Optimizing Economizer Operation by Virtual Commissioning through Remote Co-Simulation

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Abstract

The authors modeled an existing building in EnergyPlus and connected the computer model to a clone of the building's air handler controller. The energy model was based on a three-story structure comprising a mix of offices and classrooms. The energy model simulated the inputs normally provided to the controller hardware by physical sensors within the building. The controller response was then fed back into the energy model for a ping-pong style co-simulation. The authors used this approach to identify and correct areas where the economizer control settings were not optimal, potentially saving the building 4% (56,000 kWh) of energy each year. This approach could be replicated on other systems and buildings as a way of performing pre-commissioning or advanced retro-commissioning of a building's energy management control system (EMS).

Introduction

This paper provides an example of the virtual commissioning process, documenting the steps, challenges, and benefits of this technology. Our aim is to support commercialization efforts and verify the reproducibility of the virtual commissioning process developed by previous research teams (Dong, et al., 2012) (Harmer & Henze, 2015) (Pang, Wetter, Bhattacharya, & Haves, 2012) (Li, Augenbroe, Dong, & O'Neill, 2012) (Wang, et al., 2013). Virtual controller commissioning links physical building control systems to energy models in a co-simulation and analyzes their performance over a full year (i.e. the simulation of a full year). If virtual commissioning can be developed, refined, and commercialized, it could become an attractive service that utilities use to ensure efficient use of energy intensive building systems. It allows for control testing and optimization without putting either occupant comfort or equipment in harm's way while ensuring proper operation of HVAC systems.

Optimal controls are essential for building efficiency. However, for every building's Energy Management Systems (EMS), there are times when the controls either malfunction or are out of tune. While the controls are being adjusted, the first year of operation for any new building can be a difficult and unpredictable time for both the occupants and the energy utilities. Older buildings also suffer from control settings that have fallen out of tune. Adjustments are required after any change in occupancy or usage. Controls might have been set to a factory default which may not be appropriate for the climate where it is installed. Although the operators at the site may have changed the settings, these may no longer be adjusted for the season or the current loads. It then falls to the building operators to correct these settings. Given that building operators often have multiple responsibilities and are driven by comfort complaints, these problems can go undetected for long periods of time. These control problems can incur exorbitant and unnecessary energy costs; commercial buildings operated in an unintended manner can increase energy consumption by 20% compared to the intended design (Westphalen & Koszalinski, 1999). Therefore, a good commissioning process is essential for the proper operation of a building. Commissioning improves both comfort and productivity in buildings (Mills, 2011). However, because every building and control system is unique, it is challenging to cost-effectively (and continuously) analyze and tune these controls through a traditional commissioning process. Virtual commissioning is one technology that can assist in this control tuning effort.

Previous work

Several research teams have shown that it is possible to commission a building by using an energy simulation (Harmer & Henze, 2015) (Li, Augenbroe, Dong, & O'Neill, 2012). This research becomes increasingly relevant as building energy modeling becomes more widespread. The connection of real building hardware to ideal software models illuminates areas of controls optimization that can save energy while maintaining occupant comfort. Virtual commissioning can be used to test advanced control strategies and is an approach that can be applied to buildings at all stages of life from start-up to current operation.

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There is a significant body of research on using energy models to commission buildings. In one study, a research team relied on a calibrated EnergyPlus model to identify abnormalities in a building's current operation in a monitoring-based commissioning (Wang, et al., 2013). While monitoring-based commissioning compares the simulation results and the building usage side-by-side, other researchers have used a method to link the building hardware directly to an energy model (Pang, Wetter, Bhattacharya, & Haves, 2012). A team of researchers at Lawrence Berkeley National Laboratory (LBNL) have pioneered work in co-simulation through the development of a software platform that enables communication between an energy model and a physical controller (Wetter, 2011). This software platform: Building Controls Virtual Test Bed (BCVTB) serves as the "middle-ware" that both the energy model and controller can communicate across (Haves & Xu, 2007). The way that BCVTB transfers information is succinctly described by Dr. Wen:

At the beginning of each time step, BCVTB blocks all the co-simulated programs and performs data exchange. Each program sends its outputs to BCVTB and gets its inputs from BCVTB through Simulator socket writing and reading respectively. As soon as the data exchange process is completed, BCVTB unblocks the operation of the programs, and each program calculates and generates new outputs during the remaining of the time step based on the newly acquired inputs. The new outputs will then get exchanged at the beginning of the next time step. The same process repeats until the specified simulation time duration is achieved (Wen, 2011).

The information is exchanged between the model and the controller through a communication protocol known as Building Automation and Control Network (BACnet) protocol. The controller is connected to the model using two "actors" (programs) inside BCVTB: the BACnetReader and the BACnetWriter. These actors rely on the open-source BACnet Protocol Stack (Karg, 2013) that downloads with BCVTB. BACnet signals comprise a series of digits that are difficult to understand without any context. The BCVTB actors BACnetReader and BACnetWriter, use associated XML files that provide syntax for the numbers so the user can more easily understand how to send or request information from the controller (Haves & Xu, 2007). In this way, simulated variables such as temperature and fan status are provided to the controller in place of signals that would typically come from physical thermostats or other analog inputs. Controllers communicate using BACnet through one of three different connections: Ethernet, Internet Protocol (IP), or Master Slave Token Passing (MSTP). BACnet Ethernet and BACnet IP can both communicate through an Ethernet cable from the controller to the computer, while MSTP communication relies on a shielded 22-gauge two-wire cable. Alternatively, BCVTB can be used to link energy models with analog signals by using a particular analog to digital converter. Using purely analog signals is an alternate pathway of model-controller communication. Previous work on model/analog data transfer has also been performed at LBNL (Nouidui, et al., 2011).

Several researchers have used BCVTB in proof-of-concept demonstrations (Pang, et al., 2011) (Wang, et al., 2013), but these have typically focused on live co-simulation. In Pang's research, the energy model was built in EnergyPlus and additional sensors were added to the EMS system. BCVTB was used to connect the model to system signals and weather at the site; they took care to synchronize the BACnet signals to real-time. Later, this same research was continued at the site as a live-fault detection strategy (Dong, et al., 2012). This is similar to the approach of (Li, Augenbroe, Dong, & O'Neill, 2012) who used BCVTB for fault detection diagnostics by sending all logged information to a database for further analysis. Li's research used this database collection to gather information that could be viewed in real time to assess the building's performance and identify any anomalous behavior.

We focused on using co-simulation to quickly commission a controller. For this reason, we used OpenStudio to quickly generate our energy model. We did not wish to pursue a live connection as had (Pang, et al., 2011) and (Dong, et al., 2012), but neither did we wish to leave the model and controller completely separate as had (Wang, et al., 2013). Instead, we used a model to controller connection and a full year's worth of simulation data to identify controller errors. We reproduced and adapted a commissioning process closest to (Li, Augenbroe, Dong, & O'Neill, 2012). What we did differently was to run remote commissioning with no live connections so we could compare responses between different pieces of control hardware from different manufacturers. This provided some reassurance to the facilities team who worried that a live connection might pose a security or operational risk. We focused our research testing on a single controller at a remote location using historical weather data for inputs. We ran annual simulations on different remote controllers instead of relying on live data feeds. We pursued a strictly digital communication pathway in our research because the number of signal inputs and outputs we were considering was greater than the number of analog ports available to us on our A/D converter hardware. This remote testing of full simulations could allow control companies to pre-test their controls in a virtual environment, limiting expenses and site visits.

We developed an energy model of a three-story office building and acquired a duplicate of the building's air-handling controller. We used the model to understand the current control settings by simulating both typical design-days and full years of local historical weather from a remote location. The model and controllers of different manufacturers were used to explore the EMS logic and test new settings. From these findings, we pursued a remotely-based work-flow around this technology. This virtual commissioning at an operational site enabled us to assess the commercial appeal of this process and helped us to identify several barriers that might hinder widespread adoption.

Methods

Site and equipment

The site selected for this project is a three-story building that serves a mix of classrooms and offices. The building's HVAC equipment consists of a typical Variable Air Volume (VAV) system with two large Air Handling Units (AHUs). One AHU serves the basement and a server room, while the main AHU provides ventilation, heating, and cooling to most of the building. The first step of the research was to develop a calibrated energy model of the existing building in the OpenStudio application for EnergyPlus. Calibration was performed by comparing the building's monthly electrical consumption for the calendar year of 2014 to the results of the EnergyPlus model simulated using an Actual Meteorological Year (AMY) file from a nearby airport for the same timeframe. This AMY file was provided by Weather Analytics. The building operators provided us with hourly load and consumption information which we used to augment the calibration process. Once we calibrated the building energy model, we connected it to BCVTB. We linked the energy simulation to a controller and then studied the differences between this, and how EnergyPlus would simulate ideal control actions, to correct and optimize control settings.
The building's main AHU is responsible for much of the building's heating and cooling. Therefore, we focused on commissioning its controller. A layout of the system and main control points is displayed in Figure 1.

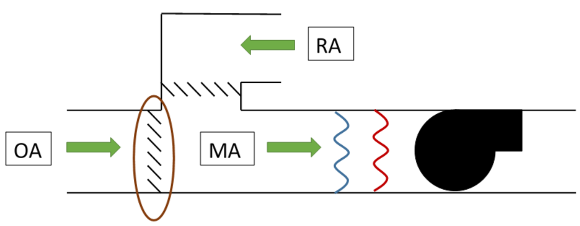

Figure 1: The test building's AHU layout: monitored data points are in boxes - return air (RA), outdoor air (OA), and mixed air (MA) temperatures. The control action point (the outdoor air damper) is circled.

This AHU is controlled by an Alerton VLCA-1688. We tested the virtual-commissioning process by focusing on one aspect of the AHU's operation: the control of the outdoor air into the building. We could have looked at optimizing discharge air temperature, chilled water temperature, the supply rate, or any number of other systems controlled in the building, but chose just one example for this study for the sake of simplicity. The building's main AHU is equipped with a damper that can regulate how much outdoor air is being brought into the building and the controller can open or close this damper to bring in more outside air if it is deemed economical to do so. In theory, the economizer will bring in more cool air from outside if the outdoor temperature is lower than that of the indoor temperature so that free cooling is provided to the spaces without relying heavily on the chilled water coils. This can save the building a significant amount of energy if the control is employed correctly, but it can also cost the building more energy if the controller setpoints are not optimal. This made it a very good candidate for this particular study.

Establishing communication

When connecting the energy model to BCVTB we learned that the software is sensitive to both Java versions and path locations. Our team found it easiest to run our application using Windows 7 with 64-bit operation and to ensure that our version of Java was also 64-bit. We also amended the windows Path variable by appending the location of the Java and EnergyPlus installations. Dr. Nouidui provided us with assistance in navigating the installation through an online forum (Nouidui, BCVTB forum, 2015). After adjusting the path variable and ensuring version consistency, we were able to run an EnergyPlus example file in BCVTB that downloads with the application.

We then connected our particular energy model to BCVTB. We exported our OpenStudio file to an EnergyPlus text file (idf) and opened this in a text editor. Next we added the external interface blocks of code to the end of the file. We imported and exported other variables from the EnergyPlus model to BCVTB by editing the energy model's text file and adding a short block of code for each variable as shown in the BCVTB user's manual (Wetter & Nouidui, Building Controls Virtual Test Bed User Manual Version 1.5.0, 2015). The variables we chose for this study included the outdoor air temperature, the outdoor air damper position, mixed air temperature, and return air temperature. We selected these variables because they are the inputs required of the controller. As an initial compatibility check, we controlled the setpoints in the model through rudimentary logic within BCVTB. Once simulation results tracking a particular variable of interest showed that editing controls within BCVTB were indeed influencing the model in an expected manner, then the research moved on to establishing the controller connection with BCVTB.

Connecting the controller to BCVTB

Establishing direct model to controller communication was performed using a stand-alone laptop that could connect to the controller on a Local Area Network (LAN). Connection from the EnergyPlus model to BCVTB was entirely virtual (occurring within the computer). The controller on the other hand, was a separate piece of hardware that was joined to the computer through an Ethernet cable. The first controller tested was the KMC Flexstat. The Flexstat communicates through BACnet MSTP only. In order to communicate with BCVTB, the Flexstat used an MSTP connection to a MACH-ProWebcom router that translated MSTP to IP. The IP connection was then set up on the laptop through creating a LAN and changing the laptop's IP address to one that was compatible with the new network. This enabled the laptop to recognize the controller and signals could be sent back and forth to the controller. These signals were tracked using a software called Wireshark which recorded every piece of communication between the controller and the laptop. Using this, we could see when the controller was recognized by displaying when signals were successfully sent and received between these devices. This set-up is shown in Figure 2.

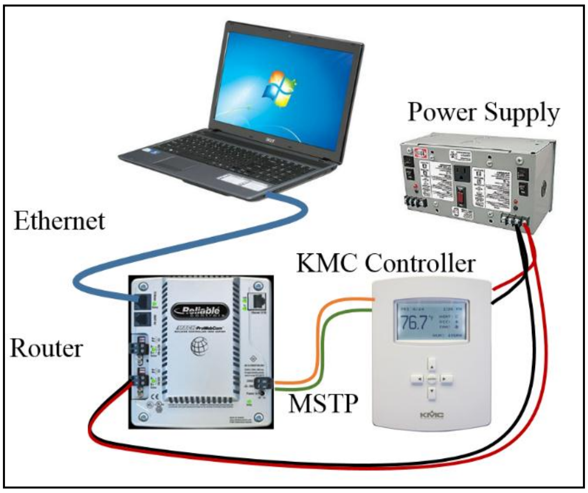

Figure 2: KMC controller to energy model set-up

Both the KMC controller and the ProWebcom router needed to use the same 10-Volt power supply. The router was the translator between the laptop and the controller that could take MSTP signals to and from the controller and LAN through the Ethernet connection to the computer. The connection to Alerton controller (a VLCA-1688 model) as shown in Figure 3 proved much simpler to set up since it could communicate through Ethernet, IP, or MSTP.

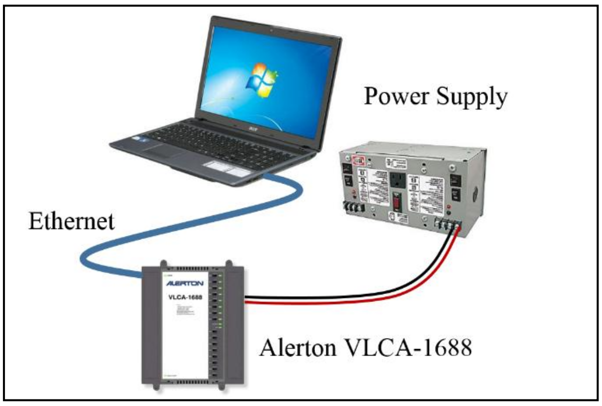

Figure 3: Alerton controller to energy model set-up

We set the Alerton connection to BACnet IP so it could communicate with BCVTB directly through an Ethernet cable as shown in Figure 3 without a router in between the laptop and the controller.

Once we learned how to set up these devices, we studied the air-handler control settings from three different perspectives: EnergyPlus, a KMC Flexstat device, and an Alerton VLCA device identical to one at the site. We had to contend with the fact that these two controllers had very different input and output signals as shown in Table 1. The objects in table 1 are the BACnet signals and their associated meanings. Without a full understanding of the control variables and their associated BACnet signals, it is impossible to understand and adjust the controller.

Table 1: Controller input and output signals

KMC -Flexstat		**Alerton VLCA-1688**	
Inputs	**Objects**	**Inputs**	**Objects**
RA Temp	AI-7	Freeze Stat Status	BI-8
OA Temp	AI-4	Fan Status	BI-5
MA Temp	AI-3	VAV's in Warmup	AV-40
Discharge Air Temp	AI-2	OA Temp	AV-0
		Econo lockout temp	AV-56
		OA Temp	AV-0
		Return Air Temp	AI-2
		Min OSA %	AV-65
		Mixed Air Temp	AI-1
		Mixed Air Max Stpt	AV-60
		Mixed Air Min Stpt	AV-61
		Cooling Signal	AV-10
Outputs		**Outputs**	
OA Damper	AO-9	Econo Command	AV-26
		Econo % Reversed	AV-29
		MA Damper Cmd	AO-4
		OA Damper Cmd	AO-3

Results

Once we connected the energy model to a controller, we contrasted its control sequence with the EnergyPlus default settings. These default settings in EnergyPlus proved to be our starting point. We recognize that these defaults are not necessarily meant to be ideal values, and these settings at any site need to be verified by practitioner aware of the climate and codes. Yet, they served as a useful starting point to contrast the current controller settings; any major differences we encountered merited further investigation. We ran a one-month simulation with each economizer situation having the same settings: a desired supply temperature of 55^{o}F and a high-limit lockout temperature of 70^{o}F. By selecting the output variable to be the damper position, we could compare the behavior of the three different control options: EnergyPlus, the KMC Flexstat, and the Alerton VLCA model. The results revealed that all three control sequences behave similarly but at different scales shown in Figure 4. The EnergyPlus default control setting opens the damper the most, the Alerton device follows the same profile, but is more conservative in its economizer usage. The KMC device is the most conservative and uses the economizer the least.

When running the simulation for the month of June, the real controllers allowed in less outside air than the EnergyPlus defaults – even when they shared the same settings. When the energy model was tied to a physical controller, the simulation results indicated higher energy use because there was less use of the economizer. The lockout temperatures on each controller, and in EnergyPlus were set to the same value, but each controller allowed in a slightly different magnitude of outside air. The stand-alone EnergyPlus model opened the damper the most, the Alerton controller opened the damper a little less, and the KMC opened the damper the least. We were encouraged to find that the three controllers behaved similarly, but through this research we realized that the actual internal PID tuning of the controllers had a significant impact on how effectively they would use the economizer.

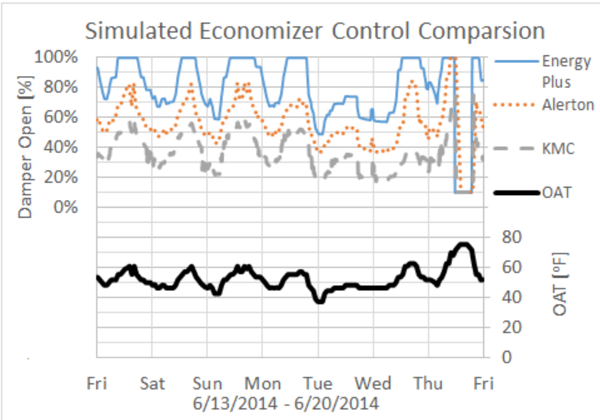

Figure 4: Snapshot of controller behaviour during a simulated week in June

After studying Alerton VLCA field controller settings (the actual controls at the site), we learned that the building is currently operating its main air-handler with a high-limit temperature lockout on the economizer of 60°F. Anytime the outside air climbs above 60°F, the system uses mostly return air from the building and only a minimal amount of outside air for ventilation. The supply air to the building is set at 55°F. Between the return air and the outside air, the building ideally uses the air that requires the least amount of conditioning to reach 55°F. Since the outside air is locked out at 60°F, the building loses the opportunity to use any outside air between 60°F and the return air temperature which is typically at 76°F or above.

In order to investigate this savings opportunity, we ran three different annual simulations focused on outside air damper control. We ran each scenario using a TMY weather file for this building site. In the first case we simulated a typical year with current controls by relying on the Alerton VLCA-1688 with the exact logic in use at the site to decide when to operate the economizer. Next, we adjusted the controller's settings to increase the maximum economizer lockout temperature to 76°F and ran the simulation again. We found that it would make a difference of over 56,000 kWh (4%) per year shown in Figure 5. Next, we performed further controller tuning by enabling the controller to modulate the supply air temperature based on internal zone temperatures thus increasing the use of the economizer. This setting was not in use at the building even though it was a benefit of such a sophisticated controller. Enabling this setting in combination with raising the economizer lockout temperature resulted in an estimated savings of 12% of the building's total energy user per year. Once again these savings were for adjustments of one control point only on a single piece of equipment. Significantly more savings could be found by further tuning and expanding the controls research beyond the economizer to other aspects of the building control such as discharge temperature, plant loop temperatures, and setback temperatures. Based on this, we are confident that implementing the developed simulation-based pre-commissioning protocol on all of the highest priority control points within the building could easily match the 20% annual savings estimate put forth by (Westphalen & Koszalinski, 1999).

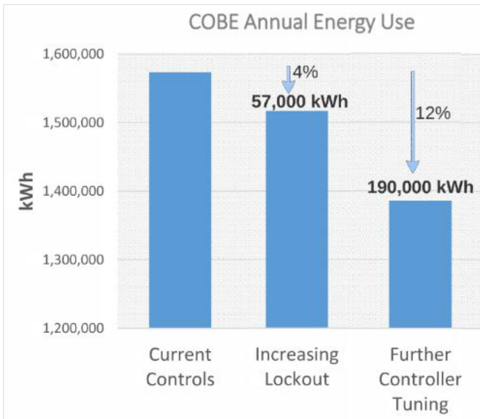

Figure 5: Potential site savings identified in the project

Discussion

One of the unique aspects of this research is that it was performed almost entirely off-site. Our research team visited the site twice briefly to verify modeling and operational assumptions, but performed the bulk of the analysis in a remote laboratory. Rather than connecting the energy model directly to the controller at the site, we simply acquired a duplicate controller of what was in place at the site and loaded the same operational logic onto it. A duplicate controller was easily procured from surplus inventory at the facility, but the research team also had to verify that the same logic was loaded onto the machine, and that we could access to the manufacturer's native program for BACnet to identify each control point as shown in Table 1.

During testing of BCVTB, we found it easiest to send signals through BACnet IP as opposed to Ethernet or MSTP. Field controllers use a mix of signals in their logic. These signals include inputs, outputs, and values and can be binary or analog. The BACnet protocol includes 18 different signal or "object" types (Swan, 1996). Two of the object types that the controller used included analog inputs, which serve as sensor inputs, and analog values, which serve as a setpoint or other analog control system parameter. The objects are typically programmed by the controls engineer before they are set in the field to receive a signal from a specific device such as a thermostat. The Alerton controller did not allow analog inputs to be over-written. Therefore, all variables required for the damper control had to be changed over from analog inputs to analog values. By changing the BACnet object type, we were able to edit these channels to the numerical values we desired. This conversion was done in the controller's native program, Envision for Backtalk. While the process of replacing analog inputs with analog values only required an hour of time for an experienced user, it was still an inconvenience and presented a minor hurdle to simulation-based commissioning and testing for the Alerton controller. The Flexstat and Reliable Controls software did not have this particular hurdle, which expedited the testing procedure. These vendor-specific issues are important for evaluating market penetration potential and anticipating routines needed for successful program or technology implementation at a large scale.

We discovered that the default settings in EnergyPlus limit the model's ability to minimize the damper position. This was due to two causes: strict Indoor Air Quality (IAQ) controls, and the modelling tool assuming ideal operation. EnergyPlus will maintain indoor air quality according to specific building standards, ventilating the building optimally to meet these standards (ASHRAE, 2007). Once we discovered these settings, we could adjust them, but we were unaware of these defaults at the beginning of this research. Another example of the EnergyPlus model's idealized operation is that the EnergyPlus model will use as much free cooling as possible. This causes the damper to operate in an ideal manner, opening the damper more than either of the physical controllers signalled.

For dry climates, it is advantageous to use the economizer when the outdoor air drybulb temperature matches that of the return air temperature. However, this is not the case in humid climates as the outdoor air can carry significant latent loads. Thus, in a humid climate it is best to manage the economizer with enthalpy control as opposed to a drybulb temperature lockout. It is possible that the KMC and Alerton controller tuning was conservatively set so that the controller would function well in a range of climate zones – opening the damper less in dry climates than might be ideal. This investigation revealed that this adjustment for economizer control specific to the climate can have a significant impact on the actual operation of the equipment and how much outdoor air is brought into the building and merits future research. In addition to the tuning adjustments required for the specific climate, this commissioning also revealed how some of the potential benefits of a controller might be under-utilized. The Alerton controller at the site was capable of modulating the supply temperature instead of keeping it static, thus allowing more dynamic operation of the economizer, yet this feature was not enabled at the site. The twelve percent savings identified as a result of implementing this ability in the controller accounted for the fact that there might be additional fan energy used as a result of modulating the supply temperature.

Another lesson learned in the process was that the energy simulation using the full loop communication cycle took much longer than an energy simulation on its own (without hardware-in-the-loop). On a typical Windows 7 laptop with four gigabytes of RAM, the model simulation required about five minutes to run the model through a full year of weather data. Adding the controller hardware-in-the-loop increased the simulation time substantially. A simulation required about 24 hours for to run through one full year of AMY weather data. The first connection to the controller significantly slowed the simulation. Adding subsequent connections to the controller, for example, testing multiple variables and parameters, slowed the simulation down only incrementally for each additional point.

The EnergyPlus user documentation recommends using at least four timesteps per hour for a traditional simulation, with a minimum of one timestep per hour. However, when running a co-simulation, this guideline does not apply. When we used fewer timesteps we observed more controller signal oscillations. While increasing the size of the timesteps allowed the model to run significantly faster, it certainly reduced the resolution of the results. When the model was running at four time steps per hour, the simulation would complete a year's run within one day of clock time. The shorter the timesteps however, the better EnergyPlus will be able to handle dynamics and larger timesteps (even at 15 minutes) could be a source of controller error.

The weather file we used in the simulation (like most) reported conditions only on an hourly basis. EnergyPlus performs a time-weighted hourly interpolation of this data, but at its heart, the data is still fairly coarse compared to the typical inputs received by a controller. For example, one of the analog inputs on the Alerton VLCA-1688 for the mixed air temperature was designed to receive data at a sampling rate of many times per second. For a TMY file, the minimum space between steps is one minute. This can be overcome by using a custom AMY file with finer measurement resolutions, but we did not explore this approach in this project. Therefore, when running courser timesteps, BCVTB provided the controller with a constant signal in between each step. This situation is a departure from a strict co-simulation approach which syncs the building to the controller in real-time. Instead, the goal here is to approximate building behavior for one year to quickly identify areas of controller tuning. Yet, even this compromise of taking a day or more of clock time to run simulations at fine timestep resolutions is a significant improvement over waiting for an actual year to pass as is required for a best-case scenario of physical commissioning.

This virtual commissioning approach intrigued two different controls industry partners on this project. One of the valuable contributions of the project was to initiate contact with these industry practitioners. Both are now aware of the potential of simulation-based pre-commissioning and are interested in the possibility of testing control sequences prior to installation at a site, as this would mitigate some of their operational risk. Utility companies and building owners would also benefit from the reduction in energy consumption.

Conclusion

We constructed a calibrated EnergyPlus model and established a co-simulation between BCVTB and EnergyPlus that communicated with EMS hardware-in-the-loop. We studied a 50,000 ft^2 three-story building serving a mix of classrooms and offices and modeled it in OpenStudio/EnergyPlus. We set up full-loop communication between this energy model and a duplicate of the physical controller at the building facilitated via BCVTB. Our research provided a practical application of the methods outlined in earlier work from LBNL (Pang, Wetter, Bhattacharya, & Haves, 2012). We replicated and extended these methods, and proved savings potential from its practical application identifying, overcoming, and documenting several problems that are necessary to repeat the method and support commercialization. This research was performed to help enable incentive programs or other value-added energy services to be developed which will improve the effectiveness of new building commissioning, existing building retro-commissioning, and promote innovative designs for high performance buildings. The project also served as an outreach to two different control companies, acquainting them with simulation-based pre-commissioning. This research showed a direct savings for a physical building and provided the researchers the means to begin expanding the use of this technology as a value-added service. Almost all of this work was performed remotely without the high expense of a day's worth of time for a commissioning agent and the facilities team. By using a controller that was separate from the actual building at the site, we were able to run full annual simulations and record the controller responses without waiting for specific conditions to occur in real time.

Connecting a calibrated energy model with a physical controller provides a streamlined diagnostic tool to identify control faults that might otherwise have gone undetected. The virtual commissioning process enables a fast comparison between a building's actual control settings versus the idealized settings in EnergyPlus. Contrasting the two controls allows for a full analysis of the system without monopolizing the time of the building operators. This shows the pathway for a potential service that can test control schemes for a new structure even before it is complete or provide continuous re-commissioning or retro-commissioning for existing buildings.

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Nomenclature

A/D – Analog Digital

AHU – Air Handling Unit

AMY – Actual Meteorological Year

BACnet – Building Automation and Control network

BCVTB – Building Controls Virtual Test Bed

EMS – Energy Management System

IAQ – Indoor Air Quality

LBNL – Lawrence Berkeley National Laboratory

MA – Mixed Air

MSTP – Master Slave Token Passing

OA – Outdoor Air

RA – Return Air

TMY – Typical Meteorological Year

VAV – Variable Air Volume

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