Taking Critical Facility Energy Conservation Measures to The Next Level

Incorporating Lessons Learned and Moving Towards AI/ML For Building Management Systems Controls

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1. Introduction

Great strides have been made in improving critical facilities availability, reliability, and resiliency. Additionally, myriad ways have been established to increase sustainability through the use of well-documented energy conservation measures (ECMs). Over one-third of the energy a multiple-system operator (MSO) consumes is in its critical facilities and data centers, so reduction of energy consumption and the associated reduction in carbon footprint in these spaces contributes to positive movement of the dial on company environmental goals.

After ECMs such as airflow optimization (AFO) and hot aisle/cold aisle configurations are in place, the next level is optimal sensor placement and development of building management systems (BMS) automation and controls algorithms. As the number of data points and disparate sources increases, it becomes clear that artificial intelligence (AI) and machine learning (ML) will be required to optimize and maintain the highest level of operational efficiency through all of the lessons learned, and the constantly changing environment both inside and out of critical facilities.

In this paper there is an overview of ECMs, their impact and lessons learned through deployment, and exploration of possible ways in which AI and ML can be used with BMS controls to optimize efficiency while maintaining expected availability, reliability, and resiliency of critical facilities.

2. Energy Conservation Measures: What & Why?

An ECM can be defined as an action that reduces or contributes to the reduction of energy consumption of a particular piece of equipment or a certain aspect of essential building services to reduce overall building energy use.

We have all have spent several years getting our critical facilities to a high level of

- ***availability*** - the percentage of time that a critical facility (and its systems components) is operational, including planned and unplanned downtime, often captured as “nines” of uptime,
- ***reliability*** – the probability that the critical system components will perform their intended function without failure over an expected period of time, often captured as “mean time between failure” (MTBF), and
- ***resiliency*** - the ability of a critical facility to withstand a major disruption within acceptable degradation parameters, and to recover within an acceptable time.

Now it’s time to improve upon that by exploring ways to make critical facility infrastructure systems more efficient. This is in line with most MSOs and other industry leaders' programs to reduce carbon footprint in the next few years. As mentioned in the introduction to this paper, over a third of an MSO’s energy is typically used by critical facilities and data centers, and nearly half of that is dedicated to cooling the information technology (IT) equipment in the facility. Great gains can be made with just a few common-sense modifications to the HVAC monitoring and infrastructure.

Several short- and long-term goals for critical facilities leadership are below:

- To “operationalize” cooling best practices, involving on-site technicians, engineers and managers in ways that are meaningful and evidence-based, while incorporating a “feedback loop” to ensure process improvement – without jeopardizing availability, reliability or resiliency.
- Provide education and guidance on deployment of appropriate conservation measures rather than sticking with entrenched ideas “because we’ve always done it that way”.
- Develop a “playbook” of guidelines and best practices for critical facilities with appropriately targeted ECMs, and how to create a desktop “scorecard” and other graphic tools to monitor progress and efficacy of ECMs over time.

One of the most important, yet often overlooked steps in a successful ECM initiative is the need for ***trending of the relevant data points*** being monitored by the critical facility BMS. Monitoring, measurement and management of applicable parameter data will be discussed later in this paper, but the point cannot be stressed enough. Trending before and after each ECM is deployed is the only way to determine the efficacy of an ECM.

Equally as important is the need for only one ECM to be deployed at a time, if possible. Otherwise, there is no way to tell which ECM yielded which result.

2.1. ECM Site Audit

We don't want to deploy ECMs at a critical facility simply because it seems like a good idea, or "everybody's doing it". While there are very few sites that would not benefit from *some* sort of ECM, it is necessary to gather information about the site to determine which ECMs would be optimal to deploy, and in what manner. Consequently, the first thing needed to deploy ECMs at a critical facility is a detailed audit of the facility, gathering all of the relevant information.

Some of the information typically needed for a critical facility ECM audit:

- Square footage, type of occupancy
- Year of construction, any upgrades or additions
- As-built drawings, design standards, operation manuals
- Rack height, floor to ceiling height, ceiling type
- Floor plan w/ racks and hot / cold aisle configurations
- HVAC equipment inventory
- BMS or building automation system (BAS) / controls type
- Current HVAC system setpoints
- Estimate for needed # of blanking panels, if applicable
- Existing airflow containment status
- Lighting inventory
- Utilities information, location of meters, historical bills
- List of any future capital improvement plans
- Preferred vendors, on site contacts

The above list is comprehensive but not necessarily exhaustive, and the amount of information needed will be based upon the size and complexity of the facility.

2.2. Common ECMs

There are a number of common "go-to" ECMs, and it will be beneficial to provide an overview of those most often considered, along with benefits of and challenges to their deployment.

2.2.1. Airflow Optimization ECMs:

Airflow optimization (AFO) is often considered the "low hanging fruit" of ECMs, and rightfully so. This is partly because of the reasonable cost (compared to major system modifications), but primarily because experience shows that AFO must be done before most other ECMs. Once AFO is established, it is akin to the settling of a wildly rocking rowboat before any forward progress can be made. As with most other ECMs, AFO must be managed since any structural or equipment moves, adds, or changes to the room under consideration will affect the AFO, and consequently most, if not all, of the subsequent ECMs that have been deployed will likewise be affected.

The most common types of AFOs are the following:

- **Hot aisle/cold aisle configuration** – where the equipment rows and racks are configured such that the equipment exhaust fans throw the heat to a common "hot" aisle, and the HVAC supply air is made available in a common "cold" aisle. This configuration is of paramount importance and must be considered a primary consideration; the success of any other AFOs (and ECMs in general) will depend upon this being in place (one exception to this is if heat extraction at the rack level is being done). Most sites typically have a hot aisle/cold aisle setup, but many may have portions or rows which are "mixed" (see Figure 1), or worse yet, a "schoolroom" configuration (see Figure 2) where the heat exhausted from the first row blows directly into the inlets of the equipment in the second row, which exhausts heat into the equipment inlets of the third row, and so on. The air is hotter row by row, and the space is consequently more difficult to cool throughout the room, resulting in premature equipment failure, most especially on the "far" side of the room. This is akin to the rowboat having a catastrophic hole.

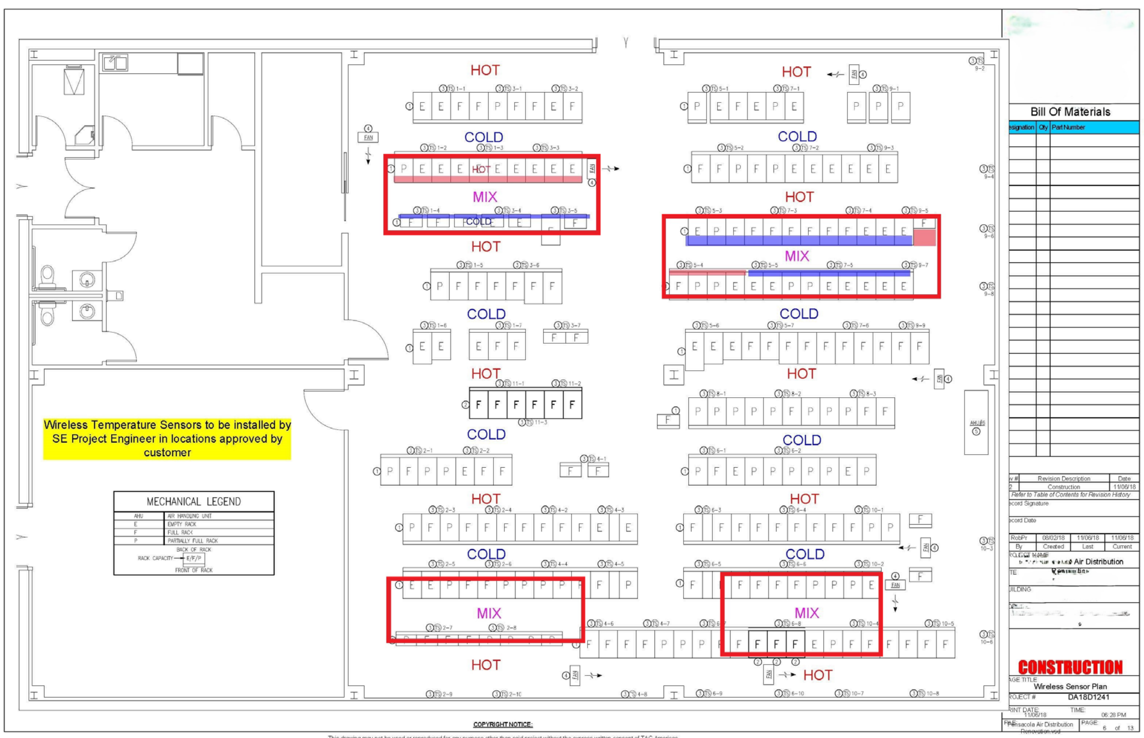

Figure 1 - "Mixed" Aisles Within Hot Aisle/Cold Aisle Setup

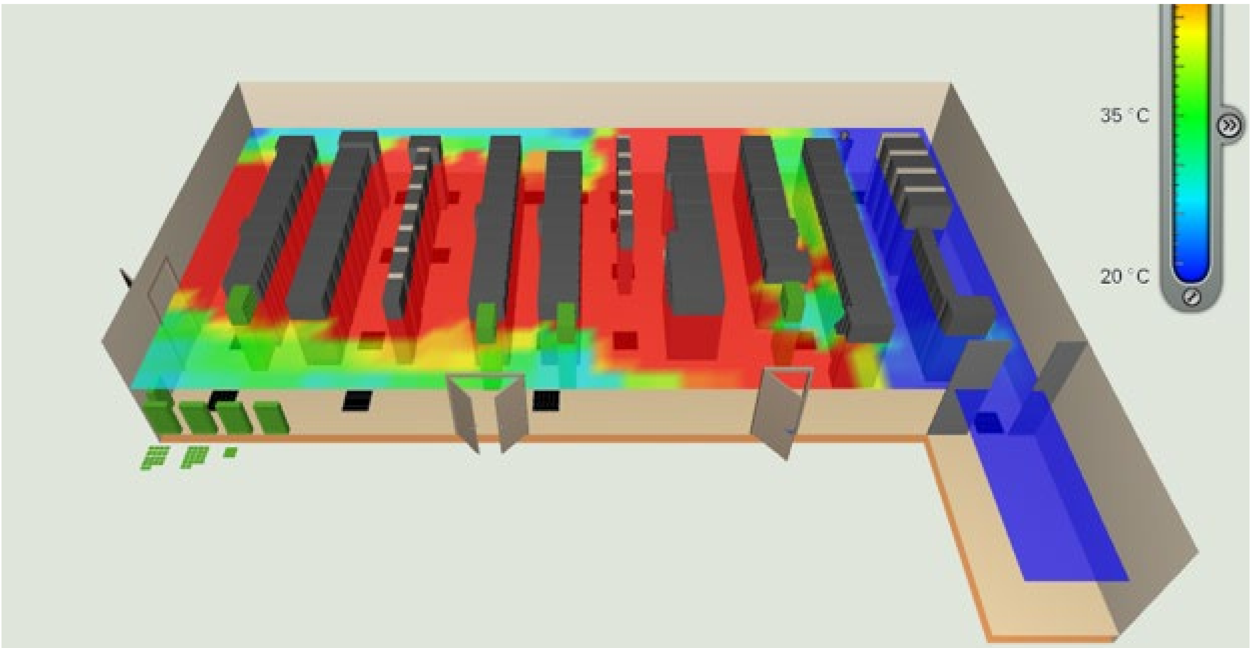

Figure 2 - "Schoolroom" Configuration

As impact of having a hot aisle/cold aisle setup is obviously beneficial, but the cost of retroactively moving there from mixed or schoolroom configurations can be very prohibitive. Most MSOs typically wait for an opportunity of a technology refresh or a planned equipment obsolescence initiative to remove end-of-life equipment and institute the hot aisle/cold aisle configuration.

- **Blanking panels installation** – these panels come in a variety of styles and price points, and in a hot aisle/cold aisle setup, can help ensure more cold air reaches the equipment inlets (see Figure 3). These panels will help airflow in most cases, but there may be some cases where either the hot aisle/cold aisle setup is not possible or small sites with wall-mounted HVAC units that are in a fully mixed air temperature environment that would ***not*** necessarily benefit from blanking plates.

Figure 3 - Blanking Panels And Sliding Containment Door

- **Airflow containment** (hot or cold aisle, partial or full) – these typically come as polycarbonate fixed doors (swing-open or sliding as shown in Figure 3) or curtains (vertical sectioned flaps) made of plastic or vinyl (see Figure 4). Containment solutions require careful consideration and planning to ensure that the fire suppression system will operate as designed. Curtains have the benefit of being portable, so they may be placed in the middle of mixed-air rows, or moved to other locations as the need arises. Curtains also can come equipped with a UL listed fuse link at the top which melts at a desired temperature and allows the curtain to fall to the floor.

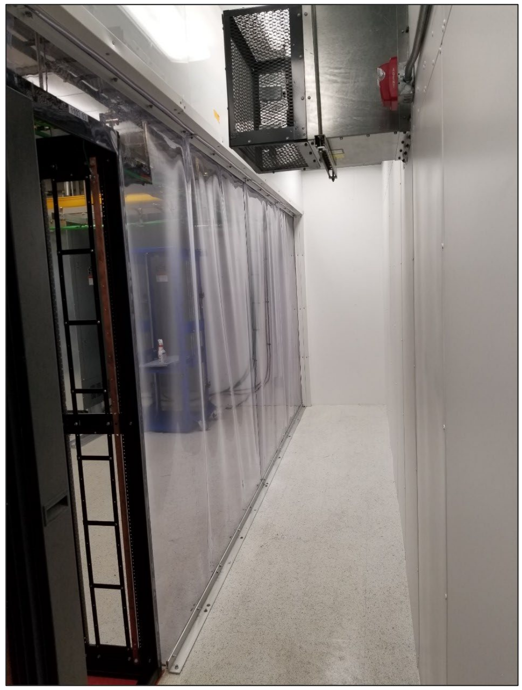

Figure 4 - Airflow Containment With Curtains

- **Ductwork modifications** – all sorts of creative modifications to overhead ductwork or wall-mounted registers can be done to ensure the cold air gets to where it is needed. These modifications should be standardized engineered designs wherever possible.

These AFOs will have varying degrees of impact and cost, and the order of their deployment at a site will depend on which of them may already be in place.

2.2.2. Retro-Commissioning (RCx) & Controls:

Once the airflow has been optimized at a site, it is usually desirable to retro-commission the existing HVAC units and modify the controls to optimize the sequence of operations. This requires evaluation of the major HVAC equipment systems and their associated controls, placement of sensors, and any other parameters involved in the most efficient operability of the HVAC system. The goal is to verify existing sequences of operation, setpoints, and equipment conditions, ensure optimal sensor and device placement and calibration, and identify any controls optimization opportunities and/or potential issues that may need correction.

Algorithms and direct digital controls (DDCs) can be used with emerging smart and next-gen equipment using machine learning to optimize climate controls and energy management for the entire facility.

Automated demand response (ADR) and electric demand limiting (EDL) systems can be integrated into the larger controls to allow for automatic reduction in facility energy consumption. This utilizes the existing BMS that controls the HVAC equipment at the facility and requires the installation of a self-contained power meter which allows for the BMS to monitor the power demand for the building and play a role in demand reduction.

The sequence of operation for the HVAC equipment would then be modified within the BMS. The revised sequences should include the ability to cycle and enable/disable (lock out) an entire piece of equipment or an individual compressor, depending on the equipment size and load.

The typical scenario would go as follows:

- The power meter monitors the building's real time power demand which will allow the BMS to shed HVAC equipment at rotating intervals.
- Once the annual demand has been determined from the utility provider it will become the initial "demand setpoint."
- As the BMS monitors the facility's power consumption, it will use this "demand setpoint" to start shedding HVAC load so that the setpoint is not exceeded.

BMS programming would have to include "failsafe" operations so that if space temperature or relative humidity starts to drift close to an adjustable setpoint, then the HVAC equipment would come out of the Automated Demand Response sequence and resume Normal operating conditions.

Variable air volume (VAV) and variable frequency drives (VFDs) can be utilized to take a more granular approach to the efficiency of the overall HVAC systems. The BMS system would be used to control these parameters as needed for each unit, based on data points and learned responses over time to ensure the most efficient and cost-effective operations, and with the same failsafe parameters in place so as not to jeopardize availability, reliability or resiliency.

After any significant changes have been made to the ductwork and air volume controls, a formal testing, adjusting and balancing (TAB) of the HVAC system should be included in the recommissioning process.

2.2.3. HVAC Replacements

When HVAC units reach end-of-life, they should be replaced with higher efficiency units if possible.

2.2.4. Increase Temp Setpoints – Based on Equipment Inlet Temp Ratings

One of the objective goals of ECM deployment in critical facilities has traditionally been to raise the HVAC temperature setpoints. This is not a straightforward process, and should be done only after the AFO, and RCx & Controls optimization have been performed. The following considerations need to be taken into account, or there will be a risk of skewed or irrelevant data with the possibility of yielding results contrary to those expected:

- All of the rack equipment specifications should to be gathered to determine where they fall in the ASHRAE allowable and recommended range for Class A1, A2, A3, and A4 equipment for temperature and humidity.
- Temperature, humidity and airflow sensor placement should be optimized. This includes moving equipment space sensors away from exterior walls, ensuring that supply and return air as well as rack inlet temperature sensors are properly located. There should be a minimum of 1 temperature sensor per cold aisle, installed per ASHRAE TC9.9 (2 inches in front of the server, 5 ft above finished floor, centered on aisle).

Once these actions are taken, and where possible, the sequence of operation and BMS programming has been revised to control the critical zone temperature within each RTU group as defined by the ductwork manifolds (or the equivalent is done depending on the HVAC system configuration), then the temperature setpoint of cold aisle sensors can be raised. This should be done by one degree Fahrenheit for each row or zone as applicable, and then all systems monitored to determine the consequent results.

It has often been found that by raising the setpoints, the equipment load increases, which is contrary to expectations. This in turn raises the building power utilization (kW load) and also the power usage effectiveness (PUE), which is a widely used metric to determine the energy efficiency of a critical facility. This may be due to increased fan speed within the equipment, which uses more power. The increased fan speed may be a result of inadequate AFO.

2.2.5. Airside Economizers (Enthalpy Control)

Since the signing of the Paris Agreement in 2016, a global effort has been made to drive down carbon emissions in any manner possible. This has driven a rise in popularity for using outside air to cool indoor spaces. The main challenge is ensuring that the quality of the outside air does not impact the operations of the critical facility. In data center or telecommunications operations air that contains sulfur dioxide (SO_2), ozone (O_3), hydrogen sulfide (H_2S), and nitrogen dioxide (NO_2) can encourage the corrosion of components within the network equipment. Also, these spaces are generally protected from the risk of fires using air sampling devices that are extremely sensitive in efforts to stop a fire before it can spread and cause larger scale losses. For these reasons, there has been reluctance to use airside economization. Times have changed, however, and better filtration, sensors and controls make this ECM more attractive by reducing the risk of a clean agent fire suppression system discharge.

There can be significant energy savings by the use of outside air economization, depending on the facility location, as shown in Figure 5.

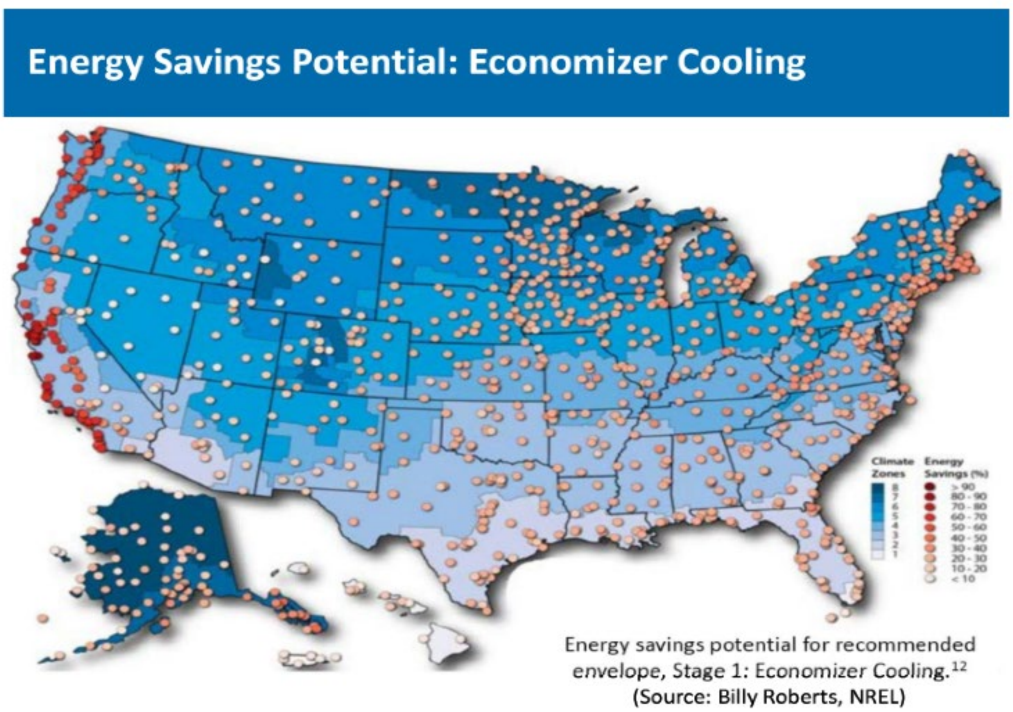

Figure 5 - Airside Economization Map Of The United States

2.2.6. *LED Lighting and Motion Sensor Controls*

Lighting admittedly accounts for a small portion of the energy used by a critical facility, but the energy reduction makes LED lighting upgrades an easy decision. Motion sensors can add to the savings, but if used, they need to have the settings optimized for the use and occupancy of the facility.

2.3. ECM Deployment Challenges

There are a number of challenges that may be faced when deploying ECM initiatives, but these are easily addressed with well-designed process and project planning, combined with clear and well-defined operational objectives. A few of the most often challenges encountered are as follows:

- TRENDING! It bears repeating that the trending of applicable data points before and after deploying an ECM is the only way to determine its efficacy. In a complex system such as a critical facility with power and mechanical and environmental factors all in play, it stands to reason that the changing of one parameter, e.g. adding blanking panels, can and will affect the balance of the ecosystem, and in ways not necessarily expected or obvious.
- Communicate with the field. All interested parties need to be on board, and clearly understand the processes and procedures to be undertaken in the ECM project, particularly if it is a centralized or corporate led initiative. This ensures goodwill and smooth project deployment.
- Education of onsite technicians, maintenance vendors, engineers and management. Everybody needs to understand the reasoning behind these ECM initiatives, and how their efforts and ongoing assistance tie into the company energy management and long-term sustainability goals. Additionally, as the automation of environmental controls increases, it needs to be understood that manual adjustments of thermostats and controls software will likely undermine the energy savings, and potentially jeopardize the critical facility availability, reliability and resiliency.
- Myth-busting entrenched ideas. Experience has shown that keeping the critical facility temperature 5 degrees Fahrenheit cooler does not buy you any significant time during an outage. It is simply not worth the additional 24/7 energy use cost and contravenes company sustainability objectives.
- Balance between personnel comfort and IT equipment optimal environment. This is a controversial issue, and requires an approach that is even-handed and fair-minded, as well as practical.

2.4. The Doctor-Patient Approach

Each critical facility is unique and dynamic, and exists not in a vacuum, but in a vibrant, continuously changing environment. There are shifting circumstances within and outside of the facility in the form of equipment moves, adds, changes, the periodic technology refresh, equipment decommissions, building expansions, electrical anomalies, extreme weather, cosmic events, and so on.

It is helpful for an engineer who wishes to deploy an ECM project or initiative to take a doctor-patient approach to each facility. In order to improve the facility efficiency and "health", the engineer (doctor) needs to know the patient's (facility's) history and current state, as well as any future plans, like a trip to Europe (building expansion) in order to make sure any prescribed processes and protocols (such as a change in diet and exercise) are in line with planned conditions down the road. A number of data points are collected (blood pressure, temperature) in a comprehensive audit, and a diagnosis is made (hot spots and restricted airflow) as well as a series of recommendations (containment) and perhaps prescriptions… you get the idea. The point is that as the facility (patient) goes through life changes, and some of the internal systems wear out and need to be replaced by newer technology, it takes a methodical operational approach to ensure healthy efficiency and longevity. Continuous monitoring and periodic site visits will help keep things looking good.

3. Data Gathering

Gathering the data needed for smooth operations of a critical facility is typically a process that evolves over time. It may start with a few closed contact alarms and a reactive approach. Advances in technology enable more connectivity and controls methods and protocols. The challenge is to determine what is the most relevant and actionable data to gather, and to avoid being overwhelmed by the ongoing wave of information available everywhere and at all times.

3.1. Monitor, Measure and Manage

You can't manage what you can't measure, and you can't measure what you can't see. This statement may not be applicable in all situations, but it is certainly true in the case of critical facility management and operations. Data visibility is essential, and this requires the deployment of monitoring and communications at multiple points throughout the critical facility. Nearly all critical facility infrastructure components can be monitored with varying levels of complexity.

Most critical facilities utilize a BMS for controls of HVAC units. If intelligent controls on both the equipment side and the BMS are available, there can be substantial gains in efficiency if the process variables and sequence of operations are properly fine-tuned. This is easier said than done however, and simply moving from wall-mount thermostats to one or two variable controls, such as area space temperature (average or high) or return air temperature per unit, and adopting a time schedule for rotation of the units can only go so far.

Legacy HVAC equipment typically consists of one or two compressors, and an air handler, and these are either on or off. High inrush current and low efficiency occur at equipment startup, which is energy-intensive, and if the thermostat controls are not set optimally, short-cycling can occur, which will considerably exacerbate the issue.

If intelligent and high efficiency IT-quality HVAC units are deployed (designed for the sensible cooling operations of a critical facility), as opposed to "comfort cooling" units, which are designed for human latent cooling operation, then there are a myriad of control and monitoring points available for consideration. Modern intelligent and efficient HVAC systems may be complex and granular, with digital scroll compressors that can be adjusted (typically 10% to 100% in step increments) to the needed percentage capacity (as opposed to 100% on or off).

When this is coupled with VFDs for the air handler fan motors and VAV dampers, the amount of air in cubic feet per minute (CFM) can be adjusted according to the needs dictated by the kW load of the equipment in the racks of any given row or room. Now we are starting to increase the number of control variables we can leverage to optimize the operations of the HVAC system according to the changing environment in the equipment room.

Lastly, the need for managing the critical facilities data that the BMS collects, as well as the data from external sources and other internal infrastructure in order to make effective business decisions and long-range planning has led to the rapid growth of the data center infrastructure management (DCIM) industry.

Most MSOs and other telecommunications companies utilize one or more DCIM products, typically combined with commercial off-the-shelf software (COTS), or customized variations, to analyze data and assist with budgeting and planning for day-to-day operations and long-term growth strategies. These can be used in any number of ways, such as the HVAC utilization analysis shown in Figure 6.

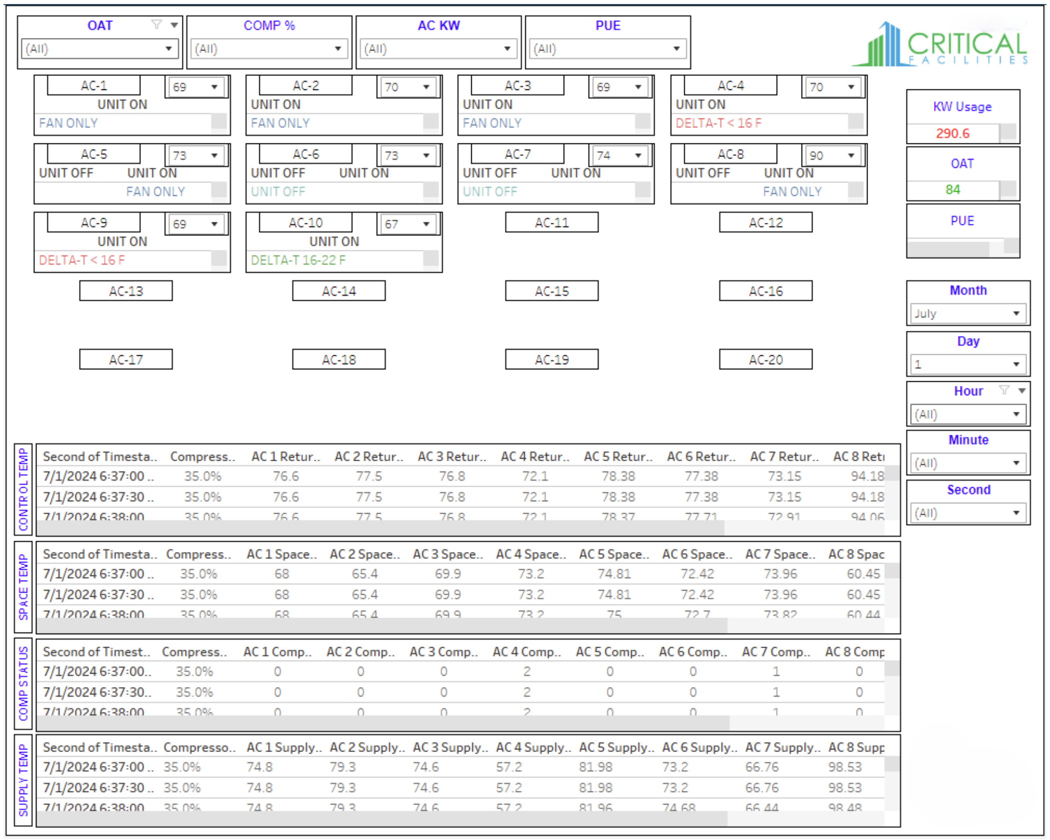

Figure 6 - HVAC Utilization Analysis

4. Automation: Simple and Complex

A thermostat that controls an HVAC based on a setpoint is about the simplest form of automation. On top of that could be the layer of a time schedule set for each unit to run or be available and enable switching with the other units to ensure they all get equal run time, as well as a failsafe to run if the temperature setpoint calls for it or another unit fails. For every layer of monitoring deployed and data points collected, there is a "sweet spot" where functionality of the ECM deployed will yield the best results for the money. The more complex systems will have additional costs initially but will increase the energy savings considerably over time. At some point, however, the law of diminishing returns takes over, and you don't get much improvement in efficiency for the extra time and money spent. The size and configuration of the site will be the two main factors driving the complexity.

4.1. Moving Beyond Setpoints and Time Schedules

Imagine a scenario where you have many data points being monitored, and they all contribute to the control of the HVAC system. Here is a list of points that are typically monitored in a critical facility, and can be leveraged for unit controls:

- Utility power load information from the main AC power switchgear and the DC Plant load, which will enable you to calculate the building PUE
- Utility power rates
- Outside air temperature (OAT),
- Airflow at multiple points in the room, including in front of the racks and within the HVAC ductwork

- Area space temp and setpoint for each HVAC unit
- Static pressure and compressor status for each HVAC unit
- Fan status for each HVAC unit
- Supply and return temp, and the resulting delta T
- IT equipment inlet temperature
- Power in kW per rack from the DC plant
- Compressor percent capacity
- VAV damper percentage

All of these and many more available data points are like the musicians in a symphony. They can all be leveraged to contribute the data needed to have the entire facility HVAC system running smoothly and in concert, and with setpoints, airflow and controls all optimized, many efficiencies and cost savings and carbon reduction can be realized. This is where we are today, and we have come a long way from the closed contact alarms (hopefully hooked up) and reactive operations paradigm.

Where do we go next? How are all of these disparate data points related, and how can they be harnessed and properly analyzed and used to help make automated and intelligent control decisions, optimizing operations without sacrificing critical operational integrity?

That's where the use of AI and ML comes in.

5. AI and ML Use Today and in The Future

AI and ML can play a significant role in the ongoing management of ECMs via the BMS and ancillary applications in a critical facility in the following ways:

- Data analysis and automation: AI and ML are critical elements in helping facility engineers and managers use their data more efficiently. These technologies can analyze and act on the vast amount of data that monitored devices generate in microseconds, streamlining building automation and helping to gain efficiencies as well as decarbonize their facility's operations.
- Energy efficiency: AI and ML can work together to cut both buildings operating costs and related emissions without compromising operational integrity (availability, reliability and resiliency).
- Predictive maintenance: AI and ML can play a pivotal role in enabling predictive maintenance within any of the critical facility infrastructure systems. This involves anticipating future failures, comprehending degradation, and scheduling maintenance activities accordingly.
- Adaptive control mechanisms: AI and ML have revolutionized the development of intelligent systems capable of learning from data and making informed decisions. These technologies leverage vast amounts of data, frequently collected in real-time, and employ computational algorithms to extract valuable insights.

MSO critical facilities engineers are exploring the use of AI and ML by utilizing linear regression, decision tree, and random forest algorithms applied to data obtained from the BMS with varying results. This is trial and error, to be sure, and while we see some correlation of variables (see Figure 7) and what seems to indicate some form of predictive PUE with ML analysis of changes in HVAC space temperatures (see Figure 8), it is still too early to tell, based on such limited data.

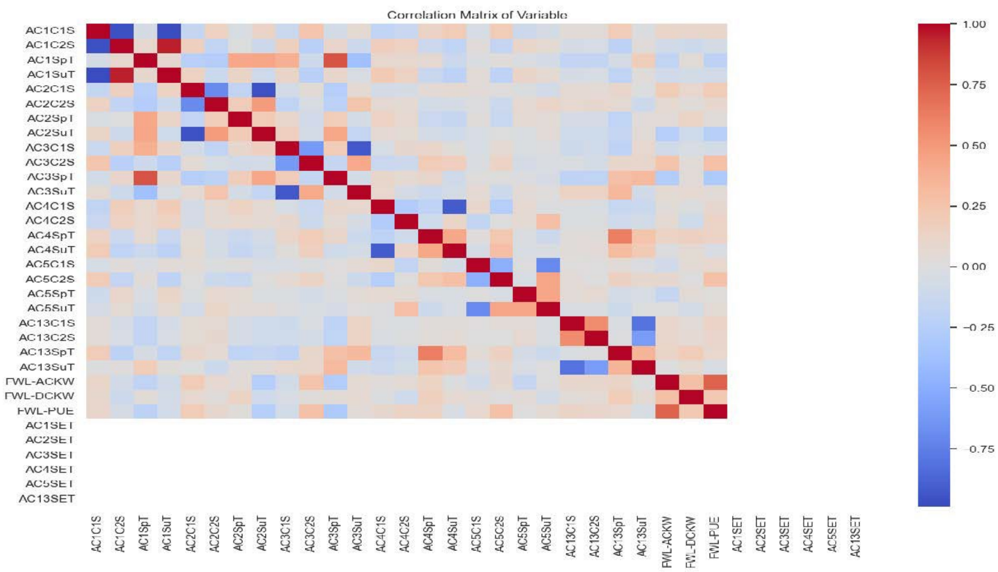

Figure 7 - Correlation Of Variables

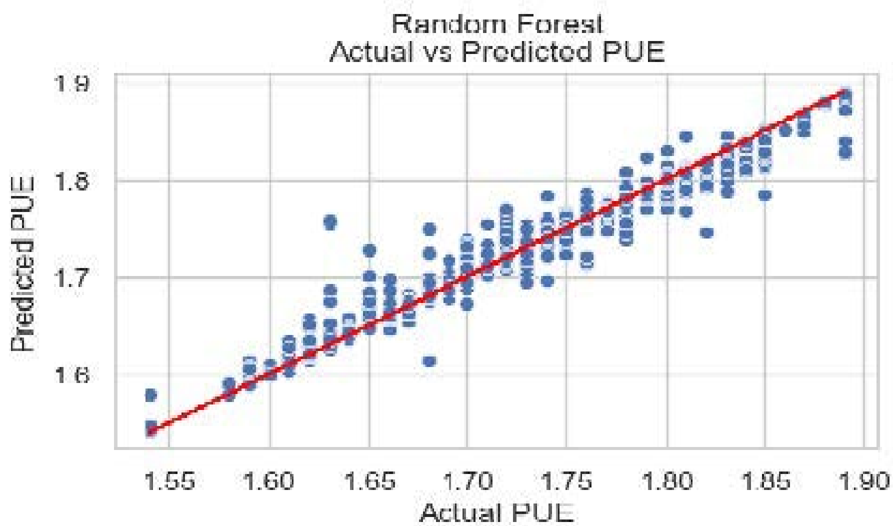

Figure 8 - Using Random Forest Algorithm To Predict PUE With Setpoint Changes

5.1. AI and ML Implementation Challenges

Implementing AI and ML in critical facilities will present some challenges, but with careful planning, the right resources, avoidance of common pitfalls, and a commitment to continuous learning and adaptation, we will certainly be able to overcome these challenges.

Here are some of the most common challenges:

- Adaptability: Implementing AI/ML requires adaptability, as these technologies need to be tailored to the unique context of the specific facility.
- Infrastructure availability: The availability of the necessary infrastructure is a key factor. This includes both the physical infrastructure to collect and transmit data, and the computational infrastructure to process and analyze it.

- Financial viability: The financial viability of implementing AI and ML technologies can be a challenge. These technologies can be expensive to implement and maintain, and it may take time to realize a return on investment.
- Lack of skilled personnel: AI and ML technologies require skilled personnel for their implementation and operation. There is a significant demand for professionals with expertise in these areas, and they can be difficult to find and retain.
- Data quality and volume: The effectiveness of AI and ML technologies is heavily dependent on the quality and volume of data available. If the data is poor or insufficient, the technologies will not function optimally. Unclean and noisy data can make the whole process extremely exhausting. We don't want our algorithm to make inaccurate or faulty predictions or decisions. Hence the quality of data is essential to enhance the output.
- Resource constraints: Implementing AI and ML systems requires large computational resources, which can be costly and complex, as well as negatively impacting the overall goal of reducing energy consumption.
- Deployment complexities: Deploying ML models into production can be complex and challenging, requiring careful planning and coordination.

When dealing with the data needed for AI and ML, there are several common pitfalls to avoid:

- Underfitting of training data: This process occurs when data is unable to establish an accurate relationship between input and output variables. This means the data is too simple to establish a precise relationship.
- Overfitting of training data: Overfitting refers to a machine learning model trained with a massive amount of data that negatively affect its performance. This is one of the significant issues faced by machine learning professionals.
- Lack of business alignment: The lack of alignment between the business problem and the data used to solve it can lead to ineffective solutions.
- Poor ML training practices: Poor training practices, such as not properly splitting the data into training and testing sets, can lead to models that do not generalize well to new data.
- Data leakage: This occurs when information from outside the training dataset is used to create the model. This can lead to overly optimistic performance estimates.

By being aware of these pitfalls and taking steps to avoid them, we can increase the likelihood of the successful use of AI and ML in critical facilities operations.

5.2. Future AI and ML Operational Opportunities

Using AI and ML for auto-controlling critical facility HVAC units and associated systems in constantly changing conditions is one thing, but the next step is to expand into the area of power utilization, ADR and real-time transactional power management through the use of various nanogrid components such as:

- Solar energy
- Linear generators
- Hybrid Supercapacitors
- Battery Energy Storage Systems (BESS)

That's a topic for another paper, however.

6. Conclusion

This paper has shown that the deployment of ECMs such as airflow optimization and hot aisle/cold aisle configurations are just the start of a comprehensive energy management program to deliver efficiencies and cost savings as well as reduction of carbon footprint, which aligns with most companies' sustainability goals. As we delve deeper into optimal sensor placement and we modify the control sequences and process variables of the HVAC systems, we can realize even greater benefits.

Finally, it has been clearly shown that we need to move in the direction of intelligent automation and utilize AI and ML to find the most efficient operational models for our critical facilities in the short- and long-term. If we keep an open mind to new opportunities, we will be learning right along with the machines.

Abbreviations

AC	alternating current
ADR	automated demand response
AFO	airflow optimization
AI	artificial intelligence
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DDC	direct digital control
EDL	electric demand limiting
kW	kilowatt
ML	machine learning
MTBF	mean time between failure
BAS	building automation system
BESS	Battery energy storage system
BMS	building management system
CFM	cubic feet per minute
COTS	commercial off-the-shelf
DC	direct current
DCIM	data center infrastructure management
ECM	energy conservation measure
H_2S	hydrogen sulfide
HVAC	heating, ventilation and air conditioning
IT	information technology
LED	light emitting diode
MSO	multiple-system operator
NO_2	nitrogen dioxide
O_3	ozone
OAT	outside air
PUE	power usage effectiveness
RCx	retro-commissioning
RTU	rooftop unit
SCTE	Society of Cable Television Engineers
SO_2	sulfur dioxide
T	temperature
TAB	testing, adjusting and balancing
TC	technical committee
UL	Underwriters Laboratories
VAV	variable air volume
VFD	variable frequency drive

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