Scholarly Report
Graduate Class of 2013

The Role of Direct Digital Controls in Commercial Buildings

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Keywords

Direct Digital Control, Energy Management System, HVAC, Demand Response, Smart Grid

I. Abstract

Direct Digital Controls (DDC) serve as an advanced integration system between building Heating, Ventilation, and Air Conditioning (HVAC) equipment, and user controllability. Such controllability allows for the implementation of Energy Conservation Measures (ECM), which reduce building energy load, enhance operation, and maintenance, through building Energy Management Systems (EMS). Optimal DDC can yield substantial building energy consumption savings and reduce energy dependence from the power grid system while also improving indoor air quality and occupant comfort. This paper discusses the benefits of DDC in commercial buildings, highlighting resultant energy efficiency and provides specific details on energy conservation measure applications available to building owners. This paper will also present a case study on ECM's implemented at Virginia Tech University's Cassel Coliseum, under a current Energy Performance Contract (EPC). Case Study details include the impact of energy efficiency improvements and comparisons of building energy consumption, pre and post building ECM installation.

II. Introduction to Building Controls

Heating, Ventilation and Air Conditioning (HVAC) can account for nearly 40% of a commercial building's energy usage (US Department of Energy, 2008). A commercial building's heating and cooling requirements constantly change throughout a typical year due to weather conditions, occupancy, building schedules and varying loads, and in some cases, buildings may need simultaneous heating and cooling. An HVAC system must be able to distribute heating, cooling and appropriate ventilation to individual zones in a building (Brandemuehl, 2013) while accounting for the variability of building requirements over time. Building owners continue to seek ways to reduce their energy consumption through the use of energy conservation measures (ECMs), which not only benefit the environment by reducing carbon dioxide emissions, but also help reduce building energy costs and equipment degradation.

An efficient way to reduce energy consumption in a commercial building is to optimize the way HVAC equipment is systematically controlled. Based on a current building energy usage profiles, a commercial building owner can potentially reduce their energy consumption by almost 20% by implementing optimized control strategies (Energy.gov, 2013). Optimized control strategies can dictate the operation of major components of HVAC systems and thus customize a buildings response to load requirements. The major components of a typical HVAC system in a commercial building consist of Air-Handler Units (AHU's), Fan and Pump Motors, Boilers, Heat Exchangers, Chillers, and Cooling Towers (HVAC Systems and Components, 2013). These components combine to serve as a system that maintains desired indoor conditions, depending on variables including but not limited to building occupancy, load demand, outdoor environmental conditions and time of day. A schematic of a typical Air Handler Unit is shown in Figure 1 as an example of an HVAC component that relates to the Virginia Tech Case Studies discussed further in Section VII. Outdoor air and Return air from the conditioned space are combined to form mixed air. Depending on the requirement of the space, the mixed air is blown over either a heating or cooling coil to provide heating or cooling supply air. The logic controller determines how much Outside and Return air is necessary based on temperature sensors and modulates the amount of air entering the AHU by the use of dampers and motorized actuators.

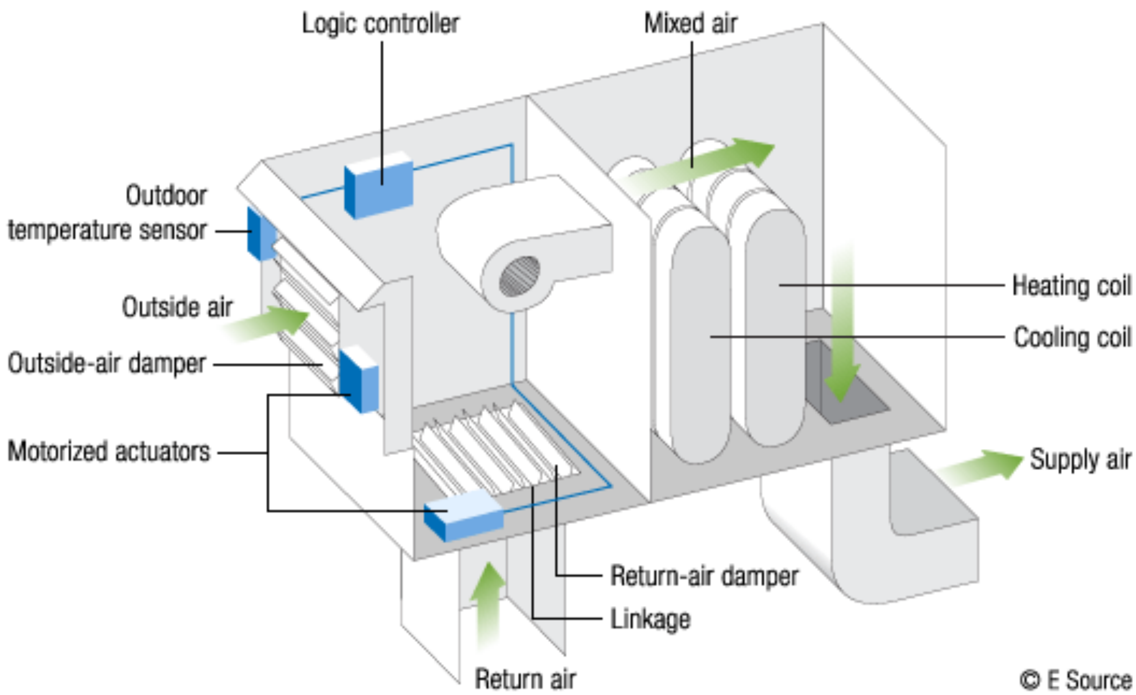

Figure 1 - Schematic showing the movement of air through an AHU to provide conditioned air for a dedicated space in a building. Courtesy of (Madison Gas & Electric, 2011)

Without a control system, a building's HVAC may deviate from designed parameters and result in building imbalances, causing instances of overheated or overcooling spaces (Culler, 2009). The implementation of a control system provides building supervisors with the flexibility of managing and maintaining their buildings using specific strategies based on desired conditions. To date, control strategies have been a major form of energy conservation measures, allowing for energy reduction during off peak or low load periods.

Control systems can be characterized on a broad scale, from a simple thermostat to a more intricate digital system consisting of four standard components; sensor, controller, controlled device and energy source (Culler, 2009). The main purpose of a control system is to cause an action based on processed information measured from within a building. Sensors serve as devices placed throughout the HVAC system to measure data such as space temperature, fan motor speed and water flow, which are also referred to as controlled mediums, providing detected information as an input to a Controller (Iowa Energy Center, 2000). The Controller produces an output directed to a Controlled Device (i.e. actuator valves, dampers, fans and pumps), based on the type of input processed from the sensors (Culler, 2009). The control output mechanically and electronically modulates the HVAC system to settings that meet desired conditions. The control system acts as a continuous feedback structure that is constantly adapting to the varying conditions of the environment, and adjusts the space conditions according to desired parameters. On a building space basis, utilizing an HVAC Control System can efficiently maintain thermal comfort conditions and optimum indoor air quality levels (Culler, 2009) based on building load. From an economic standpoint, a Control System provides opportunities to reduce energy usage and manpower costs, in addition to increasing building operation efficiencies by matching energy output to the building's load demand (Culler, 2009). Figure 2 below shows the configuration of a basic control loop used for controlling air temperature supplied to a conditioned space.

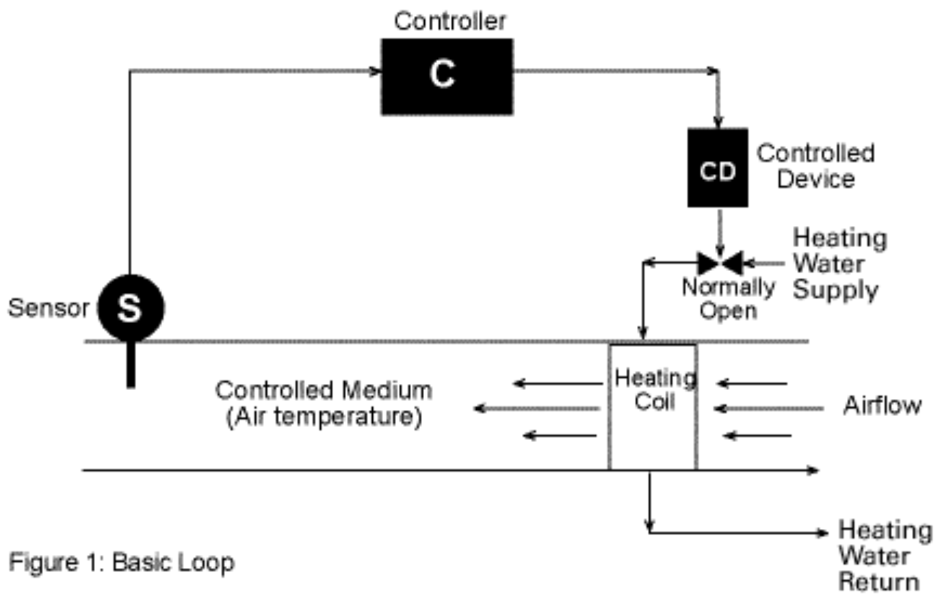

Figure 2. Control Loop Schematic of air temperature heating control in an air handler via a hot water flow. (Courtesy of *Introduction to Direct Digital Control System)*

In the control loop schematic shown in Figure 2, air temperature is the controlled medium in an air handler unit. The Sensor measures the actual supply air temperature and provides the data to the Controller. The Controller processes the temperature data received from the Sensor, and sends a signal to the Controlled Device, which in this case is a Heating Water Supply (HWS) valve. If the supply air temperature is below the desired controlled temperature, the hot water supply valve will open to supply hot water flow to the heating coil, thus increasing the air temperature in the space. The HWS valve will close when hot water flow is no longer needed for the heating coil.

III. Pneumatic Controls

Pneumatic Control Systems were widespread for large buildings from 1950 throughout the 1980s, which provide both on-off and modulating control of building mechanical equipment. Pneumatic Controls use clean, dry & oil free compressed air as the control medium, with an input pressure to directly open and close valves, dampers and energize HVAC equipment (Culler, 2009). When a Sensor in a Pneumatic Control System senses a variable such as temperature, it produces a pressure signal over a particular range (i.e. 3 psig to 15 psig) to a controller. The compressed air pressure serves as data for the pneumatic controlled device. Based on the pressure value present in a control system, the controlled device will open, close or modulate a valve or damper which controls a desired parameter such as air or water flow, and temperature (Invensys Building Systems, 2001). When pneumatic controls were introduced, they presented precision and temperature control that building owners needed for their tenants (TES Engineering, 2011). As technology matured, pneumatic controls remained but were superseded by more advanced electronic control systems.

IV. Direct Digital Controls

Direct Digital Controls (DDC) were introduced in the 1980s and provide vast improvements to the aforementioned pneumatic controls, including the ability to provide feedback to a central workstation computer where all building control activities are logged. Electronic controls allow for a building facility manager to remotely control building space parameters (TES Engineering, 2011), without being physically present in each space. DDC is the most common control system deployed today, which use sensors and output devices (actuators, relays) to control building mechanical equipment. Sensory inputs are converted to a digital form, where algorithms perform comparison and control of actual conditions and system parameters (Culler, 2009). Similar to a Pneumatic System, an electronic control system requires a sensor, controller, controlled device and source of energy. Sensors used in DDC Systems include resistance sensors, voltage sensors and current sensors. Resistance sensors use copper, platinum and thermistors to sense thermal change, which is converted to a temperature reading. Similarly, Voltage and Current Sensors measure temperature, humidity and pressure based on either a typical voltage range (i.e. 0 to 10 Volts direct current) or current range (i.e. 4 to 20 milliamps) respectively (Invensys Building Systems, 2001). Digital Controllers produce either two types of electronic signals; voltage outputs or current outputs (4 to 20 milliamps) (Invensys Building Systems, 2001) to a Controlled Device. In a DDC system, Controlled Devices can be modulating, meaning they can accept a range of voltages and/or currents. The Controlled Device sends an output to an actuator, which operates valves and dampers (Invensys Building Systems, 2001), to control equipment in an HVAC system such as modulating fan speeds, temperature and water flow. The precision and speed of signals flowing in a Direct Digital Control System are ideal for today's HVAC equipment standards, and allow for increased awareness of equipment operation. Figure 3 shows the evolution of building controls from the early 1900s to the recent 2000s. Implementation of DDC was accomplished by control logic programs such as BACnet and Lon in the mid 90s. BACnet and Lon serve as industry standard control logic language programs that allow users to create control strategies for HVAC equipment. Both programs serve the same purpose but are different stylistically in the way control logic programs are written. Heavy reliance on BACnet and Lon in the 90s has shifted to an all-encompassing approach in the 2000s where DDC systems are able to integrate with web services to store system behavioral data (Sinclair, 2001).

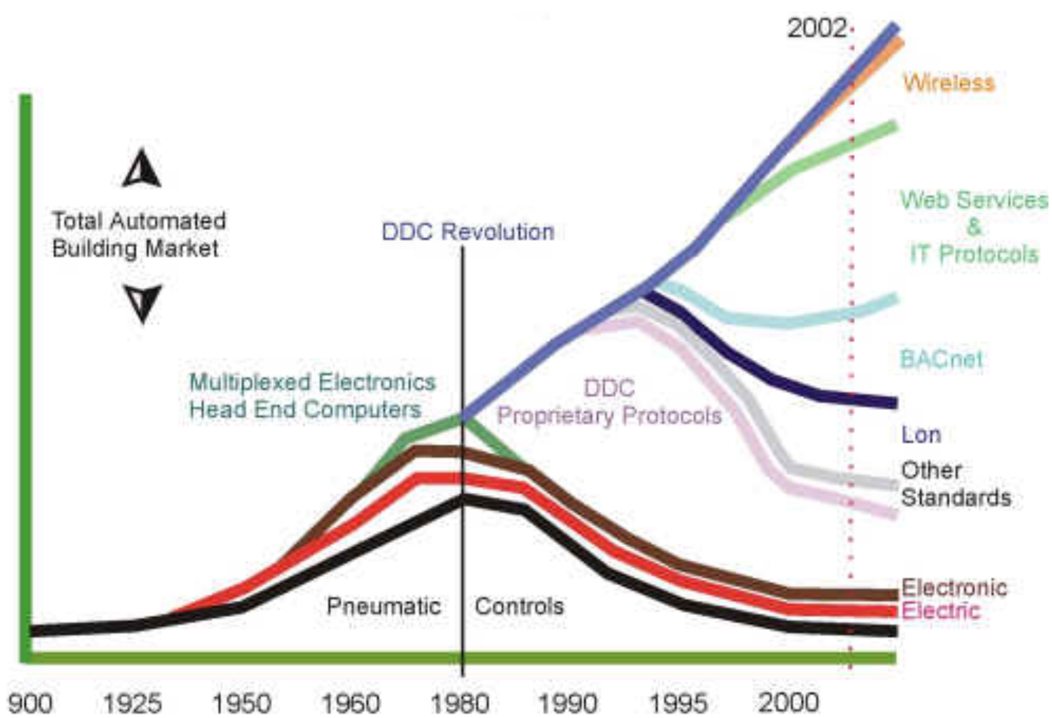

Figure 3 - The evolution of building automated controls from 1900 - 2002. The DDC Revolution began in 1980. Courtesy of AutomatedBuildings.com.

V. Energy Management and Building Automation Systems

The implementation of DDC Systems in today's commercial buildings has become commonplace due to the increased financial benefits for building owners. DDC systems use a computer or a network of computers to control the mechanical infrastructure of a building, allowing for a continuous flow of real time building information available for processing. In a DDC System, the input and output modules in the control loop send information to and from a microprocessor-based controller, which is programmed to perform a specific task in the HVAC System (Culler, 2009). The function of computers in DDC System is to monitor the overall system, store control strategy programs, and record any alarms and trending functions. Implementing a DDC System in a building allows for implementing complex controls and energy management strategies for equipment, which will be highlighted in Section VII. Figure 4 shows specific elements within a DDC control loop system. DDC software is placed in the Controller, which determines outputs based on how the inputs relate to control logic.

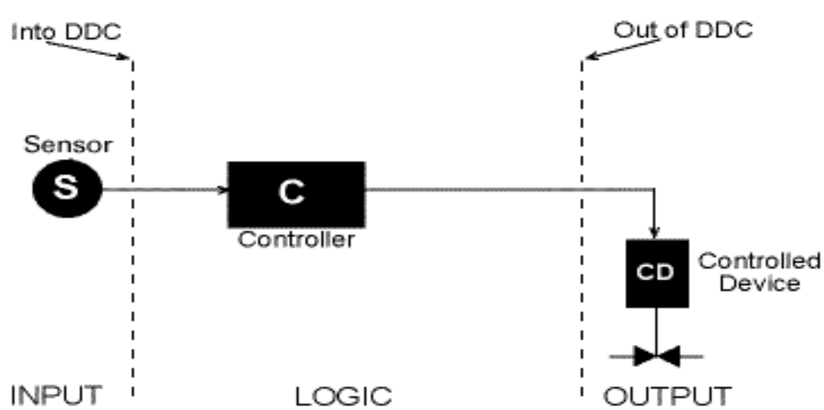

Figure 4. Schematic of DDC Control Loop showing the flow of sensed data as an input through a controller, to producing an output in the controlled device based on control logic. (Courtesy of *Introduction to Direct Digital Control System)*

A key aspect of DDC systems is how data storage locations within the system (Iowa Energy Center, 2000), also known as "points" are monitored. Points can be one (or a combination) of four types; Analog input (AI), Digital input (DI) Analog output (AO) and Digital output (DO). Inputs can be referred to as sensors, while outputs are known as actions or outputs in an HVAC system. Analog Inputs (AI) can place equipment in a range of motions and provides such positional data to the controller. Examples of analog inputs are: temperature, pressure, carbon dioxide or airflow (Culler, 2009). Analog signals are referred to as “proportional, numerical or modulating” meaning that signals are based on a range of extremes (Invensys Building Systems, 2001). An Analog Output can be defined as “a varying, or modulating signal from the controller” (Invensys Building Systems, 2001). The Analog Output is the action produced based on the Analog Input, such as modulating a fans damper position for air flow or the amount of hot water flow modulated by hot water valves. Digital signals are binary, providing status changes on equipment in an HVAC system. A Digital Input monitors the status of equipment, which is either ON or OFF, such as water flow status or building occupancy status (Invensys Building Systems, 2001). A Digital Output switches a device from one status or another based the Digital Input signal. An example of a Digital Output is turning on a fan based on a building being occupied. Figure 5 shows a flow diagram of sensory inputs to a controller for producing outputs.

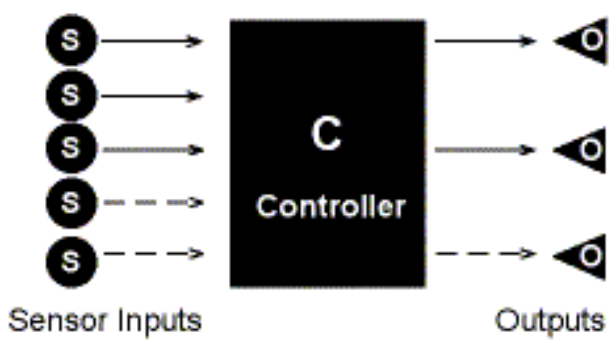

Figure 5. Flow of sensor inputs through a controller to produce outputs. Outputs serve as actions that control HVAC equipment components. (Courtesy of *Introduction to Direct Digital Control System)*

The series of inputs and outputs make up the control loop process, where processors send a control signal to a controlled device. The controlled device gives constant feedback to the processor. With a DDC System, the processor stores control algorithms that determine the way each space in a building is controlled. The processor acts as the hard drive that stores applications and algorithms for the DDC specific to a building such as equipment time schedules and set point values (Invensys Building Systems, 2001). A processor can be programmed to perform numerous control algorithms, which determine how building equipment behaves throughout a 24-hour period.

Energy Management Systems (EMS) serve as a front-end supervisory system that integrates building functionalities under one network. An EMS is essentially the backbone of a smart building, in which the system efficiently controls everything from a building's lighting system to HVAC equipment and emergency protocols. An insightful example of how an EMS might behave is apparent during an emergency fire, where smoke detection may trigger an alarm which causes all exhaust fans to dispel smoke from a space, and pressurize neighboring areas to prevent smoke from entering these areas (Culler, 2009). Such a protocol is one of many ways an EMS can optimize a building in real time. Below is a figure showing how controllers throughout a building can communicate with one another, on a local area network (LAN). In the case of an outdated pneumatic system, "controllers only react to a few conditions rather than to the needs of the whole system" (Culler, 2009). But in a DDC system as shown in Figure 6, not only is the system able to produce outputs to building equipment, it also has the ability to provide feedback and keeps a log of equipment status, environmental and mechanical conditions on a server.

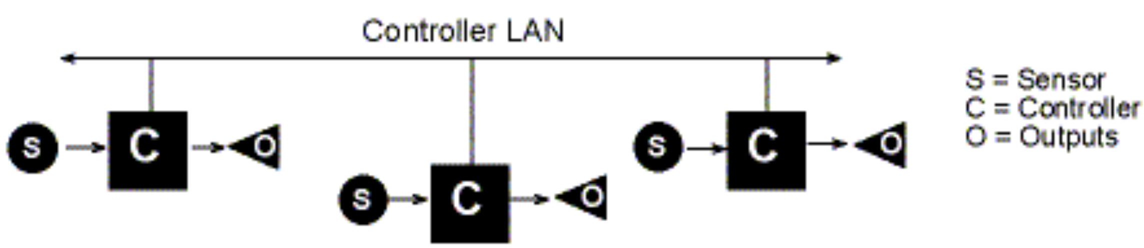

Figure 6. Schematic of LAN communication showing how controllers are placed on HVAC equipment throughout a building that communicate with each other via a controller network. (Courtesy of *Introduction to Direct Digital Control System)*

The advantages using DDC in conjunction with an EMS are paramount to any standalone pneumatic control system. DDC allows for a whole system to be controlled from one central location, allowing for an operator to have a broad idea of building operation but also allows for using innovative ideas to target areas in a building for specific control strategies. Operators are also able to change set points such as room temperature throughout a building, from a centralized location. The reliability of a DDC is advantageous to a building operator since the microprocessor has a standard procedure to control building parameters via algorithms and calculations based on system inputs. The DDC is able to make complex adjustments based on all sensor data, by processing all inputs and optimizing outputs for the entire building, eliminating the chance for human error. All records can also be provided in printed reports for further analysis of building operations. Lastly, DDC allows for conservation of energy strategies since building owners have more stringent control of the overall system. Energy conservation strategies may include adjustments to equipment run time and set point temperature during unoccupied times, reducing mechanical cooling. By monitoring a building's energy load, equipment can be controlled accordingly and match the buildings actual demand (Culler, 2009).

VI. Energy Conservation Measures

Building owners are striving to improve the energy efficiency of their buildings to reduce energy consumption, utility costs and carbon footprints. To achieve such reductions, building owners are implementing energy conservation measures (ECM), which improve the energy efficiency of a building, including heating, cooling ventilation systems, control systems, roofs and windows. To implement an ECM, energy audits are performed to characterize a buildings existing condition of equipment energy usage. Detailed energy audit results will reveal cost effective recommendations for equipment retrofits, replacements and building energy reduction potential to building owners. It is ideal that the projected energy savings potential for a given ECM is able to offset the capitalized cost for ECM installation under a reasonable payback period. Integrating DDC with ECMs can serve as a valuable tool for monitoring the performance of installed measures in a given building makes it easier to implement widespread ECMs that control HVAC equipment. A DDC System will allow building owners to trend all equipment points, trend energy consumption and print status reports for performance verification. Below are brief examples of ECMs that can be implemented and enhanced with a building's DDC system.

Unoccupied Hours Setbacks

When implementing unoccupied hours setbacks in a building, the DDC Controller will determine the occupancy status of a building by an internal time clock, a dry contact or the building management system. If the building is in unoccupied mode, the DDC controller will automatically change its operating sequence and either shut off or cycle the mechanical equipment (Chillers, Boilers, Air Handler Units, etc.) to maintain unoccupied room temperature set points (Greenheck, 2011). Unoccupied temperatures are raised enough to allow for energy savings since equipment will tend to operate with a lower power requirement, thus saving electric or fuel costs. An example of an unoccupied setback is raising a room's cooling mode set point temperature from 70°C during occupied periods to 78°C during unoccupied periods. By raising the room temperature 8°C, the rooms dedicated air handler unit (AHU) will consume less energy for cooling a space, since cooling mode supply air temperature is increased.

Chilled Water Temperature Resets

The implementation of a Chilled Water Temperature Reset ECM involves monitoring outdoor conditions to reset chilled-water temperatures. If the weather is mild and minimal cooling is required for a building, chilled water supply temperatures can be increased to help match the chiller output to the actual load (Energy Star, 2008). Since chiller efficiencies can increase when the leaving water temperature is raised, optimal chiller efficiency is achieved when the chilled water supply temperature (CHWST) is as high as systematically possible (Steven T. Taylor, 2012). Raising the CHWST can be accomplished on the DDC system work station by a building operator.

Hot Water Temperature Setbacks

Implementing Hot Water Temperature Setbacks involves saving energy by matching the supply of steam or hot water, with the building's demand for heating. The DDC allows for lowering the steam or hot water temperature supply temperature based on outdoor temperature. For example, if the outdoor temperature is mild (65°C), the building's heating demand reduces, thus reducing the demand for hot water and/or steam supply temperatures (Energy Star, 2008). Implementing this ECM can result in thermal energy (Natural gas or Steam) cost savings for the building owner.

Air Side Economizers and Outdoor Air Temperature Reset

Installation of this ECM involves using outdoor air to partially or totally cool a space, thus lowering mechanical cooling loads (Energy Star, 2008) and receiving "free cooling" to a given space. The DDC will monitor the outdoor air temperature and adjust Air Handler Unit supply air temperatures to provide comfortable conditions for building occupants (Greenheck, 2011) during periods when outdoor air temperature is equal or lower to building supply air setpoints. Implementing this ECM will result in cooling energy savings while still meeting cooling demand for a given space.

Demand Controlled Ventilation

Implementation of this ECM utilizes Carbon Dioxide (CO2) sensors in the DDC that monitor CO2 levels of the air inside a building, and thus regulates the amount of outdoor air admitted into the building for ventilation. CO2 levels can predict the activity levels in a building based on occupancy, since occupants exhale CO2 into the building. The building's air conditioning equipment will then modulate or cycle based on occupancy, saving cooling energy during low occupancy periods (US Department of Energy, 2013).

VII. Virginia Tech University Case Studies

In 2011, Pepco Energy Services (PES) was awarded an Energy Services Performance Contract (ESPC) by Virginia Tech University (Blacksburg, Virginia) to provide energy savings solutions throughout the campus. As an Energy Services Company (ESCO), PES was chosen to provide Virginia Tech with energy conservation measures to optimize the existing HVAC equipment and control system serving Cassell Coliseum, a 9,847-seat multi-purpose arena on campus. The existing HVAC system was deemed inefficient and in need of optimization to reduce energy costs for the University. As part of the ESPC, PES recommended three controls ECMs, Heating Setback, Demand Control Ventilation and Economizer Controls to reduce energy consumption.

To model the energy savings potential of all three ECMs, PES determined the cooling and heating loads for Cassel Coliseum in the existing condition by using the Bin Method. The Bin Method procedure sorts monthly weather data for a given location into discrete temperature groups or bins. Each bin includes the number of average hours of occurrence during a month or year of a particular range of weather conditions. Temperature data are based on weather measurements from the national weather service (Woodbury, 2013). The Bin Method can properly account for seasonal temperature variation, thus accounting for HVAC system variations in performance. For example, a chiller plant consumes the majority of its cooling energy usage during cooling months (May - August), while a boiler consumes the majority of its heating energy during the heating months (November - March). Since the annual energy consumption of a building's HVAC equipment is dependent on weather conditions, using the Bin Method results in a fairly accurate calculation of building load for a given year (Woodbury, 2013).

Case Study Part #1 - Cassell Coliseum Heating Setback Control

Before their need of energy conservation improvements, Virginia Tech used 18 steam Heating Ventilation (HV) units to provide heating to approximately 57,088 square feet of Cassell Coliseum, without using setback controls. Each HV unit is capable of providing 320,000 BTUs of heating to building occupants. PES recommended implementing a Heating Setback Control energy conservation measure (ECM) for Virginia Tech to reduce heating energy consumption. The scheduled heating setbacks would occur during both occupied and unoccupied periods for (18) heating ventilation units throughout Cassell Coliseum. During occupied periods (4 AM – 5 PM), the heating set point would reduce 2°F from 72°F to 70°F. In other words, less heating energy would be required to heat the building to 70°F than if the setpoint remained at 72°F. During unoccupied periods (5 PM – 4 AM), the heating set point would reduce 12°F from 72°F to 60°F, enabling even greater energy savings potential than in the occupied periods. Under this ECM, PES would utilize the existing DDC system serving Cassell Coliseum, to control the 18 HV unit temperature setpoints via a control sequence. The DDC would set all HV units in either Occupied or Unoccupied Mode based on the time of day and enable temperature setbacks accordingly.

To characterize the potential energy savings for this ECM, PES used the inputs shown in Table 1.1 below for the Bin Energy Model for Cassell Coliseum;

Table 1.1

Model Input		
	Value	**Unit**
Heated Area	57,088	sf
Max. Heating input	5,760	MBH
Number of Heating Ventilation Units	18	
Heating Input per Unit	320	MBH
Design Outside Air Temp	10	°F
Heating System Eff.	80%	

Table 1.1 - HVAC design inputs used for Bin Energy Model development for Cassell Coliseum.

Utilizing the Bin Method Model, PES estimated the Heating Setback Control ECM to reduce Virginia Tech's heating load by 1,600 MMbtu or 12% at Cassell Coliseum each year. The Bin Model used to determine the energy savings potential of this ECM can be found in the Appendix.

Based on the model inputs shown in Table 1.1, implementation of the Heating Setback Control ECM is projected to result in the following energy usage improvements shown below in Table 1.2;

Table 1.2

Model Energy Summary		
Type	**Value**	**Unit**
Baseline Energy Use	13,493	MMBTU
Post-Implementation Energy Use	11,893	MMBTU
Total Heating Savings	1,600	MMBTU
Energy Usage Reduction (%)	12%	

Table 1.2 - Energy usage pre and post ECM implementation results from the Bin Energy Model inputs shown in Table 1.1

Graphs below compare heating energy usage during both Occupied and Unoccupied modes. 84% of heating energy savings occur during the unoccupied mode, versus 16% in the occupied mode. The bulk of the savings occur when outside air temperature is between 30°F to 54°F during the unoccupied mode.

Table 1.3

	Savings	**Unit**	% of Total
Occupied Mode	250	MMBTU	16%
Unoccupied Mode	1,349	MMBTU	84%
Total	1,600	MMBTU	

Table 1.3 - Savings allocation for Occupied and Unoccupied mode of the heating setback control ECM.

Figure 1.1

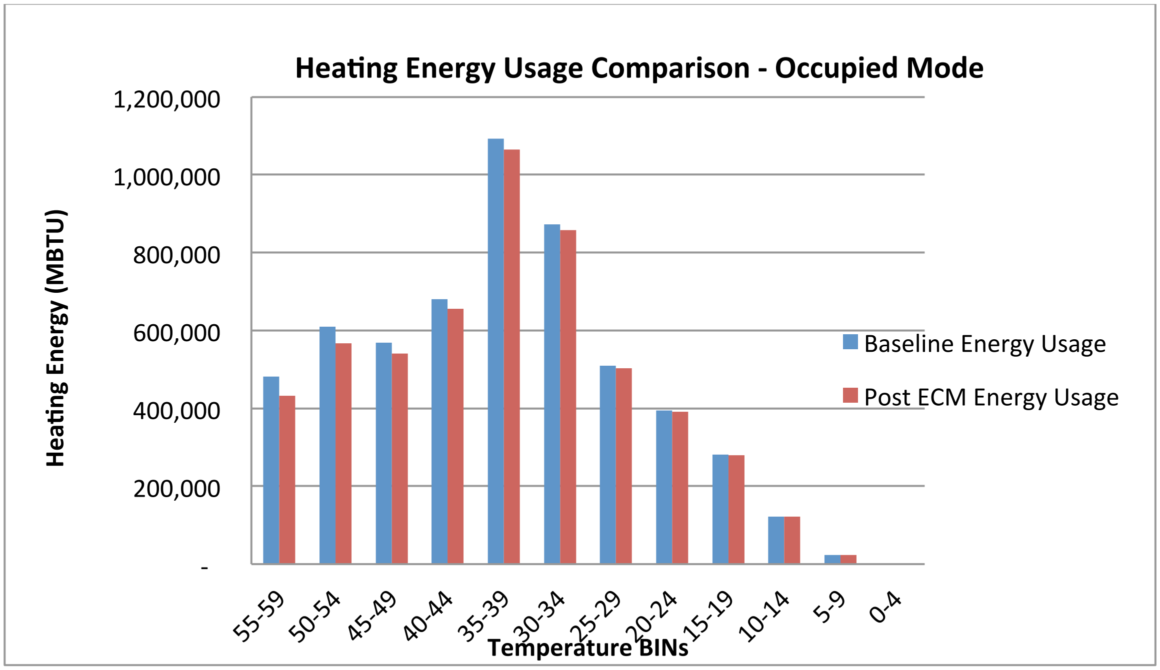

Figure 1.1 - Heating energy usage for each temperature bin from 0°F - 59°F during Occupied Mode. Blue bars represent Baseline energy usage whiles Red bars represent Post ECM energy usage.

Figure 1.2

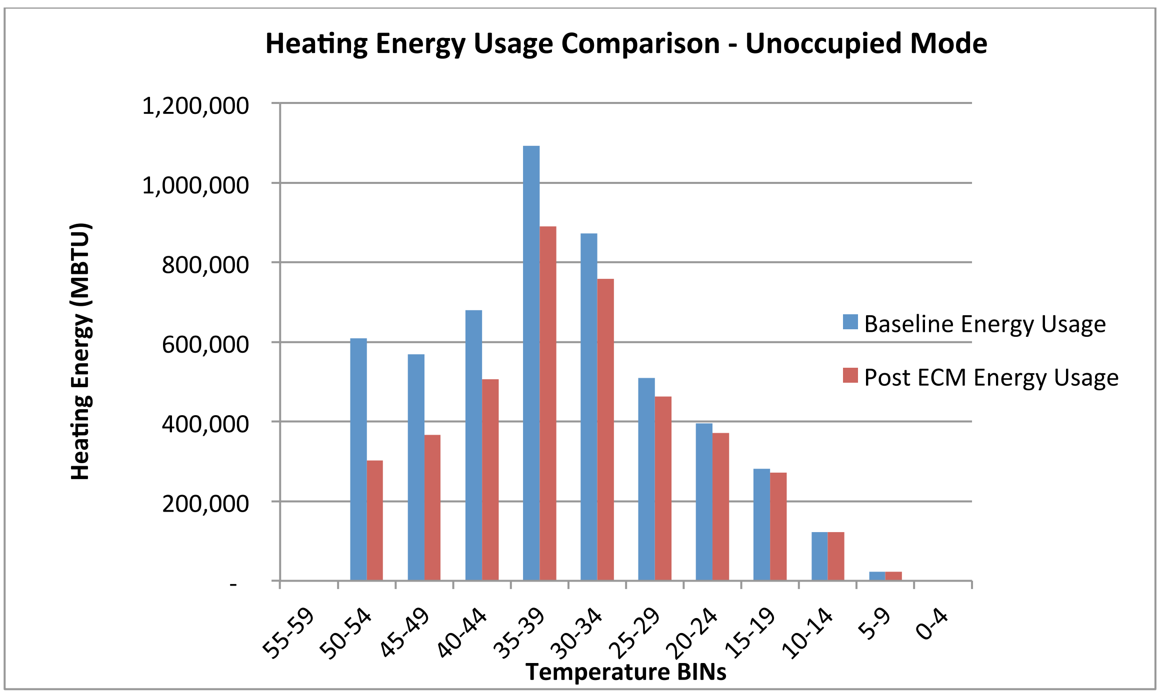

Figure 1.2 - Heating energy usage for each temperature bin from 0°F - 59°F during Unoccupied Mode. Blue bars represent Baseline energy usage whiles Red bars represent Post ECM energy usage.

Case Study Part #2 - Cassell Coliseum Demand Control Ventilation

The Bowman Room is an all purpose room with fluctuating occupancy in Cassel Coliseum. Pepco Energy Services proposed the installation of Demand Control Ventilation in the Bowman Room, providing the existing Air Handler Unit (AHU) with the capability of adjusting outside air intake based on CO_2 levels, to save heating and cooling energy during intermittent occupancy (Pepco Energy Services, 2012). Prior to implementation of Demand Control Ventilation, the dedicated AHU for the Bowman Room used 3,250 cubic feet of outside air per minute, while providing either heating or cooling during occupied hours (6 AM - 10 PM). PES utilized a Bin Method model to estimate the potential outside air intake reduction and total heating and cooling energy savings. For modeling purposes, PES established outside air intake ranges for determining the required about of outside air necessary for CO_2 concentrations. It is assumed that when CO_2 concentrations are 100 ppm or less, 0% of outside air is needed. Additionally, at CO_2 concentrations of 1000 ppm or more, 100% of outside air is necessary. CO_2 sensors were used during the development phase of this ECM to trend CO_2 concentration levels in the Bowman Room for two weeks. Linearization is used to correlate trended CO_2 measurements with the required amount of outside air based on the aforementioned outside air intake ranges. Results showed that Virginia Tech could reduce Cassell Coliseum's outside air intake by approximately 26% during occupied hours on average, lowering outdoor airflow rates from 3,250 cfm to 2,480 cfm. Under this ECM, PES would utilize the existing DDC system to control AHU #3 serving the Bowman Room. The DDC would set the required outside air flow rate based on the CO_2 content in the air.

To characterize the potential energy savings for this ECM, PES used the inputs shown in Table 2.1 below for the Bin Energy Model for Cassell Coliseum;

Table 2.1

Model Inputs		
Type	**Value**	**Unit**
Location:	Roanoke, VA	
Occupied Hours:	6 AM - 10 PM	
Unoccupied Hours	10 PM - 6 AM	
*Operating Days:	5	*days/wk*
Occupied Indoor Temperature:	72	*°F*
Unoccupied Indoor Temperature:	72	*°F*
Seasonal Cooling Efficiency:	0.79	*kw/ton*
†Seasonal Heating Efficiency:	100%	*%*
Maximum Outside Air:	3,250	ft^3/min
Minimum Outside Air:	0	ft^3/min
Heating Air Temperature:	90	*°F*
Cooling Air Temperature:	55	*°F*
Cooling Air Enthalpy:	18.54	*Btu/lb*

Table 2.1 - HVAC design inputs used for Bin Energy Model development for Cassell Coliseum.

*Operating days are taken into account in the Proposed Condition by multiplying the Occupied Bin Hours by a fraction of 5/7.

†Seasonal Heating Efficiency is assumed to be 100% due to the reliance on steam. Plant efficiency has been accounted for in the production of steam.

Utilizing the Bin Method, PES estimated the Demand Control Ventilation ECM to reduce Cassell Coliseum's heating and cooling load for ventilation air by 47% annually.

Based on the model inputs shown in Table 2.1, implementation of the Demand Control Ventilation ECM is projected to result in 180,500 Mbtu of heating savings and 14,623 kwh of cooling savings. Project savings equate to a 47% reduction in heating and cooling energy used for ventilation annually. The Bin Model used to determine the energy savings potential of this ECM can be found in the Appendix.

Table 2.2

	Model Energy Summary			
	Heating		Cooling	
Type	Value	Unit	Value	Unit
Baseline Energy for Ventilation Use	383,485	Mbtu	31,067	kWh
Post-Implementation Energy Use	202,985	Mbtu	16,444	kWh
Total Energy for Ventilation Savings	180,500	Mbtu	14,623	kWh
Energy Usage Reduction (%)	47%	%	47%	%

Table 2.2 - Energy usage pre and post Demand Controlled Ventilation implementation results from the Bin Energy Model inputs shown in Table 2.1.

Figures 2.1 and 2.2 below show heating and cooling energy usage pre and post demand control ventilation (DCV) implementation;

Figure 2.1

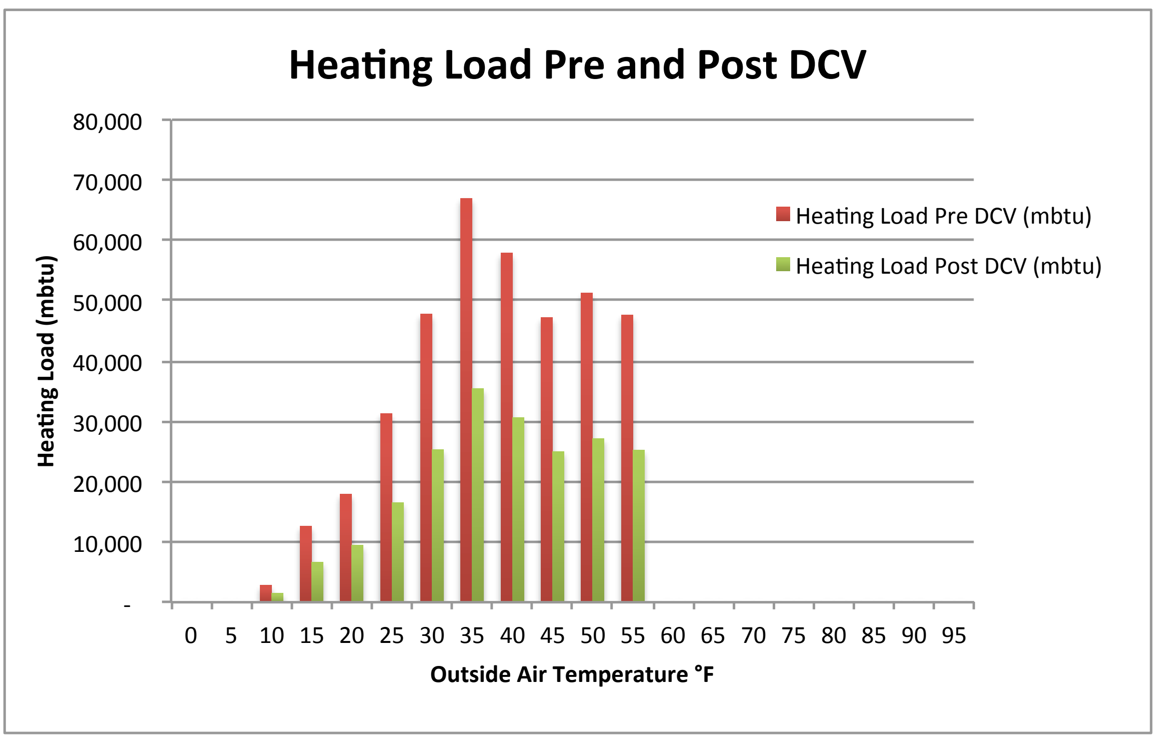

Figure 2.1 - Heating Load pre and post Demand Controlled Ventilation implementation for outside air temperatures ranging from 0°F to 55°F.

Figure 2.2

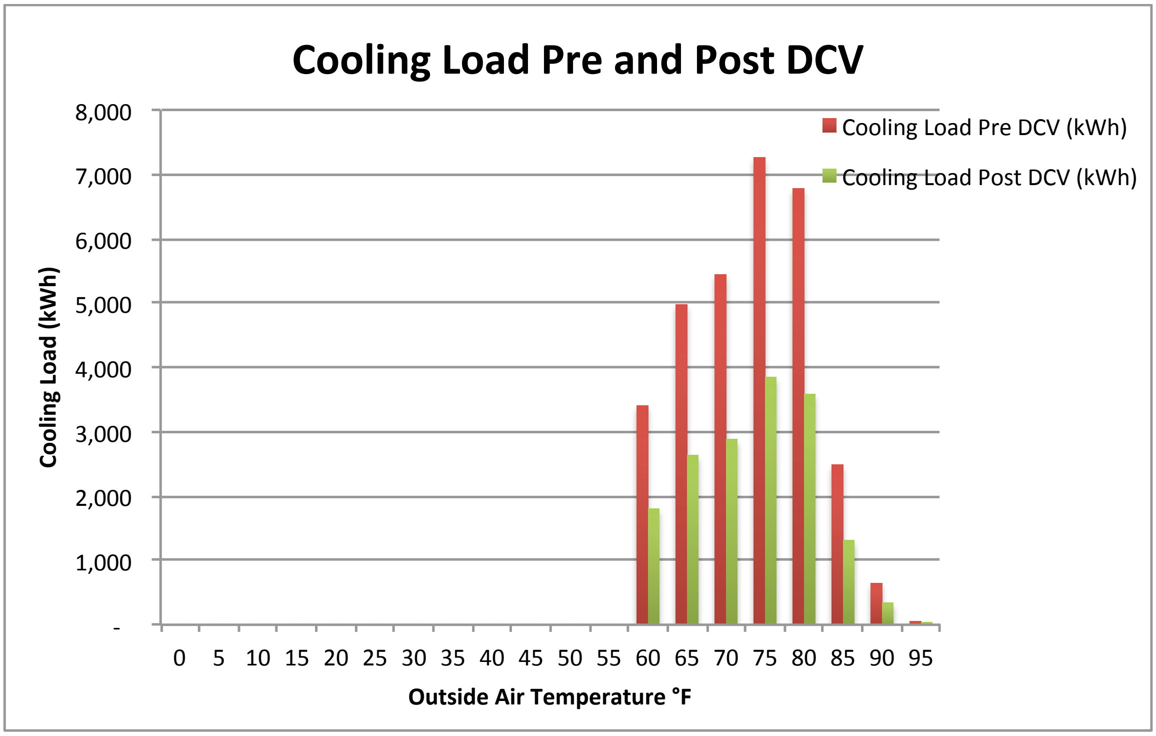

Figure 2.2 - Cooling Load pre and post Demand Controlled Ventilation implementation for outside air temperatures ranging from 60°F to 95°F.

Case Study Part #3 - Cassell Coliseum Economizer Control

Pepco Energy Services proposed Economizer Controls on Air Handler Units (AHU's) #1 and #2, both serving areas in Cassell Coliseum. The strategy would enable both AHU's to use outdoor air to cool the building during preferred weather conditions which inherently reduce the building's cooling load and electricity consumption (Pepco Energy Services, 2012). Prior to the implementation of Economizer Controls, Virginia Tech consumed cooling energy when outside air temperature was 60°F to 95°F. Economizer controls allow Virginia Tech to utilize "free cooling" from outdoor air when temperatures are 0°F - 65°F. PES utilized a Bin Method model to estimate cooling energy savings potential of implementing Economizer Controls for both occupied and unoccupied periods. Under this ECM, PES would utilize the existing DDC system to shut off mechanical cooling for AHU's #1 & #2 when outdoor air temperatures meet the required temperatures for free cooling (60°F - 65°F).

To characterize the potential energy savings for this ECM, PES used the inputs shown in Tables 3.1 and 3.2 for the Bin Energy Model for Cassell Coliseum;

Table 3.1

Model Input - AHU #1		
Type	**Value**	**Unit**
Location:	Roanoke, VA	
Occupied Hours:	6 AM - 10 PM	
Unoccupied Hours	10 PM - 6 AM	
Occupied Temperature Setpoint:	71	*°F*
Unoccupied Cooling Setpoint:	80	*°F*
Temperature Balance Point:	55	*°F*
Cooling Design Point:	95	*°F*
Seasonal Cooling Efficiency:	0.79	*kW/ton*
Cooling Air Enthalpy:	18.54	*Btu/lb*
Existing Air Flow:	11,000	ft^3/min
Cooling Design Load:	530	*MBH*
Unoccupied Cooling Load:	331	*MBH*

Table 3.1 - HVAC design inputs for AHU #1 used for Bin Energy Model development for Cassell Coliseum.

Table 3.2

Model Input - AHU #2		
Type	**Value**	**Unit**
Location:	Roanoke, VA	
Occupied Hours:	6 AM - 10 PM	
Unoccupied Hours	10 PM - 6 AM	
Occupied Temperature Setpoint:	75	°F
Unoccupied Cooling Setpoint:	80	*°F*
Temperature Balance Point:	55	*°F*
Cooling Design Point:	95	*°F*
Seasonal Cooling Efficiency:	0.79	*kW/ton*
Cooling Air Enthalpy:	18.54	*Btu/lb*
Existing Air Flow:	9000	ft^3/min
Cooling Design Load:	435	*MBH*
Unoccupied Cooling Load:	326	*MBH*

Table 3.2 - HVAC design inputs for AHU #2 used for Bin Energy Model development for Cassell Coliseum.

*Occupied Hours were determined from equipment trending data provided by Virginia Tech University.

**Operating days are taken into account in the Proposed Condition by multiplying the Occupied Bin Hours by a fraction of 5/7.

Applying the Bin Method model, PES estimated the Economizer Control ECM to reduce Virginia Tech's cooling load annually by 25% for AHU #1 and 26% for AHU #2. Based on the model inputs shown above in Table 2.1 and 2.2, implementation of this ECM is projected to result in 11,995 kwh and 10, 359 kwh of cooling energy for AHU's #1 and #2 respectively.

Table 2.3

Model Energy Summary - AHU #1		
Type	**Value**	**Unit**
Baseline Cooling Energy Use	47,066	kWh
Post-Implementation Cooling Energy Use	35,071	kWh
Total Cooling Savings	11,995	kWh
Energy Usage Reduction (%)	25%	

Table 2.4

Model Energy Summary - AHU #2		
Type	**Value**	**Unit**
Baseline Cooling (or chiller) Energy Use	39,507	kWh
Post-Implementation Energy Use	29,149	kWh
Total Cooling Savings	10,359	kWh
Energy Usage Reduction (%)	26%	

As mentioned earlier, savings are only obtained when outdoor air temperatures range from 60°F - 65°F. Though the combined savings Economizer Controls aren't as substantial as the aforementioned ECMs (Demand Control and Heating Ventilation Setbacks), Virginia Tech would still benefit from a combined 22,353 cooling energy reduction annually.

VIII. The Future of Energy Conservation

Implementing control strategies are a proven way to reduce energy consumption for building HVAC equipment. Another emerging energy conservation strategy is the use of a demand response program in accordance with smart grid infrastructure to reduce grid congestion. Demand Response is a feature embedded in a power system that allows utility companies and power suppliers to reduce energy load and inherent from the grid during peak demand hours. As a customer, enrolling in a demand response program can help reduce demand charges paid to the utility by avoiding the costs associated with the tiered rate structure. The smart grid utilizes automation in power systems by communication between system components including Power Generation, Transmission, Distribution and the Consumer. Communication between each component creates an optimal flow of real time energy data, allowing immediate effective strategies during peak load hours. Smart grid technology can also improve power system reliability and energy efficiency due to the increased awareness of system behavior.

Typically, demand rates are higher during peak periods since the utility exhausts more of its resources to meet the demand of the grid. In such a case, the utility company activates Demand Response by communicating with their customer's equipment including smart meters and energy management systems "to reduce their consumption at critical times or in response to rising market prices of electricity" (Yang, 2012). If a commercial building has a dedicated DDC and/or energy management system in place, it can serve as a device that communicates their energy consumption and usage patterns with the utility company. An example of a demand response strategy is when the utility company recommends that a commercial building turn off a number of air handler units or chillers to reduce electrical load for an hour. If the customer complies with the strategy, they will reduce their peak load and energy costs for that hour. During demand response periods, the utility has the ability to curtail power available to a building and recommend that the customer follow certain procedures to maintain building operation in lieu of equipment shutdowns. Utility companies may also recommend their customers to use alternative sources of on-site power generation (i.e Solar Photovoltaic) to avoid the grid entirely (Yang, 2012).

The smart grid and demand response serve as a partnership between utility companies and their customers to raise energy awareness and strategies to optimize energy production, consumption and avoid increasing costs. Implementing smart grid and demand response technologies in a power system is analogous to installing DDC and energy management systems in a commercial building. Both implementations educate the customer to optimize their energy consumption and reduce energy costs, while reducing supply requirements for the utility companies. The smart grid and demand response allows the utility to optimize the power systems energy performance while meeting consumer energy demand requirements. Analogously, a building's DDC and energy management system optimizes a buildings equipment functionality and energy usage to meet building occupant requirements. The increase of utility company funds available for demand response compliance are enabling more customers to seek strategies to employ in their buildings, to receive incentives. Customers have the option of seeking professional assistance in implementing demand response directly into their existing energy management systems. Energy companies such as Siemens, offer a Demand Response Management System (DRMS) that is designed with the electric utility, energy marketer and consumer in mind" (Siemens, 2013). Siemens' DRMS automates the demand response process for their clients, having the ability to "accurately monitor and verify load shedding and present the information to the utility and consumer" (Siemens, 2013). The DRMS will include automated protocols for removing HVAC equipment power consumption from the grid while still meeting the demands of building tenants. DRMS alleviates the need of building tenants to react to demand response events, since the control system directly communicates with the building HVAC equipment and utility company.

IX. Conclusion

As people globally seek solutions to reduce their energy consumption and avoid increased fuel costs, there have been a number of energy efficient technologies introduced to the public. Specifically for commercial buildings, Direct Digital Controls and Energy Management Systems have become an industry standard due to their energy savings potential. As shown in the Virginia Tech case studies, DDC strategies can saving building owners at least 20% of their energy load. Ultimately, building owners are interested in reducing their energy bills and prolonging service life of their expensive equipment. EMS and DDC not only allow building owners to reduce operating costs and optimize the way their buildings function on a daily basis, they allow for automated load shedding during demand response events. Continued deployment of DDC and EMS in both newly constructed buildings and older buildings will allow for increased energy savings across the commercial sector for the foreseeable future.

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