ENERGY AUDIT REPORT

FAWCETT CENTER FOR TOMORROW (284)
2400 Olentangy River Road

Dec 2010

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1.0 EXECUTIVE SUMMARY

An energy audit of the Fawcett Center (178,195 ft^2) began in the fall of 2010. Eight energy conservation measures (ECMs) were identified that if implemented at an estimated cost of $337,517 would save $140,137 annually yielding a 2.4 year simple payback at the current utility rates. Estimated project completion would take 12 – 18 months after funding was secured.

Additional benefits of these ECMs would be a reduction in carbon dioxide equivalent (CO_2e) emissions of 1,343 metric tons/yr, and a 31% reduction in the energy utilization index (EUI), a measure of energy intensity based on building gross square footage. Implementation of these recommended ECMs aligns with the University's Climate Action Plan (CAP) to reduce energy consumption and green house gas emissions; expected outcomes are found in Table 1.

Table 1: Annual and Estimated Consumption and EUI

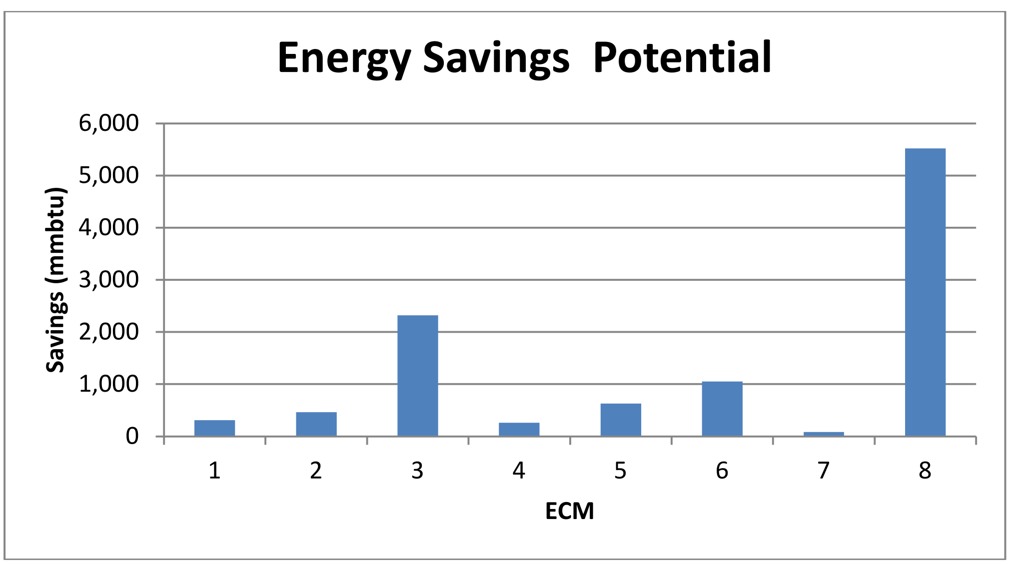
Annual Consumption	**Energy (mmbtu/yr)**	**EUI (kbtu/ft^2)**
Without ECMs	33,870	190
With ECMs (estimated)	23,276	131
Reduction	10,594	59
Percent Reduction	31	31

Without ECMs: FY08 - 1st half of FY11

Energy conservation measures are discussed in Section 7.0 including energy losses and potential savings associated with each ECM, see Figure 1. The following eight energy conservation measures are recommended for implementation:

ECM 1: Retrofit T-12 fixtures and replace incandescent lamps with compact fluorescents (CFL)
ECM 2: Reduce lighting levels (watts/sq ft)
ECM 3: Install variable frequency drives (VFDs) on the constant volume air handling units (AHUs) 1-7
ECM 4: Replace AHU motors (1-9) with high efficiency motors
ECM 5: Implement temperature/night setbacks on AHUs 2-7
ECM 6: Replace HVAC controls with Direct Digital Controls (DDC) on AHUs (1-9) and boiler
ECM 7: Reduce minimum outside air (OA) on AHU 3
ECM 8: Install a high efficiency condensing hot water boiler

Figure 1: Estimated Savings Potential for Each ECM



2.0 Building Description

Fawcett Center opened in 1970 and was named after the 8th OSU president, Novice Fawcett. It is a meeting and conference center that accommodates small to large groups with expandable ballrooms, lounges, meeting rooms, theater, and a restaurant. The 14 story hotel section of the building was recently converted to office space for the athletics department. WOSU public broadcasting radio and television stations are located in the basement. There are nine constant volume AHUs for the facility, Table 2. The 2004 WOSU renovation project provided new office and broadcasting space. AHU 1 and associated ductwork was modified to support this area and now operates continuously. A dedicated 50 ton, multi-stage, roof mounted, air cooled, direct expansion (DX) condensing unit was installed and operates during the heating season allowing the two main building chillers to stay off-line reducing energy consumption and operational costs.

Table 2: Air Handling Units

AHU	Type	HP	CFM	% OA	Service
1	Dual Duct	40	23,210	25	Conf & Dining, retrofitted to serve WOSU area
2	Dual Duct	50	29,590	25	Conf & Dining
3	Draw Thru	15	10,250	25	Auditorium
4	Dual Duct	50	32,560	25	Alumni Center & Tower
5	Draw Thru	30	30,000	33	TV Studios
6	Dual Duct	40	26,510	25	Telecom
7	Draw Thru	20	11,000	--	Film & Video recording
8	Draw Thru	5	3,000	--	Master control
9	Draw Thru	7.5	12,200	--	Kitchen (transfer)
	Totals	257.5	178,320		

There are 751 remaining T-12's with in-house maintenance retrofitting fixtures as they fail. HVAC controls are original stand alone pneumatics with manual change over switches. Heating hot water is supplied by the two original 200 hp boilers; domestic hot water (DHW) was supplied by a stand-alone steam system but after a failure the DHW is now provided by the main boilers. Chilled water was supplied by a 475 ton natural gas engine driven chiller and a 265 ton hot water absorption unit. During the 2006 tower retrofit the original chillers were removed and replaced with two 343 ton electric chillers, a new cooling tower, variable speed chilled and condenser water pumps. A 56,000 cfm make-up air unit with an energy recovery wheel was installed on the roof and supply and exhaust fans were added to pressurize the stairwells and exhaust the equipment room. A split DX A/C unit was added to cool the elevator equipment room and new efficient lighting fixtures were installed in the office areas.

3.0 Utility Summary

Annual electricity and natural gas usage (Figure 2) at the Fawcett Center is displayed in Figures 3 & 4 and Tables 3 & 4. Utility consumption data was obtained from the Energy Services and Sustainability InStep data base for FY08 -1st half of FY11. Consumption data was normalized to calendar months since the raw data had inconsistent meter reading periods.

Figure 2: Annual Electric and Natural Gas Consumption (mmbtu)

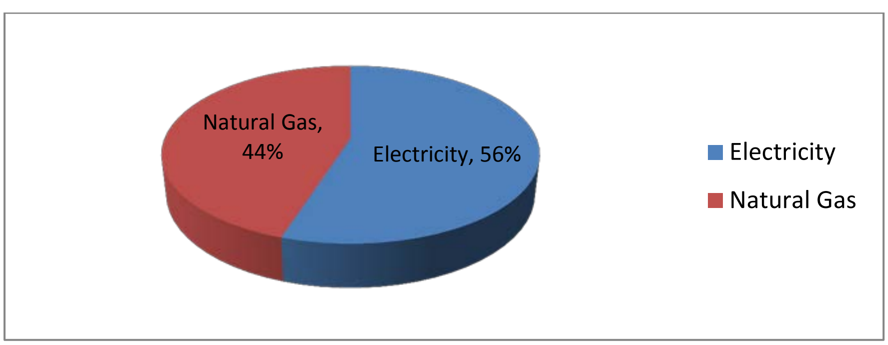


Figure 3: Electricity Consumption (mmbtu & mwh)

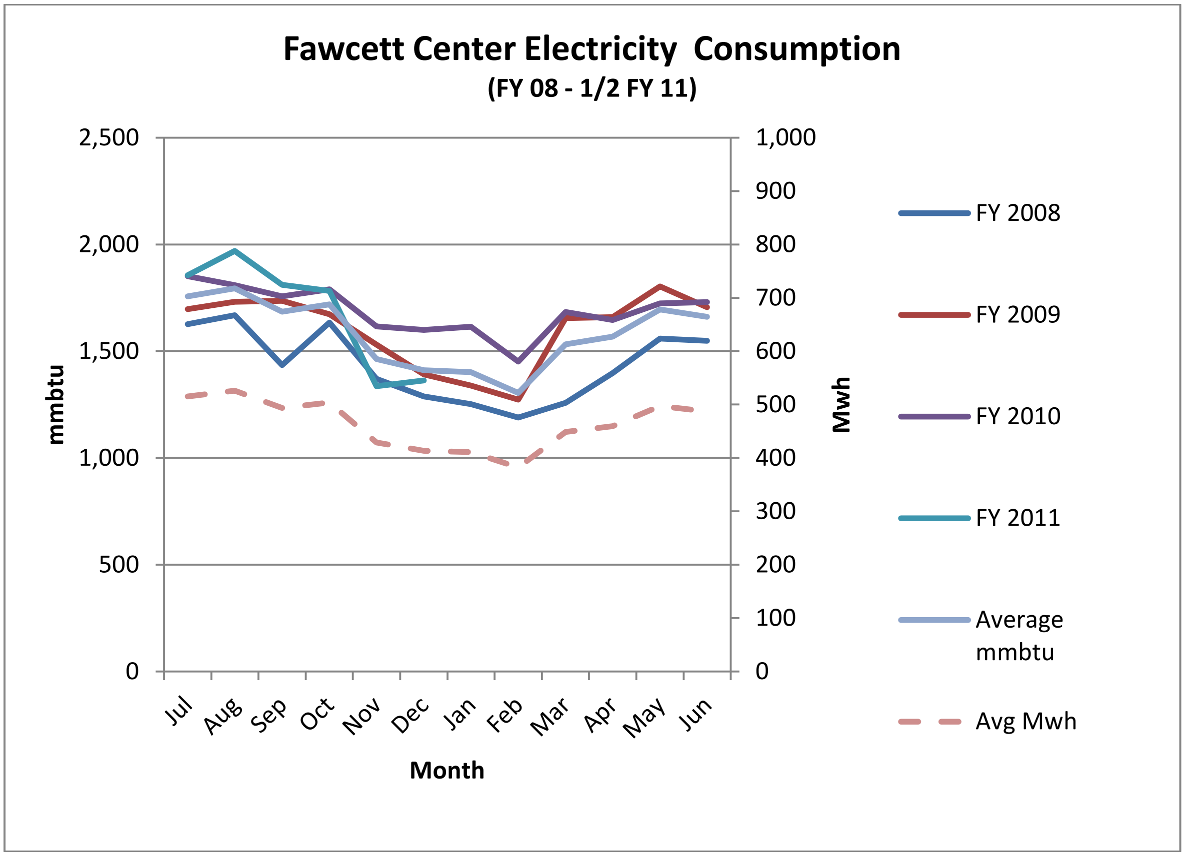


Table 3: Monthly Electricity Consumption (mmbtu & mwh)

Month	FY 2008 (mmbtu)	FY 2009 (mmbtu)	FY 2010 (mmbtu)	FY 2011 (mmbtu)	Average (mmbtu)	Average (mwh)
Jul	1,626	1,697	1,851	1,856	1,757	515
Aug	1,669	1,731	1,810	1,970	1,795	526
Sep	1,434	1,736	1,757	1,811	1,685	494
Oct	1,634	1,673	1,790	1,783	1,720	504
Nov	1,371	1,531	1,615	1,336	1,463	429
Dec	1,288	1,392	1,600	1,363	1,411	413
Jan	1,252	1,339	1,614		1,401	411
Feb	1,189	1,273	1,452		1,305	382
Mar	1,257	1,654	1,684		1,532	449
Apr	1,397	1,659	1,646		1,567	459
May	1,560	1,804	1,724		1,696	497
Jun	1,549	1,705	1,730		1,661	487
Annual Total	17,226	19,193	20,272	1/2 yr	18,994	5,567

Figure 4: Natural Gas Consumption (mmbtu & ccf)

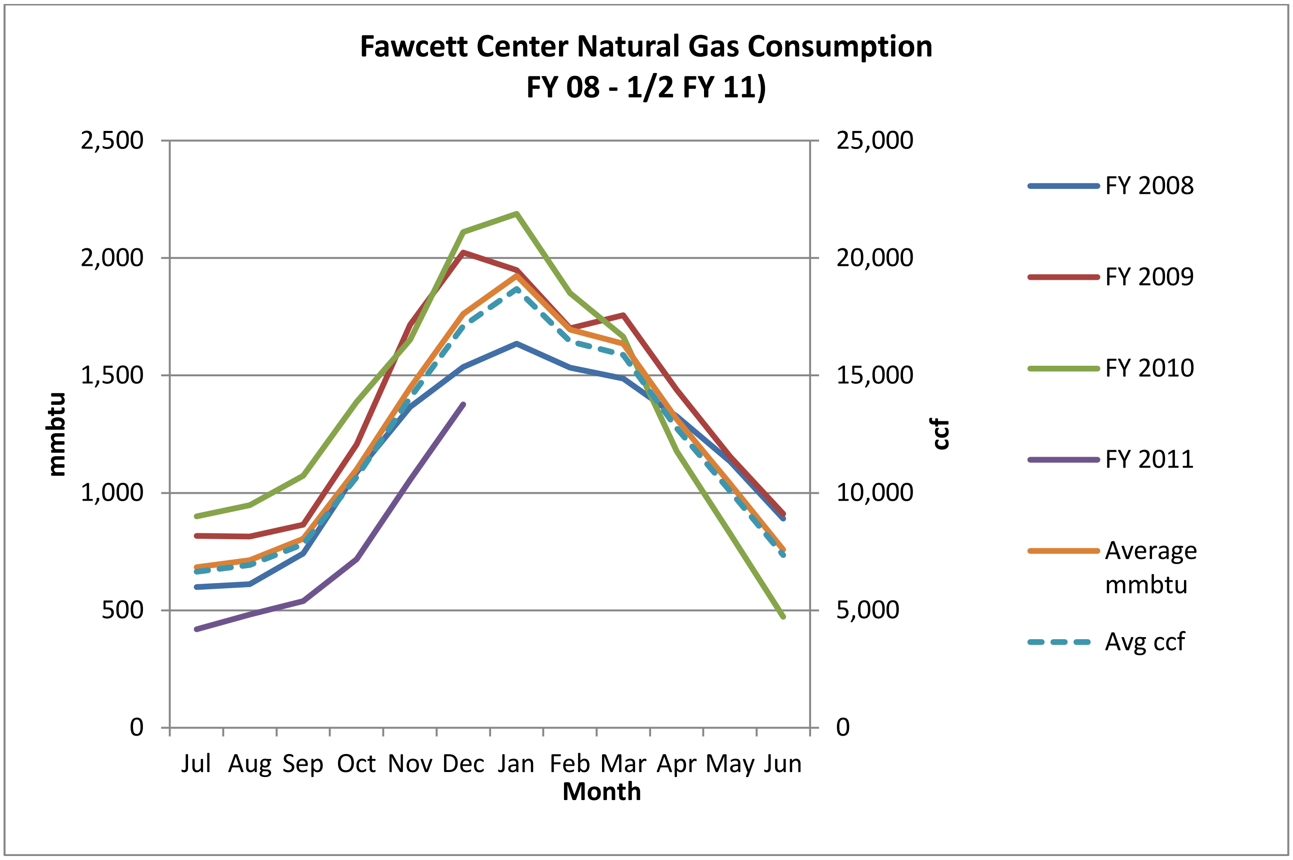


Table 4: Monthly Natural Gas Consumption (mmbtu & ccf)

	mmbtu	mmbtu	mmbtu	mmbtu	mmbtu	ccf
Month	FY 2008	FY 2009	FY 2010	FY 2011	Average	Average
Jul	599	817	900	419	684	6,637
Aug	611	815	947	482	714	6,929
Sep	742	865	1,073	538	805	7,813
Oct	1,087	1,207	1,387	717	1,100	10,677
Nov	1,366	1,716	1,652	1,055	1,447	14,049
Dec	1,535	2,024	2,111	1,377	1,762	17,105
Jan	1,635	1,949	2,188		1,924	18,679
Feb	1,534	1,701	1,850		1,695	16,458
Mar	1,486	1,757	1,665		1,636	15,884
Apr	1,326	1,440	1,178		1,314	12,762
May	1,134	1,155	827		1,038	10,082
Jun	890	911	472		758	7,357
Annual Total	13,946	16,354	16,252	1/2 yr	14,876	144,431

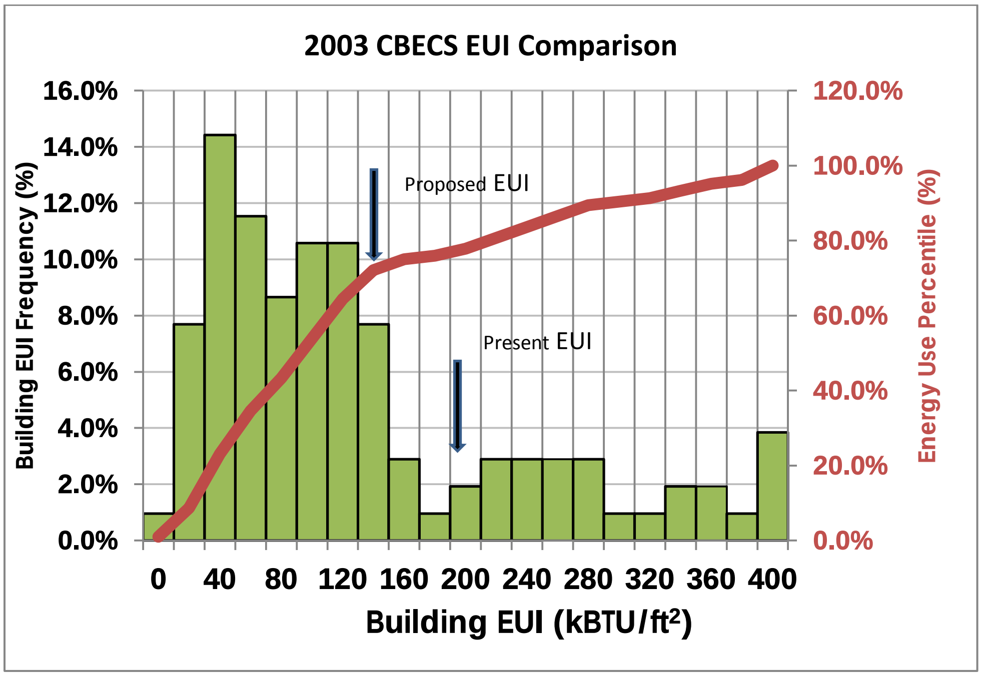
4.0

Benchmarking

The Fawcett Center EUI was calculated to compare and benchmark against similar buildings using the U.S. Department of Energy's 2003 Commercial Buildings Energy Consumption Survey (CBECS). CBECS is a national data base created from U.S. Census surveys of commercial buildings characteristics, energy consumption and expenditures. This database statistically represents the entire stock of U.S. commercial buildings. Figure 5 shows Fawcett Center's EUI compared to other buildings in the CBECS database.

With the current EUI at 190 kbtu/ft^2 this is within approximately the 77th percentile for energy consumption, with twenty three percent of the buildings surveyed using more energy per square foot. However after implementing the recommended ECMs the EUI would be approximately 131 kbtu/ft^2, for a reference point the FY10 campus building EUI average was 219 kbtu/ft^2. A 59 kbtu/ft^2 reduction would be a 31% decrease.

Figure 5: 2003 CBECS EUI Comparisons



5.0 Utility Rates

The following utility rates were used:

Table 5: Utility Rates

FY	Gas ($/mmbtu)	Water ($/Kgal)	Elec ($/kwh)	Cooling ($/mmbtu)
11	$10.29	$7.50	$0.0565	$3.02

Gas cost
($10.50/1000
ft3)/(1020btu/ft3)x(1,000,000btu/mmbtu)=$10.29/mmbtu

Chilled water rate

eff @ 0.641kW/ton and current electrical rate $/kWh
0.641 kW/Ton * Ton-hr/12,000 Btu * $0.0565/kWh*1,000,000/mmbtu=
$3.02/mmbtu

6.0 Energy Conversion Units

Energy conversion units:

1 mmbtu = 1,000,000 btu
1 kwh = 3,412 btu
On-site chiller efficiency = 0.641 kw/ton

1kbtu = 1,000 btu
1 ft^3 of natural gas = 1020 btu

Customer billing rate calculations:

Natural Gas:	(\$10.50/1000 ft^3) / (1020 btu/ft^3) x (1,000,000 btu/mmbtu) = \$10.29/mmbtu
Chilled water:	chiller eff @ 0.641 kw/ton and current electrical rate (0.641 kw/ton) x (ton-hr/12,000 btu) x (\$.0565/kwh x (1,000,000BTU/mmbtu) = \$3.02/mmbtu

The metric ton carbon dioxide equivalent (CO_2e) factors:

1 mmbtu (natural gas) = .053 CO_2e

1 kwh = .000718 CO_2e

7.0 Energy Conservation Measures (ECM)

We met with the maintenance supervisor (Rick Powell) and his staff. Jim Hamilton took us on an initial walk through to familiarize us with the various interior spaces and the mechanical and electrical equipment. We provided Rick with a list of possible ECM strategies (Appendix A) sorted by cost categories and a pre-audit questionnaire (Appendix B). One ECM noted was the maintenance staff is retrofitting the remaining T-12 fixtures as they fail and wants to devote time to complete this retrofit over the next 12 to 18 months. Another ECM Rick wanted to consider was if it would be a good return on investment to install VFDs on the nine AHUs. He was also interested in reducing the natural gas consumption if possible. Over the next few months ESS made several on-site visits to collect additional data to complete the calculations. During that time Rick retired and Paul Primmer took over the maintenance department. During the course of this audit Paul has been a great source of information. He is interested in reducing energy consumption and has begun to make an impact at the Fawcett Center while simultaneously improving and maintaining the quality of the indoor environment.

Based on the results of the pre-audit and walk through the audit focused on areas and equipment where the greatest energy and cost savings were possible. Table 6 summarizes the energy and greenhouse savings, implementation cost, and simple payback for each recommended energy cost measure. Based on the analysis the following eight ECMs are recommended for implementation:

ECM 1: Retrofit T-12 fixtures and replace incandescent lamps with compact fluorescents (CFL)
ECM 2: Reduce lighting levels (watts/sq ft)
ECM 3: Install variable frequency drives (VFDs) on the constant volume air handling units (AHUs) 1-7
ECM 4: Replace AHU motors (1-9) with high efficiency motors
ECM 5: Implement temperature/night setbacks on AHUs 2-7
ECM 6: Replace HVAC controls with Direct Digital Controls (DDC) on AHUs and boiler
ECM 7: Reduce minimum outside air (OA) on AHU 3
ECM 8: Install high efficient condensing hot water boiler

Table 6: Recommended Energy Cost Measures (ECMs)

ECM	ECM Description	Annual Savings	Cost to Implement ECM	Simple Payback (yrs)	Annual Heating Savings mmbtu/yr	Annual Elec Savings kwh/yr	Annual Elec Savings mmbtu/yr	Total Annual Savings mmbtu/yr	MT CO_2e
1	Lighting retrofit T-12 to T-8, ballasts/lamps & CFLs	$5,100	$26,285	5.2		90,263	308	308	65
2	Reducing Lighting levels (watts/sq ft)	$7,616	$4,100	0.5		134,800	460	460	97
3	Install VFD's on constant volume AHUs 1-7	$38,446	$54,100	1.4		680,453	2,322	2,322	489
4	Replace AHU motors (1-9) with high efficiency motors	$4,272	$36,200	8.5		75,606	258	258	54
5	Implement temperature night setbacks on AHU's 2-7	$9,678	$1,640	0.2	116	150,165	512	628	114
6	Replace HVAC controls with DDC 9 AHUs & boiler	$14,025	$169,700	12.1	446	167,000	570	1,016	144
7	Reduce minimum OA for AHU 3	$1,073	$492	0.5	42	11,338	39	81	10
8	Install high efficiency condensing boiler	$59,928	$45,000	0.8	5,026	145,320	496	5,522	371
	Totals	**$140,137**	**$337,517**	**2.4**	**5,630**	**1,454,945**	**4,964**	**10,594**	**1,343**

Bundling ECMs 5 & 6 would provide a 7.2 year payback.

*customer billing rates = internal rates; university rates = average external (utility company) rates

The energy savings generated by implementing the recommended ECMs are estimates based on current understanding of the building construction, occupancy patterns, system design, and equipment operation. Actual energy use and cost savings may differ slightly from predicted values due to variations such as occupancy changes, final equipment selection, alternate building construction, equipment maintenance, utility rate changes, and weather. In light of these variables conservative engineering assumptions were used to ensure the predicted savings are obtainable without leaving significant savings “on the table”.

Several ECMs were analyzed that typically require little to no initial investment (low/no cost). These are mostly operational control and maintenance strategies that reduce energy use through optimization of existing equipment and controls. A list of ECMs that were considered is located in Appendix A. Descriptions of the recommended ECMs are provided below; saving calculations were completed using university utility rates, see Table 6.

ECM 1: Replace T-12 fixtures with T-8 ballasts/lamps and install compact fluorescent lamps (CFL) wherever possible. At the time of the lighting audit there were seven hundred and fifty one (751) T-12 fixtures remaining to be retrofitted. Reasons to retrofit: reduce energy use, increase light levels, enhance light quality (improvement in color rending index-CRI), reduce maintenance cost, prolong product life (T-8 lamp burn time exceeds T-12), possible rebates, increase worker productivity, consolidate lamp types, reduce startup time, reduce environmental impact and cooling load, and increase product availability (magnetic ballast are being phased out). The CRI is a scale measurement identifying a lamp's ability to adequately reveal color characteristics. The scale maximizes at 100, with 100 indicating the best color-rendering capability, for a reference point today CFLs commonly have an 80 or greater CRI. Calculations are in Appendix C.

ECM 2: Reduce lighting levels to meet lighting power densities (LPD) watts/ft^2 recommended in ANSI/ASHRAE/IESNA Standard 90.1-2004 Table 9.6.1, Appendix D. Table 7 list the areas by floor levels in which the LPD could be reduced. Reducing lighting levels can be accomplished through simple methods such as delamping or reducing the number of fixtures to meet or exceed ASHRAE levels. Other strategies include changing interior finishes (such as color) and texture which improves reflectance allowing additional light wattage reduction. Reductions could also be achieved by installing high-performance T-8 lamps and electronic ballasts, high-performance T-8 lamps have an efficacy of 90-plus nominal lumens per watt. Since the maintenance staff is actively retrofitting the T-12 fixtures this is an optimal time to consider reducing LPD levels in the areas listed in Table 7. Another topic that may be of interest is a University of Minnesota research project which studied the effects of different light levels on humans’ moods. Lower lighting levels can create a more “relaxed mood”, consequently creating a relaxed mood by lowering light levels in a restaurant/dining area helps to create a pleasurable dining experience. Details are in Appendix D.

Table 7: Recommended Areas to Reduced Lighting Levels to Meet ASHRAE Standard 90.1-2004
(LPD watts//ft^2)

Area	Ground Floor		Tower		Basement	
	As found	Target	As found	Target	As found	Target
Office-enclosed	1.4	1.1	1.24	1.1	N/A	
Offices-open	1.5	1.1	1.5	1.1	1.5	1.1
Lobby	1.8	1.3	1.5	1.3	1.8	1.3
Restrooms	1.0	0.9	N/A		N/A	
Theater	3.5	2.6	N/A		N/A	

ECM 3: Install variable frequency drives (VFDs) on the constant volume AHUs 1-7. VFDs are adjustable drives that change the speed of the motor to match the building thermal loads, running at full capacity is not required 24/7 since the building maybe at design load for only a few hours per year. Reducing the frequency, or speed, to match the actual building load profile can result in significant energy savings. Calculations are in Appendix E.

ECM 4: Replace the drive motors on AHUs 1-9 with high efficiency motors (existing motors are 80% efficiency). ECM 3 savings were accomplished with high efficiency motors on AHUs 1-7 with VFD drives, thus motor savings were not counted twice. Calculations are in Appendix E.

ECM 5: Implementing Temperature & Night Setbacks for AHUs 2-7. The goal of this ECM is to reduce the heat transfer through the building envelope by reducing the difference between inside and outside temperatures during unoccupied hours. During unoccupied hours in the cooling/heating mode the temperature is allowed to increase/decrease from the occupied setpoint to 80°F/60°F. During unoccupied hours (11 p.m. to 5 a.m.) the supply air fan static air setpoint is reduced which allows the motors to operate at reduced horsepower level and unless an area requires additional heating or cooling to maintain temperature in the zone. Reduced fan operation results in not only electric motor savings but heating and cooling savings as well. Modification to setback schedules may be necessary for occupancy pattern changes. Setback changes are easily implemented via the building automation system. Calculations are in Appendix F.

ECM 6: Replace the existing stand-alone pneumatic controls with a direct digital control (DDC) system to allow energy saving optimizations to be implemented. Although this ECM has a high initial cost the stand alone annual savings is $14,025 with a 12.1 year payback however by combining ECM 5 and 6 a 7.2 year payback can be achieved. It is possible to implement ECM 5 w/o this ECM (#6) however the existing pneumatic controls with time clocks would require additional funds. If spending is required strongly suggest installing DDC controls, a better investment of resources than restoring night setback capability of the existing pneumatic controls. See Appendix G.

ECM 7: Reduce minimum outside air on AHU 3. Reducing the amount of minimum outside air (OA) to meet ventilation requirements established by ASHRAE Standard 62, will require less energy to heat and cool the OA. Outside air measurements were taken on AHUs 1-6, with, potential savings possible only for AHU 3. The maintenance staff has made recent changes to minimize the amount of required conditioned OA. Since AHU 1 in now dedicated to the broadcasting portion of the building a larger amount of OA is required to allow the economizer to cool the building with minimal mechanical cooling when the OA temperature is at 55^0 F or below. Calculations are in Appendix H.

ECM 8: Install a small high efficiency condensing boiler. The large summer hot water load is no longer required since the 265 ton hot water absorption chiller was replaced with two main 343-ton electric chillers. After the original steam boiler failed, the large Cleaver Brooks boilers were operated to produce the required summer DHW. Significant savings are possible by installing a small high efficiency condensing boiler while keeping the original boilers also provides redundancy and additional capacity as required. See Appendix I.

Paul Primmer and the maintenance staff have begun to make changes that will help reduce energy consumption and as funding becomes available; and implementing these ECMs will assist in meeting the Fawcett Center customer needs as efficiently as possible with an attractive 2.4 year payback.

ABBREVIATIONS

A/C	Air Conditioning
ACR	Air Change Rates
AHU	Air Handling Unit
ANSI	American National Standards Institute
ASHRAE	American Society of Refrigeration and Air Conditioning Engineers
BTU	British Thermal Unit
CBECS	Commercial Building Energy Consumption Survey
CAP	Campus Action Plan
CFL	Compact Fluorescent Light
COND	Condensate
CRI	Color Rendering Index
CV	Constant Air Volume
CFM	Cubic Feet per Minute
DD	Dual Duct Air Handling Unit
DDC	Direct Digital Controls
DHW	Domestic Hot Water
DHWH	Domestic Hot Water Heater
DHWR	Domestic Hot Water Return
DHWS	Domestic Hot Water Supply
DX	Direct Expansion Air Conditioner
eQuest®	Whole-building energy simulation analysis software, interface for DOE2
ECM	Energy Cost Measure
ESS	Energy Services and Sustainability
EUI	Energy Use Index
FDC	Facilities Design and Construction
FOD	Facilities Operations and Development
FPM	Feet per Minute
GPM	Gallons per Minute
HID	High Intensity Discharge Light
HPS	High Pressure Steam
HVAC	Heating, Ventilating and Air Conditioning
IUC	Inter University Council
IESNA	Illuminating Engineering Society of North America
KV	Kilovolts
KVA	Kilovolt Amps
KW	Kilowatt
KWH	Kilowatt per Hour
LPD	Lighting Power Density
LPS	Low Pressure Steam
MA	Mixed Air
MMBTU	Million Btu
MPS	Medium Pressure Steam
CO_2e	Metric Tons Carbon Dioxide Equivalent
MZCV	Multizone Constant Volume Air Handling
MA	Mixed Air
MU	Makeup Unit
OA	Outside Air
O & M/OPS-RIO	Operations and Maintenance
PRV	Pressure Reducing Valve
PSIA/G	Pounds per Square Inch Absolute/Gage
RA	Return Air
RM	Room
SA	Supply Air
SF	Square Feet
SS/SR	Steam Supply/Steam Return Line
TR	Terminal Reheat
V	Volts
VFD	Variable Frequency Drive
VAV	Variable Air Volume

APPENDIX A

ECM LIST

LOW-COST / NO-COST MEASURES (often requires little to no initial investment, typically operational control and maintenance strategies that reduce energy use through optimization of existing equipment and controls)

• Scheduling – Equipment is enabled only during occupied hours, off during unoccupied hours
• Scheduling – Lighting is on more hours than necessary

• Economizer/Outside Air – Inadequate free cooling, damper or setpoint problems, what are the MA setpoint(s)
• Economizer/Outside Air – Over ventilation (damper/linkage/actuator problems) outside air grille clean
• Economizer/Outside Air – Economizer operate correctly on all AHUs

• Controls Problems – Simultaneous heating and cooling
• Controls Problems – Thermostat problems (calibration, suitable location-not on outside wall)
• Controls Problems – Controls “hunt” (loop tuning or heating/cooling setpoint changes needed)

• Setpoint Changes – No or inadequate setup/setback
• Setpoint Changes – Fan speed variation, are the VFDs working correctly
• Setpoint Changes – Pump speed variation, are the VFDs working correctly
• Setpoint Changes – VAV boxes are the minimum flow setpoints too high/low, operating correctly
• Setpoint Changes - Nighttime thermostat setback operational, if applicable

• Reset Schedules – Hot water supply temperature reset is not implemented or is sub-optimal
• Reset Schedules – Hot water head pressure reset, if applicable
• Reset Schedules – Chilled water supply temperature reset is not implemented or is sub-optimal
• Reset Schedules – Supply air temperature reset is not implemented or is sub-optimal
• Reset Schedules – Condenser water temperature reset is not implemented or is sub-optimal
• Reset Schedules – Supply air static pressure reset, return air (RA) if applicable

• Efficiency/Load Reduction – Consider daylighting controls in over-lit spaces, schedule lights off during daylight hours
• Efficiency/Load Reduction – Are there areas where occupancy sensors could be used, conference rooms

• Ventilation Quantity – What are the air change rates in lab areas, possible to reduce lab ventilation rates?

INTERMEDIATE PAYBACK (normally simply payback less than 8 – 10 years)

• Variable frequency drives on all fan and pump motors? Any good candidates for adding a VFD

• Lighting equipment retrofits (lamps/ballasts, fixture replacement). T-12 and incandescent still in use.
  Type of outside lights—are standard MH or pulse start MHs being used, any good applications for LEDs
• Lighting strategy – would task/daylighting work; is delamping an option to reduce consumption
• Lighting controls – any existing lighting controls in the bldg, if so-operational/programmable/working, etc

• Fume hood replacement/retrofits been implemented, if not are any labs that would be a good candidate
• Fume hood occupancy sensors (face velocity reduction, auto-sash positioning, & occupancy)
• Air change rate reduction possible (e.g. 10 ACH to 6 ACH)
• Demand control ventilation, possible to install CO^2 sensors
• Electrostatic filtration-static pressure reduction equates to fan energy reduction

CAPITAL PROJECTS (Long-term Payback) (normally simple payback greater than 10 years)

- Upgrade to DDC (stand alone pneumatic/electronic, older/outdated legacy DDC systems)
- Plant (chillers, boilers, cooling towers)
- Heat recovery chillers
- Distribution systems changes to correct areas where air is stagnant and areas that may have been isolated
- Motor replacement, high efficiency
- Pump replacement, VAV and high efficiency motors
- Fan replacement, high efficiency
- Isolated small computer rooms, added to the existing building HVAC systems. Requires main AHU to run during unoccupied hours; possible to install a standalone computer room system, i.e. Liebert
- Aircuity System for labs (central unit samples multiple labs for TVOCs and reduces airflow whenever possible; requires fume hoods and/or HVAC systems to be VAV and controls must be compatible, Phoenix)
- Variable air volume conversion
- Variable exhaust volume (fan staging, exhaust stream chemical sensing)
- Zone level cooling (e.g. chilled beams)
- Replace constant volume bypass fume hoods with low flow VAV hoods with sensors
- Heat recovery wheel, not recommended for applications in which cross contamination is possible (i.e. Labs)
- Run around HX coils

APPENDIX B

Pre Audit Questionnaire

Background/Objectives
Have you implemented any energy savings programs or energy cost measures (ECM) in the last 2-4 years?

Are there any ECMs planned for the immediate future?

What is the desired IRR (e.g. 5%) or simple back criteria (e.g. <8 yr payback) on implemented ECM's?

Are there any recent building mechanical, electrical, & structural system improvements that may affect energy consumption?

Are there any planned improvements in the afore mentioned systems?

Envelope
Roof Renovation repairs/changes - new insulation?

Any major/minor changes in the building thermal envelope (windows, etc)?

Are there any drafts in the building, location?

Any negative/positive pressured areas (doors, hallways, stairways.)

Lighting
Are there any over/under interior lit areas?

Any problems with exterior lighting, type of lamps/fixtures (HPS, MH, pulse start MH, etc)?

Any major changes in lighting systems over the last 10 years?

HVAC/Mechanical Systems
Any areas/zones that have temperature, humidity, or thermal comfort issues?

Any spot cooling/heating being used in the buildings?

Any areas that require simultaneous heating and cooling?

Is terminal reheat being used in the building?

Any dedicated stand alone heating/cooling equipment for specific areas (computer labs, etc)?

Type of mechanical HVAC systems (HW heating/DX and/or CW); AHUs single/multi-zone, dual duct, VAV, etc)

Are there any VFD retrofitted air handlers, are the drives operational?

Condition of VAV boxes, induced air, HW or electric reheats; are the controls operational?

HVAC controls? Stand alone electronic or pneumatic, vintage/legacy or newer DDC systems?

Overall sense of the level at which the major building systems are maintained and/or funded to meet current occupant requirements? Are filters being changed on a regular schedule, are all other PM's being accomplished as required on mechanical and/or electrical systems? If not what are your concerns?

Are there any labs in the building? If so, what type of fume hoods: (e.g. constant volume w/by-pass, to VAV hoods that work in concert with the VAV HVAC systems? What is the air change rate in these labs? If contaminants are not present does the hood/HVAC system reduce the air change rates to save energy?

Any stand alone type of equipment served by a water cooling loop & what its' parameters? Series or parallel VAV fan boxes?

Are AHU's cycled, night setback schedules for HVAC equipment, if AHU's are off are the exhaust fans cycled as well?

HVAC Controls

Any significant temperature/humidity swings, any hunting problems?

When were the HVAC controls last calibrated?

Are there any control components (relays, controls, E/P, actuators, etc) that are not operational, any significant leaks (air/water/etc) Do valves seal?

Does the OA economizer sequence work and is it working, what are the days/times the buildings is unoccupied?

Is the water-side economizer activated on DB or WB temperature?

Consider the following? Are set points reasonable, zone heating/cooling temps, supply discharge temperature, cooling tower leaving temp (fixed/varied), chiller lock out temperature, boiler lock out temperature, supply air/HW/CHW reset schedules (from OA, RTN, other, none), zone overrides (lights, temps, how long), optimized routines, optimal start/stop, summer/winter cool/warm using OA reset, condenser water reset, fan static pressure reset on VAV AHUs, demand control ventilation, optimal chiller/boiler sequencing, Variable air flow pressure reset from greatest individual demand, Distribution pump reset from greatest individual demand.

Central Mechanical

Is steam utilized for heating are they significant leaks, does the desuperheater work, and does the condensate return system work properly? Operational status of condensate/PMP pumps, steam traps (blow through/blocked/etc).

Are the PRVs operating correctly, if the desuperheater is not operational what protection has been implement to protect the PRV's and other downstream equipment from the superheated steam (w/a desuperheater most prv's, valves, and other downstream equipment is rated for 300 degree F)

Are there any two pipe systems?

If there are boilers do any of them short-cycle under low load? Does hot water flow through the boiler even when it's not firing?

Does the boiler have stack dampers?

Are there any oversized fans/pumps/motors with excessive throttling?

Domestic Water Usage

Are there showers? If so, how many and frequency of use? Are low flow fixtures being used (showers-1.5-2.5 gpm, lavs-0.5-1 gpm, urinals 1gpf or less, water closets 1.6 gpf or less)? What is the DHW discharge or set point temperature?

Other Equipment

Is there any other major energy consuming equipment in the building not covered? Is there any equipment that runs constantly that could be turned off? Is there anything that has constant temperature/pressure that could be reset or cycled? Do you have any information on the utility meters? Master and sub meters?

Appendix C Lighting Retrofits T-12 to T-8

From lighting survey number of T-12 fixtures to be retrofitted.		T-12 34 watt lamps		T-8 28 watt lamps	
	each	fixture	watts	fixture	watts
2-lamp fixtures	395	1 lamp	42	1 lamp	30
3-lamp fixtures	5	2 lamp	76	2 lamp	58
4-lamp fixtures	351	3 lamp	118	3 lamp	86
subtotal	751	4 lamp	152	4 lamp	114

		kwh/yr
2-lamp fixtures	395 fixtures/ (76-58) watts/fixture* (4380 hrs/yr)/(kw/1000watts)	31,142
3-lamp fixtures	5 fixtures/ (118-86) watts/fixture* (4380 hrs/yr)/(kw/1000watts)	701
4-lamp fixtures	351 fixtures/ (152-114) watts/fixture* (4380 hrs/yr)/(kw/1000watts)	58,420
	subtotal	90,263

TABLE 9.6.1 Lighting Power Densities Using the Space-by-Space Method			
Common Space Types	LPD (W/ft^2)	Building Specific Space Types	LPD (W/ft^2)
Office-Enclosed (private)	1.1	Gymnasium/Exercise Center	1.4
Office-Open Plan	1.1	For Play Area	0.9
Conference/Meting/Multipurpose	1.3	For Exercise Area	
Classroom/Lecture/Training	1.4	Courthouse/Police Station/Penitentiary	
For Penitentiary	1.3	Courtroom	1.9
Lobby	1.3	Confinement Cells	0.9
For Hotel	1.1	Judges Chambers	1.3
For Performing Arts Theater	3.3	Fire Stations	
For Motion Picture Theater	1.1	Fire Station Engine Room	0.8
Audience/Seating Area	0.9	Sleeping Quarters	0.3
For Gymnasium	0.4	Post Office-Sorting Area	1.2
For Exercise Center	0.3	Convention Center-Exhibit Space	1.3
For Convention Center	0.7	Library	
For Penitentiary	0.7	Card File and Cataloging	1.1
For Religious Buildings	1.7	Stacks	1.7
For Sports Arena	0.4	Reading Area	1.2
For Performing Arts Theater	2.6	Hospital	
For Motion Picture Theater	1.2	Emergency	2.7
For Transportation	0.5	Recovery	0.8
Atrium-First Three Floors	0.6	Nurse station	1.0
Atrium-Each Additional Floor	0.2	Exam/Treatment	1.5
Lounge/Recreation	1.2	Pharmacy	1.2
For Hospital	0.8	Patient Room	0.7
Dining Area	0.9	Operation Room	2.2
For Penitentiary	1.3	Nursery	0.6
For Hotel	1.3	Medical Supply	1.4
For Motel	1.2	Physical Therapy	0.9
For bar Lounge/Leisure Dining	1.4	Radiology	0.4
For Family Dining	2.1	Laundry-Washing	0.6
Food Preparation	1.2	Automotive-Service/Repair	0.7
Laboratory	1.4	Manufacturing	
Restrooms	0.9	Low Bay (<25 ft Floor to Ceiling Height)	1.2
Dressing/Locker/Fitting Room	0.6	High Bay ($\geq$25 ft Floor to Ceiling Height)	1.7
Corridor/Transition	0.5	Detailed Manufacturing	2.1
For Hospital	1.0	Equipment Room	1.2
For Manufacturing Facility	0.5	Control Room	0.5
Stairs-Active	0.6	Hotel/Motel Guest Rooms	1.1
Active Storage	0.8	Dormitory-Living Quarters	1.1
For Hospital	0.9	Museum	
Inactive Storage	0.3	General Exhibition	1.0
For Museum	0.8	Restoration	1.7
Electrical/Mechanical	1.5	Bank/Office-Banking Activity Area	1.5
Workshop	1.9	Religious Buildings	

Common Space Types	LPD (W/ft^2)	Building Specific Space Types	LPD (W/ft^2)
		Worship Pulpit, Choir	2.4
		Fellowship Hall	0.9
		Retail [For accent lighting, see 9.6.3(c)]	
		Sales Area	1.7
		Mail Concourse	1.7
		Sports Arena	
		Ring Sports Area	2.7
		Court Sports Area	2.3
		Indoor Playing Field Area	1.4
		Warehouse	
		Fine Material Storage	1.4
		Medium/Bulky Material Storage	0.9
		Parking Garage	0.2
		Transportation	
		Airport-Concourse	0.6
		Air/Train/Bus-Baggage Area	1.0
		Terminal-Ticket Counter	1.5

ECM #2 Reducing LPD (watt/ft2)	
(From eQuest runs)	
Annual Electrical Usage	Kwh/yr
Baseline	5,706,300
LPD reduction	5,571,500
Annual average by reducing	**134,800**

Annual Energy Savings Estimator for		Appendix E: VFD Savings & efficiency motors	
Variable Frequency Drives (VFDs) on		80 % vs. 90 % with 90% eff motors running	
HVAC Applications (Fans and Centrifugal Pumps)		at reduced sp during unoccupied hrs	

Compares VFD capacity control versus other types capacity control. 0.8 0.9

To make Comparisons and Estimate Savings, need to know following:

a. Motor horsepower.

b. Cost of KwH of electricity.

c. Total hours of operation per year.

d. Present method of capacity control (guide vanes, fan curves, discharge vanes, cv's, etc.) That VFD will replace

80 % eff motors		
	680,453	kwh/yr
	$38,446	per yr
90 % eff motors		
	604,847	kwh/yr
	$34,174	per yr
Delta (90% vs. 80%)		
	75,606	kwh/yr
	$4,272	per yr

Step 1: Converting motor Horsepower to Kw

245 HP x .746 = 182.77 Kw_A

Step 2: Multiply the Adjustable Frequency Drive Power Ratio (from table below) times Kw_A from Step 1.

0.28 Ratio x 182.77 Kw_A = 51.1756 Kw_B (using VFD)

0.28

Step 3: Multiply the Power Ratio of the presently employed control (see below) times Kw_A from Step 1.

0.62 Ratio x 182.77 Kw_A = 113.3174 Kw_C (method now employed)

Step 4: Subtract Step 2 Kw_B from Step 3 Kw_C.

113.3174 Kw_C – 51.1756 Kw_B = 62.1418 Kw_D (savings using VFD)

Step 5: Multiply Step 4 KW_D savings, times hours per year of operation, times cost of electricity per KwH.

62.1418 Kw_D x 8760 Hrs x $ 0.0565 $/KwH = $ 30,756 VFD Annual calculated savings

Fans at 60% of maximum flow	
Ratio	**Flow Control Method**
0.28	Variable Frequency Drive
0.62	Inlet Guide Vane
0.88	Outlet Damper
0.88	Fan Curve
1.00	Bypass Damper

Pumps at 70% of maximum flow	
Ratio	**Flow Control Method**
0.40	Variable Frequency Drive
0.94	Discharge Valve
1.00	Bypass Valve
1.00	No control

Appendix F: Temperature and Night Setback for AHUs 2-7 (w/VFDs no double savings)

SB= setback	9pm-4am 7 days/wk	205	HP's of AHU's 2-7
Hrs saved per day =	7		AHU 1 not used due to large heat loads (TV/radio)
Days/wk of operation =	7		
Wks/yr Ahu is in operation =	52		
Hr/wk office occupied=	50		8am - 6pm; 5 days/wk = 50hrs/wk
SA fan (hp) =	51.3	51.25	going with 25% based on fisher RCx
RA fan (hp) =	0		very conservative, because with VFD's
kwh/hp =	0.746		only savings will be for reduced
Elec rate ($/kwh) =	0.0565		
Motor efficiency =	0.9		assumes new VFD's are install on ahu's 2-7,
AHU total cfm:	34,978		CFM reduction(25% based on Fisher reduction almost 40%)
OA_{min} (%) =	10%		using conservative 25% -> 75% airflow
Gas cost ($/mmbtu) =	$10.29		at fisher the original operation mode was VFD's did not
cooling cost ($/mmbtu) =	$3.02		operate thus they were 100%, so the 40% reduction was
Unoccupied heating setpoint	62		base on VFD's running at 100%, in this case the VFDs will
Unoccupied cooling setpoint	78		be operational but only have a 25% reduction since the
Avg OA winter DB temp	37.8		VFD's will be operational.
Winter length (wks) =	25.5		
Avg OA summer DB temp	77.6		
Summer length (wks) =	23.8		
10^6 BTU to cool air =	41.818		With VFD in night setback mode the motor runs all the time
FLE =	1		the reduction comes from slowing down in unoccupied mode

Fan or Pump Electrical Savings

kwh/yr saved = hrs/wk x wks/yr x .746/hp x hp/motor eff

Heating Savings (mmbtu/yr) = hrs/wk x wks/yr x total cfm x OAmin (%) x 1.1 min btu/hr ft deg F

x (avg indoor temp - avg OA winter temp)

Cooling Savings (mmbtu/yr) = hrs/wk/occupied hrs/wk x total cfm x OAmin (%) x 10^6 BTU to cool air

kwh/yr saved =	108,240	
Motor savings/yr =	$6,116	
heating (mmbtu/yr) =	116.3	
heating savings/yr =	$1,197	
		kwh
cooling (mmbtu/yr) =	143.3	41,924
cooling savings/yr =	$433	
		total kwh saved
Total Savings =	$7,746	150,165

Appendix G

ECM 6 Savings: Install DDC Controls on Nine (9) Air Handling Units (1-9)

Installing DDC controls on the AHUs 1-9 will save 3% above all related ECMs previously listed affecting the nine Air handling units. Optimization with reset schedules, occupancy schedules, etc.

ECM 6 Savings	mmbtu (NG)	kwh
3% reduction	446	167,000

Appendix H: Savings to Reduce OAmin to original design on AHU 3

From Wright-Patterson AFB in Dayton

Appendix H: Savings to Reduce min OA to original design on AHU 3

assume below 55 deg heating, 55 deg & above cooling; MA setpoint at 55 deg F

Dry Bulb Deg F.	Range Deg F.	Annual Totals Hours	Mean WB	Av. DB	h Btu/lb	Hrs	
100	104			102			
95	99	3	75	97	38.2		
90	94	52	74	92	37.6		
85	89	221	72	87	35.8		
80	84	415	69	82	33.4		
75	79	600	67	77	31.6		
70	74	792	65	72	30.0		
65	69	811	61	67	27.2	4281	total hrs >55 deg F, after correction economizer OA_{min}, currently 841 cfm over OA_{min}
60	64	745	56	62	23.8	-1,070	subtract # of night setback hrs during the cooling hrs above min OA
55	59	642	52	57	21.5	3,211	total cooling hours excess air above min OA minus setback hours
50	54	606	47	52	18.6	4494	total hrs below 55 deg F
45	49	598	43	47	16.8		
40	44	623	38	42		3208	assume 54 deg F to 30 deg F at min OA position 20% of the time
35	39	699	34	37		20%	
30	34	682	30	32			
25	29	500	25	27		641.6	20 % of hrs, 54 to 30 deg F
20	24	314	20	22			
15	19	209	16	17		1286	hrs at 29 deg or below, assume at min OA position 80% of the time
10	14	127	11	12		80%	
5	9	70	6	7		1,028.8	80% of hrs 29 deg F and below
0	4	41	2	2			
-5	-1	19	-3	-3			
-10	-6	5	-7	-8		1,670.4	total heating hours at min OA position.
-15	-11	1	-13	-13		-417.60	subtract # of night setback hrs during the total heating hrs at min OA
-20	-16		-16	-18		1,253	total heating hours at min OA position, non setback hours
		8775					
		8760					

night setback hrs 11pm - 5am
6hrs/24hrs 0.25

reference actual min OA measurements made on AHU 3, above min OA = 841

Winter: q=1.1 x OA cfm (excess) x delta T x hrs/yr

cfm OA below minimum = 841 Avg T_{in}= 74 Avg DB winter temp= 37.8

1.1x 841 x (74-37.8) x1253

Gas cost ($/mmbtu) = $10.29 Avg DB summer temp= 77.6

q (btu/yr)= 41,954,543

42 mmbtu/yr

$/yr = $432

H= seasonal cooling load for OA (10^6 btu/year 1000 cfm)

Summer: q= excess OA cfm x H x operating hrs/wk/50 operating hrs/wk

H = 41.818 for Columbus OH 41.818

841x41.818x55/50 /1000

operating hrs/wk = 55

q (btu/yr)= 38,685,832 equivalent kwh cost of cooling ($/mmbtu) = $3.02

39 mmbtu/yr 11,338

$/yr = $117

Total savings ($/yr) $549 Total savings (mmbtu/yr) = 81

Appendix I: Savings from ECM 8-Instaling High Efficient Condensing Boiler

ECM 8	bbtu	mmbtu	kwh
New boiler	22.30	22,300	5,706,300
eQuest	15.12	15,120	5,498,700
Full Yr Savings	7.18	7,180	207,600
70% Yr Savings	5.03	5,026	145,320