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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

American Recovery and Reinvestment Act (ARRA) FEMP Technical Assistance U.S. General Services Administration – Project 193 John W. Bricker Federal Building, Columbus, Ohio

J Arends
WF Sandusky

May 2010

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Federal Energy Management Program
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Pacific Northwest National Laboratory
Richland, Washington 99352

(a) Redhorse Corporation

Executive Summary

This report documents the findings from an onsite audit of the John W. Bricker Federal building located in Columbus, Ohio. The Federal landlord for this building is the General Services Administration (GSA). The focus of the audit was to identify various no-cost or low-cost energy efficiency opportunities that, once implemented, would either reduce electrical and gas consumption or increase the operational efficiency of the building. This audit also provided an opportunity to identify potential capital cost projects that should be considered in the future to acquire additional energy (electric and gas) and water savings to further increase the operational efficiency of the building.

The audit identified six measures that could be implemented immediately that would result in a total savings of 4,881 MBtu of electrical and thermal energy resulting in an annual cost savings of $77,700. The estimated cost to implement the measures is $95,579, so the payback for such an investment would be 1.2 years.

Two capital item projects were identified related to utilization of the available solar resource. This would result in saving an additional 349 MBtu of energy, resulting in a cost savings of $7,146 annually. At this point in time, the economics for implementation of these measures is not cost-effective unless required for increasing the amount of onsite power generation from renewable resources.

Implementation of both the no-cost or low-cost measures would decrease greenhouse gas (GHG) emissions to the atmosphere, as well as create job opportunities. For the no-cost or low-cost measures, it was estimated that 395 metric tons of GHG emissions to the atmosphere would be avoided and one job would be created. If the capital projects were implemented, eight jobs would be created and 111 metric tons of GHG emissions to the atmosphere would be avoided.

Contents

Figures

Tables

Acronyms

AEP	American Electric Power
AHU	Air handling unit
ARRA	American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BAS	Building automation system
Btu	British thermal unit
CF	Cubic feet (ft^3)
DDC	Direct digital control
DOE	U.S. Department of Energy
DX	Direct expansion
ECM	Energy conservation measure
ft^2	Square feet
FEMP	Federal Energy Management Program
GSA	General Services Administration
kBtu	10^3 Btu
kW	Kilowatt
kWh	Kilowatt hour (1 kWh = 3412 Btu)
LBNL	Lawrence Berkeley National Laboratory
Mcf	Million cubic feet (natural gas)
MMBtu	10^6 Btu
NOFA	Notice of funding available
ODOD	Ohio Department of Development
OEO	Ohio Energy Office
O&M	Operation and maintenance
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
Retro-CX	Retro-commissioning
SHW	Solar domestic hot water
VAV	Variable air volume
Yr	year

1.0 Description of ARRA Program

The Federal Energy Management Program (FEMP) facilitates the Federal Government's implementation of sound, cost-effective energy management and investment practices to enhance the nation's energy security and environmental stewardship. Late in fiscal year 2009, FEMP received funds specific to the American Recovery and Reinvestment Act (ARRA) of 2009.

These funds were allocated to expand the Department of Energy's (DOE's) laboratory and contractor support to agencies and to quickly provide technical advice and assistance to expand and accelerate project activities. FEMP requested that agencies submit projects in need of technical assistance in the following areas:

- Initial screenings or assessments of facility needs and/or feasibility of a particular technology
- Project prioritization
- Strategic energy planning and benchmarking
- Technical reviews of designs and proposals
- Energy audit training
- High-performance green building technical support
- Federal vehicle fleet technical support
- Operations and maintenance
- Detail of key lab staff to work within agencies for a limited duration (normally not more than 24 months)
- All of the above with special emphasis on particular technologies in the areas of the labs' expertise.

The General Services Administration (GSA) submitted a response to this call requesting that an energy audit be conducted at the John W. Bricker Federal building in Columbus, OH with the goal of identifying energy conservation measures that could be implemented in a timely manner. This request was selected by FEMP and designated as Project 193.

1.1 Site Audit Activities

This energy and water audit was conducted November 30 and December 1, 2009 using the protocols and guidance developed by Pacific Northwest National Laboratory (PNNL) to support previous FEMP activities related to assessment of load and energy reduction technologies (ALERT), energy savings expert teams

(ESET), and energy efficiency expert evaluations (E4) audits at Federal sites. The primary focus of the protocols is to identify various no-cost and low-cost opportunities for major energy consuming equipment within the building. During the audit, however, other capital cost equipment opportunities were also considered with respect to future energy efficiency projects that could be undertaken by the sites to acquire additional energy, water, and cost savings.

An out-briefing of the preliminary audit results was provided to site personnel on December 1, 2009. A draft of this audit report was provided to the GSA point-of-contact for review and comment.

2.0 Background

2.1 Site Description

The John W. Bricker Federal Building is located at 200 N. High Street in Columbus, Ohio. The seven-story office building was constructed in 1976 and has 229,242 ft^2 of space, mainly occupied by tenants with office suites and a cafeteria. Each of the seven floors has approximately 30,000 ft^2 of space. There is also a smaller basement with six offices, locker rooms and showers, and a penthouse area that contains most of the building's mechanical and control systems. The first floor has a unique layout, including a loading dock and reception and security area. Figure 1 is a photograph of the building and parking garage.

Figure 1. Columbus Bricker Building and Garage

The adjacent parking garage is 191,366 ft^2. This energy and water audit was focused on the office building, but also considered potential energy conservation measures (ECMs) for the garage area.

Major upgrades to the building were completed in 2005 and included new double pane low-e windows, T-8 lighting systems, building automation system (BAS) upgrades to direct digital controls (DDCs) in all areas except the post office area on the first floor, and installation of new forced draft boilers. During the 2005 upgrades, improvements in water use efficiency were achieved by installing low flow / no touch faucets and toilet fixtures.

2.2 Major Building Energy Uses

Air Handling Systems

The building is heated and cooled by two variable air volume (VAV) air handling unit (AHU) systems. AHU-1 and 2 have Allen Bradley variable frequency drives controlling both supply and return fans. Outside air is tempered to 55°F by hot water heating coils in each of the air handlers. Mixed air is cooled by chilled water cooling coils in the air handlers. Both of the AHUs deliver 55°F supply air via ductwork to the building terminal boxes. Both of the air handlers are capable of using full outside air for economizer operation. No humidification or dehumidification is provided in the AHUs.

Hot Water Heating Boilers

Hot water delivered to the air handler heating coils is produced by two hot water heating boilers located in the penthouse. Heating water is also distributed to the VAV terminal boxes located in the perimeter zones of the building. New boilers were installed in 2005, and each has a capacity of 2.1 million British thermal units (MMBtus). The boilers are set up to operate on a standard schedule if outside air temperatures are below 60°F, and they are shut off nightly by the building automation system (BAS).

Heating Water Reset Schedule

When the outside air is less than or equal to 0°F, the heating water temperature setpoint is 180°F. The heating water temperature is proportionately adjusted downward as the outside air temperature rises and the setpoint is 130°F when the outside air temperature is 60°F.

Chillers and Cooling Units

Chilled water delivered to the AHU cooling coils is produced by two chillers located in the penthouse. Heat from the chillers is rejected by cooling towers located on the roof of the penthouse. Chilled water supply setpoint is currently maintained at 45°F.

Several computer server rooms also have dedicated direct expansion (DX) cooling units to handle the additional cooling loads.

Terminal Unit Distribution Boxes

The perimeter zones of the building are served by VAV terminal boxes equipped with hot water reheat coils. Supply air for the perimeter zones is provided by VAV AHU-2 located in the penthouse. Space setpoints are maintained by modulating the air volume to cool the space. If a space requires heating, the VAV box air flow is modulated to its minimum position and the heating coil hot water control valve modulates to maintain space temperatures. No simultaneous heating and cooling is permitted.

The core zones of the building are also served by VAV terminal boxes. However, these VAV terminal boxes do not have reheat coils. Supply air for the core zone is provided by VAV AHU-1 located in the penthouse. Space setpoints are maintained by modulating the air volume when necessary to cool the space.

Occupancy sensors located throughout the building control lighting. These occupancy sensors also provide status for the VAV box controller. Occupied and unoccupied setpoints for the space temperature are also triggered by the lighting occupancy sensors. The operation of these occupancy sensors was questioned during the site visit because lights remained on in many areas that were unoccupied.

The BAS for the building has been upgraded to direct digital control (DDC), except for the post office area on the first floor. The post office area terminal boxes are all pneumatic. This area is served by a separate air handler located above the ceiling.

2.3 Climate, Facility Type, and Operations

The climate for the site is considered cool, but humid. Based on data available from the National Climatic Data Center, the maximum mean monthly temperature occurs in July (75.1°F), with the minimum mean monthly temperature occurring in January (28.3°F). The highest recorded temperature during the period from 1971 through 2000 was 104°F on July 14, 1954, while the lowest reported temperature during the period of 1948 through 2001 was -22°F on January 19, 1999. Based on the most recent mean data available (1971-2000), the site should experience 16 days with a maximum temperature exceeding or equal to 90°F, while the minimum temperature should be at 32°F or below for 113 days. Annually, the site should anticipate 5492 heating degree days (HDD) and 951 cooling degree days (CDD).

Mean annual precipitation for the site is 38.52 inches. The highest daily reported precipitation was 5.13 inches for July 13, 1992. The highest reported monthly precipitation, 12.36 inches, occurred in July 1992. The daily precipitation should be at or greater than 0.01 inches for 140 days during the year. Mean annual snow fall for the site is 28.4 inches, but the highest monthly snowfall was reported for January 1978 (34.4 inches). The highest daily snow fall was 17+ inches on January 23, 1978.

The facility is a standard commercial office facility. At the time of the site audit, the building was approximately 80% occupied (estimated 500 to 520 persons). The office building occupancy hours are approximately 6 a.m. to 6 p.m., Monday through Friday, with some Saturday hours for the Internal Revenue Service office. Tenants are charged for utility costs outside of the normal occupancy hours. Two electric meters serve the site that includes the office building and parking garage. One electric meter serves the penthouse equipment (chillers, cooling towers, boilers, and pumps) and the other electric meter serves the balance of electrical loads (lights and office equipment). However, the only submeter for the building covers electricity usage for the cafeteria.

3.0 Energy Use

The Bricker Federal building electrical usage is metered by the servicing utility (American Electric Power [AEP]) through two electrical meters. One meter serves the penthouse mechanical room with the pumps, cooling tower, chiller, and air handlers. The other meter serves the building lighting and occupant equipment loads. The parking garage is also served by this meter. The only submetered area is the cafeteria, but the building is currently receiving advanced metering capabilities.

3.1 Current Energy, Gas, and Water Use

Figures 2, 3, and 4 represent the combined usage by Federal fiscal year. The fiscal years showing higher-than-average electrical usage may be attributable to construction.

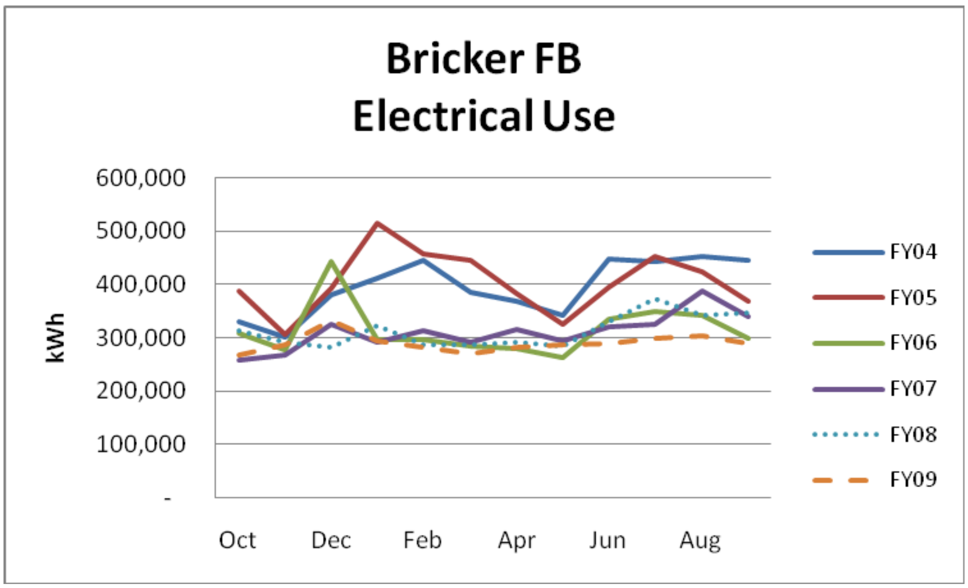


Figure 2. Columbus Bricker Federal Building Electrical Use

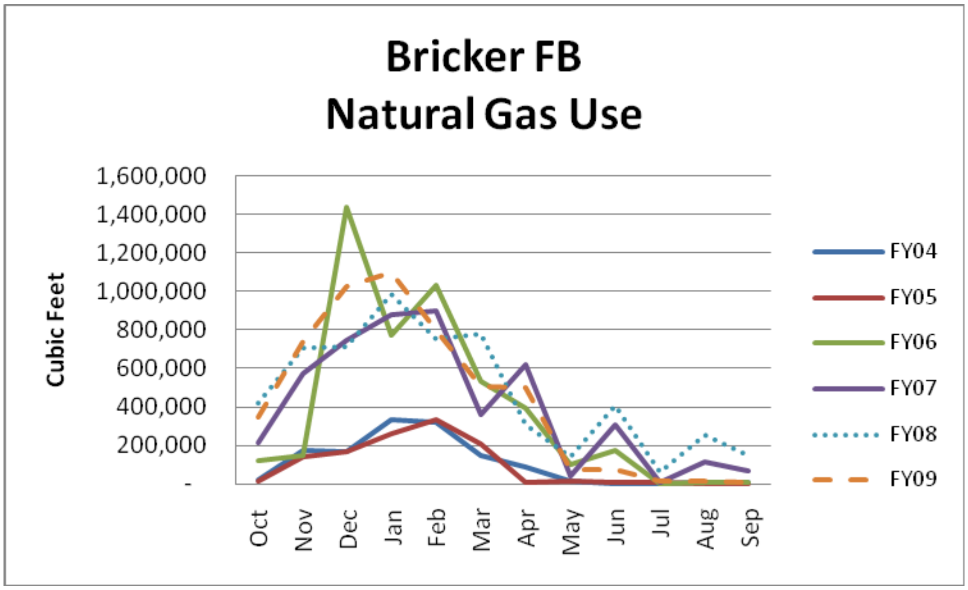


Figure 3. Columbus Bricker Federal Building Natural Gas Use

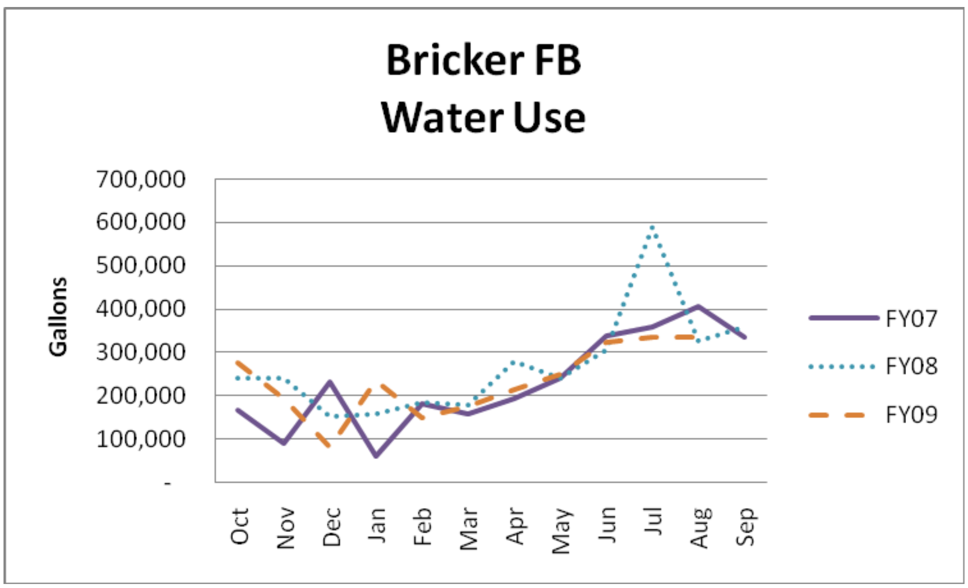


Figure 4. Columbus Bricker Federal Building Water Use

3.2 Current Rate Structure

American Electric Power provides service under Tariff 242, and this rate is applied to the monthly sum of all three electric meters. Tariff 242 is a medium general service tariff, which is available for general service customers with maximum demands greater than or equal to 10 kilowatts (kW) but less than 8,000 kW. Columbus Bricker's peak load in the last fiscal year ranged from 600 to 1100 kW. Therefore, the current Tariff 242 is appropriate for this site.

Columbia Gas of Ohio provides natural gas under a commercial service rate. During the last fiscal year (FY09), the consumption was 5.2 million cubic feet (Mcf), which falls under small general transportation for customers consuming less than 300 Mcf.

The City of Columbus provides water under a commercial service rate.

4.0 Energy Conservation Measures Identified

4.1 Summary of Proposed Measures

Four main areas were identified where ECMs are recommended for immediate implementation. These ECMs were evaluated in reference to annual energy and cost savings, using a simple payback method. A detailed savings summary is included in Table 1. Energy savings estimates are based on individual results and do not represent the interactive effect they have on each other. Savings in Table 1 are estimated reductions in energy use compared with the baseline or existing building energy usage model. The four areas identified were:

1. Optimum start/stop of AHUs, chillers, and boilers
2. AHU supply air temperature reset and static pressure reset and unoccupied space setpoints
3. Boilers — oxygen trim controllers and exhaust stack dampers
4. Building retro-commissioning
    a. BAS temperature sensors calibration
    b. Occupancy sensors calibration (used for both lighting and heating, ventilation and air conditioning (HVAC) setpoint control).

Several renewable energy projects were also identified for the building, including installation of a solar hot water (SHW) system and solar photovoltaic (PV) generation. The evaluation did not include the impact of obtaining rebates or incentives.

The team also identified (but did not evaluate in detail) the following additional possible recommendations during the visit:

- AHU heat recovery
- Web-based access for building automation system
- Condensing boiler (but keep one dual-fuel boiler)
- Infrared (IR) survey to detect areas of heat loss
- Training for the Columbus ARRA team on operations and maintenance (O&M), energy efficient operation, and troubleshooting of systems. Everyone on the team, including the onsite contract operator, has less than 1 year of experience with the building systems, and they will certainly benefit from comprehensive training, such as the web-based FEMP training on recommissioning and operations and maintenance.

Table 1. Columbus Bricker Federal Building Recommended Energy Conservation Measures (ECMs)

Table 1: Recommended Energy Conservation Measures (ECMs)											
ECM #	Energy Saving Recommendations	Electrical Savings (kWH)	Natural Gas Savings (Therms)	Energy Savings (Millions of Btus)	Water Savings (Gallons)	Electrical Savings ($)	Natural Gas Savings ($)	Water Savings ($)	Total Annual Savings ($)	Cost to Implement ($)	Simple Payback (Years)
1	Optimum Start/Stop	20,200	2,200	289		$ 1,600	$ 2,500		$ 4,100	$ 300	0.1
2a	Supply Air Temperature Reset	296,200	21,756	3,187		$ 23,459	$ 24,726		$ 48,185	$ 300	0.01
2b	Static Pressure Reset	38,300	-2,000	-69		$ 3,033	$ (2,273)		$ 760	$ 1,200	1.6
2c	Unoccupied Space Setpoints	17,955	850	146		$ 1,422	$ 966		$ 2,388	$ 2,000	0.8
3a	Boilers (oxygen trim controller)	0	2,700	270		$ -	$ 3,069		$ 3,069	$ 20,000	6.5
3b	Boilers (exhaust stack damper)	0	2,100	210		$ -	$ 2,387		$ 2,387	$ 3,000	1.3
4	Building Retro-commissioning	177,260	2,440	849		$ 14,039	$ 2,773		$ 16,812	$ 68,779	4.1
	Total (Non-interactive)	**549,915**	**30,046**	**4,881**		**$ 43,553**	**$ 34,147**		**$ 77,701**	**$ 95,579**	**1.2**
	Percent Savings (Non-interactive)	**16%**	**58%**	**28%**							
	Renewable Energy										
SHW	Solar domestic hot water		803	80		$ -	$ 912		$ 912	$ 10,000	11.0
SPV	Solar power generation (70 kW)	78,713		269		$ 6,234	$ -		$ 6,234	$ 700,000	112.3
	Total Renewable Energy	**78,713**	**803**	**349**		**$ 6,234**	**$ 912**		**$ 7,146**	**$ 710,000**	**99.4**
2009 Reference Data											
		Annual Electrical Use (kWH)	**Annual Natural Gas Use (Therms)**	**Annual Energy Use (Millions of Btus)**	**Annual Water Use (Gallons)**	**Electrical Cost**	**Natural Gas Cost**	**Water Cost**	**Total Annual Utility Use ($)**	**Total Annual Energy Use ($)**	
	Cost Per Unit 2009					**0.0792**	**1.1365**	**0.00892**			
	eQUEST Baseline 2009	3,545,200	51,900	17,290	NA	$280,780	$ 58,984	NA	NA	$ 339,764	
	eQUEST / Actual Use Ratio	**101.8%**	**99.9%**	**101.2%**	Modeling estimates should fall within 5% of actual usage.						
	Actual Baseline Usage 2009	3,481,840	51,942	17,078	2,924,680	$275,762	$ 59,032	$ 26,088	$360,882	$ 334,794	
	Actual Energy Use Intensity (EUI) - (BTU/SF-YR)	28,253	12,349	40,602							

ECM1 - *Optimum Start/Stop of AHUs, Chillers and Boilers*

Optimum start/stop is a standard option provided in the building automation system control strategies. This control strategy starts the building systems in advance of the building occupancy to bring space comfort temperatures to occupied setpoints before the building is occupied. Each day, the start of systems is calculated by the control system to determine how much time is needed to bring the space temperatures to the desired setpoint. Currently, the building systems are started at the same time each day on a set time schedule. Energy savings can be gained by automatically adjusting the daily start time to just meet the requirements of the building.

An eQUEST energy model was developed (Appendix A), and the estimated annual energy savings are summarized in Table 1.

ECM2.a - *AHU Supply Air Temperature Reset*

The supply air temperature for a single-duct VAV system is usually set at a constant 55°F. This setpoint is used in the design of air handling systems to calculate the maximum air flow to satisfy the maximum cooling load conditions. If the setpoint is left at 55°F, significant reheat will occur in the winter when air flows reach their minimums and the heating load increases. The system is in a heating mode and the supply air temperature is often reset upward to minimize simultaneous cooling and heating. The reset schedule can be based on either return air temperature or outside air temperature. Resetting the supply air temperature not only affects the cooling and heating energy consumption, but also the fan power consumption. If the supply air is reset too high, it may result in a fan power consumption penalty.

An eQUEST energy model was performed (Appendix A), and the estimated annual energy savings are summarized in Table 1. The energy efficiency measure wizard option for supply air reset (55/65°F) based on zone loads was used for these estimates.

Air handling systems that serve both the core areas of the building and the perimeter areas of the building have limited opportunities to use supply air reset control strategies. This limitation is most evident in the winter when the perimeter zones are in heating and the core areas of the building continue to require cooling. If the supply air temperature is reset upwards, the core area VAV terminal boxes will increase air flows to maintain space temperature. This increase in air flow will cause an increase in fan energy. For a net energy savings, this increase in fan energy use would have to be offset by the energy savings in the perimeter zones that would be required for less reheating at the terminal boxes. The optimal supply air temperature needs to take into account the thermal and electrical energy costs to achieve the minimum total operating costs. Generally, the amount of reset is limited by the percent of building area included in the core areas of the building; perimeter areas are affected by the weather and present greater opportunities for temperature reset. Significant energy saving opportunities can be gained if the building perimeter and core zones are served by separate VAV air handling systems.

During the winter, occupants of the building will complain about cold drafty air flows from a VAV system if the supply air temperature is left at 55°F. These complaints are justified because the VAV boxes throttle back to minimum flows in the winter during heating, and the supply air diffusers do not distribute the air as effectively with low air flow velocities. This cold air tends to drop down around the occupants, and many complaints will be registered with the operations staff. Resetting the supply air upwards will reduce comfort complaints. The most common supply air reset schedules vary the supply temperature between 55°F and 65°F.

ECM2.b - *AHU Static Pressure Reset*

Air static pressure in a VAV air handling system is normally maintained by modulating the speed of the fan. Air is distributed throughout the building by ductwork, and VAV terminal boxes control the flow of cool air delivered to the space they serve. As the space cooling load increases, the flow of cold air increases to maintain the space temperature. If space cooling loads decrease, the requirements for cold air flow to cool the space decrease. The air flow to the VAV terminal boxes is delivered at a system static pressure. The static pressure level is established by the minimum pressure required for the terminal boxes to deliver full cooling flows. During the winter, air flow requirements drop to their minimum levels and the static pressure required at terminal boxes decreases. This reduced air flow requirement brings about an opportunity to reduce the system static pressure levels along with reducing energy usage. Static pressure reset control strategies have been in use for more than 20 years and have been proven to provide significant levels of energy savings.

An eQUEST energy model was developed (Appendix A), and the estimated annual energy savings is summarized in Table 1. The energy efficiency measure wizard option to model static pressure reset is not included in the current version of eQUEST. The magnitude of energy savings was estimated by modeling the baseline VAV system as a forward-curved fan system with inlet vane dampers, and the static pressure reset option was modeled as a standard VAV system with variable speed drives.

Implementation of the improved air static pressure reset control can greatly increase the energy savings. Since 1999, American Society of Heating, Refrigerating & Air Conditioning Engineers (ASHRAE) 90.1 has required that static air pressure be reset for systems with DDCs "i.e., the setpoint is reset lower until one zone damper is nearly wide open." However, system design deficiencies often limit the potential energy savings. These design deficiencies create problem zones that cause the reset scheme to underperform because they frequently or constantly generate zone pressure increase requests.

Common causes are:

- Undersized VAV box because of improper selection in the design phase, or because unexpectedly high zone loads are added to the space after construction
- Cooling thermostat setpoint below design condition
- Thermostats with heat releasing equipment under them (typically microwaves and coffee pots)
- Air distribution design problems — high-pressure drop fittings or duct sections.

The first three items cause the zone to frequently demand maximum or near-maximum zone air flow rates. Depending on zone location relative to the fan, a constant demand for high air flow rates indirectly causes the zone to generate frequent or constant pressure requests. The fourth problem directly results in pressure requests: for example, a zone with a fire/smoke damper installed in the

6-inch (150-millimeter [mm]) high-pressure duct at the box inlet. Small smoke dampers have little free area so pressure drop will be very high.

Ways to mitigate the impact of problem zones on static pressure reset control sequences include:

- Exclude the problem zones from the reset control sequence. They can be excluded by ignoring the problem zone's pressure requests or including logic that ignores the first few pressure requests. Of course, ignoring the zone results in failure to meet zone air flow and temperature setpoints. This failure may be acceptable if the zone is a problem because the temperature setpoint is too low, but it clearly can be an issue if the zone is more critical.

- Limit thermostat setpoint adjustments to a range that is close to space design temperatures. DDC systems typically have the ability to limit the range; occupants can adjust setpoints from the thermostat. This means of mitigation can prevent cooling setpoints that are well below design conditions.

- Request that all thermostats are free of impact from appliances directly under them.

- Fix duct restrictions and sizing issues. This choice is clearly better than ignoring the zone and letting it overheat, but the cost to make revisions may be higher than the owner is willing to invest. It is best, of course, to avoid these restrictions in the first place. For instance, avoid using flexible duct at VAV box inlets, avoid oversized inlet ducts when they extend a long way from the duct main, and avoid small fire/smoke dampers in VAV box inlet ducts.

- Add auxiliary cooling to augment the VAV zone. If the problem results from an undersized zone or unexpectedly high loads, a second cooling system, such as a split air conditioning (AC) system, can be added to supplement the VAV zone capacity. However, this solution is also expensive.

ECM2.c - *Unoccupied Space Setpoints*

Unoccupied areas in the basement of the building are heated and cooled during normal building hours. Lighting in these areas also remained on continuously. Both the lighting and the space temperatures are controlled by the occupancy sensors. Occupancy sensors in these areas need to be replaced or adjusted as they currently remain in the occupied status. There are other areas of the building that have had similar problems, and the operations staff has corrected many areas. However, there were some areas that have not been corrected.

Another option for correcting this problem is building retro-commissioning, which is discussed below.

ECM3.a – *Boilers - Oxygen Trim Controllers*

All combustion requires oxygen; too much or too little can cause undesirable effects. However, the error is almost always intentionally on the high side (too much oxygen) because the main effect on the high side is low efficiency. Too little air results in carbon monoxide formation, as well as sooting and even explosion if accumulated soot and other non-combusted gases suddenly receive enough oxygen to rapidly burn.

When boiler burners are manually tuned on a periodic basis, they are typically adjusted to about 3% excess oxygen, which is about 15% excess air. These levels are used because there are many ambient and atmospheric conditions that can affect oxygen and air supply. For example, colder air is denser and contains more oxygen by volume than warm air; wind speed affects every chimney, flue, and stack differently; and barometric pressure further affects draft. Therefore, an excess oxygen and air setting at the time of tuning assumes there will still be enough oxygen available for complete combustion when conditions worsen.

From an efficiency standpoint, the excess oxygen means there is more air in the combustion stream than necessary. The amount of excess oxygen is roughly proportional to the efficiency lost.

Although it may be possible to monitor and adjust the burner on a daily basis, it is not practical. Automatic oxygen systems (Figure 5) continuously monitor the flue gases and adjust the burner air supply. They are generically called “Oxygen Trim Systems.”

Figure 5. Components of Automatic Oxygen Monitoring System

An electronic sensor is inserted into the boiler flue, near the boiler, ahead of dampers or other sources of air leakage into the boiler or flue. The sensor is connected to a control panel that measures oxygen and sends a signal to a control damper on the burner air supply.

An eQUEST energy model was performed (Appendix A), and the estimated annual energy savings are summarized in Table 1. The energy conservation measure wizard was used to model the energy savings by adjusting the overall combustion efficiency by 4%.

ECM3.b – *Boilers - Exhaust Stack Dampers*

Gas-fired furnaces, small boilers, and water heaters require a flue that has a good draft to eliminate the products of combustion after most of the heat has been removed. Newer appliances have fans and are called “forced” or “induced” draft venting. Older equipment and most small boilers still rely on natural draft. Figure 6 shows a picture of a typical exhaust stack damper. Figure 7 is a picture of a typical installation on two boilers.

Figure 6. Exhaust Stack Dampers

Figure 7. Exhaust Dampers Installed

The problem arises when the draft is occurring all of the time, drawing air out of the facility, even when it is not necessary to remove flue gases (when the burner is off). A vent damper is an automatic device that shuts off the flue pipe when the burner is not running, saving off-cycle losses of heated air. Therefore, if the appliance is in an unheated space, there is no benefit to a vent damper. The Columbus Bricker building boilers are located in a heated space, and exhaust vent dampers will reduce heated air energy loss.

An eQUEST energy model was performed (Appendix A).and the estimated annual energy savings are summarized in Table 1. The energy conservation measure wizard was used to model the energy savings by adjusting the overall combustion efficiency by 3%.

ECM4 - *Building Retro-commissioning*

Retro-commissioning (or Retro-Cx) is a form of commissioning. Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner’s operational needs. Retro-commissioning is the same systematic process applied to existing buildings that have never been commissioned to ensure that their systems can be operated and maintained according to the owner's needs. For buildings that have already been commissioned or retro-commissioned, it is recommended that the practices of recommissioning or ongoing commissioning be applied.

Recommissioning is the term for applying the commissioning process to a building that has been commissioned previously (either during construction or as an existing building); it is normally done every 3 to 5 years to maintain top levels of building performance or after upgrades to identify new opportunities for improvement.

Researchers at Lawrence Berkeley National Laboratory, Portland Energy Conservation, Inc., and the Energy Systems Laboratory at Texas A&M University concluded in a study published in December 2004 (Mills et al. 2004) that retro-commissioning is one of the most cost-effective means of improving energy efficiency in commercial buildings. The researchers statistically analyzed more than 224 new and existing buildings that had been commissioned, totaling more than 30 million ft^2 of commissioned floorspace (73% existing buildings and 27% new construction). The results revealed the most common problem areas and showed that both energy and non-energy benefits were achieved. Analysis of commissioning projects for existing buildings showed a median commissioning cost of $0.27 per ft^2, an energy savings of 15%, and a simple payback period of 0.7 year.

The Retro-commissioning Process

Retro-commissioning should follow a four-step approach of planning, investigation, implementation, and continuation.

Step 1 is the planning step, which includes assembling the Retro-Cx core team that will work with the Retro-Cx provider and is composed of building management staff with skills in equipment operation, energy management, and engineering. During this step, the overall objectives and strategy are established.

Step 2, the investigation step, includes several significant activities. During a typical Retro-Cx effort, the providers become familiar with the building and its systems via walk-throughs, gathering and reviewing equipment and design documentation, and evaluating O&M practices. As part of the investigation step, a list of potential ECMs for the building is developed. The Department of Energy's (DOE's) Industrial Assessment Center maintains an exhaustive data base of 2,300 potential ECMs, most of which are no cost/low cost (less than $500). The Retro-Cx provider identifies applicable ECMs, develops cost estimates, and prioritizes the opportunities.

Step 3 is implementation of ECMs. ECMs determined to be easy to complete, measure, and most likely to succeed are the first to be addressed. The results of these ECMs are then used to build up credibility for the Retro-Cx approach and gain support to accomplish the full range of ECMs. Completed ECMs are tested and monitored for results with readjustments made as necessary.

Step 4 in the Retro-Cx effort is that of continuing the onsite efforts with activities such as monitoring building energy data, periodic review of operational changes, occupant and operator feedback, and monthly update reports. Ongoing monitoring of building performance helps to ensure that the retro-commissioned building systems continue to operate in their optimized state and that energy savings continue to be realized.

The value of retro-commissioning is most obvious with the ongoing problematic occupancy sensors in the building, as noted in the basement of the building where lighting is on continuously and the space temperatures are maintained as occupied spaces. Retro-commissioning would include a thorough assessment and adjustment or replacement of faulty occupancy sensors.

4.2 Renewable Energy Measures Evaluated

Solar Hot Water

The Bricker building is occupied by about 500 people, and the needs for hot water are primarily the cafeteria kitchen area, other small kitchen areas, and bathroom faucets. Solar hot water heating is a viable renewable energy system in Ohio. The State of Ohio encourages the use of solar hot water and offers partial incentive funding on a first come first served basis (see below). The Bricker building has limited rooftop space that would be suitable for a solar photovoltaic collector field. Solar collector areas of the roof should not be shaded to allow for direct solar absorption on the collector surface. Therefore, only two areas are preferred: the area to the south of the penthouse on the main roof, and the roof area above the penthouse. The system proposed for the Bricker building would require almost 1,000 square feet of roof area for the solar collector field.

The annual production of solar heated water was estimated using a solar hot water heating estimator from RETScreen (NRC 2010) that uses solar data for Columbus, Ohio.

Solar Photovoltaic Power Generation

Solar photovoltaic power production is also a viable renewable energy producer in Ohio. The State of Ohio encourages the use of solar power generation and offers partial incentive funding on a first come first served basis (see below). As noted in the discussion of solar hot water, the roof area of the Bricker building has limited areas that are suitable for optimum solar collector placement. The collector field area needed to produce 70 kilowatts (kW) of solar power is equal to the roof area of the penthouse or 7,000 ft^2 of roof area. However, a structural analysis of the roof structure will be required.

The annual production of electricity was estimated using a PV Watts solar production estimator using solar data for Columbus, Ohio. The power produced is used by the building and no power is transferred to the grid. Solar PV rebates and incentives may be available, but they have not been factored into the cost of implementing the project, as found in Table 1.

5.0 Potential Green House Gas Reduction

The proposed ECMs will reduce greenhouse gas (GHG) emissions. All reported calculations in Table 2 below are based on the Environmental Protection Agency (EPA) GHG emissions calculator and are reported as carbon dioxide equivalent (CO_2e). The EPA calculator estimates for kWh savings are based on CO_2 only. If the recommended ECMs are implemented, the actual kWh savings can be used to determine GHG emissions reductions using the EPA eGRID model (Pechan 2008), using actual data from the specific electricity provider, which takes into consideration complex factors such as utility generation mix from coal, natural gas, nuclear and renewable energy sources.

Table 2 Estimated GHG Emissions Reductions for each Proposed ECM

ECM#	kWh savings estimated	therm savings estimated	metric tons GHG avoided (kWh estimated) in CO_2e	metric tons GHG avoided (therms estimated) in CO_2e	estimated total metric tons GHG avoided in CO_2e
1	20,200	2,200	14	11	25
2a	296,200	21,756	207	109	316
2b	38,300	-2,000	27	-10	17
2c	17,955	850	13	4	17
3a	0	2,700	0	14	14
3b	0	2,100	0	11	11
4	177,260	2,440	124	12	136
Solar Hot Water	0	803	0	4	4
Solar Power Generation	78,713	0	55	0	55
TOTALS	**628,628**	**30,849**	**440**	**154**	**594**

Reference: http://www.epa.gov/rdee/energy-resources/calculator.html

To calculate jobs created/retained, we assume one job for every $92,000 in funds expended. The baseline non-interactive energy efficiency retrofits ($95,579) will result in one job created and 535 tons of carbon dioxide equivalent (CO_2) emissions avoided. If the proposed renewable energy projects are implemented, the estimated investment would be $710,000. This would result in eight jobs created and 59 tons of carbon dioxide equivalent (CO_2) emissions avoided.

6.0 Action Plan for Implementation of ECMs

6.1 Priorities and Next Steps

There are three ways to implement the recommended measures:

1. Use the audit report findings to immediately implement the no-cost and low-cost ECMs identified.

2. Further analyze ECMs with moderate cost or longer simple payback times.

3. Conduct a more comprehensive audit or recommissioning to identify ECMs that may be less desirable now because of implementation obstacles or capital cost considerations.

    - The first action item should focus on implementing the no-cost/low-cost recommendations. To implement these measures, GSA can request a proposal to implement the measures from the operations contractor.

    - Building retro-commissioning implementation is a four-step process, and the planning stage is the first step once funding is secured.

    - The solar energy projects need further study and require the services of an engineering consultant to design these systems.

    - Replacing the natural gas boilers or installing AHU heat recovery systems are capital projects that require an engineering consultant to begin project development.

    - Recommended resources for Bricker building operations staff:

      ✓ FEMP Retro-commissioning
      http://www1.eere.energy.gov/femp/pdf.om retrocs.pdf
      ✓ FEMP Best Practices Operations and Maintenance
      http:///www1.eere.energy.gove/femp/operations maintenance/om bpguide.html

6.2 Funding Assistance Available

AEP of Ohio is the servicing utility for the facility, and incentives may be available. All business (non-residential) customers in AEP Ohio's service territory in the State of Ohio are eligible to participate. Qualifying customers will receive a financial incentive payment that is customized to the specific results of the energy-saving technologies implemented. Energy-saving incentives ($0.08/kilowatt hour) are paid on the estimated first year kWh savings, and demand incentives ($100/kW) are paid based on the equipment's contribution to AEP Ohio's peak demand reduction (in kW). All incentives are on a first-come, first-served basis and are contingent on AEP Ohio's review and acceptance of savings claims.

Renewable energy funding may also be available for purchase and installation of the renewable technologies. The Ohio Department of Development's (ODOD) Ohio Energy Office (OEO) is seeking applications to implement renewable energy projects limited to solar electric, wind electric, and solar thermal systems for commercial, industrial, institutional and governmental entities in Ohio. In accordance with the authority provided the Director of the ODOD under Ohio Revised Code §4928.61-63, qualifying applicants will be eligible to apply for grant assistance to cover a portion of the costs of eligible projects located in the service territories of the four investor-owned electric distribution companies. Grant funds are limited, but qualifying applications will be funded until all the funds for this Notice of Funding Available (NOFA) are awarded or the OEO determines the program no longer suits the best interest of Ohio's energy plan. Additional information can be found at the following web site: http://www.development.ohio.gov/cdd/oee/ELFGrant.htm#NOFA_08-09

Solar electric systems incentives are available at a rate of $3.50/watt for systems that generate at least 10 kW. The maximum incentive cannot exceed 50% of eligible system costs, and the maximum incentive as a total of eligible system costs is limited to $150,000.

Solar thermal systems incentives are available at a rate of $30 per thousand British thermal units (kBtu)/day for systems that can provide at least 200 kBtu/day. The maximum incentive cannot exceed 50% of eligible system costs, and the maximum incentive as a total of eligible system costs is limited to $150,000.

Federal projects can be financed by various means. The most readily available funding source would be ARRA funds at the agency level. An alternative approach for Federal projects is the use of either energy savings performance contracts (ESPC) or utility energy savings performance contracts (UESC) that provide up-front funding to install systems and make modifications with repayment made from the resulting cost savings as results of the energy savings.

7.0 Assessment Team Members and Site Team

The Redhorse ARRA assessment team for the audit included Jim Arends, PE, CEM, Energy Audit Team Technical Lead; and Darcy Anderson, Energy Audit Team Member. Site support was provided by Courtney Blake, GSA Property Manager; Jordon Dykstra, GSA Assistant Property Manager; and Bonnie Robertson, GSA Building Management Specialist. Additional interviews were conducted with Aaron Heil, Operations Project Manager (onsite contract operator) with Facility Services Management, Inc.; Gary Hill, Boiler Service Technician with Brunner Corporation; and James Hornback, Sales Engineer with Brunner Corporation.

8.0 References

Mills, E, H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M. Piette. 2004. *The Cost-Effectiveness of Commercial-Building Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States*. LBNL-56637. Lawrence Berkeley National Laboratory, Berkeley, California. *Can be accessed at http://eetd.lbl.gov/emills/PUBS/PDF/Cx-Costs-Benefits.pdf*.

National Resources of Canda (NRC). 2010. *RETScreen® Clean Energy Project Analysis Software from RETScreen International*. *Can be accessed at http://www.retscreen.net/ang/t_software.php.*

E.H. Pechan & Associates (Pechan). September 2008. *The Emissions & Generation Resource Integrated Database for 2007 (eGRID 2007).* Report Number 08.09.006/9011.239. Springfield, Virginia.

APPENDIX A

Model Output Files

Appendix A – Model Output Files

Energy Simulation Output: Baseline Energy Use

eQUEST Model Results Baseline Use													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	30	28.1	32.4	42	55.9	66.7	63.2	59.4	53.7	33.2	23.7	30.8	519.20
Heat Reject.	0.5	0.5	0.8	2.2	4.6	7	7.6	6.7	5.3	1.6	0.5	0.4	37.5
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.5	0.4	0.4	0.2	0.1	0	0	0	0	0.1	0.3	0.4	2.4
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	73.3	65.5	47.1	39	38.9	35.1	22.7	24.8	24.1	30.2	43.8	62.3	506.6
Pumps & Aux.	16.5	15.7	19.8	19.5	18.3	19.3	17.1	16.3	16.5	16.6	15.2	18.1	208.9
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.40
Total	301.9	280.7	302.6	303.8	304.3	328.3	305.9	295.2	287.3	270.2	255.7	309.3	3,545.20
Gas Consumption (Btu x000,000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	1.05	0.93	0.75	0.33	0.11	0.03	0	0	0.05	0.24	0.53	0.85	4.88
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.31
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.08	0.96	0.78	0.36	0.13	0.06	0.02	0.03	0.07	0.27	0.55	0.88	5.19

Energy Simulation Output: Optimum Start / Stop

eQUEST Model Results Optimum Start/Stop													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	29.7	27.8	32.1	40.2	54.9	66	63.2	59.4	53.7	32.5	23.4	30.7	513.6
Heat Reject.	0.5	0.4	0.7	2.1	4.5	6.9	7.5	6.7	5.3	1.6	0.4	0.4	37.1
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.5	0.4	0.4	0.2	0.1	0	0	0	0	0.1	0.3	0.4	2.3
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	72.7	64.7	46.1	35.4	37.1	33.6	22.7	24.8	24	28.6	41.2	61.6	492.6
Pumps & Aux.	16.5	15.7	19.8	19.4	18.3	19.3	17.1	16.3	16.5	16.6	15.2	18.1	208.8
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	300.8	279.6	301.2	298.3	301.5	326.2	305.9	295.2	287.2	267.9	252.8	308.5	3,525.00
Gas Consumption (Btu x000,000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	1.01	0.9	0.72	0.3	0.1	0.03	0	0	0.05	0.23	0.5	0.82	4.66
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.31
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.04	0.92	0.75	0.33	0.12	0.05	0.02	0.03	0.07	0.25	0.53	0.85	4.97

Energy Simulation Output: Supply Air Temperature Reset

eQUEST Model Results Supply Air Temperature Reset													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	13.1	12.9	14.1	18.4	33.2	53.5	58.5	50.3	39.7	18.2	11	12.2	335.1
Heat Reject.	0.1	0.1	0.1	0.5	2.4	5.8	7.1	5.9	4	0.6	0.1	0	26.7
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0.2	0.3	1.4
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	67.2	61.2	40.9	22.5	19.4	24.8	26.9	24.2	20.7	21.6	33.6	55.9	418.7
Pumps & Aux.	14.7	14.1	18	18	17.7	19.1	17.1	16.3	16.1	15.6	13.9	16.1	196.5
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	276.5	259.2	275.4	260.3	259.3	303.5	304.9	284.7	268.1	244.5	231	281.7	3,249.00
Gas Consumption (Btu x000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	705.9	627	393.3	83.3	17.2	1	0	0	8.1	78.2	272.6	519.5	2,706.10
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	27.1	26.5	30.9	30.2	26.1	26.2	24.2	22.2	22	23	22.5	27.6	308.3
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	732.9	653.4	424.2	113.5	43.3	27.2	24.2	22.2	30.1	101.1	295	547.2	3,014.40

Energy Simulation Output: Static Pressure Reset

eQUEST Model Results Static Pressure Reset													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	30.5	28.3	32	41.6	55.7	65.8	62	58.4	52.8	32.7	23.3	30.8	513.9
Heat Reject.	0.5	0.5	0.8	2.2	4.5	6.9	7.5	6.6	5.2	1.6	0.4	0.4	37.2
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.5	0.4	0.4	0.2	0.1	0	0	0	0	0.1	0.3	0.4	2.5
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	73.1	64.5	43.8	36.5	37.4	31.7	16.5	19.9	20.1	27.4	41.6	61.6	474.1
Pumps & Aux.	16.5	15.7	19.8	19.4	18.3	19.2	17.1	16.3	16.5	16.5	15.2	18.1	208.6
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	302.1	279.9	298.9	300.9	302.5	324	298.4	289.4	282.2	266.8	253.1	308.6	3,506.90
Gas Consumption (Btu x000,000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	1.11	0.98	0.78	0.34	0.11	0.03	0	0	0.05	0.25	0.55	0.9	5.09
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.31
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.14	1.01	0.81	0.37	0.13	0.06	0.02	0.03	0.07	0.27	0.57	0.92	5.39

Energy Simulation Output: Unoccupied Setpoints

Note: The whole basement area was simulated; however, only 15% of this area would benefit from corrections. Therefore, only 15% of the total is included in Table 1.

eQUEST Model Results Unoccupied Setpoints													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	27.9	25.9	30	37.3	49.1	58.7	58.8	55.5	50.6	30.2	21.9	28.8	474.8
Heat Reject.	0.5	0.4	0.7	2	4.1	6.3	7	6.2	4.9	1.5	0.4	0.4	34.4
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.4	0.4	0.3	0.1	0	0	0	0	0	0.1	0.2	0.4	2.1
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	67.9	60	44	32.3	30	25.2	22.6	24.2	23.3	25.5	37.5	58.5	450.9
Pumps & Aux.	15.3	14.5	18.3	17.9	16.9	17.8	15.8	15.1	15.2	15.3	14	16.7	192.7
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	293	271.8	295.5	290.6	286.6	308.3	299.5	289	281.7	261.1	246.3	302.1	3,425.50
Gas Consumption (Btu x000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	946.9	825.5	677.9	262.6	72.4	14.5	0	2	42	208.8	475.5	785.2	4,313.30
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	27	26.4	30.8	30.2	26.1	26.1	24	22	21.9	22.9	22.4	27.6	307.4
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	973.9	851.9	708.7	292.8	98.4	40.6	24	24	63.9	231.7	497.9	812.8	4,620.60

Energy Simulation Output: Boiler O_2 Trim Controller

eQUEST Model Results Boiler O2 Trim Controller													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	30	28.1	32.4	42	55.9	66.7	63.2	59.4	53.7	33.2	23.7	30.8	519.2
Heat Reject.	0.5	0.5	0.8	2.2	4.6	7	7.6	6.7	5.3	1.6	0.5	0.4	37.5
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.5	0.4	0.4	0.2	0.1	0	0	0	0	0.1	0.3	0.4	2.4
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	73.3	65.5	47.1	39	38.9	35.1	22.7	24.8	24.1	30.2	43.8	62.3	506.6
Pumps & Aux.	16.5	15.7	19.8	19.5	18.3	19.3	17.1	16.3	16.5	16.6	15.2	18.1	208.9
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	301.9	280.7	302.6	303.8	304.3	328.3	305.9	295.2	287.3	270.2	255.7	309.3	3,545.20
Gas Consumption (Btu x000,000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.99	0.88	0.71	0.31	0.1	0.03	0	0	0.05	0.23	0.5	0.81	4.61
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.31
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.02	0.91	0.74	0.34	0.13	0.06	0.02	0.03	0.07	0.25	0.52	0.83	4.92

Energy Simulation Output: Boiler Exhaust Stack Damper

eQUEST Model Results Boiler Exhaust Stack Damper													
Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	30	28.1	32.4	42	55.9	66.7	63.2	59.4	53.7	33.2	23.7	30.8	519.2
Heat Reject.	0.5	0.5	0.8	2.2	4.6	7	7.6	6.7	5.3	1.6	0.5	0.4	37.5
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0.5	0.4	0.4	0.2	0.1	0	0	0	0	0.1	0.3	0.4	2.4
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	73.3	65.5	47.1	39	38.9	35.1	22.7	24.8	24.1	30.2	43.8	62.3	506.6
Pumps & Aux.	16.5	15.7	19.8	19.5	18.3	19.3	17.1	16.3	16.5	16.6	15.2	18.1	208.9
Ext. Usage	1.3	1	1.1	1.1	0.8	0.8	0.8	1.3	1.2	1.3	1.3	1.3	13.4
Misc. Equip.	107.7	101.6	121.7	121.1	113.6	121.1	116.9	112.4	111.8	112.3	102.6	116.9	1,359.80
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	71.9	68	79.3	78.7	72.1	78.4	77.7	74.4	74.6	74.9	68.3	79	897.4
Total	301.9	280.7	302.6	303.8	304.3	328.3	305.9	295.2	287.3	270.2	255.7	309.3	3,545.20
Gas Consumption (Btu x000,000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	1.01	0.89	0.72	0.32	0.1	0.03	0	0	0.05	0.23	0.51	0.82	4.67
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.31
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.03	0.92	0.75	0.35	0.13	0.06	0.02	0.03	0.07	0.26	0.53	0.85	4.98

Energy Simulation Output: Retro-commissioning

eQUEST Energy Model Results	kWh	Therms
Baseline	3,545,200	48,800
Estimated Savings Percent	5%	5%
Estimated Savings Retro-commissioning	177,260	2,440

Energy Simulation Output: Solar Hot Water

Retrscreen Tool				
Technology		Solar water heater		
Load characteristics	**Unit**	**Base case**	**Proposed case**	
Load type		Office		
Number of units	Person	500		
Occupancy rate	%	80%		
Daily hot water use - estimated	gal/d	402		
Daily hot water use	gal/d	400	400	
Temperature	°F	130	130	
Operating days per week	d	5	5	
Supply temperature method		Formula		
Water temperature - minimum	°F	42.9		
Water temperature - maximum	°F	59.5		
Heating	million Btu	68.3	68.3	
Resource assessment				
Solar tracking mode		Fixed		
Slope	°	0.0		
Azimuth	°	0.0		
Solar water heater				
Type	Unglazed			
Manufacturer	Heliocol			
Model	HC-10			
Gross area per solar collector	ft²	10.37		
Aperture area per solar collector	ft²	10.37		
Fr (tau alpha) coefficient		0.87		
Wind correction for Fr (tau alpha)	s/ft			
Fr UL coefficient	(Btu/h)/ft²/°F	3.75		
Wind correction for Fr UL	(Btu/ft³)/°F			
Number of collectors		60	22	
Solar collector area	ft²	621.00		
Capacity	kW	40.45		
Miscellaneous losses	%			
Balance of system & miscellaneous				
Storage		Yes		
Storage capacity / solar collector area	gal/ft²	1		
Storage capacity	gal	621.9		
Heat exchanger	yes/no	Yes		
Heat exchanger efficiency	%	60.0%		
Miscellaneous losses	%	10.0%		
Pump power / solar collector area	W/ft²	0.00		
Electricity rate	$/kWh	0.053		
Summary				
Electricity - pump	MWh	0.0		
Heating delivered	million Btu	60.2		
Solar fraction	%	88%		
Heating system		**Base case**	**Proposed case**	**Proposed Savings**
Fuel type		Natural gas - therm	Natural gas - therm	Natural gas - therm
Seasonal efficiency		75%	75%	
Fuel consumption - annual	therm	910.7	108.0	802.8

Energy Simulation Output: Solar Power Generation

PV Watts AC Energy & Cost Savings

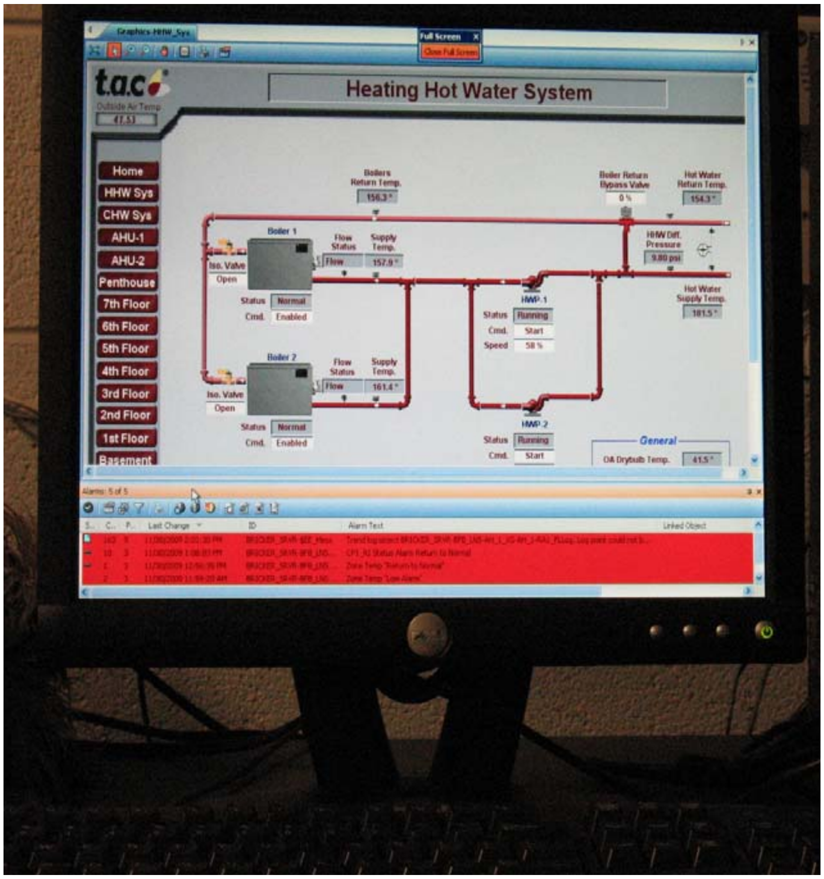
Station Identification			Results		
City:	Columbus		Month	Solar Radiation $(kWh/m^2/day)$	AC Energy (kWh)
State:	Ohio				
Latitude:	40.00° N		1	2.91	4,940
Longitude:	82.88° W		2	3.24	4,986
Elevation:	254 m		3	4.03	6,610
PV System Specifications			4	5.07	7,847
DC Rating:	70.0 kW		5	5.07	7,766
DC to AC Derate Factor:	0.77		6	5.47	7,957
AC Rating:	53.9 kW		7	5.26	7,802
Array Type:	Fixed Tilt		8	5.56	8,371
Array Tilt:	40.0°		9	4.96	7,338
Array Azimuth:	180.0°		10	4.51	7,133
			11	2.77	4,356
			12	2.20	3,609
			Year	4.26	78,713

APPENDIX B

Photographs

Appendix B – Photographs

Jim Arends, Redhorse CEM, collecting nameplate data for FEMP audit in December 2009.



BAS diagram of heating hot water system.

Gary Hill, boiler service technician with Brunner Corporation conducting boiler tests during FEMP audit, December 2009.

Aaron Heil, Operations Project Manager (onsite contract operator) with Facility Services Management, Inc. performing chilled water control system check during FEMP audit, December 2009.

Jim Arends, Redhorse CEM, reviewing motor efficiency on large air handling unit during FEMP audit, December 2009.