Finding Fault: How AFDD Can Deliver Efficiency at Scale for the Military and Beyond

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ABSTRACT

Automated Fault Detection and Diagnostics (AFDD) is a powerful, yet underutilized tool for finding and resolving hidden energy waste in buildings. The Department of Defense (DoD) spends $4 Billion powering 300,000 buildings on U.S. military installations. Like many institutional building operators, DoD must manage aging infrastructure with limited resources and busy facilities teams, so common mechanical faults can go unfound and unresolved. But finding piles of faults is only half the battle. Sorting through the pile, finding issues that matter, and getting them fixed is what counts. Through a multi-year pilot, we show how AFDD as a service can overcome common barriers to scale. An AFDD platform was deployed at Hanscom Air Force Base and Marine Corps Air Station Beaufort, connecting to and utilizing Building Automation System (BAS) data from over 140+ buildings. Weekly remediation calls, led by expert analysts, guided local facilities teams and controls vendors to resolve impactful faults and track energy savings. This work summarizes the process, tools, benefits, challenges, and lessons learned. Several attributes contributed greatly to the successful outcomes, including ease of connectivity, process-driven remediation, and expert-in-the-loop.

Introduction

It is no secret that buildings often fail to operate as intended. Mechanical systems inevitably degrade due to failing hardware (sensors, valves, dampers), bad control sequences, and everything in between. Maintaining efficient HVAC and energy systems across fleets of buildings – commercial, institutional, or even military Installations – is a perpetual struggle.

Critical failures in heating and cooling systems are easy to detect. When the boiler fails, zones get too cold, alarms go off, and the occupants complain. But a longer list of hidden issues can go unnoticed, silently ticking away and wasting energy, sometimes for months or years. These hidden issues can lead to bad outcomes like poor indoor air quality, mold growth, premature equipment failure, energy waste, and more. It's hard to fix what you don't notice.

Several approaches can restore and improve how buildings and equipment operate. One-time Recommissioning and Retrocommissioning (RCx) have a strong track-record, though such projects can be labor and time intensive, involving building walkthroughs, deep-dive audits, and manual analysis, making them difficult to scale.

The energy savings realized by an RCx project can deteriorate over time, sometimes rapidly. One study looked at 28 sites over six years and found an average persistence in savings ranging from 49-76% (Gunasingh et al. 2018). That study reviewed the literature and found that the standard assumptions for efficiency measure life ranges from 2-20 years. Facilities staff turnover was noted as a potential contributing factor to deteriorating savings.

Monitoring-based commissioning (MBx) uses automated data analytics to help maintain persistence of savings after initial or retro-commissioning. MBx methods vary, but often use known-good baseline of operations to detect when a system is drifting operating out of spec. More sophisticated tools use Automated Fault Detection and Diagnostics (AFDD) algorithms to detect issues. These algorithms may not require building-specific baselines to detect issues or energy savings opportunities.

Actual savings opportunities are inconsistent and vary widely across each level of the system, from component, equipment, system, building, campus, and enterprise.

The ability to fix known faults can also vary greatly across sites. Some sites have well-staffed and experienced facilities teams who are empowered to deploy resources and implement fixes. Many sites, however, are deficient in some areas, creating obstacles to implementation.

In addition, several challenges hinder the widespread adoption and limit the effectiveness of commissioning campaigns. First, commissioning is labor intensive and time consuming, which limits ability to scale. Second, it requires skilled analysts who may be in short supply. Third, due to the manual nature of analysis, many important issues can be missed. Some issues occur only seasonally, for example, and may not surface during the commissioning project. Others require correlation analysis that is difficult for humans to spot. Finally, after issues get corrected, many will resurface over time. Some very soon after they are fixed.

In contrast, Automated Fault Detection and Diagnostics (AFDD) tools use software, algorithms, services, and processes to help teams overcome these challenges. Using operational data from the control systems, AFDD tools look for and track mechanical issues continuously. Not all AFDD tools are equal. And these approaches come with a different set of challenges related to connectivity, startup cost, training, and process.

This paper summarizes the preliminary findings from a multi-year AFDD pilot of *Cimetrics Analytika*, an automated fault detection and commissioning platform, at two DoD Installations. The remainder of this introduction provides a brief background on AFDD solutions, DoD-specific motivations, barriers to adoption, and project goals and metrics. Subsequent sections describe the DoD Host Sites, Technology, Fault Detection in Action, and Results.

Correcting mechanical faults can yield HVAC-related energy savings of 15-20% (Roth et al., 2005, EPA 2007, Mills 2011, Hart 2012). If fully adopted, we estimate that AFDD tools could reduce DoD's $4 billion facilities energy expenditure by up to $115 million per year, or about 6% of *total* facility energy expenditures.[1]

Automated Fault Detection and Diagnostics

Automated Fault Detection and Diagnostics (AFDD) tools[2] analyze the operational data from building systems to identify likely issues and their root cause.

The methods and approaches used by different AFDD vendors can vary widely in both capabilities and sophistication. Analytical techniques may include a mix of visual dashboards and graphs, rules-based analytics, digital twin models, bill analysis, benchmarking, machine learning, artificial intelligence, and more.

Likewise, the user experience and processes enabled by these tools can also vary widely. At one end of the spectrum, some tools just provide simple widgets or dashboards for viewing data and leave the "heavy lifting" analytical work to the end-user. At the other end (this

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[1] Estimated by applying a 20% energy cost savings to half of DoD's building HVAC energy expenditure; HVAC represents 28% of commercial building primary energy use (DOE 2018).

[2] Fault detection tools can go by many names. Without getting too technical, this paper uses the term AFDD to cover automated fault detection and diagnostics for finding root cause of building faults.

demonstration), skilled analysists use AFDD tools to curate issues and help teams diagnose and resolve the important ones.

Building Automation Systems (BAS) often include some basic tools or dashboards to help users find some of the more basic issues. But even these integrated tools require significant user engagement and expertise to be effective. Facilities teams generally lack the time, expertise, or resources to hunt for issues, especially when they are busy addressing the day-to-day emergencies.

Fortunately, most BAS collect troves of data from sensors and control points that can be useful for identifying and diagnosing faults. But without special configuration, many of these systems do not retain trend data for more than a few days. In general, it can be difficult to export data to third-party systems for continuous analysis. According to the facilities teams at one DoD host site, several prior AFDD vendors struggled or failed to access and interpret their control systems data. In some cases, the AFDD vendors required significant effort from the onsite team to manually create trends and export the data.

Common Energy Saving Opportunities

A list of energy saving opportunities, Table 1, can be supported by AFDD or Energy Metering Information Systems (EMIS) tools. Depending on the context, the issues detected by AFDD tools could be energy conservation opportunities, mechanical or controls faults, or some combination. The analytics service under test could address each of these opportunities, though several were more prevalent as noted later.

Table 1. Common HVAC Savings Opportunities (LBNL 2022).

Category	Opportunity
Scheduling Equipment Loads	Improve scheduling for HVAC, lighting, plug loads
Economizer / Outside Air Loads	Improve economizer operation/use Reduce over-ventilation
Control Problems	Reduce simultaneous heating and cooling Tune controls loops to avoid hunting Optimize equipment staging Zone rebalancing
Controls: Setpoint Changes	Adjustment of heating/cooling and occupied/unoccupied space temperature setpoints Reduction of VAV box minimum setpoint Duct static pressure setpoint change Hydronic differential pressure setpoint change Preheat temperature setpoint change
Controls: Reset Schedule Addition or Modification	Supply air temperature reset Duct static pressure reset Chilled water supply temperature reset Chilled water supply temperature reset Hot water supply temperature reset or hot water plant lockout
Equipment Efficiency Improvements	Add or optimize variable frequency drives Pump discharge throttled or over-pumping and low deltaT

Occupancy Behavior Modification	Routinely share energy information or guidance on proper use of equipment with occupants through EMIS Hold an energy savings challenge using EMIS data
Retrofits	Lighting upgrade or improve lighting controls, replace lighting fixtures with more efficient fixtures, add lighting control system High efficiency HVAC equipment airside; replace airside HVAC equipment with more efficient equipment High efficiency HVAC equipment waterside: replace waterside HVAC equipment with more efficient equipment

Barriers to Adoption

Although many commercial AFDD tools, products, and services have surfaced over the years, several barriers can limit adoption. This is not a comprehensive list, but in this pilot we focused on a few common barriers that could impact all projects:

- Burdensome DoD cybersecurity approval and connectivity process
- Difficulty connecting to and reading data from the BAS
- High burden on facilities teams to configure analytical models
- Limited time and resources of facilities teams
- Limited budget or resources available to address found issues
- Limited technical knowledge to diagnose and troubleshoot issues
- High turnover among facilities teams, leading to a lack of continuity
- Lack of interest or incentives for facilities teams to use the analytics or fix issues

This project aims to show how such barriers can be overcome using an interoperable approach to connectivity paired with an end-to-end service-based model to find, troubleshoot, track, and resolve issues. Critically, the technical barriers are only one part of the equation. Understanding and overcoming the human and process barriers can be even more important.

Project Goals, Metrics, and Challenges

This project set out to demonstrate how AFDD as a service could help the DoD achieve its building-related energy efficiency targets cost effectively and at scale. Our prime focus was on improving the energy efficiency of HVAC and related mechanical systems, with a secondary focus on detecting and correcting operational faults.

The DoD has unique challenges when adopting commercial technology. Solutions that work for the private sector may require small tweaks or significant modifications to be effective in DoD applications. Cybersecurity approvals, especially, were a standout challenge for this project. And more specifically, navigating DoD’s Risk Management Framework to gain Authority to Operate (ATO) on DoD’s control systems networks. Key requirements center around data flows, remote access, multifactor authentication, encryption, and approved Cloud solutions. While the architecture(s) that are ultimately permitted in DoD applications remain a bit uncertain, these elements do not greatly affect the results or conclusions of this pilot.

Technology Description

This section describes the experience deploying AFDD at two DoD Installations. Subsections are generally organized chronologically.

Host Sites and Buildings

Our initial goal was to connect to and analyze data for about six to twelve large buildings, for a total of 300,000 ft^2. Soon after we achieved this target, the facilities teams at both sites asked if we could expand the scope to cover the entire Installation (virtually all the buildings on the control system network). The AFDD vendor agreed, and within months, we were analyzing data from over 140 buildings, covering more than 3,000,000 ft^2. This demonstrates the potential to scale rapidly. Table 2 provides a summary of the host sites and the BAS systems connected.

Table 2. Site Descriptions & Connectivity

Site	**Hanscom Air Force Base**	**Marine Corps Air Station Beaufort**
Location	Hanscom, MA (near Boston)	Beaufort, SC
No. Buildings Connected	82	68
Building Floor Area (ft^2)	2,075,976	1,000,000+
Other Systems Connected	Central Chiller Plant	-
Controls Vendor	**Johnson Controls** Metasys, Facility Explorer Central Chiller Plant	**Automated Logic** WebControl
Connectivity	BACnet/IP	BACnet/IP
No. Points Polled		
Directly	30,778	36,501
Computed	127,478	117,482
Constants	2,277	1,699
Total	**160,533**	**156,380**
Point Naming Quality	Messy	Very Clean
Config Effort (hours)		
AFDD Vendor	103	130
Host Site	10-20	20-40
Issues Detected	**4,418**	**1,176**
Savings Identified ($/yr)	$459,336	$26,852
Savings Addressed ($/yr)	$258,720	$10,377

Mechanical Systems and Features

The AFDD vendor stated a clear preference for connecting to larger buildings, like laboratories or hospitals, with complex built-up mechanical systems and central plants. These tend to use the most energy and have the most issues, leading to the greatest opportunity.

In reality, the buildings we encountered were mostly moderate in size and less complex, with a mix of rooftop air handlers, packaged units, heat pumps, some central chilled or hot water loops, dedicated outdoor air systems, energy recovery ventilation, VAV boxes, and the like. A few buildings had unusually high demand, like a corrosion control hangar, with extremely high air flow rates, but these were the exception. Building floor area ranged from 1,000 to 250,000 ft^2 (median 16,600 ft^2).

Site Work & Initial Prep

The initial preparatory site work involved several activities: Meeting with the facilities teams. Getting to know the people. Learning the existing processes for addressing mechanical and controls issues. Getting familiar with the control systems. Selecting priority buildings to include or exclude. Providing facility onboarding forms to collect information about priorities, operational schedules, equipment, recent upgrades, known challenges, and similar background information. Requesting optional (but helpful) information like mechanical schedules, balancing reports, points-list exports from the BAS, or any other available mechanical or controls information. And finally, requesting information about the local BAS network and approvals process to enable connectivity.

Data Collection via CachePoller Appliance

Accessing and making sense of BAS data is a significant barrier to many AFDD tools or vendors. It is wise to consider testing an AFDD vendors' ability to access and process data before committing to a larger project.

To collect operational data in this project, the AFDD vendor used a proprietary device called a CachePoller. This read-only device connects to the local facility-related control system network and directly polls data directly from the thousands of endpoints (sensors, motors, schedules, etc.). The CachePoller is controls vendor-agnostic and interoperable with most common control system vintages and protocols. For compatibility, it does not need to interface directly with the BAS head-end. Many controls vendors operate proprietary databases, making it difficult or impossible to access the data that way.

By default, data is polled in fifteen-minute intervals and stored locally on the device until it can be uploaded to the cloud for analysis. Custom polling frequencies or micro-trends can be enabled to investigate specific issues. By design, and for security reasons, the CachePoller is read-only and is unable to modify BAS controls or issue commands to operate equipment. Any detected faults must be addressed manually by a system operator, technician, or controls vendor.

Figure 1. A Cache Poller installed at MCAS Beaufort collects operational data directly from the building automation system endpoints and sends it to the cloud for analysis.

Connect & Configure

For many sites, and especially for the DoD, gaining access to BAS data and making sense of the data are the most challenging and time-consuming steps in the configuration process. In this pilot, however, the analytics vendor made configuration seem easy. Connectivity involved the following Steps (and Responsibilities):

1. Export complete points list from BAS front-end. (Facilities)
2. Provide any mechanical schedules, as-builts, balancing reports, etc. (Facilities)
3. Identify desirable points to poll (AFDD Vendor)
4. Expose points and/or unblock access (Facilities)
5. Connect polling appliance to the control system network (AFDD Vendor)
6. Perform initial "scrape" to identify all visible BAS points (AFDD Vendor)
7. Map BAS points to Vendor naming convention (AFDD Vendor, some Facilities)
8. Calculate virtual BAS points for analysis (AFDD Vendor)
9. Initialize database to store polled points (AFDD Vendor)
10. Initiate polling (AFDD Vendor)
11. Enable fault detection algorithms (AFDD Vendor)
12. Refine configuration as new information comes to light (AFDD Vendor)

Connectivity went smoothly and took about half a day at each site. The initial point scrape took hours to days to discover the visible points. Subsequently, polling was enabled gradually a few buildings at a time, to ensure this did not interfere with network stability. Polling had no apparent impact on network or system performance.

To streamline the point mapping process, the AFDD vendor used a combination of proprietary automated tools and scripts developed and refined over decades to translate the BAS points into their standard convention. Minimal input was needed from the facilities teams to define the site's point naming conventions (if any), to identify the common mechanical system architectures, and to clarify unknown or unusual point names. Both facilities teams expressed great satisfaction with the low level of effort needed for the configuration.

Fault Detection Engine

Fault detection vendors use a variety of analytical methods for detecting faults, including simple alarms or dashboards, rules-based algorithms, machine learning, artificial intelligence, and more. In this pilot, the AFDD vendor primarily relied on fault-rules to detect issues. In short, this means running thousands of proven and customizable algorithms against the historical operational data to look for specific behavior. These algorithms are re-run on an ongoing basis to detect likely issues. They also re-detect issues that resurface after getting fixed.

Without getting too technical, each fault rule has its own data sufficiency criteria. If there are enough data points available to model the system or component, the fault rule algorithm will engage and automatically run against that system or component.

In practice, not all equipment will measure or report all the BAS points needed to model specific faults. This can make it hard to apply fault rules universally. To get around this challenge, the AFDD vendor's tool first estimates the values of any missing points (when possible) and uses these estimates when applying the fault rules.

Adjustable threshold parameters exist for many of the fault rules to reduce the occurrence of false-negative or nuisance issues. Examples would include the cycling frequency and duration needed to flag as equipment short-cycling, or the temperature setpoint deviation needed to flag a sensor as potentially faulty. It was generally not necessary to change any of the default values.

In some cases, more than one fault will trigger for the same equipment, leading to multiple potential causes. The tool tracks the evidence for whenever each fault has been detected and presents this on a timeline to make it easier to diagnose issues. When more than one potential cause is identified, all causes will be shown together, with the "best guess" of the root-cause shown first. This approach greatly cuts down on diagnostic time, and in the hands of an expert analyst, can streamline root-cause analysis.

User Portal: A Giant Pointer

The user portal acts as a "A Giant Pointer." It tells you where to look, and gives you hints and clues about what might be wrong. But ultimately, operators need to use some critical thinking to make decisions on how and where to act. The portal is the main interface for sorting through, managing, and tracking the detected issues.

Separate screens support different functions: Home, Executive Dashboard, My Issues, Utility Manager, Favorites, Graphs, Equipment, Reports, and Admin. Most hands-on work is spent on the "My Issues" page, where detected issues populate automatically into a master list.

Selecting an issue brings up related information, including diagnostic evidence, timeline of when the fault was triggered, suspected root cause analysis, and all related BAS points and equipment involved in the relevant fault-rule. The underlying fault-rule logic is also provided, giving a clear indication of what is going wrong.

Issue status can be manually changed to permanently ignore, snooze (to revisit later), or close an issue (after it is fixed). Users can add comments, add work order numbers, or upload relevant drawings or documents to help with troubleshooting.

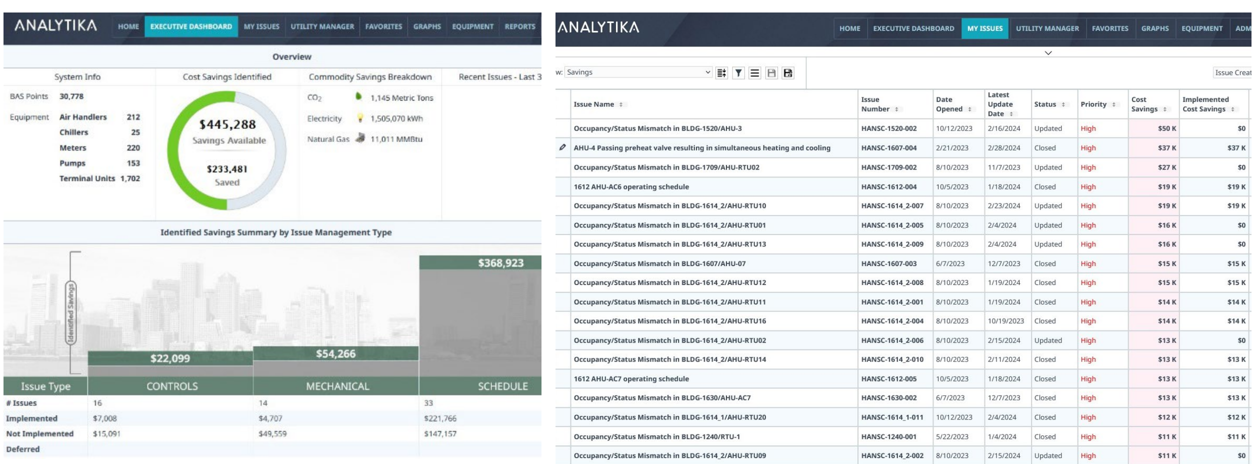

Figure 2. Analytika Portal Executive Dashboard and Issues Screens.

Remediation Workflow

Once issues begin populating into the portal, it is useful to establish a strategy for choosing issues to investigate and a workflow to address them. In this project, the AFDD vendor provided hands-on analyst support as an ongoing service to help facilities teams identify, troubleshoot, and fix the important issues. The analyst led weekly or bi-weekly support calls, about an hour long, with each team. Before the meetings, the analyst would prepare a prioritized list of issues to review. Priority was given to issues that are persistent, actively occurring, and have high impact: significant energy or operational savings potential.

The calls were held virtually on screen-sharing web conference meetings. The analyst would navigate to specific issues, review the evidence and root causes, and diagnose the issue in real-time together with the facilities team.

Typically about 3-5 issues could be addressed during each one hour call, depending on issue type and complexity. Some issues could be dismissed immediately, for instance, if the equipment was known to be out of service. In other cases, some deeper investigation was needed. Usually, the facilities team would look for the related BAS points on their front-end in real-time to confirm or reject the issue. If confirmed, additional diagnosis could then take place, or the issue could be dismissed as not important.

Simple issues could be fixed right away. A prime example is control points that were mistakenly left in manual override, forcing equipment to run or stop perpetually. Here, the point could be released in the controls front-end, resolving the issue in minutes.

For issues with less obvious root-causes, real-time functional testing was used to isolate or exclude potential causes. Valves, dampers, pumps, and motors can be cycled or commanded open and shut. And based on the response of nearby points, like temperatures or flows, the likely root cause becomes apparent. Having an expert analyst on the call, who has seen and diagnosed similar issues hundreds or thousands of times, makes the investigation fast and efficient.

Some issues require field investigation or mechanical repair. Once the possible causes are identified and narrowed, the facilities team may issue a work order to send a technician to diagnose further. Doing the analytical legwork ahead of time can reduce the amount of time and effort spent by the field technicians to diagnose these issues.

After a fix is implemented, the system will automatically continue searching for faults. If the analyst marks an issue as “closed” it will get re-detected if the fault rule triggers again. This helps maintain persistence and to accurately evaluate measure effectiveness and savings.

Finally, if a fault has an energy-savings component, the analyst can prepare an energy savings and cost impact analysis. Pre- and post- measure operational data inform engineering calculations to estimate annualized weather-normalized energy savings using a TMY3 bin analysis. Energy cost savings are based on blended utility rates specific to each site. Implementation rate (%) is automatically calculated and applied to adjust the savings for how much of the problem has actually been resolved.[3]

All assumptions[4], equations, and underlying data are provided to the user in “open book” spreadsheet format. These energy savings calculations can be submitted as justification for utility or efficiency program rebates or to justify a return on investment for capital-intensive issues. Specific examples of these calculations will be provided in the Final Report.

[3] For example, if simultaneous heating and cooling was happening 80% of the time, and a control revision reduced this to 20% of the time, the system would only count the savings that were actually realized.
[4] When unknown, the analyst assumed common values for flow rates or motor power for fans and pumps in consultation with the facilities team.

Fault Detection in Action

In this section, we provide a summary of detected issues, followed by some illustrative examples of issue diagnosis and remediation to give a sense of the AFDD workflow. Table 3 summarizes issues by type that were investigated and/or addressed during the 1+ year pilot phase. Many hundreds more issues were detected but not investigated due to time constraints, low impact, or both.

Table 3. Summary of issues with energy savings potential at one host site.

		Energy Cost Savings	
Issue Type	**Count**	***Potential***	**Realized**
Occupancy & Status Mismatch	29	*$329,765*	$185,725
Operating Schedule	2	*$31,657*	$31,657
Simultaneous Heating & Cooling	3	*$47,152*	$36,936
Economizer Control Logic	15	*$22,635*	$7,008
Actuators, Valves, & Dampers	13	*$15,210*	$6,170
TOTAL	**62**	***$446,419***	**$267,496**

Issue #1: Excessive Equipment Runtime

Equipment sometimes runs when it should not. Though basic, this fault category had the greatest impact and was among the easiest items to address. Evidence for excessive equipment runtime is easy to detect and verify. For example, the heatmaps in Figure 3 show the equipment status (LEFT) and occupancy command status (RIGHT) for an air handling unit. The equipment status initially follows the occupancy command following a daytime/nighttime schedule. At some point, the equipment starts to deviate and begins operating on a continuous 24x7 schedule, even though the command schedule is correct.

The causes are usually something simple, like a manual override, incorrect schedule programming, faulty sensor, or similar. When the issue was controls related, the operator could usually make the corrections in a matter of minutes, and sometimes in real-time during our calls. Occasionally, a group of equipment or buildings would all experience a similar schedule-related issue. Here, the operator could apply the same fix to many buildings during free time. In other cases, the intended schedule of operation for certain buildings or equipment was not clearly established and had to be verified with the building owner. Estimated energy cost savings per incident ranged from about $1,000 to $50,000 depending on the impacted equipment.

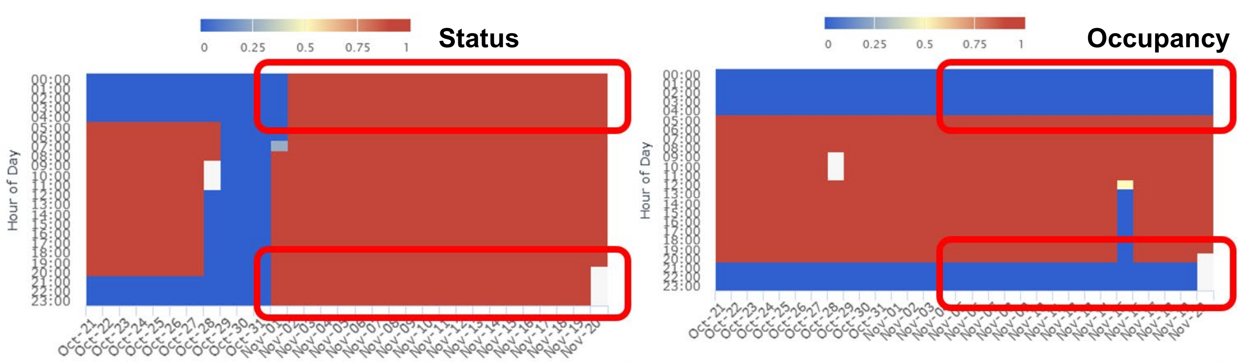

Figure 3. Equipment status and occupancy mismatch.
An air handler begins running overnight while the building is unoccupied.

Issue #2: Simultaneous Heating & Cooling

Equipment that heats and cools at the same time can waste energy without getting noticed or reported. We detected an Air Handling Unit with suspected preheat valve and direct expansion cooling valve both opened at the same time. We verified both the signal and position of the valves in the data, and in the BAS front-end to confirm the issue. Zone temperatures were within spec and this issue had occurred for months on end. Unfortunately, the impacted unit was controlled by a proprietary controller and not by the primary BAS, so an outside controls vendor would need to get involved to correct the logic. Cases like this were tracked with comments in the portal so the issue could be addressed at the controls vendor's next site visit.

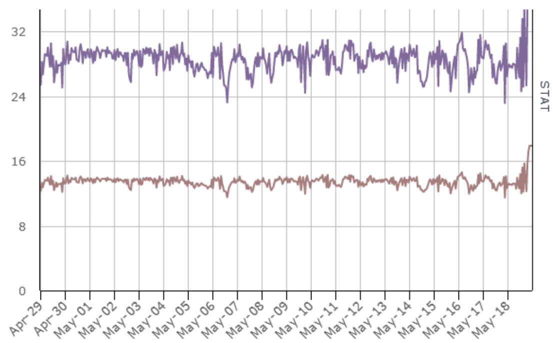

Figure 4. Heating and cooling valve position: both opened simultaneously for weeks.

In a second instance, an air handling preheat valve was failing (passing fluid), and the chilled water valve was opening to compensate, resulting in simultaneous heating in cooling. In addition, the chilled water valve was hunting. The facilities team made tuning adjustments to the control loop to address the issue and investigated the failing valve. This issue was wasting about $37K per year and has largely been corrected.

Issue #3: Compressor Short-Cycling

Not all issues are strictly related to energy savings. Some issues, if left unaddressed, can lead to premature equipment wear and failure. In this case, we identified a compressor short-cycling due to low cooling load conditions. Short-cycling can cause premature compressor failure. The host site confirmed a similar short-cycling issue on a different chiller that led to compressor failure and cost $50K to replace and repair. Accumulated fifteen-minute polling data was sufficient to detect the issue. To get even more clarity, the analyst configured a one-minute polling microtrend on the involved BAS points. In this case, a fix was not possible because the compressor sequencing control logic was built into the chiller equipment itself, and is not controlled by BAS commands. However, if the issue results in premature failure, the evidence could be used to support a warranty claim, motivate the equipment vendor to make changes to the underlying logic, or to support better equipment sizing design practices.

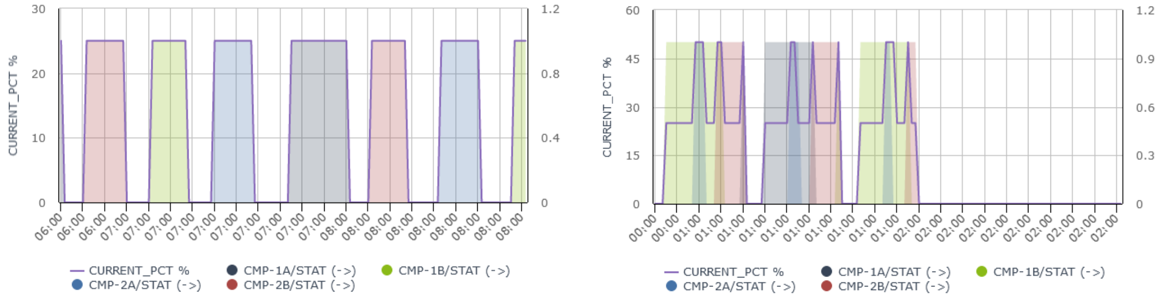

Figure 5. Four-stage chiller compressor cycling microtrend over two hour window. Each color represents a separate stage. LEFT: Normal operation, compressors alternate in sequence and cycle times are greater than 5 minutes. RIGHT: Short-cycling (1-3 min.) on all compressors.

Optimization: Reducing Excessive Ventilation

Some sites have relatively few issues, but still have opportunities for energy savings. At one site, the facilities team was especially well-staffed, skilled, highly proactive, and had already completed retrocommissioning on their buildings. Consequently, few impactful energy-wasting faults were available to address. Nevertheless, the analytics service identified significant opportunities to save energy through controls optimization related to excessive ventilation rates.

The analyst worked with the host site to review the minimum flow rates for the Variable Air Volume (VAV) units. For VAV units of significant size (500+ cfm), the team reviewed opportunities to lower the minimum airflow setpoints during unoccupied periods. Minimum airflows can be set too high for a several reasons, like changing energy codes, outdated design practices, or changing building operation. Adjusting and reducing minimum airflows can reduce outdoor air intake, fan energy, and the need for cooling and heating energy.

Decisions on how far to adjust minimum airflows required some judgment and monitoring to ensure good comfort and performance. How far to reduce the flow rates also depends on the zone characteristics. In a gymnasium, for instance, the diffusers were located high above floor. Reducing minimum flows too far would reduce the air velocity and could make it hard to keep the zone comfortable. In two buildings, adjusting the minimum flow rates are estimated to save about $4,600/year without adversely impacting thermal comfort in the zones.

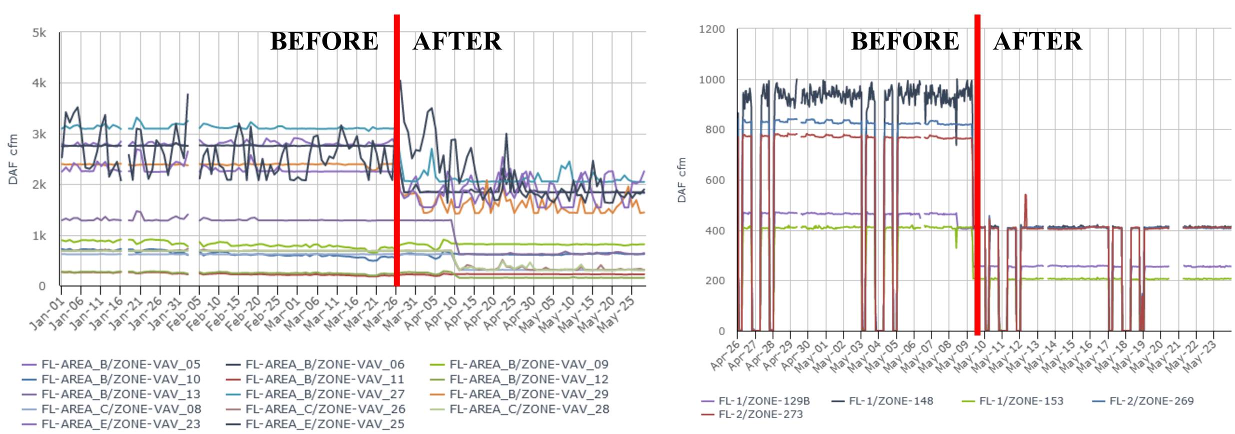

Figure 6. Reducing VAV minimum flow rates in two building saved about $4,600/year.

Flexible Approach: Facilities Teams' Expertise

The two sites had some key differences, which clearly impacted the available savings and ability to address issues. Specifically, the team at MCAS Beaufort was in the top 1% of the most capable and "on-the-ball" facilities teams that the analytics vendor had encountered. That site had done a number of commissioning projects prior to this pilot, and the team was well versed at troubleshooting issues and fixing mechanical issues. They were also highly capable of adjusting controls logic themselves for most issues. However, this also meant that there were relatively few issues to find, and of those we did detect, most were relatively small energy savings impact. Nonetheless, that team found the tool valuable for non-energy operational benefits, in support of finding bad or out-of-calibration sensors, and in some cases, for finding hunting controls sequences.

The second site had a more typical facilities team, with good knowledge of their building automation system and buildings and a mechanical shop to address field issues. However, that team was slightly short-staffed on the facilities side, sometimes had trouble getting replacement parts, and relied on outside vendors to make significant changes to the controls logic. We found many more savings opportunities at this site, and were able to focus on the high-impact and addressable items. For activities that required more expert controls knowledge, we packaged lists of issues to program under a separate project, essentially to hire a controls vendor for a day to fix those items.

So while both sites had different levels of experience, the analytics programs can be tailored to meet the needs and abilities of each.

Best Practices and Lessons Learned

Even when the analytics technology is effective at finding faults, ongoing commissioning campaigns can still fail for many reasons. Here we briefly discuss some factors that likely contributed to the success of this demonstration. These lessons are likely to benefit similar efforts involving process change. In particular, these best practices apply most to the Champion or person who runs the analytics effort. In our case, this role of Champion was split between the Analytics vendor, whose expert analyst coached the teams as a service in curating and addressing the issues, and the local person in charge of overseeing the effort, like an energy manager or facilities manager.

1. Get Buy-in (Or Don't Bother)

Get to know all the local stakeholders. Get buy-in. Get it early. Without sufficient support, you can spend a lot of time, effort, and money getting connected, only to find that issues don't get fixed. Without sufficient buy-in, the entire activity could turn into a colossal waste of everyone's time.

To get this project moving, we needed cooperation on many levels from facilities teams, the mechanical shop, IT security, energy managers, and the chief of engineering. Get leadership to commit to supporting these teams. Aim for a minimum time allotment (1-2 hours per week) to review and work on issues. Ensure teams are empowered to make changes, issue work orders, and fix things.

2. Play the Numbers

Fault detection is a numbers game. If you connect to too few systems or buildings, you may get unlucky and not find enough meaningful savings opportunities. Faults may occur disproportionately in certain equipment, buildings, or campuses. Ask the facilities teams about known problem areas and focus on these. If you are unable to connect to and analyze the entire campus, consider focusing on buildings with the greatest complexity and highest energy intensity, since this is where the most impact is likely to be.

3. Get to Know the People and Process

Find out who can do what. Get to know their expertise and limitations. Who has access to mechanical drawings? Who can view or operate the BAS front-end? Who can make changes to programming? How knowledgeable are they? How much experience do they have? Is there an outside controls vendor? How are known mechanical issues addressed? What is the process for issuing work orders? What can the local mechanical teams do? What work requires outside contractors? Knowing about constraints upfront can avoid wasting time chasing issues that cannot be fixed.

It also helps to have a main point of contact who will interface with the analyst (or AFDD tool) to get things done. For our project, this person had access to the BAS front-end and had intimate knowledge of the buildings and equipment. They would run functional tests on mechanical equipment from the BAS, perform preliminary troubleshooting and diagnosis, and coordinate with mechanical shop to do field work. Building a strong working relationship with this POC through weekly meetings made the project run smoothly. Make these people look good. Give them credit.

4. Dispel Misconceptions

Most facilities teams will not be familiar with AFDD tools. Some may even be skeptical of AFDD solutions. Help the personnel understand that you are not out to make anyone look bad. You're on the same side. You want to make their job easier and more effective. Finding a long list of issues is common and does not (usually) mean the facilities team has been neglecting their duties. Make sure they know this.

5. Build Trust with Quick Wins: Start Slow and Easy

After the analytics are up and running, it may be tempting to go right for the biggest dollar value savings opportunities. But that could be a mistake. It may be better to start out on simple items to build knowledge and trust with the team.

6. Regular Meetings & Accountability

Establish a cadence that works for the teams. This could start out as an hour every week, or two hours every other week. Eventually it could evolve into a monthly meeting. Or a quarterly on-site visit. Keep a rhythm. Checking in frequently helps hold people accountable and closes the loop on outstanding issues. Stay flexible. Sometimes emergencies come up. Don’t become a burden to the facilities team when they are dealing with bigger issues.

7. Focus on the Issues that Matter

Teams have limited time to focus on new problems. Focus on issues that have meaningful savings impact. Don't dwell on the minor things, especially at first. Is it worth changing a control sequence and risking new issues?

8. False Positives: Don't Lose Credibility

Especially early on, make sure to focus on issues with high confidence. It's important not to waste facilities teams time with nonsense or nuisance issues, or they may quickly become doubtful. If you keep requesting that service technicians investigate issues that aren't real, you will lose credibility and cooperation may drop off. After building success, and after the low hanging fruit is mostly addressed, the team may be ready to spend more time on advanced issues or those with less certainty.

9. Meet Teams "Where they Are"

Not all sites will have the time, expertise, or resources to address all faults. Meet teams where they are. If certain issues are too difficult or out of their league, consider making a punch list and bring in outside vendors or contractors to do the remediation work. Ask sites about their current pain points. Make an effort to solve problems on the buildings or equipment that are causing headaches.

10. Maintain Data Integrity

Over time, data integrity tends to degrade. Sensors may lose calibration, points may drop out, equipment may go offline. It is important to keep on top of the data, or else the accuracy of the analytics will suffer over time. In this pilot, at the start of each call, the AFDD vendor would flag any suspicious or missing points and ask questions. Is that equipment being serviced? Is the building offline? Are you have connectivity issues? Clarifying and fixing these issues usually took only a few minutes, but that ensures that data quality and confidence remains high.

Conclusions

An Automated Fault Detection and Diagnostics tool and service deployed at two military Installations delivered cost-effective HVAC energy savings, suitable for the military and beyond. Key achievements demonstrated to date include:

- Compatibility: connected to multiple BAS control systems, vendors, and vintages
- Scalability: able to onboard two DoD Installations in about one year (3,000,000+ ft^2)
- Configurability: AFDD vendor-driven process, low effort needed by facilities teams
- Identification: 1,500+ faults identified
- Process: effective, lightweight working meetings to implement fixes, ~1 hour per week
- Impact: annualized savings of $200,000+ realized in the first year

Next steps to enable widespread DoD adoption would likely require cybersecurity package development and approval for both the CachePoller appliance and the Cloud Portal.

This project is scheduled to conclude in September of 2024. The final report will ultimately be published on the SERDP-ESTCP website under project number EW19-5095. See also related ESTCP projects led by the U.S. Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) that looked at a range of FDD tools: EW19-5167. And another with the National Renewable Energy Laboroatory (NREL) and CERL developing an Energy Management and Information Systems (EMIS) Playbook for the DoD: EW22-7299.

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