Overview

The Foundations publication is an educational resource produced by BACnet International for its members. BACnet International is the cornerstone of your success, and Foundations builds on that by providing the ground level knowledge in connecting the dots in building automation. Foundations is written by volunteers from the BACnet community for integrators, installers, appliers and specifiers/consultants. It complements the BACnet International Journal and the association’s monthly enewsletter, Cornerstones.

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Energy performance modeling is a highly sought-after service in the facility design and construction industry, but is arguably becoming more so in the existing building renovation and upgrade industry. Whether in an energy savings performance contract (ESPC) or a large facility controls upgrade, savvy industry-participants are turning to sophisticated energy modeling to create a business case for bankable energy savings. This article explores these interdependencies in existing buildings, where they can be misconstrued, and in some instances a case of the blind leading the blind.

While energy modelers are not required to perform detailed walkthroughs of existing buildings, it is difficult to truly understand systems and control sequences without the in-field guidance of a building’s controls integrator. Modeling teams are scouring existing buildings throughout the world and are modeling savings from a known-quantity of energy conservation measures (ECM), often without really knowing what existing controllers are doing. If this is the case for one of your projects it is very likely that modelers know even less about what existing controllers are incapable of. It is also true that energy modelers are not completely aware of the capabilities of their project’s controls integration contractor, and vice versa. This is often the beginning stage of a poorly executed ESPC or controls upgrade, when bankable savings are a key component of financing or payback. As a result modelers are forced to assign a contingency factor to their analysis, to which energy service companies (ESCO) then add their layer of contingency. So what is really bankable in that scenario?

Energy modelers also rely on simulated control strategies during energy model calibration, matching models to actual weather and billing data, which is often performed in a vacuum-like digital environment. This is especially true if controls and integrator limitations are unknown, and more so when expectations of energy models are vague. If these two attributes are not understood and ECMs are simulated in a vacuum-like environment the proposed measures are unrealistic, compounding their eventual lack of bankability. Limitations and unstated expectations are not new to engineering or building controls, but they skew the fundamentals associated with ECMs (several of which will be discussed herein).

As an energy modeler and analyst, I often come across new communication techniques to facilitate team-building, and modeling tools to account for the imperfect nature of facility automation. Whether we create our own tools, or use a great new development of our peers, one thing is clear: sophisticated modeling and modeled savings rely heavily on equally sophisticated building automation system (BAS) controls. Taking that interdependency one step further, these two digital sectors have something even more critical in common, and aside from experienced software operators: their reliance on motivated and trained facility managers (FMs). While FMs are not the focus of this article, their role is a lot like the base of a typical team pyramid; they can either create a reliable foundation for continued performance or exacerbate systems degradation.
Because modelers and integrators rely so heavily on FMs, it is important to also integrate expectations and limitations of a project’s FM. Project delivery and bankability becomes much more reliable once the entire team is able to admit what they, and the controls, cannot do. FMs do not necessarily need to know what a points list is, but it is important for them to know which systems can talk to one another and which can only be read. It seems commonsensical, but not only will informed FMs be willing to step out of their comfort zones when they are part of the conversation, they will be less likely to raise issue about something that is an immovable weakness in a BAS.

Realistically Forecasting Controls Upgrades

When creating a business case for a controls upgrade, financial performance metrics like payback and cost/benefit ratio are highly dependent upon simulated BAS conditions, which rely further upon communication with FMs and controls integrators. As a result of these interrelations, it is the energy modeler’s responsibility to seek out conversations with other team-members. If modelers stay in their silos there is no communication loop, which leads to improper assumptions in a simulated environment and unreasonable assumptions when programming ECMs into a BAS.

Forecasting future building performance requires the input of all facility stakeholders before, during, and after a controls project’s implementation. The most common breakdowns occur between performance modeling and controller programming during implementation. As financial performance metrics for ECMs are provided to ESCOs and FMs, these forecasts are often provided with built-in contingencies and disclaimers specifically regarding building operation. These contingencies are becoming good practice in the modeling industry as more becomes known about the role of other team members when bankable savings are on the line.

Financial performance metrics like simple and discounted payback, return on investment, life cycle cost, opportunity cost, cost/benefit ratio, and annual energy cost savings rely heavily on good energy-modeling assumptions. Unfortunately many of these assumptions are products of research projects and databases, especially as related to maintenance cost impacts, when more accurate figures can be obtained from FMs and experienced contractors. Many facility managers, controls contractors, and building owners tend to forget that their roles in these assumptions are equally (or more) important than analysis predictions. If a BAS receives detrimental assumptions, annual energy savings benchmarks could easily be missed by 200%.

Maintenance costs, overhaul costs, and useful lives of equipment are key components of life cycle performance predictions; often driving a particular ECM ahead of the pack among a series of ECMs identified for a given facility. Regardless of the assumptions an energy modeler makes during an analysis, a breakdown has occurred somewhere if: Chiller 1 is predicted to be the best option over Chiller 2 on paper, but requires twice as much maintenance than predicted for Chiller 2. While controls integrators will receive the brunt of an FM’s displeasure stemming from an underperforming system, the cause is sometimes traced back to performance models built without BAS communication inefficiencies.

If you do not operate in the ESPC market or in bankable energy cost savings projects, you may not yet see how deep energy savings often rely on superior performance in energy models. In most cases there are two primary factors that lead to underperformance, as compared to predicted consumption. First, facility managers are largely responsible for keeping to building management schedules, setpoints, setback temperatures, building warm-up times, and other systems performance factors in the BAS. If an energy performance model is unaware of the fact that existing controls prohibit the dedicated outside air systems (DOAS) from reacting to signals from the heat pump, then condenser water loop overheating or cooling will occur. Similarly if boiler pumps cannot communicate with signals from differential pressure sensors, excessive reheat may occur in VAV systems. In both of these cases models will assume...
everything is responsive and communicating, and an ECM to dynamically reset boiler output for varying VAV reheat loads is unknowingly not bankable during financial performance tests. The unfortunate breakdown in these scenarios lies among the modeler assuming open-protocol communication among controllers, and the contractor assuming the modeler somehow knows all of the details supporting the implementation of ECMs affected by the BAS.

The second impending factor related to underperformance is a result of scope-creep. Because modelers in an ESPC or a bankable savings project often rely on contractors for access to trend logs and points lists, some modeling professionals may be restricted to an energy modeling scope alone. More often than not, understanding trend analysis is crucial in making informed decisions about simulated building performance, including sub-meter data where available. These datasets are important when determining whether to include safety factors in models that keep equipment running just a bit longer than a basis of design or shop drawings. Regardless of the industry sector or modeling purpose, parasitic nighttime and weekend loads obtained from trend analysis can be the difference between a useful energy model and a rule-of-thumb. Without the ability to run meaningful trends in an existing building, and scope to evaluate them, an energy model can be more misleading than useful.

In many cases modeling is more than changing control temperatures and features, the “whole picture” needs to be evaluated; this is especially true as trend analysis begins to relate to inter-zone dynamics (air-flow, reheat, etc.) when modeling with powerful industry-leading software.

**Pre-Communicating Findings**

In existing buildings, from audit, to analysis, to install, the following best practices and considerations are precursors to communicating findings to an FM or another owner’s representative.

- Ensure that the actual controls engineer is in the ECM discussion to verify plausibility and contingency factors, introducing actual effectiveness into the conversation (i.e. actual air distribution and limitations to comfort and control).
- Energy models assume that the BAS has complete ability to flawlessly control building systems and needs to be told that older existing buildings do not recover as quickly as new construction, more infiltration is likely, and ECMs often change a building’s stability as a result of affects to its mass-balance.
- Bring light to the fact that some analysis tools are sometimes flawed, especially with VFDs, and it is important to diagnose complicated systems in hourly output reports (in lieu of default monthly or annual reports). Teams should be asking questions like: “Can a pump or fan realistically turn down that low? Is building pressure going to become an issue with a new sequence? Is a terminal unit’s control damper really able to be that dynamic?”
- In a digital-pneumatic hybrid facility or in a partial upgrade project, before qualitative implications from ECMs are discussed, specific and fundamental questions should be asked. These questions should include: “How can our controller go from analog to digital, on a legacy version, of a marginally open protocol?” And, “Are there enough points in the controller module to accomplish this new sequence?”
- Performance curves for major pieces of existing equipment should be modified to reflect existing power draws, efficiencies, and outputs; simulation programs should not be allowed to use default performance – which assumes that equipment is functioning like new. Systems degradation and fouling/scaling factors are important in areas with poor water quality or poor preventative maintenance practices.

Prior to project implementation, a successful team should take the time to review assumptions and limitations of the proposed controls system, as well as the means used to calculate energy savings. If an energy modeler is using a dynamic load reset schedule to achieve cooling-plant savings, each of the inputs should be clearly stated and either accepted or adjusted by the controls integrator. Many times a single measure in an energy model involves more than a dozen field implications, some of which may not be possible. In this regard, it is helpful to create a how-to-guide framework for communicating project hand-off.
A successful example of handoff documents should include the following five parts.

1. A brief explanation of a proposed measure, to be used as initial conversation with the building owner in order to obtain authorization to proceed.
2. A list of temperatures, schedule-implications, and power-demand savings.
3. A list of all affected equipment associated with the measure.
4. Known limitations or approximations of the energy modeling software or calculation.
5. A written review of how to implement the measure by the controls integration engineer.

While it is ideal for the individual responsible for implementing the savings measure to provide the review in step five, many ingrained workflows do not allow for this type of interaction. Many times automation contractors rely on project managers to interface with a project team, and be a liaison to the building owner and installation team.

When communication is perfect, traditional workflows are acceptable, but perfect communication is rarely the case and controls project managers often juggle more than one project at a time. For this reason, a written five or six-step guide is a tangible piece of documentation to refer to, and more importantly is a basis of design. A recommended sixth step would be a post-implementation trend analysis by the energy modeler to confirm successful implementation. When written plans are not presented and agreed upon, the field integrator responsible for programming new or existing controls may be forced to assume a set-point or schedule in order to finish his or her work on time.

While it does not necessarily make sense for modelers to follow controls integrators into the field to observe the installation of new controls, a project closeout procedure should take place. Should scope-creep or tight budgets be a concern, it may be difficult for the energy modeler to generate post-installation trend logs, and communication breakdowns occur at the end of an ESPC or bankable controls upgrade. When a modeler is able to observe post-installation trends, systems adjustments are typically necessary, which is especially helpful to know before the controls contractor receives a punch-list or final payment. A post-install facility walkthrough will also help confirm installed conditions as compared to the basis of design, closing the loop of bankability.

ABOUT THE AUTHOR

Mr. Higgins founded Vibrantcy after experience working in both a specialty sustainability consulting firm and a large commercial and government M/E/P engineering firm. Mr. Higgins has worked on over 300 new and existing building energy modeling projects, over 100 of which had an associated LEED® certification goal. His expertise also includes extensive energy measurement and verification studies, ENERGY STAR® building certifications, life cycle cost analysis, creation of specialize analysis tools, and a breadth of public speaking experience throughout the southwest.
The Benefits of Integrating Environmental Sensors into Building Management Systems

By Andrew White
President, Comptus

Building owners and facility managers are becoming increasingly aware of the influence of weather on the performance of buildings and structures. System integrated weather monitoring can help manage energy performance, occupant comfort, and structural/safety aspects of a facility. Of specific interest is the influence of wind. Wind can impact building air pressure balance, air infiltration, occupant comfort, and safety. With the advent of BACnet®, many sub-systems, from HVAC system performance, to surveillance, to fire and security alarms, are now interconnected, monitored and communicated on. With the increased capabilities of these systems, the opportunity exists to incorporate environmental monitoring inputs for very low incremental costs.

Case Examples:
The building manager at a company in San Francisco arrived at work and found deck furniture on the ground outside the facility. After reviewing surveillance video, they determined that high wind had blown the furniture over the railing of their 6th floor employee lounge deck. Fortunately, no one was hurt and there was no significant property damage.

A luxury high-rise hotel in Los Angeles became concerned when it was realized that high winds were moving unsecured furniture around on the 26th floor rooftop pool deck.

In Montreal, Quebec, wind-blown spray from cooling towers was entering the building’s indoor air system through adjacent fresh air make-up handlers.

Solutions:
In San Francisco, the company connected a wind alarm with analog outputs into their building automation system.

In Los Angeles, the hotel has mitigated their concerns by incorporating two sets of wind speed and direction transmitters into their building management system.

In Montreal, there were several air intakes and cooling towers on the roof. The building engineer realized a wind direction transmitter could be installed to automatically control the system so fresh air would only be drawn from the up wind air intake. The system was included as a component for LEED® certification of the building.

In both Los Angeles and San Francisco, when threshold events occur, the Comptus transmitters communicate analog signals to their respective building management systems, which in turn automatically notify key personnel via SMS and e-mail.

Connection of environmental sensors to BACnet systems is straightforward. Environmental sensors with analog outputs may be connected as objects directly to a network device. A unique instance number must be assigned to each object. In addition a change of value (COV) may be used with event rules. In this case a COV Server that accepts subscriptions and sends COV notifications to a COV client should be used. Example notification levels include wind speeds over preset levels, or wind direction out of a given compass point. In critical applications it is recommended to include polling from the COV client to ensure timely notification of events is made.

Additional Examples:
Large municipal water management districts incorporate rainfall transmitters into their systems so their storm drain management systems can be controlled in response to localized microclimate weather events. Benefits include lower labor costs, energy savings and reduced wear on system pumps, gates and valves.
Passenger and equipment safety on the Barrakka Lift in Malta is controlled with wind speed and light sensors incorporated into the elevator system. If there is a high wind event the lift will slow down or stop to ensure passenger comfort and safety. The system will also turn on elevator lighting after dark or during weather events.

Other applications include automated monitoring of membrane roofs in agricultural and other systems, fountain controls, awning control systems, and more. With BACnet there are many opportunities for managing the relationship between the outdoor environment and building systems that can improve energy efficiency, occupant comfort, and safety.

ABOUT THE AUTHOR

Andrew White is the President of Comptus. The company works closely with a wide range of customers from large automation product manufacturers, to engineering firms, government and municipal agencies, contractors, distributors and end users. Comptus products are deployed on all seven continents and in addition to the building automation industry are used in environmental research, renewable energy, fountain and other markets.

BACnet and Numbers

By Bennet Levine

R&D Manager, Contemporary Controls

BACnet can be a little confusing when it comes to its numbers. There are MS/TP MAC address numbers, BACnet/IP IP address numbers, device instance numbers, network numbers, etc.

In some cases these numbers must be unique. In some cases these numbers should be the same. Here we will outline the rules for some of the more obscure BACnet numbers and why BACnet has these requirements.

I think most people understand IP address numbers. IP addresses and their rules are fairly well understood and there are many sources to explain these rules. MS/TP MAC addresses are also fairly simple; addresses range from 0 to 127 (for master devices) and must be unique on the MS/TP network. However if you have multiple MS/TP networks, which are not directly connected, each network can use the same set of MAC addresses, for example MS/TP network 1 can have MACs 0, 1, 2, and 3. On MS/TP network 2 you can also have MACs 0, 1, 2, and 3 (see figure 1). This is not an issue as the two networks will also have a network number to help distinguish the full identity of the device. For example on network 1 we have MAC 0. To talk to this device you would talk to network 1/MAC 0. To talk to MAC 0 on network 2 you would use network 2/MAC 0.

Device instances are another set of numbers which can seem a little superfluous as each device has its own network address such as a MAC address or IP address, etc. However, the device instance is used as a way to uniquely identify

Figure 1: Two MS/TP networks connected to one head-end through two BACnet routers
a device in the network. The rule in BACnet is each BACnet device must have its own unique device instance number. You may ask, “How does this help?” Carrying on with the previous example, you can have two MS/TP MAC 0 devices but on different networks. As we have given each of these devices their own unique device instance we can simply use their device instance to help identify the device. For example we use 111 for network 1 device with MAC 0 and 222 for network 2 device with MAC 0. Then we only need to use 111 to fully address the first device and 222 to fully address the second device. The device instance can be thought of as the “numeric domain name” of the BACnet device. You don’t need to know the IP address of google.com. You only need to know google.com, the website’s domain name. This also allows the IP address to change if needed and the domain name remains the same and is easier to remember. The same is true in BACnet. Once a head-end is given a device instance with which to communicate, the device’s physical address or its network number can change and the head-end will learn how to talk to this device through BACnet discovery techniques (see figure 2).

Let’s discuss BACnet network numbers a little further. As we said, the network number must be unique for each network. What does this mean? In our previous example the network number 1 & 2 was used to help differentiate between the two different MS/TP networks. These network numbers are usually only configured in BACnet routing devices as these devices generally apply these network numbers to messages that flow through them. Therefore it is important in our example that the two BACnet routers in figure 1 know their connected MS/TP network numbers are 1 & 2. However, their BACnet/IP network numbers must also be set. The question becomes are these unique as well? In this case the answer is no. The two BACnet routers are directly connected. Therefore each of these BACnet/IP network numbers should be the same. We can set the BACnet/IP network number for both routers to 3. This allows requests which come from the head-end to be addressed to devices on network 1 & 2 and for the responses to those messages to go back to network 3 where the head-end is located (see figure 3).
As you may have noticed, BACnet has requirements for a few unique numbers. It is best to create a system for developing these numbers and somewhere to document these numbers so you don’t reuse a number that must be unique. The device instance number is a 22-bit number and the network number is a 16-bit number. This gives you 1 to 65534 for your network numbers (0 and 65535 are not allowed) and 0 to 4,194,303 (4,194,304 is not allowed). These may appear to be large ranges but it is recommended to have a system where you are able to keep the numbers unique and perhaps even easy to remember if you encode them using a system. This makes it nice when you are trying to remember all of these numbers.

For example you could use XXYYY for your network numbers where XX=floor (01 to 65) and YYY=zone (0 to 534). Or you could use a portion of the IP address of the router to indicate the network numbers. For example you could use XYZZZ. If your network was 10.0.0.0/24 you could use the last octet of the IP address (001 to 254) for the ZZZ portion, X=1 for MS/TP, X=2 for BACnet/IP, etc. and Y the port number of the router. As each BACnet router would probably have the same BACnet/IP network number you can use the IP address of the head-end for the ZZZ portion of the network number for the BACnet/IP network number for all BACnet routers.

At this point you may be wondering when the BACnet/IP network needs to be different. All BACnet communications to the same UDP port number, 47808 for example, should use the same BACnet/IP network number. If your system used multiple UDP ports, say you want to isolate BACnet/IP traffic between groups of devices and your head-end supports this, you can assign different UDP port numbers for the different groups. For example, you can assign 47808 to the first group, 47809 to the second and so on. Broadcast traffic sent to one group (one UDP port) will not be seen by the other group (see figure 4). This can help keep the broadcast messages to a minimum in each group.

One popular system for keeping track of all of this is an Excel spreadsheet. Here you will find the IP addresses, device names, device instances and network numbers for all BACnet devices. This makes it easy to remember and easy to make sure the unique numbers (and names) are not duplicated.

As you can see, BACnet has a few numbers which must be handled properly and with some planning you can create a comfortable system for controlling these numbers, thus creating a well working BACnet system.

Here is a list of the BACnet numbers and their rules as discussed here.

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device Instance Range</td>
<td>0-4,194,303</td>
<td>Unique in the entire system</td>
</tr>
<tr>
<td>Network Number Range</td>
<td>1-65534</td>
<td>Mostly unique</td>
</tr>
<tr>
<td>MS/TP MAC address</td>
<td>0-127 for masters (0-255 for slaves)</td>
<td>Unique on the MS/TP bus</td>
</tr>
</tbody>
</table>
BACnet Developers Q & A

By Steve Karg
Senior Engineer, WattStopper

Over the years while being involved in the BACnet committee and developing BACnet products, I have fielded questions about BACnet product development. Some of those questions are answered by the official BACnet Testing Laboratories “Implementation Guidelines”. However, some questions are beyond the general scope of that document.

Question: When I run my bacnet server device, it will broadcast an I-Am on start-up. In the Device object, the “I-Am” bit is set in the protocol-services-supported property. When I run a BTL pre-testing tool with my device, it flags an error that suggested “Only A-Devices (Client Devices) should EXECUTE I-Am. (Read Addendum K.5.1-K.5.4 carefully)” So I read K.5.1 and K.5.2 DM-DDB-B and the way I understand it, is that a server should “execute” Who-Is and then “initiate” I-Am and my device should not execute I-Am. What is correct?

Answer: BACnet protocol-services-supported property bit value “Execute” is equivalent to “consume” or “handle”. In your BACnet code, you would determine which BACnet Services are being decoded and “handled” to know which bits to set in the protocol-services-supported property. Your device, as configured, uses Who-Is and I-Am to bind addresses for COV & Alarm & Event notifications. Your device acts as a client device (also known as an “A” device) to bind addresses and “handles” the I-Am to determine the address. If your product doesn’t implement or use those notification features, and therefore, doesn’t “handle” the I-Am, you should not set the I-Am bit in the protocol-services-supported property.

BACnet devices can be a mix of client (A) and server (B), or server-only (B). A client-only device is not permitted since all BACnet devices must support ReadProperty as a server (B).

Question: I’m writing an open source BACnet software library implementation and was wondering what number I should put in the default Vendor-ID field. I quickly checked the official vendors list, but don’t see any “not defined” or something like it. I’m reticent to ask for my own Vendor-ID because the software library will probably end up being used by a bunch of different people anyway. Is there a throwaway or undefined number for this kind of situation?

Answer: Although the BACnet committee reserved Vendor IDs 555, 666, 777, 888, and 999 to use in example documentation, open source software projects and libraries should use an official free BACnet vendor ID. A Vendor ID can be obtained by anyone, even non-companies and open source software libraries and applications. The official procedure is here:


Question: Could someone tell me the best way to organize firmware updating through BACnet communication? AtomicWriteFile, PrivateTransfer, or something else?

Answer: I have used AtomicWriteFile service in combination with ReinitializeDevice to perform firmware updating in products.

In one device (single board computer with RTOS and file system), a new firmware file is sent with AtomicWriteFile service and confirmed with AtomicReadFile service. Then the device was instructed to use the file as the new firmware using ReinitializeDevice service with a special password.

In another device (microcontroller), the device was instructed to go into bootloader mode using ReinitializeDevice service with a special password. Then the firmware was sent using AtomicWriteFile service and confirmed with AtomicReadFile service or by reading an object property value that represented the file checksum. Then the bootloader was instructed to use the new firmware using ReinitializeDevice service with a special password.
Note that sometimes writing or erasing flash memory takes longer than BACnet MS/TP timing allows for responses or token passing (if your device was using the MS/TP datalink layer), so buffering may be needed.

Of course, PrivateTransfer could be used for updating firmware, but then only your tools could be used to update your device firmware in the field.

ABOUT THE AUTHOR
Steve Karg is a Senior Engineer at WattStopper, in Birmingham, Alabama. He has been an active member of ASHRAE SSPC 135 (BACnet) since 2001, and convenes their Lighting Applications working group. He wrote an open source BACnet Protocol Stack hosted on SourceForge.net, and continues to help maintain the BACnet decoder in Wireshark.

We Want to See You at PlugFest!

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The BACnet International BACnet Testing Laboratories Working Group (BTL WG) invites manufacturers of BACnet products to attend the 16th annual Interoperability Workshop at The University of New Hampshire in Durham, NH. This event permits vendors to test their BACnet products with BACnet devices from other vendors in a neutral and friendly environment.

In 2015, nearly 85 BACnet engineers representing 34 companies attended the workshop and improved their BACnet implementation and testing methods.

Discover details on the PlugFest website, [www.bacnetinternational.org/plugfest](http://www.bacnetinternational.org/plugfest).

For more information and registration details or questions contact Membership and Trade Show Manager David Nardone at [david@bacnetinternational.org](mailto:david@bacnetinternational.org).
BACnet International is an industry association that facilitates the successful use of the BACnet protocol in building automation and control systems through interoperability testing, educational programs and promotional activities.

**BACnet is leading the world in Building Protocol Standard:** It plays a significant role in building automation projects worldwide.

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