V

In Figure 2, the engineering draft was used as the basis of materials and construction.



PROJECT DATA:
380V DC SYSTEM CONFIGURATION:

1. DAY-1 SIZING = 42kW EQUIPMENT LOAD (N+1 MODULAR REDUNDANT)
2. ULTIMATE FULL LOAD = 105kW (N+1 MODULAR REDUNDANT)
3. FACILITY WIRED FOR 105kW DAY-1 (A + B DISTRIBUTION PROVIDED)
4. FACILITY AC POWER SOURCE = 480/ 277VAC, 3-PHASE, 4-WIRE
5. BATTERY CONFIGURATION
    A. = 42kW for 4 hours
    B. = 105kW for 4 hours
6. 45kVA 480 - 120 / 208v XFMER PROVIDED FOR 120VAC LOADS

Figure 2 - 380VDC Study Configuration

3.2.1. System Ratings

- Ultimate rating 120 kW ,105 kW n+1
- Initial rating 45 kW n+1 , expandable in 15kW modules
- Input voltage 480 VAC, 3 phase + ground (4 wire)
- Batteries – 4 hour back-up (cabinetized), initially 3 cabinets , ultimately 7 cabinets

For this site a busway distribution was selected for flexibility and ease of future expansion.

3.2.2. Distribution to Equipment Racks

The busway is rated for the ultimate rating of the facility from day one (400A). The overhead busway is provided on top of the equipment racks as shown in Figure 2. The busway contains provisions for A+B distribution. Distribution to individual racks is via busway plug-ins containing circuit breakers via connectorized cables. The drops can be installed live and are located directly above the served rack. One plug –in services A side and the other B side of internal rack distribution. Internal rack distribution consists of power strips with receptacles. Serviced equipment (load) can be hot plugged into the strip. This type of distribution provides the following benefits:

- One time installation, no need for additional wiring during future expansion
- Allows flexibility in selecting/ changing rack densities and loads without additional wiring
- Totally plug and play concept allows safe and easy expansion in terms of adding racks, modification of racks content without system shutdown

3.2.3. Batteries and Battery Distribution

Batteries are mounted in cabinets each containing a circuit breaker. Overhead busway serves as a collector bus. The busway can accommodate up to 7 cabinets for ultimate site rating, 3 cabinets are supplied day one. Each cabinet is wired to busway via a plug-in containing a circuit breaker. This arrangement allows addition of the future cabinets without system shutdown and extensive wiring additions.

3.2.4. General Notes

The above described distribution was selected in this study due to its flexibility. Other distribution arrangements can be provided, i.e. fixed wiring in connection with distribution cabinets. It is anticipated that such fixed distribution would be less expensive, but would not offer the ultimate flexibility.

3.3. Equipment Estimate: 380VDC

The following materials were scoped out for the above proposed installation:

Table 2 - 380VDC Equipment Estimate

DC System			
1		DC Power System w/Rectifiers	120kW DC power system 60kW total rectification (rectifier modules are 15kW equipped with 4 rectifiers)
4		DC Plant Breakers (distribution feed)	2 - 400A Breakers
Distribution			
1		Distribution Busway	400A distribution busway with A+B distribution paths
16		Busway Drops	30A','no'metering
16		Power strips	24 plugs
Batteries			
1		Battery Busway	400A battery busway
3		Batteries Cabinets	

The total equipment cost for overall is $132,500

3.4. MODEL: 48VDC Greenfield Statement/Scope of Work

Research and pricing has been conducted that outlines what a 48 volt infrastructure build would include:

- Install a 48VDC Power Plant
- Install 2 strings of 1500Ah batteries including battery containment and battery disconnect
- Install 2 dual load BDFB's
- Install 7 Distribution panels with frame grounds into existing racks
- Provide and install a 750 MCM green from the existing MGB to the new power plant (18')
- Provide and install a 2/0 green from the existing MGB to above the new power plant and batteries for frame grounds and tap to each
- Provide and install a 2/0 main aisle ground to above all equipment racks and tap for rack grounds
- Provide and install approx. 125' of 2"x15" grey cable rack to support DC power cable installation
- Provide and install the following DC cabling:
- 750 MCM per polarity per load (2 circuits) from the power plant to BDFB #1 (35' one way)
- 750 MCM per polarity per load (2 circuits) from the power plant to BDFB #2 (35' one way)
- MCM per polarity from the power plant to battery string #1 (25' one way)
- 750 MCM per polarity from the power plant to battery string #2 (25' one way)
- 4/0 per polarity per load from BDFB's to each of 7 Distribution panels (25' one way)
- 72A and 72B circuits of #6 from Distribution panels to equipment (10' one way)

The sample provided installation labor cost was $43,670 and materials $39,075 to complete the job that totaled $82,745.

3.5. Engineering Description: 48VDC

The following engineering draft Figure 3 was used as the basis of materials and construction.

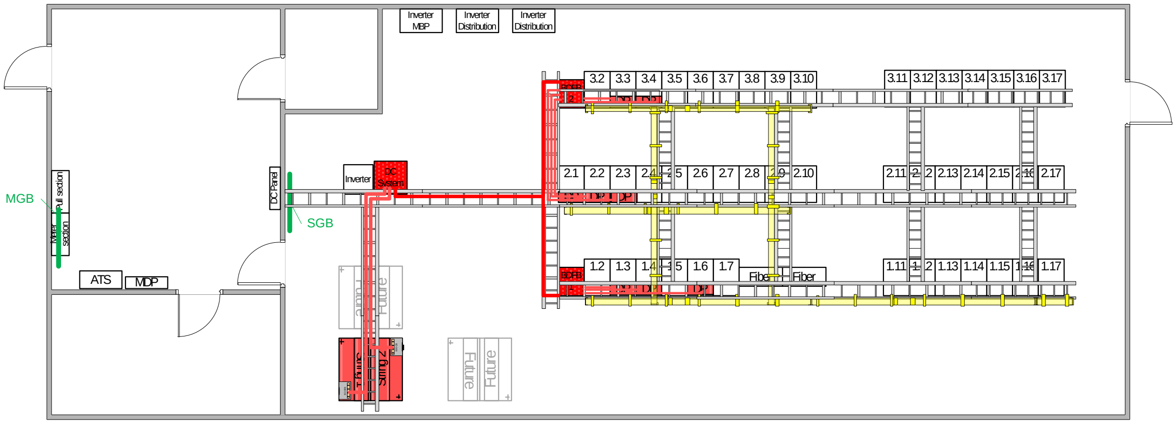


Figure 3 - 380VDC Engineering Drawing for BOM

3.5.1. *System Ratings*

- Ultimate rating 120kW ,116kW n+1
- Initial rating 44kW n+1 , expandable in 4kW modules
- Input voltage -480VAC, 3phase + ground (4 wire)
- Batteries – 4hour back-up (2000Ah strings-2V cells) , initially 2 strings with infrastructure to support 4 strings

3.5.2. *Distribution to Equipment Racks*

Distribution is design around industry standard BDFB and distribution panel topology. BDFB is rated for dual 800A inputs, supporting A+B architecture. The BDFB is upgradable to support both additional breakers requirement and great load capacity. Distribution panels are rated for 400A isolated A+B inputs, and provide rack/equipment level power.

3.5.3. *Batteries and Battery Distribution*

Batteries consist of two strings of 2V cell system design. Each string is equipped with an 800A battery disconnect and is individually cabled back to the DC power plant. Infrastructure included in installation is design to support two additional string and allowing for batteries to grow and support future load growth.

3.5.4. *General Notes*

This system represents the current standard method of DC power distribution. It was selected as a base point to provide a comparison of the potential benefits of a 380VDC architecture.

3.6. Equipment Estimate: 48VDC

The following materials in Table 3 were scoped out for the above proposed installation:

Table 3 - 48VDC Equipment Estimate

DC System			
1		DC Power System w/Rectifiers	120 kW DC power system 44 kW total rectification (rectifier modules are 4kW equipped with 11 rectifiers) 8 TPL fuse positions
4		DC Plant Fuses (BDFB feed)	TPL fuse, 800 AMP
BDFB			
2		BDFB	Isolated A/B 800A Input Bus BDFB 1 panel per bus 20 bullet breaker positions per panel
16		BDFB Breakers (Distribution Panel feed)	225A bullet breaker (2-pole)
Distribution			
8		DC Distribution Panel	Isolated A/B input breaker panel 400 A per bus 10A/10B bullet breaker sockets -48VDC
78		Distribution Panel Breaker (Equipment feed)	60 A bullet breaker
4		Distribution Panel Breaker (Equipment feed)	30 A bullet breaker
Batteries			
2		Batteries	2000 Ah – 48VDC Battery
2		Battery Disconnect	800 A Battery Disconnect

The total equipment cost for overall is $87,613.

4. Summary and Further Considerations

The objective of this short study is to identify potential benefits (impact) of deploying 380VDC vs 48VDC in broadband service provider critical facilities.

The methodology was to identify a sample site and compare pricing of the 48VDC and 380VDC solutions based on quotes obtained from equipment suppliers and installation contractor. The compiled results were submitted to SCTE for an objective evaluation.

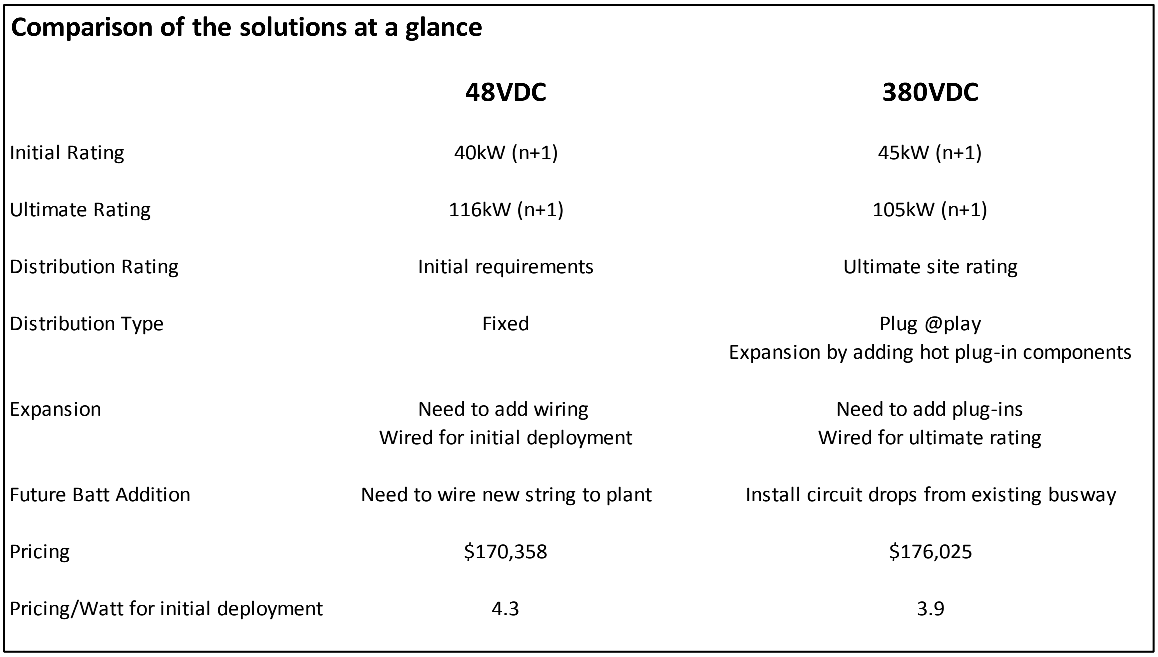
The results do not include a wide range of vendors and *may* not quite emulate the competitive bidding environment, but provide a reasonable benchmark for further evaluation.

It *should* be noted that in general the results might substantially differ dependent on the site geography and loading requirements. There are larger facilities which can lead to longer wiring distances favoring a

380VDC solution. In addition some of the system components prices (like power strips, connectors, batteries, etc.) are expected to decrease with increasing volumes (this is not factored in).

In general, the total rack wattage required to support new load continually increases. This increases results in a greater focused on I squared R losses, which 380V helps alleviate. The impact on the site's cable distribution and structural considerations for cable support was not considered.

The general observation is that utilizing 380VDC distribution significantly reduces site wiring content and installation costs, both initial and in future expansion. See Figure 4.



Comparison of the solutions at a glance

	48VDC	**380VDC**
Initial Rating	40kW (n+1)	45kW (n+1)
Ultimate Rating	116kW (n+1)	105kW (n+1)
Distribution Rating	Initial requirements	Ultimate site rating
Distribution Type	Fixed	Plug @play Expansion by adding hot plug-in components
Expansion	Need to add wiring Wired for initial deployment	Need to add plug-ins Wired for ultimate rating
Future Batt Addition	Need to wire new string to plant	Install circuit drops from existing busway
Pricing	$170,358	$176,025
Pricing/Watt for initial deployment	4.3	3.9

Figure 4 - 48VDC vs. 380VDC Comparison at a Glance

For a site employing multiple power plants the savings would be multiplied by the number of deployed power plants. Regardless of the voltage (380VDC or 48VDC), distributed solution provides better wiring costs than a centralized solution. This is due to shorter DC cable runs. But this requires multiple batteries located in close proximity to powered equipment. Additional studies *may* have to be performed to understand impacts on building structural requirements (weight of batteries) and battery maintenance cost (multiple batteries). The benefit of this approach *may* be better scalability and lower initial deployment costs.

First cost of ownership *should not* be the primary deciding factor in considering adopting a 380VDC power distribution approach in a greenfield build. The 380VDC concept is competing with years of legacy AC and -48 systems. The slight elevated cost is not unusual for leading edge, game changing technology. NOTE: this study does not examine brown field cost application OR expandability considerations between -48 and 380 V.

EPRI and Duke Energy conducted a trial based on Figure 5.

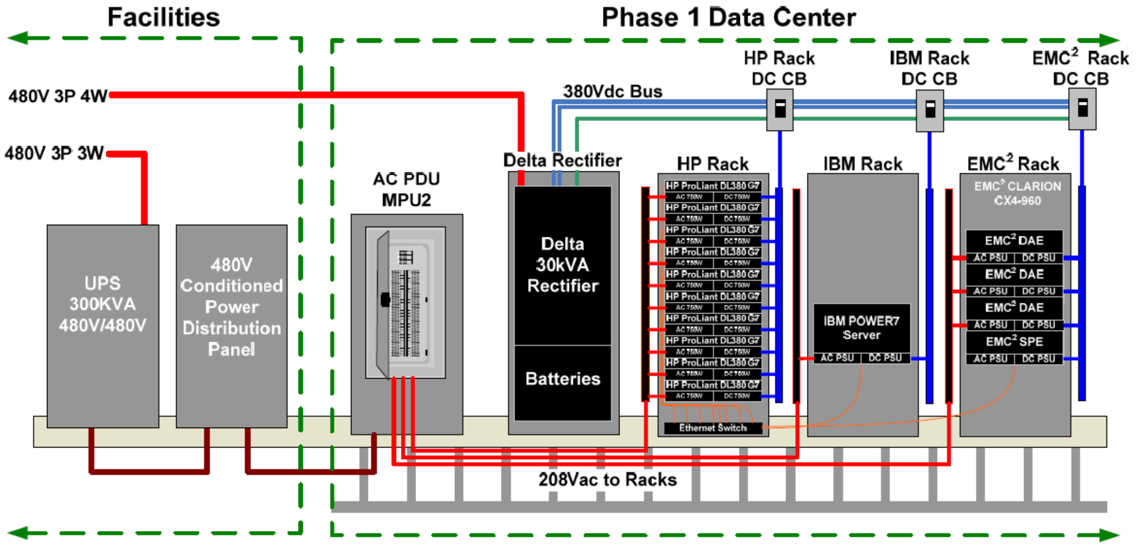


Figure 5 - EPRI Duke Energy 380VDC Trial Configuration

The trial demonstrated that more inefficient data centers could realize an average of 15% reduction in server energy reduction.

As availability of power in respect to utility power loss continues to become a growing concern, DC power with a solid strategy of battery deployment will benefit from the higher voltage 380 approach to reduce loss.

Finally with the gain of efficiency in power across the supply chain, would be a gain in cooling efficiency due to heat load reduction.

5. Abbreviations and Definitions

5.1. Abbreviations

AC	Alternating current
Ah	Ampere-hour
ATS	Automatic transfer switch
AWG	American wire gauge
BICSI	Building Industry Consulting Services International, Inc.
DC	Direct current
EPA	Environmental Protection Agency
kcmil	thousands of circular mils
MGB	Master ground bar
NEC	National Electric Code (NFPA-70)
NFPA	National Fire Protection Association
PDU	Power distribution unit

SGB	Secondary ground bar
SCTE	Society of Cable Telecommunications Engineers
V	Volt

5.2. Definitions

busway	System of prefabricated electric distribution, consisting of several bars inside a protective housing, including straight sections, devices and accessories.
N+1	Components have at least one independent backup in the event of primary device failure, +1 will assume function of failed device

6. References

6.1. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

- No normative references are applicable.

6.2. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

6.2.1. SCTE References

- SCTE 184 2015 SCTE Energy Management Operational Practices for Cable Facilities
- SCTE 218 Alternative Energy, Taxes, Incentives, and Policy Reference Document

6.2.2. Standards from Other Organizations

- ANSI/BICSI 002-2014: Data Center Design and Implementation Best Practices, December, 2014
- ATIS-0600315.01.2015 “Voltage Levels for 380V DC-Powered Equipment Used in the Telecommunications Environment”
- ANSI/BICSI 002-2011 Data Center Design and Implementation Best Practices
- EMerge Alliance Data/Telecom Center Standard Version 1.0
- ETSI EN 300 253 V2.1.1 (2002-04) Environmental Engineering (EE); Earthing and bonding configuration inside telecommunication centres
- ETSI EN 301 605 V1.1.1 (2013-07) Environmental Engineering (EE); Earthing and bonding of 400 VDC data and telecom (ICT) equipment
- ETSI EN 300 132-3-1 V2.1.1 (2012-02) Environmental Engineering (EE); Power supply Interface at the input to telecommunications and datacom (ICT) equipment: Part 3: Operated by rectified current source, alternating current source or direct current source up to 400V; Sub-part 1: Direct current source up to 400 V

6.2.3. Published Materials

- Maintaining Mission Critical Systems in a 24/7 Environment; Curtis, Peter M., IEEE Press 2011
- EMerge Alliance 380 Vdc Architectures for the Modern Data Center

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