12-2017

Campus Energy Analysis Team: Academics Buildings Report

University of Dayton, Hanley Sustainability Institute

Campus Energy Analysis Team

Academic Buildings Report

Energy Audits 01-04: Roesch Library, Miriam Hall, Kettering Labs, and Fitz Hall

Assessment Dates: 10/17/2017 – 11/7/2017
Report Issue Date: 12/15/2017

UNIVERSITY of DAYTON
Hanley Sustainability Institute

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Meet Our Team

The Campus Energy Team was formed to identify cost-effective solutions to reduce campus energy usage, with a preliminary goal of reducing campus emissions by 26-28% by 2025. Our team is made up of a diverse mix of faculty, staff, graduate, and undergraduate students. We're thankful for the opportunity to present our results.

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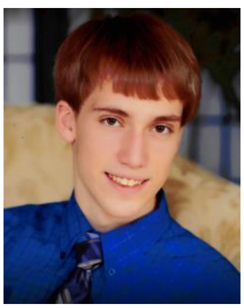

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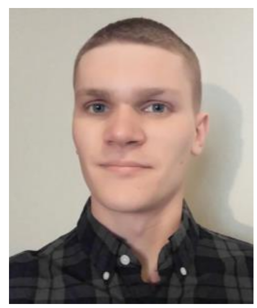

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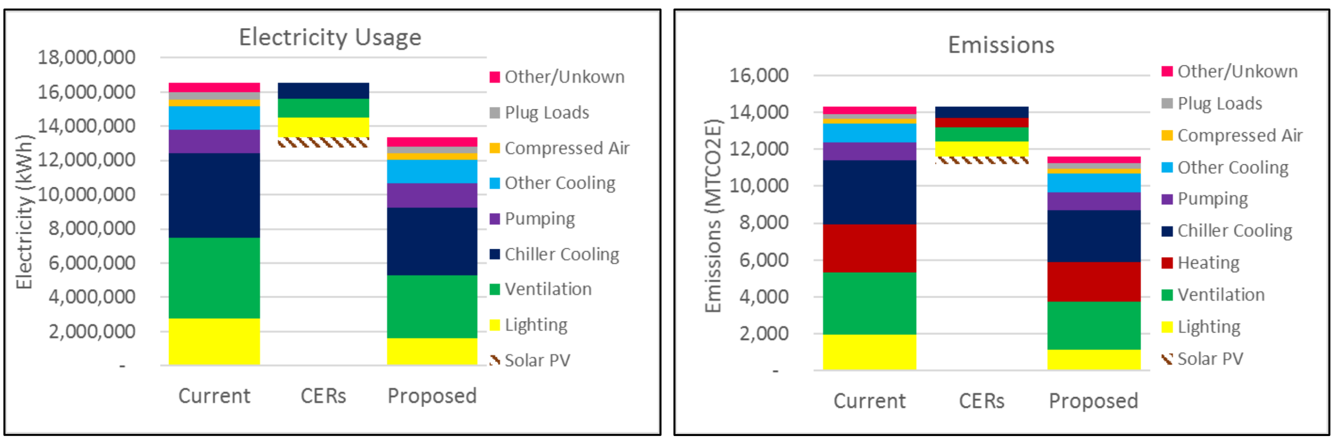
Executive Summary

Our team audited four academic buildings – Roesch Library, Miriam Hall, Kettering Labs, and Fitz Hall – between October 17th and November 21st, 2017. These assessments are funded through the University of Dayton Hanley Sustainability Institute, and also includes volunteers from the Industrial Assessment Center (IAC) and Ohio Lean Buildings Program (OLBP). More information about the program is available at: https://udayton.edu/artssciences/ctr/hsi/index.php

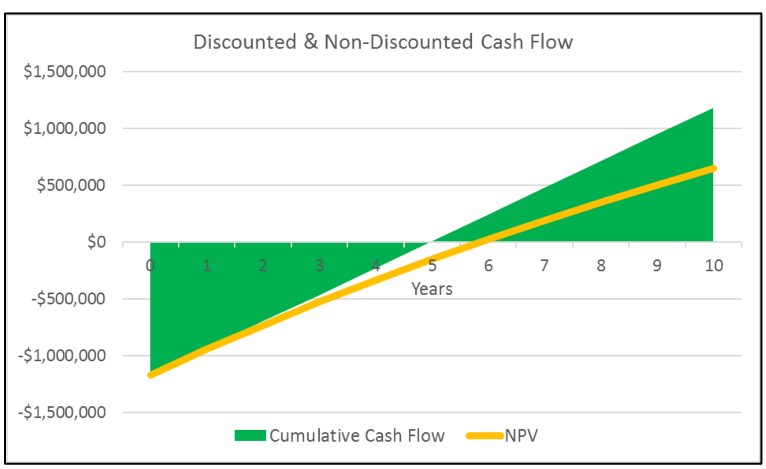
SUMMARY OF TOTAL SAVINGS AND INVESTMENT METRICS

We analyzed four academic buildings – Roesch Library, Miriam Hall, Kettering Labs, and Fitz Hall – and identified the following:

- Currently, total utility costs are about $911,995 per year for electric and $319,614 per year for natural gas.
- Currently, total energy related CO_2 emissions are about 17,070 metric tonnes per year which is equivalent to the typical annual CO_2 emissions of about 1,843 homes or 41.8 million vehicle miles driven.
- We identified a total of 10 clean energy recommendations (CERs) which have the potential to reduce electricity by 24%, natural gas by 18%, and emissions by 23%. That correlates to 3,895 metric tons of CO2, which is equivalent to taking about 421 homes off the grid or driving 9.5 million less vehicle miles each year. These recommendations have a total implementation cost of $1,166,322 and annual savings of $235,046 for a simple payback of 5 years, and 10-year NPV of $648,637 with a 15% IRR.



Total Electricity and Emissions Breakdown of Current and Proposed Amounts after CERs for all Four Buildings



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Breakdown by Building

A total of four 'green revolving fund' (GRF) projects are recommended, with one per building audited. The clean energy recommendations were identified by reducing the most emissions with a simple payback constraint of 5 years.

Building	Annual Savings							Investment Metrics			
	Electricity		Natural Gas		Emissions		Utility	Project	Simple	10-yr	10-yr
	kWh	% total	mmBTU	% total	$MTCO_2$	% total	Costs	Cost	Payback	NPV	IRR
Roesch Library	699,829	33%	1,588	36%	703	33%	$44,476	$236,033	5.3 years	$151,124	15%
Miriam Hall	680,077	25%	1,078	20%	659	24%	$39,163	$200,853	5.1 years	$134,342	15%
Kettering Labs	932,442	23%	2,407	31%	952	24%	$62,466	$291,600	4.7 years	$245,399	18%
Fitz Hall	1,548,901	21%	3,971	12%	1,580	19%	$88,941	$437,836	4.9 years	$325,461	16%
TOTAL	3,861,249	23.7%	9,044	18.1%	3,895	22.8%	$235,046	$1,166,322	5.0 years	$648,637	15%

Breakdown by Clean Energy Recommendation

The majority of the clean energy recommendations are control based recommendations that pay back their upfront cost in a matter of months. Their favorable economics can finance other recommendations with a longer payback, such as solar PV, while still having an overall 5 year simple payback.

	Clean Energy Recommendation	Annual Savings				Project Cost	Simple Payback	NPV	IRR
		kWh	mmBTU	MTCO2	$				
1	FT8s to LEDs with occ sensors	1,150,354	0	1,017	$65,577	$153,090	2.3 years	$353,278	42%
2	AHU Scheduling & Thermostat Setbacks	561,565	1,417	572	$30,458	$11,400	0.4 years	$223,787	267%
3	Chilled Water Control	551,213	0	487	$21,167	$15,280	0.7 years	$148,163	139%
4	Demand Ventilation	187,252	6,658	519	$48,974	$86,333	1.8 years	$291,828	56%
5	Relocate AHU VFD pressure sensors	543,779	0	481	$20,881	$20,880	1.0 years	$140,358	100%
6	Install VFDs on AHUs	148,050	0	131	$5,685	$36,240	6.4 years	$7,659	9%
7	Reduce Excess Air in Boilers	0	969	51	$6,081	$520	0.1 years	$46,439	1170%
8	Install Primary Pump and VFD on Secondary	81,228	0	72	$3,120	$11,265	3.6 years	$12,827	25%
9	Reduce Compressed Air Set-point	10,427	0	9	$522	$64	0.1 years	$3,967	816%
10	Install Rooftop Solar PV	627,381	0	555	$32,593	$831,250	25.5 years	-$371,886	0%
	Total	3,861,249	9,044	3,895	$235,058	$1,166,322	5.0 years	$648,731	15%

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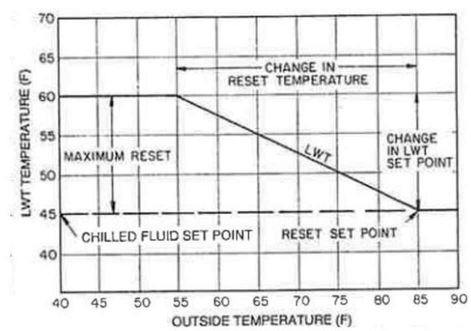
Summary of Clean Energy Recommendations

1. Replace FT8 & CFLs with LEDs and Install Occupancy Sensors

Fluorescent T8 lamps can be directly replaced with direct-wire LED tubes after removing the ballast. LEDS offer several advantages, such as consuming around 50% less energy, a longer rated lifespan, and are directional, meaning that more of the light emitted from the lamp illuminates the work plane. A total of 17,802 4ft-FT8s are recommended to be replaced with 14,049 15W 4ft-LEDs in offices and classrooms and 3,564 12.5W 4ft-LEDs in hallways and bathrooms in order to maintain the area's required illuminance. A total of 539 ceiling mounted sensors and 323 wall mounted sensors are estimated to be required for proper lighting controls.

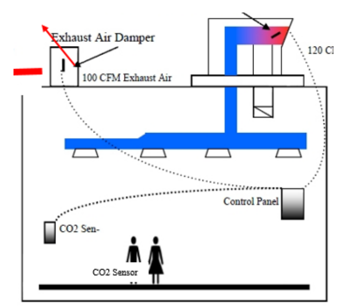
2. Improve Chilled Water Control

Currently the chillers are set to cool a closed-loop water system to a set-point of around 42 F. During our investigation there appeared to be a form of chilled water reset control in Metasys already, but it is not aggressive enough to achieve any noticeable energy savings. By controlling the chilled water temperature to increase when it is cold outside and lower when it is warmer outside, the chillers will allow them to operate more efficiently. We recommend having Carrier and TRANE technicians enable chilled water controls in the current chiller interface system.



3. Install CO2 Sensors for Demand Ventilation

Mechanically ventilated spaces in commercial buildings typically set the minimum amount of outdoor air entering a building based upon ventilation required at full occupancy. However, buildings are mostly only partially occupied. A demand ventilation system works by measuring the amount of carbon dioxide released by the building occupants, so it can maintain indoor air quality while reducing the amount of outdoor air ventilation, and thus less air to heat and cool, during times of partial occupancy. We recommend installing CO2 sensors in each air handling unit (AHU) and inputting appropriate controls in Metasys.



4. Schedule Air Handlers and Setback Thermostats during Unoccupied Periods

Buildings with areas that are unoccupied during a significant number of hours each evening can schedule AHUs to turn off or program thermostats to reduce their set-point during the winter months, and increase the set-point during summer months. A lower temperature difference between the inside and outside air results in reduced heat transfer and infiltration losses. Although it requires some additional energy to reheat the plant in the morning, it is significantly less than the energy saved by reducing the temperature during un-occupied hours. We recommend utilizng Metasys to implement these controls.

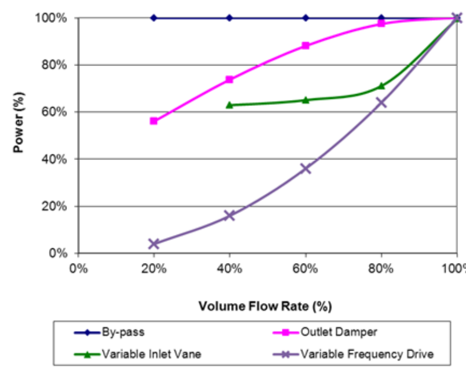
Item	Value	Description
OCC-SCHEDULE	Not Set	Occupancy Schedule Command
OCC-MODE	Occupied	Occupancy Mode Status
EFF-OCC	Occupied	Effective Occupancy
SYSTEM-MODE	Auto	System Mode Status
ZN-T	71.8 deg F	Zone Temperature
ZN-SP	70.6 deg F	Zone Temperature Setpoint
CLGOCC-SP	72.0 deg F	Cooling Occupied Setpoint
CLGUNOCC-SP	82.0 deg F	Cooling Unoccupied Setpoint
HTGOCC-SP	70.0 deg F	Heating Occupied Setpoint
HTGUNOCC-SP	61.0 deg F	Heating Unoccupied Setpoint

5. Relocate pressure sensors for AHU VFDs

AHU supply fans can be controlled by a static pressure sensor in the ductwork tied to a variable frequency drive (VFD) on the fan. However, in Miriam and Fitz Hall, the static pressure sensors were located at the outlet of the supply fan in each AHU. This location for the static pressure sensor makes for simple installation, but requires a higher pressure set-point than if the sensor were in a remote location. By relocating the sensors 2/3 into the ductwork in accordance with industry best practices, this can significantly reduce AHU supply fan's energy usage.

6. Install VFDs on AHU supply motors in Fitz Hall

In Fitz Hall, a total of sixteen 7.5-HP AHU supply fan motors were found without variable frequency drives (VFDs), therefore running based on the outlet damper. Significant energy savings can be realized by installing VFDs to more efficiently vary the motor power based on the required flow rates. We recommend installing VFDs on these AHUs while ensuring to locate the pressure sensors properly.



7. Reduce Excess Air in Boilers

In Roesch and Fitz Hall, the boilers use linkages that connect natural gas supply valves with combustion air inlet dampers. The optimal excess combustion air in a gas heating system for energy efficiency and pollution prevention is about 10%. Higher levels of excess air dilute the combustion stream and decrease the quantity of useful heat available to the process. We recommend tuning the boiler's mechanical linkages during regular maintenance to maintain a proper excess air ratio of 10% to improve efficiency and therefore yield substantial natural gas savings.

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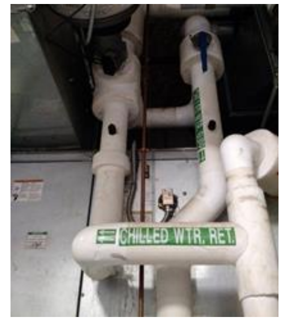
8. Eliminate Bypass Chilled Water Pumping



In Miriam Hall, the pumps which circulate chilled water through Miriam Hall were found to run at constant speed with 3-way bypass chilled water valves on each of the 8 AHUs. In this configuration, the chilled water pumps will run at full speed anytime chilled water is required. We recommend removing all 3-way bypass chilled water valves and piping and replacing them with 2-way control valves. Additionally, we recommend installing a VFD on the current 30-hp chilled water distribution pump to enable it as a secondary pump, and installing a 7.5-hp primary chilled water pump to maintain adequate circulation through the chiller.

9. Reduce Air Compressor Pressure Set-point

In Kettering Labs, the compressors' pressure set-points were noticed to be set at 120 psig. The highest compressed air pressure required is likely around 90 psig. Typically, a 10 psig difference between set-point pressure and end-use pressure is more than sufficient to account for pressures losses across the dryer, filters, and pipes. Therefore, we recommend lowering the operating set-point pressure of both 25-hp compressors to reduce the compressor power draw.

10. Install Rooftop Solar PV

All four buildings' rooftops have areas that see ample sunlight throughout the year. Those areas unobstructed by equipment and shade can be utilized for energy generation with solar PV panels. This breaks down to around 100 kW for Roesch, 75 kW for Miriam, 125 kW for Kettering Labs, as well as 175 kW for Fitz Hall while limiting the combined building CERs' simple payback to 5 years. While solar PV's economics are poor for UD due to their low marginal energy costs, it can be financed when paired with other CERs with very favorable economics.

I. Baseline

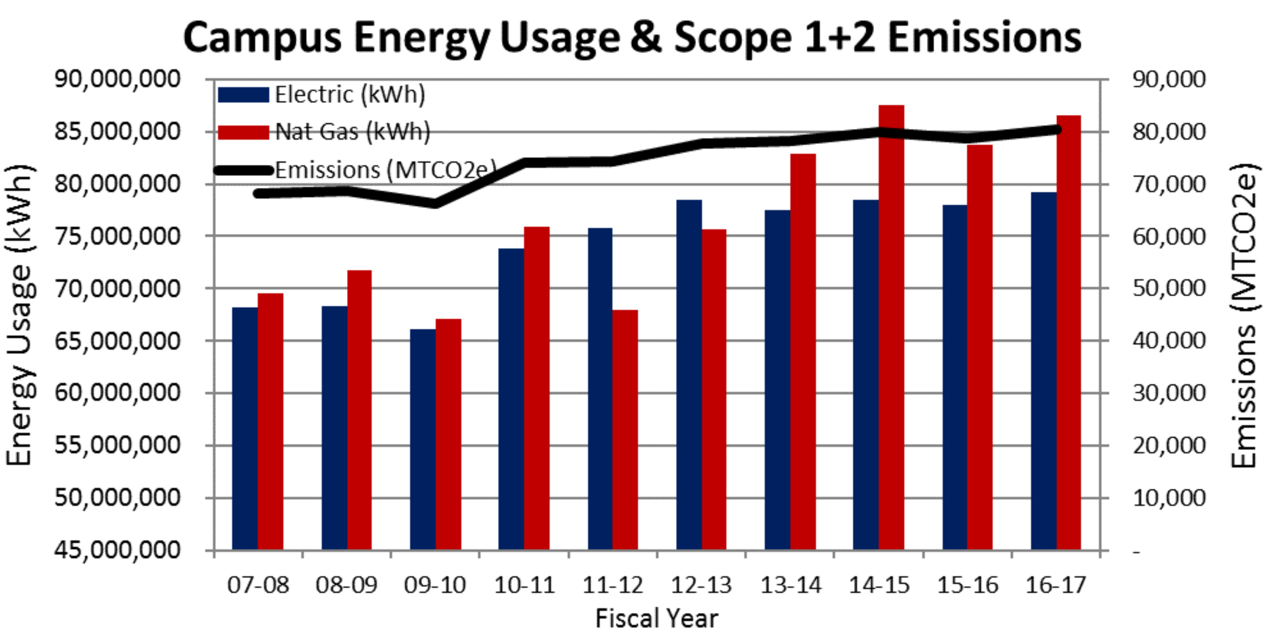
The following campus baseline provides insight campus energy usage. It includes four sections:

- **Campus Energy Usage**: Historical trends in energy and emissions broken down by building type, and recent clean energy projects
- **Campus Buildings Energy Breakdown:** Campus electricity broken down by building types, as well as electricity breakdowns in academic buildings by energy systems such as lighting, ventilation, cooling, heating, etc.
- **Utility Analysis:** Annual energy, annual costs, and marginal cost breakdowns
- **Building Envelope:** Heating and cooling information for four academic buildings

A. CAMPUS ENERGY USAGE

Campus Energy Trends

The University of Dayton scope 1 and scope 2 emissions[1] have increased somewhat steadily over the past decade, peaking in fiscal years 2014/2015 and 2016/2017 at 79,891 and 80,356 metric tons of carbon dioxide equivalent, as shown in Figure 1. This seems primarily due to an expanding campus, both in enrollment and overall square footage.



[1] Scope 1 emissions correspond to direct on-site energy generation, for UD that's natural gas, and scope 2 emissions correspond to energy purchased off site, for UD that's electricity. Scope 3 emissions are not directly controlled by the organization and thus outside of the scope of this work, but do make up around 15% of UD campus emissions. Student neighborhood emissions are not included in these totals due to unconfirmed data.

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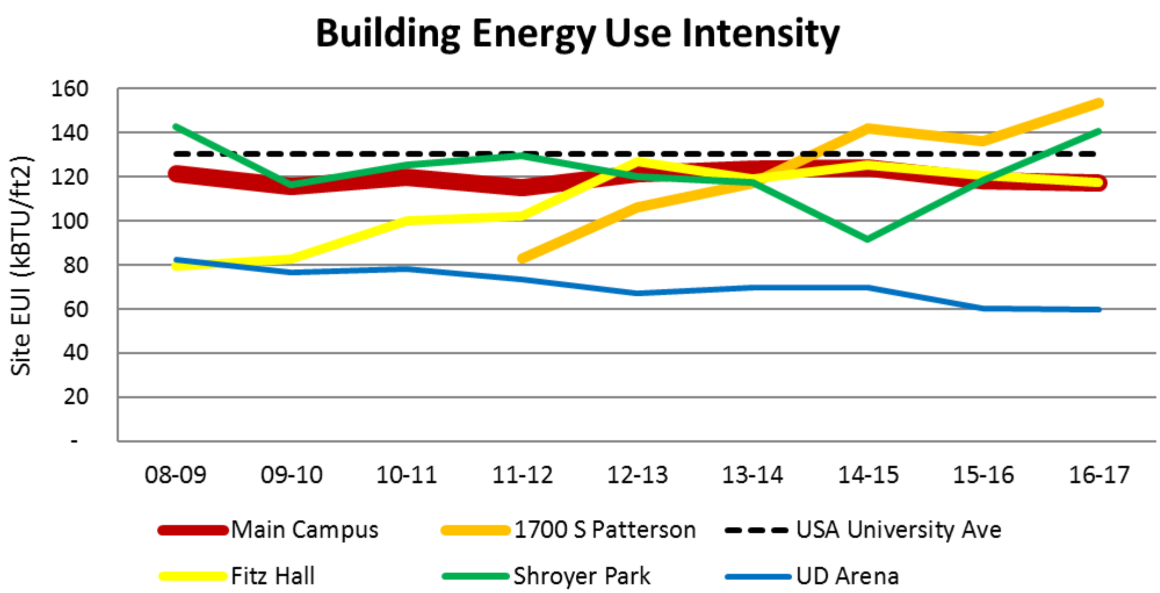
Separating relative energy usage of all five major electric and natural gas accounts by site energy use intensity (EUI) provides a visual representation of increases in energy per square foot in each of the five major accounts. This indicates that the recent increases in overall campus energy and emissions can be attributed to the expansion of operation in Fitz Hall and 1700 S Patterson buildings, as shown in their increasing EUI in Figure 2.



In order to tackle these growing emissions, the green revolving fund was founded in 2016 to implement cost-effective clean energy projects on campus.

Current Campus Clean Energy Projects

To date, the green revolving fund has funded over 30 projects, primarily focusing on lighting upgrades. The completed projects have reduced emissions by 980 metric tonnes of CO2 (MTCO2) equivalent, or 1.2% of campus scope 1 and 2 emissions. Projects that are in-progress, focusing on lighting and HVAC controls, are estimated to have the potential to reduce an additional 1,485 MTCO2, bringing the total to 3.1%. Projects being proposed, focusing on shower heads as well as energy awareness in the student neighborhood, are estimated to reduce an additional 590 MTCO2, bringing the total emission reduction to 3,055 MTCO2, or 3.8% of scope 1 and 2 campus emissions.

These projects are a good start to making a dent in campus emissions, but in order to make the significant short-term progress required to meet our team's goal of a 26-28% reduction by 2025, systematic building energy audits and large scale portfolio-wide implementation are required. By conducting energy audits on a representative of the largest campus energy users, our team hopes to provide these clean energy solutions and make a real dent in campus emissions.

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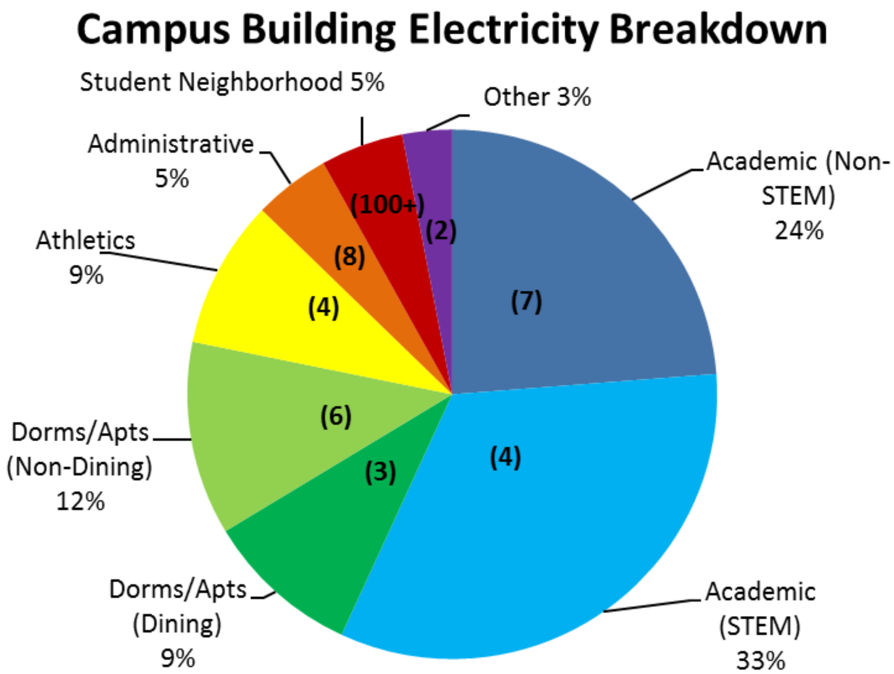
B. BUILDING ENERGY BREAKDOWN

Total Campus Electricity Usage

To determine the type of buildings to focus on, our team utilized sub-metered electricity data to break down campus electricity usage by building types. Since natural gas is not sub-metered at individual building levels, it is assumed to correspond with electricity usage. Academic buildings are shown to make up the largest share of electricity usage on campus, at 57%, followed by residence buildings (non-housing) and athletics, at 21% and 9% respectively. Therefore, we focused our first energy audits on a representative sample of academic buildings to ensure our work had the largest potential impact on emission reductions. Residences halls and athletics will be the focus of the next round of audits in Spring Semester 2018.



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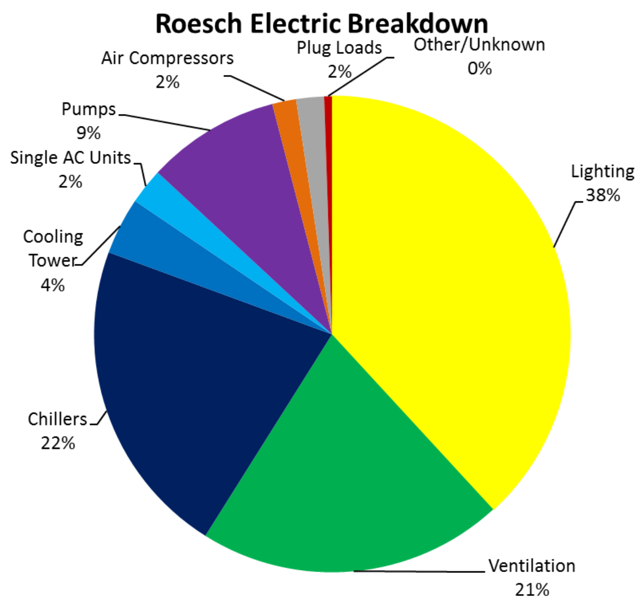
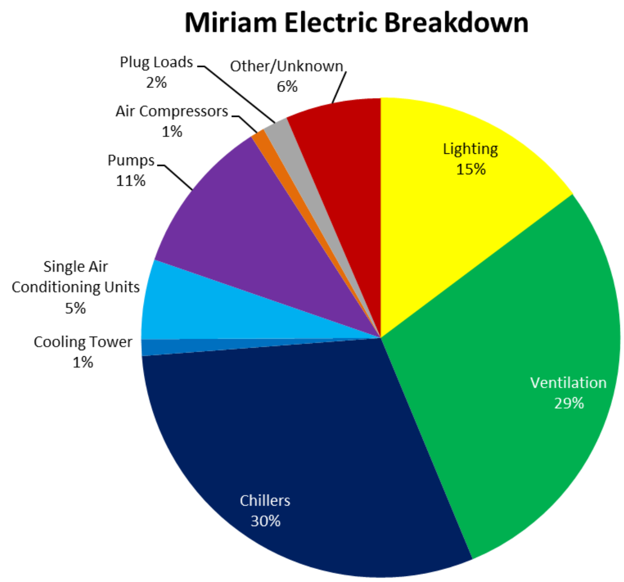
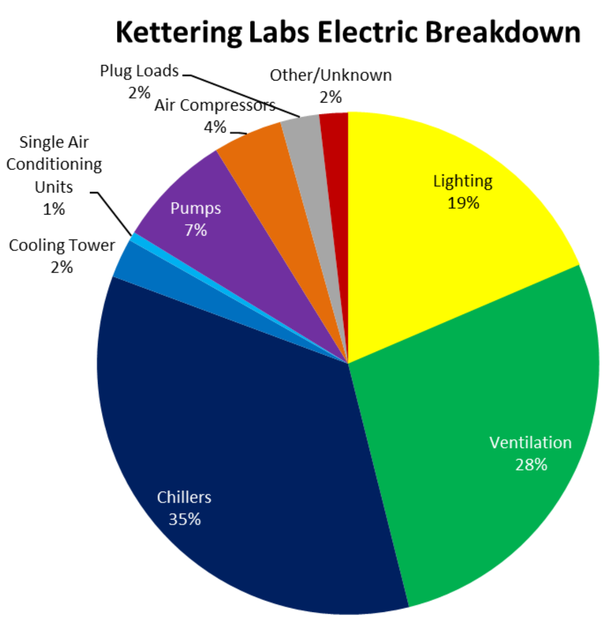
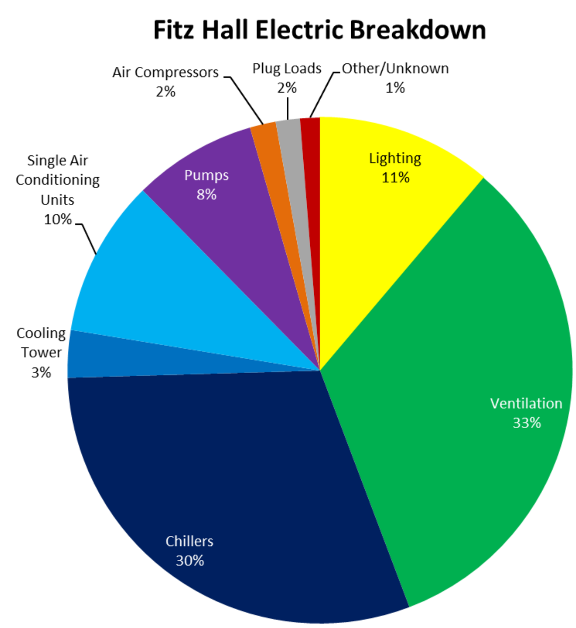
Major Academic Buildings Electricity Usage

After deciding to focus on academic buildings, we sought to understand the energy shares of various systems and equipment. We broke down electricity usage for each building by energy system type, as shown below, using equipment lists provided by Facilities management and estimated load and annual operating hours. This enabled our team to focus on energy efficiency opportunities for these major energy users in each building.









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C. UTILITY ANALYSIS

Annual Energy Usage

Building	Annual Electricity				Annual Natural Gas			Annual Emissions
	Energy (kWh)	Demand (kW)	Cost	Unit ($/kWh)	Usage (mmBTU)	Cost	Unit ($/mmBTU)	(MTCO2)
Roesch Library	2,131,544	-	$120,693	$0.057	4,354	$28,445	$6.53	1,739
Miriam Hall	2,721,000	-	$154,070	$0.057	5,559	$36,311	$6.53	2,220
Kettering Labs	3,969,000	-	$224,734	$0.057	8,108	$52,965	$6.53	3,238
Fitz Hall	7,479,378	14,608	$412,498	$0.055	33,347	$201,894	$6.05	7,061
Total	16,300,922		$911,995	$0.056	51,368	$319,614	$6.22	14,258

Assumes 0.1 MMBtu/ccf natural gas, 1.56 lb CO_2/kWh electricity and 117 lb CO_2/MMBtu natural gas
1 typical U.S. home = 9.3 tonnes CO_2 /year

- The main campus and Fitz Hall building pays an average of **5.7** cents & **5.5 cents** per kWh for electricity under their new contract with Dynegy.
- The main campus and Fitz Hall pay an average of **$6.53 & $6.05** per MMBtu for natural gas.
- These buildings annual CO_2 emissions equal 14,258, equivalent to about **1,533** typical U.S. homes.

Rate Structures

Contracted Dynegy & DP&L Rate Structure 803:

Service Charge: $95/month
Demand Charge: $8.52 / kW
Energy charge: $0.03890 / kWh for first 833,000 kWh
$0.03841 / kWh for all over 833,000 kWh
Power Factor Charge: Unknown

Contracted IGS & Vectren Service G Rate Structure:

Service Charge: $500/meter/month
Energy charge: $6.568 for first 5,135 MMBtu
$6.456 for next 15,405 MMBtu
$6.276 for all over 20,540 MMBtu

Marginal Costs

Marginal costs represent the cost savings you would see from modifying your usage by a given amount. Marginal costs are calculated based on the electricity and natural gas utility bills provided. We use the following marginal costs to calculate savings in all of our recommendations.

Electricity: Demand Charge**:** $8.52 / kW
Energy Charge: $0.0384 / kWh

Natural Gas: $ 6.276 /MMBtu

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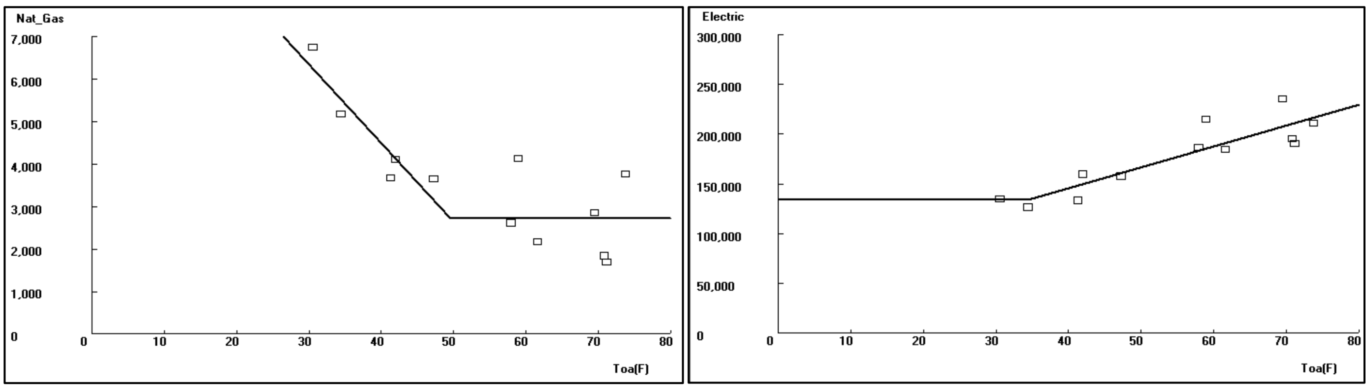
D. BUILDING HEATING AND COOLING INFORMATION

To determine the appropriate building envelope information required in our energy efficiency calculations, Energy Explorer software (Kissock, 2007) was utilized to determine the heating and cooling slopes and balance temperatures. Energy explorer is able to disaggregate energy use corresponding to the outdoor air temperature. Annual energy data was taken from utility bills, and temperature data taken from the Dayton file obtained in an archive maintained by the University of Dayton, available at: http://academic.udayton.edu/kissock/http/Weather/. Since sub-metered natural gas was not available to provide heating information, their values were estimated based on their relative electricity to Roesch Library and Fitz Hall.



Example: Roesch Library's 3-pc regression model of variations in electricity and natural gas with outdoor air temperature

Facility electricity use can be related to outdoor air temperature by the following equation:

$E\ (kWh/mo) = I\ (kWh/mo) + WD\ (kWh/mo\text{-}F) \times [T_{oa}\ (F) - T_{cp}\ (F)]^{+}$

The constant *I* represents electricity use independent of weather. *WD* relates electricity use to outdoor air temperature above the change point temperature. The change point temperature (T_{cp}) is the outdoor air temperature above which electricity use begins to increase as a function of outdoor air temperature (T_{oa}).

Building	Heating		Cooling	
	Slope (mmBTU/F-mo)	Tbal (F)	Slope (kWh/F-mo)	Tbal (F)
Roesch Library	19	49.6	2115	34.4
Miriam Hall	24.3*	55*	2397	35.9
Kettering Labs	33.9*	55*	4987	42.2
Fitz Hall	37.2	63.8	5647	30.5

* Estimates from electric data

II. Clean Energy Recommendations (CERs)

This section provides specific details to the clean energy recommendations in each building, including our estimates of savings and cost of each recommendation. For each building, a one page summary outlines the energy and cost details for each recommendation, and then each CER is outlined in detail.

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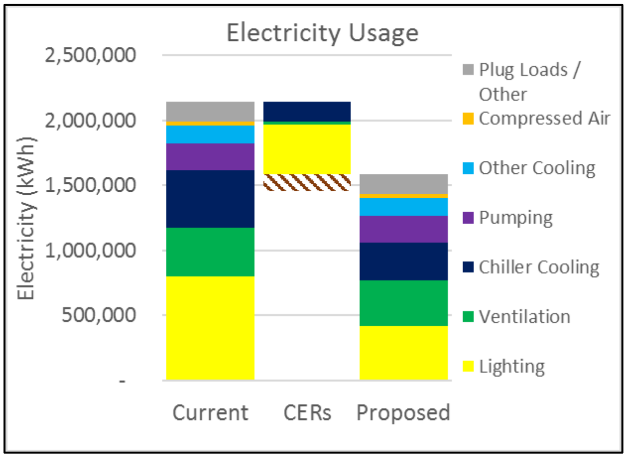
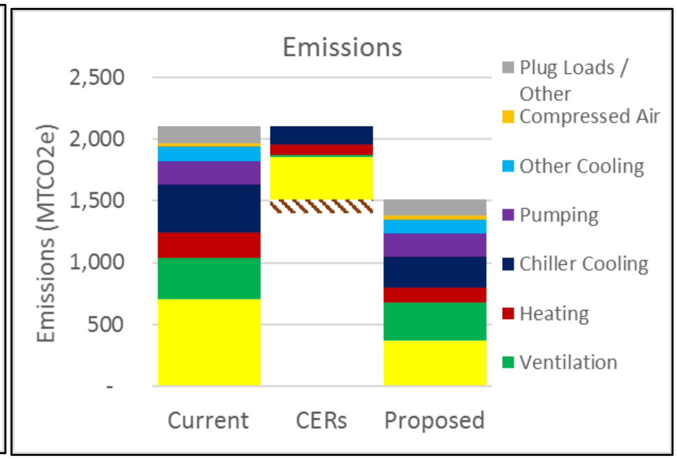
ROESCH LIBRARY

Summary

A total of 6 clean energy recommendations for Roesch Library are estimated to reduce electricity by 33% and natural gas by 36%. This is equivalent to reducing emissions by 33%, or 703 metric tons of CO2. These recommendations have a total simple payback of 5.3 years, and 10-year NPV of $151,124 with a 15% IRR.





	CLEAN ENERGY RECOMMENDATIONS	Annual Savings				Project Cost	Simple Payback (years)	NPV	IRR
		kWh	mmBTU	$MTCO_2$	$				
Lighting									
1	Replace all 4' Fluorescent T8s to 12.5W / 15W LEDs with occ. sensors in all areas but 1st & 2nd Floor	381,390		337	$20,493	$55,597	2.7	$102,642	35%
	Lighting Reduction	48%							
Building Cooling									
2	Reset chiller set point based on outdoor air temp.	79,783		71	$3,064	$3,040	1.0	$20,617	101%
3	Set back thermostats during closed hours	25,565		23	$982	$1,200	0.4	$23,498	267%
4	Install Demand Control Ventilation	54,067		48	$2,076	$936	0.1	$54,877	773%
	Chiller Reduction	36%							
Building Heating									
3	Set back thermostats during closed hours		188	10	$1,182	-*	-*	-*	-*
4	Install Demand Control Ventilation		1,315	70	$8,255	-*	-*	-*	-*
5	Reduce Excess Air in Boilers		84	4	$527	$260	0.5	$3,800	202%
	Heating Reduction		36%						
Ventilation									
3	Set back thermostats during closed hours	26,944		24	$1,035	-*	-*	-*	-*
	Ventilation Reduction	7%							
Renewable Energy									
6	Install 100 kW rooftop Solar PV	132,080		117	$6,862	$175,000	25.5	-$78,288	0%
	Reduction in Building Energy/Emissions	6%		6%					
	Roesch Clean Energy Recommendations Total	**699,829**	**1,588**	**703**	**$44,476**	**$236,033**	**5.3**	**$151,124**	**15%**
	Roesch Energy & Emissions % Reduction Total	**33%**	**36%**	**33%**					

* Not applicable since CERs energy savings are broken down by equipment. Total costs and economics for these CERS are included under cooling savings

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Roesch CER 1: Replace all 4ft-FT8 with LED and occ. sensors in all areas but 1st/2nd Floor

Bulb Type & Lighting Area		Implementation Cost				Annual Energy Savings		Annual Cost Savings				Simple Payback (yrs)
		Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Energy	Demand	Re-lamping	Total	
4ft-T8	Library Book Shelves	$9,626	$7,431	$3,770	$13,287	119,599	11	$4,594	$1,078	$898	$6,569	2.0
	Open Study Areas	$16,982	$10,937	$5,916	$22,003	118,807	13	$4,563	$1,301	$235	$6,100	3.6
	Study Rooms / Classrooms	$5,523	$4,064	$2,608	$6,979	21,978	5	$844	$558	-$16	$1,386	5.0
	Hallways / Stairwells	$5,204	$3,317	$2,178	$6,343	74,027	6	$2,843	$599	$331	$3,774	1.7
	Offices	$2,791	$2,032	$1,339	$3,484	8,718	3	$335	$286	-$37	$584	6.0
	Mech Rooms / Storage	$2,226	$1,515	$1,168	$2,572	31,894	2	$1,225	$250	$260	$1,735	1.5
	Bathrooms	$616	$619	$306	$929	6,366	1	$245	$84	$16	$345	2.7
Total		**$42,967**	**$29,915**	**$ 17,285**	**$55,597**	**381,390**	**41**	**$ 14,649**	**$ 4,156**	**$ 1,687**	**$ 20,493**	**2.7**

Analysis

4ft T8 Lamps in Book Shelves Area

During our walk-through, our team counted a total of 5,923 4ft-T8 fluorescent lamps that were on or need replacement. However, the 1st & 2nd floors are about to begin a renovation and therefore not included in this analysis, bringing the total lamps analyzed to 4,022. Of that total, 2,336 were in open study areas and study desks lining the walls, 1,089 for book shelves area, 732 for hallways and stairwells, 632 for study rooms or classrooms, 567 for offices, 254 for mechanical rooms, 222 for archive rooms and areas, and 92 for bathrooms. During the walk through, some of the lamps were identified as 32W and some 25 W, so their average is estimated to be 28W. According to building staff, all lights are turned off during closed hours, except those in hallways and stairwells which operate 8,760 hours per year. During the operating hours, open areas and book shelves are open 100% of the time, office lights are estimated to be on 9 hours a day 6 days a week, mechanical rooms estimated at 60% of the time, archives almost never, and bathrooms 85% of the time. Therefore, their annual hours could be determined based off the building operating hours of 133.5 hours per week during the school year, and 70 hours per week during the summer, for a total of 6,133 hours per year.

Fluorescent T8s can be directly replaced with direct-wire LED tubes after removing the ballast. LEDS offer several advantages, such as consuming around 50% less energy, a longer rated lifespan, and are directional, meaning that more of the light emitted from the lamp illuminates the work plane. They are also better suited for lighting control systems.

No lighting control systems were identified during our walk-through. Occupancy sensors can provide energy savings by only turning lights on when the area is occupied. This building has numerous areas that are unfrequently occupied, most notably the lights over the book shelves areas.

Recommendation

We recommend **replacing all 5,923 4ft-FT8 bulbs** and ballasts and installing **2,167 LED 12.5-W** tubes in hallways, stairwells, bathrooms, mechanical rooms, and over the large book shelve areas, and installing **3,756 LED 15-W** tubes in open study areas, classrooms, study rooms, and offices.

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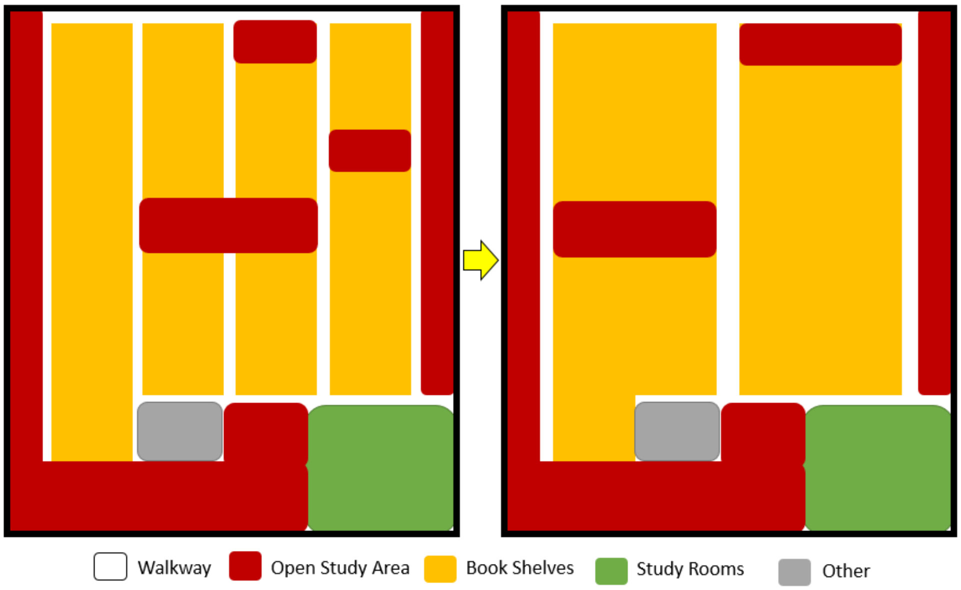
We also recommend installing **ceiling occupancy sensors** in all hallways, open areas, and large classrooms, and installing **wall mounted occupancy sensors** at the doors of office rooms, bathrooms, mechanical rooms, and at each hallway door. The recommended time delay settings are 5 minutes for book shelves areas, 10 minutes for hallways, stairwells, and bathrooms, 15 minutes for study rooms and offices, and 1 hour in mechanical rooms.

A **key implementation step** on floors 4-6 involves moving book shelves together in pairs of two in order to reduce the number of walkways from 5 to 3 and prevent occupancy sensors over the book shelves from false triggering as occupants walk past, as visualized below.



Expected Energy, Emissions and Cost Savings

We estimate that retrofitting a fluorescent T8 with a LED direct-wire tube and removing the ballast would take about 10 minutes per lamp, and installing a ceiling sensor would 1 hour and a wall sensor would take 30 minutes. According to facilities management, the in-house labor rate is $32 per hour.

FACILITY DATA	
Marginal Demand charge	$8.50 /kW-mo
Marginal Energy charge	$0.03841 /kWh
Labor rate	$32 /hr
Relamping labor	0.17 hr/lamp
Occupancy Sensor Installation labor	1.00 hr/sensor

Either 12.5W or 15W LED tubes are recommended in order to satisfy the required lighting levels for each area, as noted in the Appendix. Ceiling mounted sensors are recommended in large open areas, and wall mounted sensors near the door are recommended for all smaller areas, as well as at each hallway door in order to trigger lights as soon as any door opens. The occupancy sensor costs for ceiling and wall mounted sensors are based off estimates from facilities management personnel.

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Lighting energy and cost savings calculations were done separately due to varying input parameters on occupancy, required sensors, and required lighting levels for each area. Below is the process used for the lighting energy and cost savings in book shelves area, and the same process was repeated for all other areas.

CURRENT LIGHTING DATA		
Light Type	4' 28 W T8	
Number of Lamps	946	lamps
Percentage Time Lights Currently On	70%	
Operating Hours	6,133	
Percentage Time Occupied	17%	
Percentage Area Occupied	10%	-

PROPOSED LIGHTING DATA		
Lamp Type	1 Tube 15-W LED	
Type of Sensor	Ceiling Mounted	
Fixtures Controlled by 1 Occ Sensor	9	fixtures/sensor
% Fixtures Controlled by Occ. Sensor	86%	*none on new walkway*
Demand Saving Months	12	mo/yr
Occupancy Sensor Cost	$50	/sensor

REBATES DATA		
Rebate Company	DP&L	
Light Rebate Type	Re-lamping	$/foot
Light Rebate Value	$4	4ft Lamp
Control Rebate Type	$/Connected Watt	
Control Rebate Value	$0.04	/Connected Watt
Maximum Rebate Type	No Cap	-

These lamp specifications and costs are based off 12W and 15W supplier specifications at 1000bulbs.com, specifics also included in the Appendix.

FIXTURE DATA				
	Present		Proposed	
Fixture Type	1 Lamp 28 W T8	-	1 Lamp 12.5 W LED T8	-
Number of Lamps	1	lamps	1	lamps
Lamp Power	28	W/lamp	12.5	W/lamp
Lamp Output	2,600	lumens/lamp	1,800	lumens/lamp
Lamp Life	40,000	hours	50,000	hours
Lamp CRI	0.85	-	0.83	-
Ballast Factor, BF	0.89	-	1.00	-
Lumen Degradation Factor, LDF**	0.93	-	0.85	-
Lamp Cost	$3.0	/lamp	$6.0	/lamp

Energy use, energy costs, CO_2 emissions, re-lamping costs and total operating costs for the existing fluorescent fixtures and the proposed LED fixtures with sensors are shown in the following table.

CALCULATIONS		
LIGHTING LEVELS		
	Present	**Proposed**
Number of Lamps	851 lamps	851 lamps
Measured Lighting Levels	30 fc	21 fc
ANNUAL ELECTRICITY COSTS		
	Present	**Proposed**
Electrical Demand	21.2 kW	10.6 kW
Electrical Consumption	130,068 kWh/year	10,470 kWh/year
Electrical Demand Cost	$2,163 /year	$1,085 /year
Electrical Consumption Cost	$4,996 /year	$402 /year
Total Electricity Cost	$7,159 /year	$1,487 /year
ADDITIONAL ANNUAL COSTS		
	Present	**Proposed**
Relamping Material Cost	$391.46 /year	$100.51 /year
Relamping Labor Cost	$696 /year	$89 /year
Total Relamping Cost	$1,087 /year	$190 /year
TOTAL OPERATING COST		
	Present	**Proposed**
Total Operating Cost	**$8,246** /year	**$1,677** /year

RESULTS	
ENERGY REDUCTION AND COST SAVINGS	
Electrical Demand	**10.6** kW
Electrical Consumption	**119,599** kWh/year
CO_2 Emissions	**85** tonnes/year
Electrical Demand Cost	**$1,078** /year
Electrical Consumption Cost	**$4,594** /year
Total Electricity Cost	**$5,672** /year
ADDITIONAL ANNUAL COST SAVINGS	
Relamping Material Cost	$291 /year
Relamping Labor Cost	$607 /year
Total Relamping Cost	**$898** /year
TOTAL OPERATING COST SAVINGS	
Total Operating Cost Savings	**$6,569** /year

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Implementation Cost & Investment Metrics

The economic viability for all lighting recommendations in this building are shown in the following table. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Implementation Mate	$42,395.00	-
Implementation Labo	$29,915	-
Rebate	$17,259	-
Total Implementatior	**$55,051**	-
Investment Metrics		
Discount Rate	5%	
Net Present Value	$102,911	
IRR	35%	
Simple Payback	2.7	years

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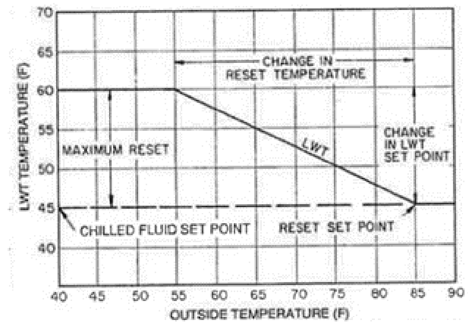
Roesch CER 2: Improve Chilled Water Temperature Control

Implemenation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$2,000	$1,040	$3,040	79,783	0	56	$3,064	12 months	$20,617	101%

Analysis



Two water-cooled chillers in this facility generate chilled water for space cooling. Currently the chillers are set to cool a closed-loop water system to a set-point of 42 F. During our investigation there appeared to be a form of chilled water reset control in Metasys already, but it is not aggressive enough to achieve any noticeable energy savings. By controlling the chilled water temperature to increase when it is cold outside and lower when it is warmer outside, the chillers will allow them to operate more efficiently.

Recommendation

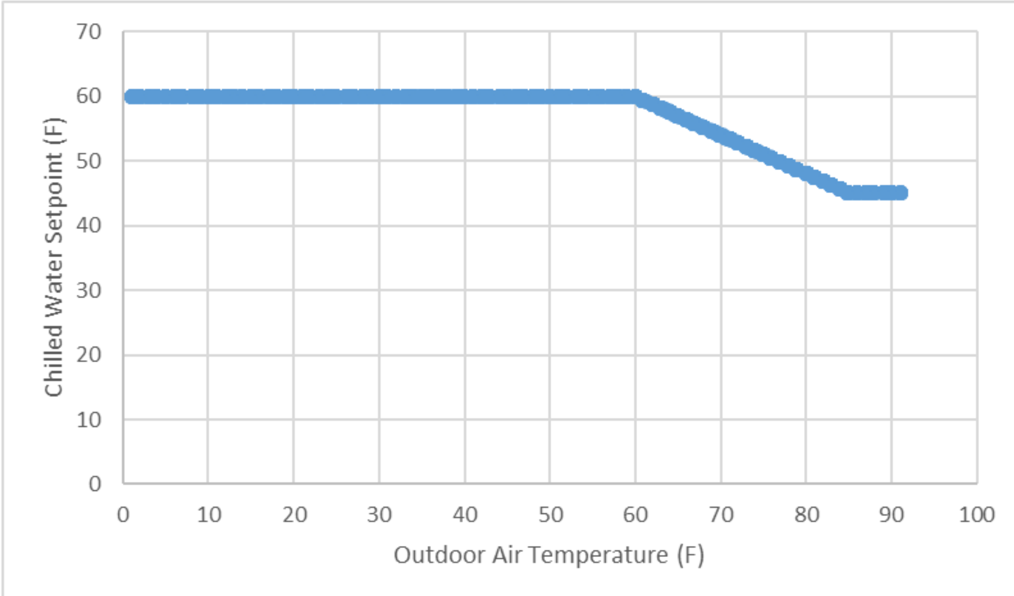
We recommend changing implementing a control strategy which changes the set-point of chilled water in the building based on the outdoor air temperature. This can be done through the facility's building automation system (Metasys) or through Carrier HVAC technicians installing the controls in the built in chiller control system.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of chillers in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in water-cooled chiller efficiency based on estimates found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT SYSTEM INFORMATION		
Chiller Rated Capacity (RC)	460	tons
Chiller Rated kW/ton (eta)	0.634	kW/ton
LCWT at Rated kW/ton (R_LCWT)*	45.0	F
Current Chilled Water Setpoint (CW_T_setpoint)	42.0	F
Current Condeser Water Setpoint (TW_T_setpoint)*	75.0	F
Cooling Slope (CS)	2.90	kWh/F-hr
Cooling Balance Temperature (Tbal)	36.1	F
*Engineering Assumption		

PROPOSED SYSTEM INFORMATION		
Maximum Temperature Reset (Tmax)	60	F
Outdoor Air Temperature at Maximum Reset (ToaMax)	60	F
Minimum Temperature Reset (Tmin)	45	F
Outdoor Air Temperature at Minimum Reset (ToaMin)	85	F



CALCULATIONS			
PARAMETER	**EQUATION**	**VALUE**	**UNITS**
Chilled Water Reset Curve Slope (Rslope)	=(Tmax-Tmin)/(ToaMin-ToaMax)	-0.6	F/F
Chilled Water Reset Curve Intercept (Rint)	=Tmax-Rslope*ToaMax	60	F
	HOURLY EQUATION		**UNITS**
Current Building Energy Use (CCEU)	=CS*(Toa-Tbal)$^{+}$		kWh
Building Load (BL)	=CCEU/eta		tons
Chiller % Load (CL)	=BL/RC		%
Standard Chiller Efficiency (eta_S)	=0.57341 - 1.2023*CL + 0.79481*CL^2 + 0.0051964*TW_T_setpoint + 0.000022926*TW_T_setpoint^2 - 0.000805732*TW_T_setpoint*CL		kW/ton
Current Chiller Efficiency (eta_C)	=eta_S+0.015*eta_S*(RLCWT-CW_T_setpoint)		kW/ton
Proposed Chilled Water Setpoint (P_setpoint)	=IF(Toa<ToaMax, Tmax, IF(Toa>ToaMin, Tmin, Rslope*Toa + Rint))		F
Proposed Chiller Efficiency (eta_P)	=eta_S+0.015*eta_S*(RLCWT-P_setpoint)		kW/ton
Proposed Chiller Energy Use (PCEU)	=CCEU*eta_C/eta_P		kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Proposed Annual Electricity Savings (Se)	ΣC_CCEU-ΣP_PCEU	79,783	kWh/year
Proposed Annual Cost Savings (Sc)	Se*Ecost	$3,064	/year

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Implementation Cost, Simple Payback, and Internal Rate of Return

We estimate the changes to the controls would take two Chiller Technicians, paid $65/hour, about 8 hours to complete in the Chiller Control System with another $2,000 in parts and sensors. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$2,000	-
Labor Cost	$1,040	-
Total Implementation Cost	**$3,040**	-
COST SAVINGS		
Energy	$3,064	/year
Demand	$0	/year
Total	$3,064	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$20,617	
IRR	101%	
Simple Payback	11.9	months

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Roesch CER 3: Implement thermostat controls in Metasys during closed hours

Breakdown by Equipment	Implemenation Cost		Annual Savings					Economics		
	Material	Labor	Electric (kWh)	Demand (kW)	Nat Gas (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
Steam Boiler				-	188	10	$1,182	N/A		
Chiller	$0	$1,200	25,565	-		18	$982	N/A		
AHUs			26,944	-		19	$1,035	N/A		
Total	$1,200		52,509	-	188	47	$3,198	5 months	$23,498	267%

Analysis

The library is closed for significant number of hours throughout the year, which vary during the school year, summer, and breaks, as shown on the following page. During these closed hours, the thermostats can be programmed to reduce their set-point during the winter months, and increase the set-point during summer months. This will decrease heating loads during winter months, and decrease cooling loads during summer months. A lower temperature difference between the inside and outside air results in reduced heat transfer and infiltration losses. Although it requires some additional energy to reheat the plant in the morning, it is significantly less than the energy saved by reducing the temperature during un-occupied hours.

Item	Value	Description
OCC-SCHEDULE	Not Set	Occupancy Schedule Command
OCC-MODE	Occupied	Occupancy Mode Status
EFF-OCC	Occupied	Effective Occupancy
SYSTEM-MODE	Auto	System Mode Status
ZN-T	71.8 deg F	Zone Temperature
ZN-SP	70.6 deg F	Zone Temperature Setpoint
CLGOCC-SP	72.0 deg F	Cooling Occupied Setpoint
CLGUNOCC-SP	82.0 deg F	Cooling Unoccupied Setpoint
HTGOCC-SP	70.0 deg F	Heating Occupied Setpoint
HTGUNOCC-SP	61.0 deg F	Heating Unoccupied Setpoint

Example Metasys Zone Temperature Setback Controls

Recommendation

We recommend utilizing UD's Metasys system to control the thermostats to reduce set-points from 70F to 60F during closed hours of heating days, and increase its set-point from 72 to 80F during closed hours of cooling days.

Expected Energy, Emissions and Cost Savings

During the school year this building is open Monday-Thursday 730AM-5AM, Friday 730AM-10PM, Saturday 10AM-10PM, Sunday 10AM-12AM. Therefore, during the school year thermostat setbacks can occur from 5-7AM Tues-Friday, Friday/Sat nights 10PM- 930AM, and Monday 12AM-7AM. During the summer, setbacks can occur everyday 8PM-830AM. During breaks, setbacks can occur 5PM-730AM during the week and 24/7 on weekends.

The setbacks should not include finals week in the Spring and Fall semester.

School Year			Breaks			Summer		
	weekday	weekend		weekday	weekend		weekday	weekend
Hr of Day	(on/off)	(on/off)	Hr of Day	(on/off)	(on/off)	Hr of Day	(on/off)	(on/off)
0:00	1	0	0:00	0	0	0:00	0	0
1:00	1	0	1:00	0	0	1:00	0	0
2:00	1	0	2:00	0	0	2:00	0	0
3:00	1	0	3:00	0	0	3:00	0	0
4:00	1	0	4:00	0	0	4:00	0	0
5:00	0	0	5:00	0	0	5:00	0	0
6:00	0	0	6:00	0	0	6:00	0	0
7:00	1	0	7:00	0	0	7:00	0	0
8:00	1	0	8:00	1	0	8:00	1	1
9:00	1	0	9:00	1	0	9:00	1	1
10:00	1	1	10:00	1	0	10:00	1	1
11:00	1	1	11:00	1	0	11:00	1	1
12:00	1	1	12:00	1	0	12:00	1	1
13:00	1	1	13:00	1	0	13:00	1	1
14:00	1	1	14:00	1	0	14:00	1	1
15:00	1	1	15:00	1	0	15:00	1	1
16:00	1	1	16:00	1	0	16:00	1	1
17:00	1	1	17:00	1	0	17:00	1	1
18:00	1	1	18:00	0	0	18:00	1	1
19:00	1	1	19:00	0	0	19:00	1	1
20:00	1	1	20:00	0	0	20:00	0	0
21:00	1	1	21:00	0	0	21:00	0	0
22:00	1	1	22:00	0	0	22:00	0	0
23:00	1	0	23:00	0	0	23:00	0	0

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To calculate savings, the building's heating and cooling baseline information was determined. The thermostat set-points were based off typical campus buildings, as its specific set-points were not found in Metasys. The efficiency of its boilers average 88%, as indicated on *Apex Mechanical Systems'* boiler analysis, and its chiller COP is taken from its nameplate. The building's heating and cooling slope, and heating and cooling balance temperatures, were identified in the lean energy analysis from annual electrical and natural gas bills, as noted in Section 1D.

CURRENT BUILDING INFORMATION		
Heating Indoor Temperature Setpoint (Tia_h)	70	F
Cooling Indoor Temperature Setpoint (Tia_c)	72	F
Heating Efficiency (eta_h)	88%	
Cooling Efficiency (eta_c)	5.5	
Building Heating Slope (HS)	19.0	mmBtu/F-month
Building Heating Balance Temperature (Tbal_h)	49.6	F
Building Cooling Slope (CS)	2115	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	34.4	F

The building has two AHUs that serve all floors but the basement, and their information is provided below. Since the basement AHU is scheduled to turn off during closed hours, it is not included in energy savings from thermostat setbacks. It is assumed that AHU's VFDs are operating at ASHRAE standards.

Current AHU Information		
Fan Motor Efficiency (eta_m)*	90%	
Supply Fan Nameplate (NFP)	96	hp
Fraction Loaded @100% (FL)*	80%	
Return Fan Nameplate (RFP)	50	hp
Total AHU Fan Power Rating (HP)	146	hp
Minimum damper position (VAVpercent_open)	30%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

Engineering Assumptions		
Heating Design Temperature (Tdesign_h)	0	F
Cooling Design Temperature (Tdesign_c)	95	F

The proposed setback temperatures are indicated below. It is also recommended to set the minimum damper positions from 30% to 5% in Metasys in order to see all potential savings.

Proposed System Information		
Heating Setback Temperature (Tsetback_h)	60	F
Cooling Setback Temperature (Tsetback_c)	80	F
Minimum damper position (VAVpercent_open_new)	5%	

The new balance temperatures during closed hours is calculated below, and used to calculate proposed heating and cooling energy. Reduced heating and cooling corresponds to reduced AHU energy.

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CALCULATIONS			
PARAMETER	**EQUATION**	**Results**	
Building UA (UA)	(HS/30.4/24*10^6*eta_h+CS/30.4/24*3412*eta_c)/2	38,595	Btu/hr-F
Internal Load (IL_h)	UA*(Tia_h-Tbal_h)	787,338	Btu/hr
Internal Load (IL_c)	UA*(Tia_c-Tbal_c)	1,451,172	Btu/hr
Heating Setback Balance Temperature (Tbal_setback_h)	Twkend_h-IL_h/UA	39.6	F
Cooling Setback Balance Temperature (Tbal_setback_c)	Twkend_c-IL_c/UA	42.4	F
Calculations	**HOURLY EQUATION**	**Annual Totals**	
Current Hourly Heating Energy Use (C_BHE)	$HS*(Tbal\_h-Toa)^+/30.4/24$	1,778	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	$CS*(Toa-Tbal\_c)^+/30.4/24$	495,930	kWh
Current AHU Energy Use (C_AHU)	FL*HP*.746*(A+xB^2+xC^2+xD^3)	252,013	kWh
Proposed Hourly Heating Energy Use (P_BHE)	$HS*(Tbal\_[none,night,wkend]\_h-Toa)^+/30.4/24$	1,464	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	$CS*(Toa-Tbal\_[none,night,wkend]\_c)^+/30.4/24$	453,321	kWh
Proposed AHU Energy Usage (P_AHU)	FL*HP*.746*(A+xB^2+xC^2+xD^3)	207,106	kWh

A steady state analysis uses the difference in indoor and outdoor temperature to calculate savings. However, in practice the thermal mass of the building reduced temperature swings. To correct for this, actual savings are assumed to be 60% of steady state savings (Kissock, 2003).

RESULTS			
ENERGY REDUCTION			
Steady State Annual Fuel Savings (SSf)	ΣC_BHE-ΣP_BHE	314	mmBtu/year
Steady State Annual Cooling Electricity Savings (SSe_c)	ΣC_BCE-ΣP_BCE	42,609	kWh/year
Steady State Annual AHU Electricity Savings (SSe_ahu)	ΣC_BCE-ΣP_BCE	44,906	kWh/year
Actual Annual Cooling Savings (ACTe_c)	SSe_c*0.6	25,565	kWh/year
Actual Annual AHU Savings (ACTe_ahu)	SSe_ahu*0.6	26,944	kWh/year
Total Annual Electric Savings (TOTe)	ACTe_c + ACTe_ahu	52,509	/year
Actual Annual Fuel Savings (TOTf)	SSf*0.6	188	mmBtu/year
COST SAVINGS			
Electric (Cost_e)	TOTe*Ecost	$2,016	/year
Natural Gas (Cost_ng)	TOTf*Ngcost	$1,182	/year
Total Savings	Cost_e + Cost_ng	$3,198	/year

Implementation Cost & Investment Metrics

We estimate that it would take 8 hours to program thermostat setbacks in Metasys at a rate of $150 per hour. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0.00	-
Labor Cost	$1,200	-
Total Implementation Cost	$1,200	-
COST SAVINGS		
Electric	$2,016	/year
Natural Gas	$1,182	/year
Total	$3,198	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$23,498	
IRR	267%	
Simple Payback	4.5	months

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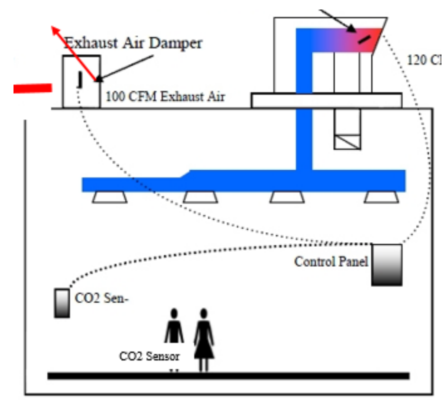
Roesch CER 4: Install Demand Control Ventilation

Implemenation Cost				Annual Savings					Economics		
Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$3,000	$1,720	$3,860	$860	54,067	0	1315	108	$10,331	1 months	$78,913	1201%

Analysis

Mechanically ventilated spaces in commercial buildings will set the minimum amount of outdoor air entering a building based upon the ventilation required at full occupancy. However, buildings are frequently only partially occupied. A demand ventilation system works by measuring the amount of carbon dioxide released by the building occupants, so it can maintain indoor air quality while reducing the amount of ventilation air during times of partial occupancy. The library operates with a fixed fraction of outdoor ventilation air while not economizing. The building cooling capacity is 460 tons with an average COP of 5.5 based on nameplate information. The boiler system efficiency is estimated to be 90% on average.



Recommendation

We recommend installing a CO2 sensor in the return ductwork to each air handling unit to measure the concentration of CO2 given off by occupants breathing and adjust the amount of ventilation air accordingly. This sensor should be incorporated into the Metasys building automation system for appropriate operation. This greatly reduces the amount of energy required to heat and cool spaces which are not constantly occupied. In schools, occupancy is typically very low during the summer months and allows this system to realize greater savings.

Expected Energy, Emissions and Cost Savings

To quantify the impact of reduced ventilation air, we simulated the energy use for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the amount of ventilation air brought into the school building currently as well as with the proposed CO2 sensor. The estimated occupancy and schedule are shown below as well as the energy calculations.

The cooling and heating temperature set-points are adjusted to include thermostat setback recommendation in order to prevent double counting savings when combined with other CERs.

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CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)	19	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h	47.9	F
Building Cooling Slope (CS)	2,115	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	36.1	F
Heating Efficiency (eta_h)	90%	
Nameplate Cooling Efficiency (neta_c)	5.5	COP
Average Cooling Efficiency (eta_c)	4.4	COP
Nameplate Total Cooling Capacity (nCap_c)	460	tons

ENGINEERING ASSUMPTIONS		
Sensible Heat Ratio (SHR)*	0.85	
Cooling Supply Air Temperature (SAT_c)*	57	F
Heating Supply Air Temperature (SAT_h)*	68	F
Economizer Low Limit (EconoLL)*	30	F
Economizer High Limit (EconoHL)*	70	F
Minimum Outdoor Air (MinOA)*	15%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

*Engineering Assumption

Occupancy rates are estimated, and AHUs are scheduled to be on 24/7 to prevent book degradation.

Hour of Day	Occupancy	Schedule (on/off)	Hour of Day	Occupancy	Schedule (on/off)
0:00	5%	1	12:00	15%	1
1:00	5%	1	13:00	20%	1
2:00	1%	1	14:00	20%	1
3:00	1%	1	15:00	20%	1
4:00	1%	1	16:00	20%	1
5:00	0%	1	17:00	20%	1
6:00	1%	1	18:00	20%	1
7:00	1%	1	19:00	20%	1
8:00	10%	1	20:00	15%	1
9:00	10%	1	21:00	15%	1
10:00	15%	1	22:00	15%	1
11:00	15%	1	23:00	10%	1

The building's hourly loads are calculated from the heating and cooling slopes found in the Lean Energy Analysis section. Savings from demand ventilation only occurs when the building is set to bring in the minimum amount of outdoor air. Therefore, the hours in the year corresponding to economizer operation are excluded. The current outdoor airflow is calculated based on the general HVAC design rule that a building should move 400 cfm of air per ton of cooling provided at design conditions. The minimum amount of outdoor air is expressed in HVAC designs is based on this value. In our calculation we propose reducing the amount of ventilation based on the estimated occupancy for each hour.

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This calculation does not consider the significantly lower summer occupancy and therefore represents a conservative estimate of cooling savings.

CALCULATIONS		
PARAMETER	**EQUATION**	**UNITS**
Hourly Building Heating Energy (BHE)	HS*(Tbal_h-Toa)$^{+}$/30.4/24	mmBtu
Hourly Building Cooling Energy (BCE)	CS*(Toa-Tbal_c)$^{+}$/30.4/24	kWh
Economizer Mode (EconoM)	IF(EconoHL>Toa>EconoLL,1,0)	0,1
Hourly Building Heating Load (BHL)	BHE/(HS*(Tbal_h-Tdesign_h)/30.4/24)	%
Hourly Building Cooling Load (BCL)	BCE/(CS*(Tdesign_c-Tbal_c)/30.4/24)	%
Current Outdoor Airflow (COA)	IF(Schedule=ON,MAX(BHL,CHL)*400*Cap_c*MinOA,0)	cfm
Current Hourly Heating Energy Use (C_BHE)	IF(Toa<Tbal_h,1.08*COA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	IF(Toa>SAT_c,1.08*COA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh
Proposed Outdoor Airflow (POA)	IF(EconoM=1,COA,COA*Occupancy)	cfm
Proposed Hourly Heating Energy Use (P_BHE)	IF(Toa<Tbal_h,1.08*POA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	IF(Toa>SAT_c,1.08*POA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh

RESULTS			
ENERGY REDUCTION			
Proposed Annual Fuel Savings (Sf)	ΣC_BHE-ΣP_BHE	1,315	mmBtu/yr
Proposed Annual Electricity Savings (Se)	ΣC_BCE-ΣP_BCE	54,067	kWh/yr
COST SAVINGS			
Electric (Cost_e)	Sf*Ngcost	$2,076	/year
Natural Gas (Cost_ng)	Se*Ecost	$8,255	/year
Total Savings	Cost_e + Cost_ng	$10,331	/year

Implementation Cost & Investment Metrics

We estimate that it would cost $1,500 per CO2 sensor for each AHU. It is also estimated to take 8 hours to program in Metasys at $150 per hour, and take two technicians, at $65 per hour, 4 hours to install each CO2 sensor per AHU. It has also been confirmed by DP&L that this would fall under a custom rebate, at $0.10/kWh saved, up to 50% of the total installed cost. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$3,000	-
Labor Cost	$1,720	-
Rebate	$3,784	-
Total Implementation Cost	**$936**	-
COST SAVINGS		
Energy	$7,228	/year
Demand	$0	/year
Total	$7,228	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$54,877	
IRR	773%	
Simple Payback	1.6	months

Roesch CER 5: Reduce Excess Air to 10% in Modulating Boilers

Implementation Cost						Economics		
Material	Labor	Total	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year
$0	$260	$260	84	4	$526	6 months	$3,800	202%

Analysis

One condensing and two modulating, 366 kW, 1.25 mmBtu per hour rated output RBI Boilers provide space heating for the building. The boilers use linkages that connect natural gas supply valves with combustion air inlet dampers. In this configuration, combustion air intake is controlled based on natural gas input to the boiler. Excess air is not constant over the firing range, but increases as firing rate decreases. It is estimated that these boilers operate 6,000 hours per year.

Modulating Boiler System

	Mod Boiler #1		Mod Boiler #2	
Firing Rate	low	high	low	high
Excess Air	39.2%	27.9%	34.9%	28.7%
Stack Temp (F)	186.4	300.2	174.4	283.8
Combustion Efficiency	87.8%	85.6%	88.2%	85.9%

The optimal excess combustion air in a gas heating system for energy efficiency and pollution prevention is about 10% ("Guide to Industrial Assessments for Pollution Prevention and Energy Efficiency", EPA/625/R-99/003), which yields an O_2 content of 1.7% in the exhaust gasses. Higher levels of excess air dilute the combustion stream and decrease the quantity of useful heat available to the process. Tuning the boiler's mechanical linkages to maintain a proper excess air ratio of 10% can improve efficiency and yield substantial natural gas savings.

Recommendation

We recommend tuning the two modulating boilers to 10% excess air at high fire when regular boiler maintenance occurs. Since the condensing boiler is already highly efficient, tuning its linkages will not result in noticeable savings.

Expected Energy, Emissions and Cost Savings

The existing and proposed steam systems were modeled using SteamSim software (Kissock,2008). SteamSim is part of the UD-IAC Energy Efficiency Guidebook and is available free of charge at:
http://academic.udayton.edu/kissock/http/research/EnergySoftware.htm.

Mechanical linkages must be tuned at high fire to prevent dropping below 10% excess air at lower firing rates. The inputs and outputs for both the current and proposed cases are shown in the following figures.

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CONSTANTS FOR NATURAL GAS		
Term	**Value**	**Unit**
LHV = lower heating value	21,500	Btu/lb
HHV = higher heating value	23,900	Btu/lb
cpp = specific heat of products of exhaust	0.300	Btu/lb-F
Tdpp = dew point temp of H20 in exhaust	140	F
AFs = air/fuel mass ratio at stochiometric conditions	17.2	

INPUTS				
Term		**Boiler 1**	**Boiler 2**	**Unit**
Excess Air (EA)	(0.1 = optimum, 0=stochiometric point)	0.34	0.318	
Combustion Air Temperature (Tca)	(Before Burner)	70		F
Exhaust Gas Temperature (Tex)		243.3	229.1	F
Rated Output (RO)		1.25		mmBtu/hr
Fraction Loaded (FL)		0.5		
Operating Hours (HPY)		6,000		hr
Natural Gas Cost (Ncost)		6.27		$/mmBtu
PROPOSED				
Excess Air (EA)	(0.1 = optimum, 0=stochiometric point)	0.1		

CALCULATIONS: CURRENT			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Temp combustion (Tc) = Tca+LHV/[(1+(1+EA)(Afs))cpp]	3060	3098	F
Water vapor latent energy (hfg) = (if Tex<140 then hfg=HHV-LHV else hfg = 0)	0	0	Btu/lb
Efficiency (E) = {hfg+[1 + (1+EA)(AFs)]*cpp*(Tc-Tex)}/HHV	0.847	0.852	
Heating Load (HL)= RO*FL	0.625	0.625	mmBtu/hr
Annual Fuel Consumption (NG1) = HPY*HL/E	4425	4400	mmBtu/yr
CALCULATIONS: PROPOSED			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Temp combustion (Tc) = Tca+LHV/[(1+(1+EA)(Afs))cpp]	3668	3668	F
Water vapor latent energy (hfg) = (if Tex<140 then hfg=HHV-LHV else hfg = 0)	0	0	Btu/lb
Efficiency (E) = {hfg+[1 + (1+EA)(AFs)]*cpp*(Tc-Tex)}/HHV	0.856	0.860	
Heating Load (HL)= RO*FL	0.625	0.625	mmBtu/hr
Annual Fuel Consumption (NG1) = HPY*HL/E	4380	4361	mmBtu/yr

By reducing the excess air in the boilers, their efficiency increases and corresponds to energy savings. Using the marginal cost of natural cost, annual cost savings can also be determined, as shown below.

CALCULATIONS: SAVINGS			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Total Fuel Savings (NG_save) = NG1-NG2	**46**	**38**	mmBtu/yr
Cost Savings (Csav) = NG_save*Ncost	**286**	**240**	$/yr

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Implementation Cost & Investment Metrics

Facilities management indicated that regular boiler maintenance already occurs, thus there is only a labor cost of $260 for two technicians to spend about an hour to tune the linkage on each boiler. The relative investment metrics are listed below, assuming a project lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0	-
Labor Cost	$260	-
Rebate	$0	-
Total Implementation Cost	$260	-
COST SAVINGS		
Energy	$526	/year
Demand	$0	/year
Total	$526	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$3,800	
IRR	202%	
Simple Payback	0.5	years

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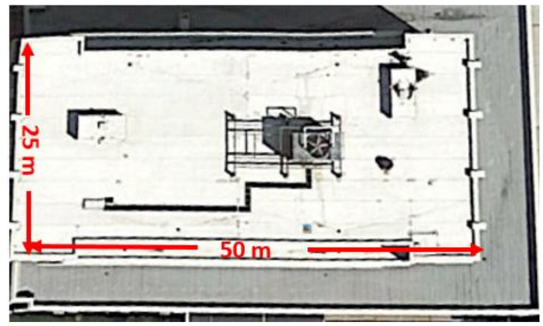
Roesch CER 6: Install 100 kW Rooftop Solar PV System

Implementation Cost			Annual Savings				Economics		
Capex	ITC	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback (years)	25 year NPV	25 year IRR
$175,000	$0	$175,000	132,080	18	93	$6,862	26	-$78,288	0%

Analysis



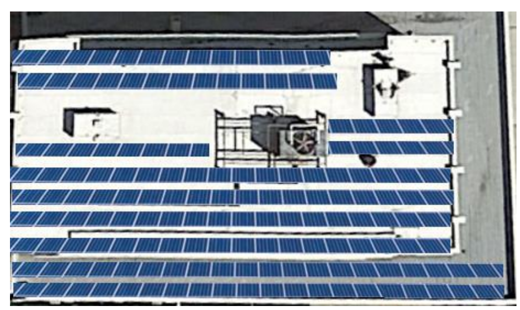
Rooftop Area

The library has an upper rooftop area of around 1,250 square meters, while the 2nd Floor outer roof has an area of around 800 square meters. Some of this area sees ample sunlight throughout the year. Parts of the roof's area unobstructed from shade of nearby objects can be utilized for energy generation by installing solar PV panels.

Recommendation

We recommend installing a 100 kW-DC solar PV array split between the 2nd floor and top floor rooftop.

Expected Energy, Emissions and Cost Savings



Rooftop Area with solar PV

The total area unobstructed from shade of nearby objects, mainly the south half of the top roof, and south part of the 2nd floor roof, was determined to be around 1,200 m2. After factoring in spacing from arrays tilted at 30 degrees south, it was determined that a total area of around 500 m2 could be utilized for solar PV. Assuming a system with generic 330 W, 1.67 m2 solar panels, this would be around 100 kW-DC. However, once inverter losses of 2.5% converting from DC to AC, and 10% losses from other factors such as soiling, mismatch, light-induced degradation, and partial shading are taken into account, the AC capacity would be around 88 kW (NREL, 2014).

To quantify the potential energy generation from the 100 kW solar PV aray, the annual solar radiation was determined by using NASA average daily horizontal radiation for each month for Dayton Ohio, downloaded from https://eosweb.larc.nasa.gov/sse/RETScreen/. This yields annual solar radiation of 1384 kWh/m2 for a horizontal surface, and after calculating increases from tilting the panels 30 degrees south, 1534 kWh/m2. This results in a DC capacity factor of 17.5%.

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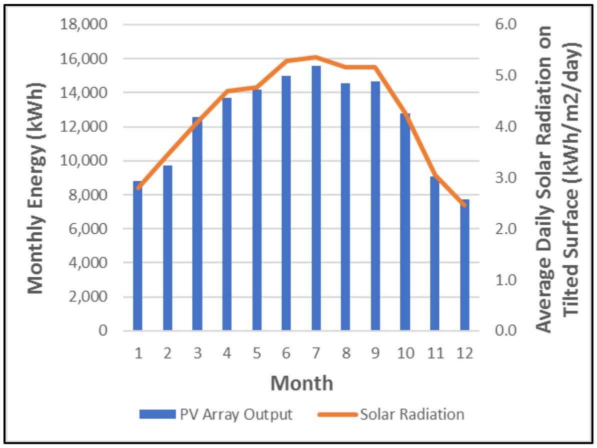

The system's annual generation can then be determined by multiplying the capacity factor by its AC capacity. Monthly demand savings are assumed to be 20% of the solar system's AC capacity. The corresponding cost savings are based on the marginal costs of energy and demand.

RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**17.6**	kW
Electrical Consumption	**132,080**	kWh/year
Electrical Demand Cost	**$1,790**	/year
Electrical Consumption Cost	**$5,072**	/year
Total Electricity Cost	**$6,862**	/year

Implementation Cost & Investment Metrics

The total cost is based on an assumption of $1.75/W-DC, assuming all solar PV recommendations is this report are done in tandem for a total system rate closer to 500 kW. The investment tax credit is not applicable to UD, as they are exempt from federal taxes under 501(c)(3). However, depending on the outcome of Congress' 2017 bill to tax endowment income, this may change.

ECONOMICS		
IMPLEMENTATION COST		
Total Cost	$175,000	-
Rebate	$0	-
Total Implementation	**$175,000**	-
COST SAVINGS		
Energy	$5,072	/year
Demand	$1,790	/year
Total	$6,862	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	($78,288)	
IRR	0%	
Simple Payback	25.5	years

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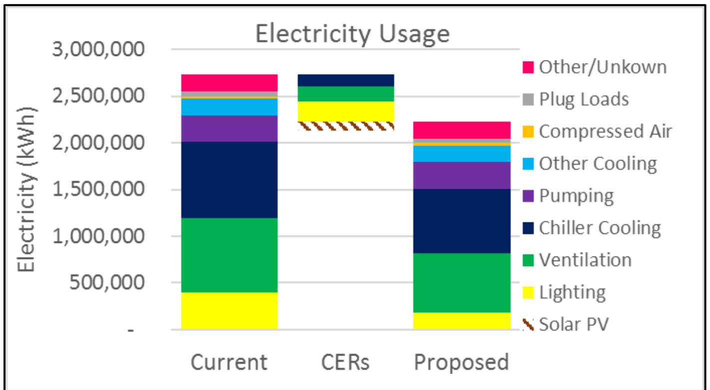
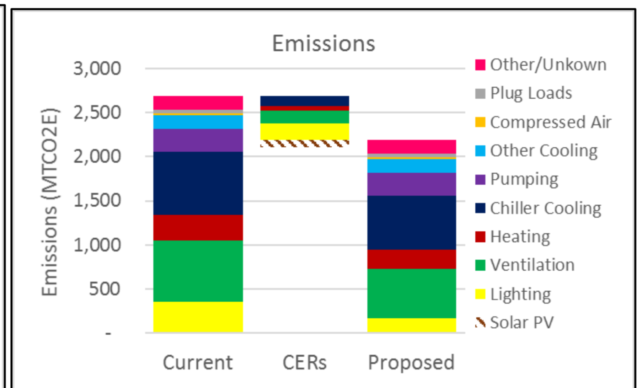
MIRIAM HALL

Summary

A total of 7 clean energy recommendations for Miriam Hall are estimated to reduce electricity by 25% and natural gas by 20%. This is equivalent to reducing emissions by 24%, or 659 metric tons of CO2. These recommendations have a total simple payback of 5.1 years, and 10-year NPV of $134,342 with a 15% IRR.





CLEAN ENERGY RECOMMENDATIONS		Annual Savings kWh	mmBTU	MTCO2	$	Project Cost	Simple Payback (years)	NPV	IRR
Lighting									
1	Replace all FT8s & CFLs with LEDs and occ. sensors	214,963		190	$13,192	$34,025	2.6	$67,840	37%
	Lighting Reduction	54%							
Building Cooling									
2	Reset chiller set point based on outdoor air temp.	85,526		76	$3,284	$2,040	0.6	$23,320	161%
3	Schedule AHUs and setback thermostats during unoccupied hours	19,416		17	$746	$1,800	0.6	$20,291	232%
4	Install Demand Control Ventilation	22,471		20	$863	$15,433	2.5	$32,294	39%
	Cooling Reduction	16%							
Building Heating									
3	Schedule AHUs and setback thermostats during unoccupied hours		231	12	$1,450	-*	-*	-*	-*
4	Install Demand Control Ventilation		847	45	$5,318	-*	-*	-*	-*
	Heating Reduction		20%						
Ventilation									
3	Schedule AHUs and setback thermostats during unoccupied hours	15,311		14	$588	-*	-*	-*	-*
5	Relocate AHU VFD static pressure sensors	142,102		126	$5,457	$5,040	0.9	$37,095	108%
	Ventilation Reduction	20%							
Pumping									
6	Install Primary Chiller Pump & Eliminate bypass chilled water pumping	81,228		72	$3,120	$11,265	3.6	$12,827	25%
	Pumping Reduction	28%							
Renewable Energy									
7	Install 80 kW Rooftop Solar PV	99,060		88	$5,146	$131,250	25.5	-$58,935	0%
	Reduction in Building Energy/Emissions	4%		3%					
	Miriam Clean Energy Recommendations Total	**680,077**	**1,078**	**659**	**$39,163**	**$200,853**	**5.1**	**$134,342**	**15%**
	Miriam Energy & Emissions % Reduction Total	**25%**	**20%**	**24%**					

* Not applicable since CERs energy savings are broken down by equipment. Total costs and economics for these CERS are included under cooling savings

Miriam CER 1: Replace all 4ft-FT8, 2ft-FT8, & 2-pin CFLs with LEDs with occ. sensors

Bulb Type & Lighting Area		Implementation Cost				Annual Energy Savings		Annual Cost Savings				Simple Payback (years)
		Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Energy	Demand	Re-lamping	Total	
4ft-T8	Classrooms	$6,875	$1,013	$2,756	$5,132	24,593	6.0	$945	$610	-$86	$1,469	3.5
	Hallways / Stairwells	$7,425	$5,708	$2,848	$10,285	76,502	7.8	$2,938	$792	$70	$3,801	2.7
	Offices	$6,788	$6,283	$4,444	$8,627	39,152	12.3	$1,504	$1,251	$44	$2,799	3.1
	Mech Rooms / Storage	$790	$747	$506	$1,031	18,757	1.1	$720	$108	$155	$984	1.0
	Bathrooms	$802	$837	$329	$1,311	11,189	0.9	$430	$90	$50	$571	2.3
2'T8	Hallways / Stairwells	$738	$559	$137	$1,160	3,600	0.3	$138	$35	$19	$193	6.0
	Classrooms	$540	$15	$392	$163	2,205	0.5	$85	$55	$5	$144	1.1
	Bathrooms	$144	$128	$57	$215	2,064	0.1	$79	$15	$49	$143	1.5
CFL	Hallways / Stairwells	$4,160	$2,363	$955	$5,567	31,765	3.7	$1,220	$377	$1,028	$2,625	2.1
	Classrooms	$680	$11	$299	$392	3,333	0.9	$128	$89	$84	$301	1.3
	Bathrooms	$120	$64	$41	$143	1,804	0.2	$69	$16	$77	$162	0.9
	Total	**$29,062**	**$17,727**	**$12,764**	**$34,025**	**214,963**	**34**	**$8,257**	**$3,438**	**$1,497**	**$13,192**	**2.6**

Analysis

During our walk-through, our team counted a total of 2,436 4ft-T8 fluorescent lamps, 182 2ft-T8 fluorescent lamps, and 361 2-pin 26W CFLs. For 4ft-T8s, 640 were in open areas, hallways, and stairwells, 603 in study rooms or classrooms, 1,010 in offices, 110 in mechanical rooms, and 73 in bathrooms. During the walk through, some of the 4ft-T8 lamps were identified as 32W and some 25 W, so their average is estimated to be 28W. All 2ft-T8s and CFLs are estimated to be 17W and 26W respectively. One week of light logger data indicated that during the school year classroom lights are on 55% of the time, office lights 33%, hallways 100%, mechanical rooms 25%, and bathrooms 92%.

4ft T8s in a Classroom

Fluorescent T8 lamps can be directly replaced with direct-wire LED tubes after removing the ballast. LEDS offer several advantages, such as consuming around 50% less energy, a longer rated lifespan, and are directional, meaning that more of the light emitted from the lamp illuminates the work plane. They are also better suited for lighting control systems.

Only a few lighting control systems were identified in some hallways during our walk-through. Occupancy sensors can provide energy savings by turning lights on only when the area is occupied.

Recommendation

We recommend **replacing all 2,436 4ft-FT8 bulbs** and ballasts and installing **520 LED 12.5-W** tubes in hallways, stairwells, and bathrooms, and installing **1,916 LED 15-W** tubes in, classrooms, offices, and mechanical rooms. We also recommend replacing all **182 2ft-T8s with 9W high lumen T8 LEDs**, and all **361 2-pin CFLs with 10W high lumen 2-pin LEDs** in order to satisfy the required lighting levels.

We also recommend installing **ceiling occupancy sensors** in all hallways, open areas, and large classrooms, and installing **wall mounted occupancy sensors** at the doors of office rooms, bathrooms, mechanical rooms, and at each

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hallway door. The recommended time delay settings are 10 minutes for hallways, stairwells, and bathrooms, 15 minutes for classrooms and offices, and 1 hour in mechanical rooms.

Expected Energy, Emissions and Cost Savings

We estimate that retrofitting a 4ft-FT8, 2ft-FT8, or CFL with a LED direct-wire tube and removing the ballast would take about 10 minutes per lamp. Installing a ceiling sensor is estimated to take 1 hour and a wall sensor 30 minutes. According to facilities management, the in-house labor rate is $32 per hour.

FACILITIES DATA		
Marginal Demand charge	$8.50	/kW-mo
Marginal Energy charge	$0.03841	/kWh
Labor rate	$32	/hr
Relamping labor	0.167	hr/lamp
Occ Sensor Installation labor	1.0	hr/sensor

For each bulb replacement, the LED replacement was chosen based on the lowest wattage required to meet the area's recommended lighting levels, as noted in the Appendix. Ceiling mounted sensors are recommended in large open areas, and wall mounted sensors near the door are recommended for all smaller areas, as well as at each hallway door in order to trigger lights as soon as any door opens. The occupancy sensor costs for ceiling and wall mounted sensors are based off estimates from facilities management personnel.

Lighting energy and cost savings calculations were done separately for each area and each type of bulb replacement due to varying input parameters on occupancy, required sensors, and required lighting levels for each area. Below is the process used for the lighting energy and cost savings of switching from 4ft-FT8s to LED T8s with sensors in **classrooms**. The same process was repeated for all other areas, as well as for 2' T8s and CFLs.

CURRENT LIGHTING DATA		
Light Type	4' 28 W T8	
Number of Fixtures	245	fixtures
Number of Lamps	603	lamps
% Area That Have Sensors	5%	
% Time On Without Sensors	40%	
% Time On with Sensors	35%	
PROPOSED LIGHTING DATA		
Lamp Type	1 Tube 15-W LED	
Type of Sensor	Ceiling Mounted	
# Rooms to have a sensor	20	rooms
Sensors per Room	2	sensors/room
% Fixtures Controlled by Sensor	100%	
Demand Saving Months	12	mo/yr
Occupancy Sensor Cost	$50	/sensor

REBATES DATA		
Rebate Company	DP&L	
Light Rebate Type	Re-lamping	$/foot
Light Rebate Value	$4	4ft Lamp
Control Rebate Type	$/Connected Watt	
Control Rebate Value	$0.04	/Connected Watt
Maximum Rebate Type	No Cap	-

These lamp specifications and costs are based off 12W and 15W supplier specifications at 1000bulbs.com. All bulb specifications are included in the Appendix.

FIXTURE DATA				
	Present		Proposed	
Fixture Type	1 Lamp 28 W T8	-	1 Lamp 15 W LED T8	-
Number of Lamps	1	lamps	1	lamps
Lamp Power	28	W/lamp	15.0	W/lamp
Lamp Output	2,600	lumens/lamp	2,100	lumens/lamp
Lamp Life	40,000	hours	50,000	hours
Lamp CRI	0.85	-	0.83	-
Ballast Factor, BF	0.89	-	1.00	-
Lumen Degradation Factor, LDF**	0.93	-	0.85	-
Lamp Cost	$3.0	/lamp	$8.3	/lamp

**Lumen Degradation Factor = lumen output at lamp half-life/initial lumen output

Energy use, energy costs, CO_2 emissions, re-lamping costs and total operating costs for the existing fluorescent fixtures and the proposed LED fixtures with sensors are shown in the following table.

CALCULATIONS				
LIGHTING LEVELS				
	Present		Proposed	
Number of Lamps	603	lamps	603	lamps
Lighting Levels	30	fc	25	fc
ANNUAL ELECTRICITY COSTS				
	Present		Proposed	
Electrical Demand	15.0	kW	9.0	kW
Electrical Consumption	52,325	kWh/year	27,732	kWh/year
Electrical Demand Cost	$1,533	/year	$923	/year
Electrical Consumption Cost	$2,010	/year	$1,065	/year
Total Electricity Cost	$3,543	/year	$1,988	/year
ADDITIONAL ANNUAL COSTS				
	Present		Proposed	
Relamping Material Cost	$157	/year	$305	/year
Relamping Labor Cost	$210	/year	$148	/year
Total Relamping Cost	$367	/year	$453	/year
TOTAL OPERATING COST				
	Present		Proposed	
Total Operating Cost	**$3,910**	/year	**$2,441**	

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RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**6.0**	kW
Electrical Consumption	**24,593**	kWh/year
CO_2 Emissions	**17**	tonnes/year
Electrical Demand Cost	**$610**	/year
Electrical Consumption Cost	**$945**	/year
Total Electricity Cost	**$1,555**	/year
ADDITIONAL ANNUAL COST SAVINGS		
Relamping Material Cost	-$148	/year
Relamping Labor Cost	$62	/year
Total Relamping Cost	**-$86**	/year
TOTAL OPERATING COST SAVINGS		
Total Operating Cost Savings	**$1,469**	/year

Economics

The cumulative economic viability for **all lighting recommendations** in this building are shown in the following table. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS	
IMPLEMENTATION COST	
Implementation Material Cost	$29,062
Implementation Labor Cost	$17,727
Rebate	$12,764
Total Implementation Cost	**$34,025**
INVESTMENT METRICS	
Simple Payback (yrs)	**2.6**
Net Present Value	**$67,840**
10 Year Internal Rate of Return	**37%**
Assumed Discount Rate	5%

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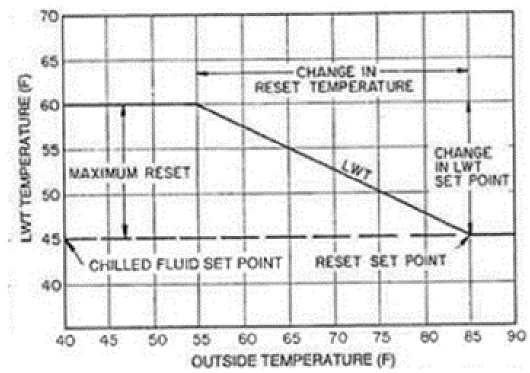
Miriam CER 2: Improve Chilled Water Temperature Control

Implementation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$1,000	$1,040	$2,040	85,526	0	61	$3,284	7 months	$23,320	161%

Analysis

One water-cooled chiller in Miriam Hall generates chilled water for space cooling. Currently the chillers are set to cool a closed-loop water system to a set-point of 42 F. During our investigation there appeared to be a form of chilled water reset control in Metasys already, but it is not aggressive enough to achieve any noticeable energy savings. By controlling the chilled water temperature to increase when it is cold outside and lower when it is warmer outside, the chillers will allow them to operate more efficiently.



Recommendation

We recommend changing implementing a control strategy which changes the set-point of chilled water in the building based on the outdoor air temperature. This can be done through the facility's building automation system (Metasys) or through Carrier HVAC technicians installing the controls in the built in chiller control system.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of chillers in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in water-cooled chiller efficiency based on estimates found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT SYSTEM INFORMATION		
Chiller Rated Capacity (RC)	460	tons
Chiller Rated kW/ton (eta)	0.634	kW/ton
LCWT at Rated kW/ton (R_LCWT)*	45.0	F
Current Chilled Water Setpoint (CW_T_setpoint)	42.0	F
Current Condeser Water Setpoint (TW_T_setpoint)*	75.0	F
Cooling Slope (CS)	2.90	kWh/F-hr
Cooling Balance Temperature (Tbal)	36.1	F
*Engineering Assumption		

PROPOSED SYSTEM INFORMATION		
Maximum Temperature Reset (Tmax)	60	F
Outdoor Air Temperature at Maximum Reset (ToaMax)	60	F
Minimum Temperature Reset (Tmin)	45	F
Outdoor Air Temperature at Minimum Reset (ToaMin)	85	F

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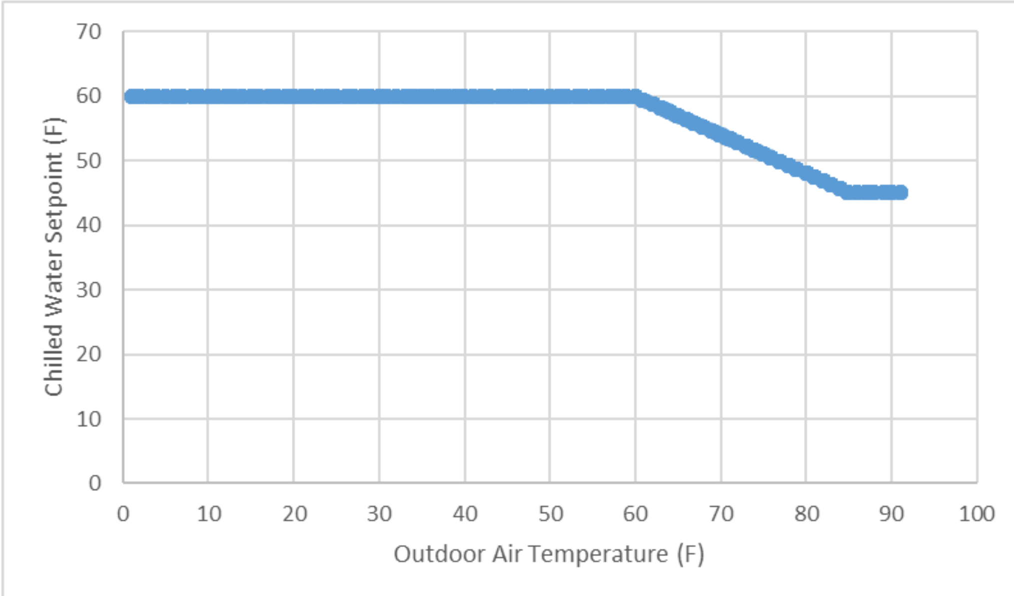

CALCULATIONS			
PARAMETER	**EQUATION**	**VALUE**	**UNITS**
Chilled Water Reset Curve Slope (Rslope)	=(Tmax-Tmin)/(ToaMin-ToaMax)	-0.6	F/F
Chilled Water Reset Curve Intercept (Rint)	=Tmax-Rslope*ToaMax	60	F
	HOURLY EQUATION		**UNITS**
Current Building Energy Use (CCEU)	=CS*(Toa-Tbal)$^{+}$		kWh
Building Load (BL)	=CCEU/eta		tons
Chiller % Load (CL)	=BL/RC		%
Standard Chiller Efficiency (eta_S)	=0.57341 - 1.2023*CL + 0.79481*CL^2 + 0.0051964*TW_T_setpoint + 0.000022926*TW_T_setpoint^2 - 0.000805732*TW_T_setpoint*CL		kW/ton
Current Chiller Efficiency (eta_C)	=eta_S+0.015*eta_S*(RLCWT-CW_T_setpoint)		kW/ton
Proposed Chilled Water Setpoint (P_setpoint)	=IF(Toa<ToaMax, Tmax, IF(Toa>ToaMin, Tmin, Rslope*Toa + Rint))		F
Proposed Chiller Efficiency (eta_P)	=eta_S+0.015*eta_S*(RLCWT-P_setpoint)		kW/ton
Proposed Chiller Energy Use (PCEU)	=CCEU*eta_C/eta_P		kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Proposed Annual Electricity Savings (Se)	ΣC_CCEU-ΣP_PCEU	79,783	kWh/year
Proposed Annual Cost Savings (Sc)	Se*Ecost	$3,064	/year

Implementation Cost, Simple Payback, and Internal Rate of Return

We estimate the changes to the controls would take two Chiller Technicians, paid $65/hour, about 8 hours to complete in the Chiller Control System with another $2,000 in parts and sensors. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$2,000	-
Labor Cost	$1,040	-
Total Implementation Cost	**$3,040**	-
COST SAVINGS		
Energy	$3,064	/year
Demand	$0	/year
Total	$3,064	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$20,617	
IRR	101%	
Simple Payback	11.9	months

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Miriam CER 3: Implement thermostat controls in Metasys during unoccupied hours

Breakdown by Equipment	Implemenation Cost		Annual Savings					Economics		
	Material	Labor	Electric (kWh)	Demand (kW)	Nat Gas (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
Steam Boiler	$0	$1,800		-	231	12	$1,450	N/A		
Chiller			19,416	-		14	$746	N/A		
AHUs			15,311	-		11	$588	N/A		
Total	$1,800		34,727	-	231	37	$2,783	8 months	$19,691	155%

Analysis

Miriam Hall has areas that are unoccupied during a significant number of hours each evening throughout the year. During these unoccupied hours, the thermostats can be programmed to reduce their set-point during the winter months, and increase the set-point during summer months. This will decrease heating loads during winter months, and decrease cooling loads during summer months. A lower temperature difference between the inside and outside air results in reduced heat transfer and infiltration losses. Although it requires some additional energy to reheat the plant in the morning, it is significantly less than the energy saved by reducing the temperature during un-occupied hours.

Item	Value	Description
OCC-SCHEDULE	Not Set	Occupancy Schedule Command
OCC-MODE	Occupied	Occupancy Mode Status
EFF-OCC	Occupied	Effective Occupancy
SYSTEM-MODE	Auto	System Mode Status
ZN-T	71.8 deg F	Zone Temperature
ZN-SP	70.6 deg F	Zone Temperature Setpoint
CLGOCC-SP	72.0 deg F	Cooling Occupied Setpoint
CLGUNOCC-SP	82.0 deg F	Cooling Unoccupied Setpoint
HTGOCC-SP	70.0 deg F	Heating Occupied Setpoint
HTGUNOCC-SP	61.0 deg F	Heating Unoccupied Setpoint

Example Metasys Zone Temperature Setback Controls

Recommendation

We recommend utilizing UD's Metasys system to control the thermostats in all areas except floors 4-7, as those AHUs are already scheduled to turn off, to reduce set-points from 70F to 60F during closed hours of heating days, and increase its set-point from 72 to 80F during closed hours of cooling days.

Expected Energy, Emissions and Cost Savings

During the school year and summer, classrooms in this building is estimated to be occupied from 7 AM to midnight during the week, 9 AM – 7 PM on weekends, and unoccupied during breaks. Offices are estimated to be occupied 7 AM – 7 PM during school year and summer weekdays, 9 AM – 5 PM on weekends, and 8 AM – 5 PM on weekdays and unoccupied weekends during breaks. Therefore, thermostat setbacks can occur during the hours that areas are not occupied. The setbacks should not include finals week in the Spring and Fall semester.

Classrooms						
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	0	0	1	0
9:00	1	1	0	0	1	1
10:00	1	1	0	0	1	1
11:00	1	1	0	0	1	1
12:00	1	1	0	0	1	1
13:00	1	1	0	0	1	1
14:00	1	1	0	0	1	1
15:00	1	1	0	0	1	1
16:00	1	1	0	0	1	1
17:00	1	1	0	0	1	1
18:00	1	1	0	0	1	1
19:00	1	1	0	0	1	1
20:00	1	0	0	0	1	1
21:00	1	0	0	0	1	1
22:00	1	0	0	0	0	1
23:00	1	0	0	0	0	0

Offices						
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	1	0	1	0
9:00	1	1	1	0	1	1
10:00	1	1	1	0	1	1
11:00	1	1	1	0	1	1
12:00	1	1	1	0	1	1
13:00	1	1	1	0	1	1
14:00	1	1	1	0	1	1
15:00	1	1	1	0	1	1
16:00	1	1	1	0	1	1
17:00	1	1	1	0	1	1
18:00	1	0	0	0	1	0
19:00	1	0	0	0	1	0
20:00	0	0	0	0	0	0
21:00	0	0	0	0	0	0
22:00	0	0	0	0	0	0
23:00	0	0	0	0	0	0

To calculate savings, the building's heating and cooling baseline information was determined. The thermostat set-points were based off typical campus buildings, as its specific set-points were not found in Metasys. The heating efficiency is assumed to be 70%, factoring in losses going from the main steam plant to heating applications, and its chiller COP is taken from its nameplate. The building's cooling slope and cooling balance temperature was identified in the lean energy analysis from annual electrical bills, as noted in Section 1D. Heating slope was estimated based on the electricity use between Roesch and Miriam, and heating balance temperature is estimated at 55F.

CURRENT BUILDING INFORMATION		
Heating Indoor Temperature Setpoint (Tia_h)	70	F
Cooling Indoor Temperature Setpoint (Tia_c)	72	F
Heating Efficiency (eta_h)	70%	
Cooling Efficiency (eta_c)	5.7	
Building Heating Slope (HS)*	24.3	mmBtu/F-month
Building Heating Balance Temperature (Tbal_h)*	55	F
Building Cooling Slope (CS)	2397	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	35.9	F
% Building Area for Classrooms/Hallways	70%	
% Building Area for Offices	30%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

*Engineering Assumption

The building has eight AHUs, but since two AHUs serve Floors 4-7 and are currently scheduled off during unoccupied hours their savings are not considered for thermostat setbacks. It is assumed that AHU's pressure sensors are fixed, as stated in recommendation 3, so that VFDs operate at ASHRAE standards.

CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Supply Fan Nameplate (NFP)	96	hp
Return Fan Nameplate (RFP)	50	hp
Total AHU Fan Power Rating (HP_all)	146	hp
Total AHU Fan Power Current Scheduled Off (HP_offnow)	57	hp
Scheduled Start Time Off (Sch_time1)	19	:00
Scheduled End Time Off (Sch_time2)	7	:00
Fraction Loaded @100% (FL)*	80%	
Minimum damper position (VAVpercent_open)	30%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

*Engineering Assumption

The proposed setback temperatures are indicated below, while only for 50% of the building since Floors 4-7 are not included. It is also recommended to set the minimum damper positions from 30% to 5% in Metasys in order to see all potential savings.

PROPOSED INFORMATION		
% Building Area to get Therm Setbacks	50%	
Heating Setback Temperature (Tsetbk_h)	60	F
Cooling Setback Temperature (Tsetbk_c)	80	F
AHU Fan Power for Therm Setback (HP_therm)	84	hp
New AHU Fan Power to Schedule Off (HP_off-new)	5	hp
Total AHU Fan Power to Schedule Off (HP_off-Prop)	62	hp
Minimum damper position (VAVperc_open_prop)	5%	

The new balance temperatures during closed hours is calculated below, and used to calculate proposed heating and cooling energy. Reduced heating and cooling corresponds to reduced AHU energy.

CALCULATIONS			
PARAMETER	**EQUATION**	**Results**	
Building UA (UA)	(HS/30.4/24*10^6*eta_h+CS/30.4/24*3412*eta_c)/2	43,582	Btu/hr-F
Internal Load (IL_h)	UA*(Tia_h-Tbal_h)	653,735	Btu/hr
Internal Load (IL_c)	UA*(Tia_c-Tbal_c)	1,573,322	Btu/hr
Heating Setback Balance Temperature (Tbal_setback_h)	Tsetbk_h*perc_setbk+T_iah*(1-perc_setbk)-IL_h/UA	50.0	F
Cooling Setback Balance Temperature (Tbal_setback_c)	Tsetbk_c*perc_setbk+T_iac*(1-perc_setbk)-IL_c/UA	39.9	F
Calculations	**HOURLY EQUATION**	**Annual Totals**	
Current Hourly Heating Energy Use (C_BHE)	HS*(Tbal_h-Toa)$^+$/30.4/24	3,046	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	CS*(Toa-Tbal_c)$^+$/30.4/24	529,396	kWh
Current AHU Energy Use (C_AHU)	FL*(HP_all-HP_offnow)*.746*(A+xB^2+xC^2+xD^3)	216,844	kWh
Proposed Hourly Heating Energy Use (P_BHE)	HS*(Tbal_[none,night,wkend]_h-Toa)$^+$/30.4/24	2,661	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	CS*(Toa-Tbal_[none,night,wkend]_c)$^+$/30.4/24	497,035	kWh
Proposed AHU Energy Usage (P_AHU)	FL*(HP_all-HP_offprop)*.746*(A+xB^2+xC^2+xD^3)	191,326	kWh

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A steady state analysis uses the difference in indoor and outdoor temperature to calculate savings. However, in practice the thermal mass of the building reduced temperature swings. To correct for this, actual savings are assumed to be 60% of steady state savings (Kissock, 2003).

RESULTS			
ENERGY REDUCTION			
Steady State Annual Fuel Savings (SSf)	ΣC_BHE-ΣP_BHE	385	mmBtu/year
Steady State Annual Cooling Electricity Savings (SSe_c)	ΣC_BCE-ΣP_BCE	32,361	kWh/year
Steady State Annual AHU Electricity Savings (SSe_ahu)	ΣC_BCE-ΣP_BCE	25,518	kWh/year
Actual Annual Cooling Savings (ACTe_c)	SSe_c*0.6	19,416	kWh/year
Actual Annual AHU Savings (ACTe_ahu)	SSe_ahu*0.6	15,311	kWh/year
Total Annual Electric Savings (TOTe)	ACTe_c + ACTe_ahu	34,727	/year
Actual Annual Fuel Savings (TOTf)	SSf*0.6	231	mmBtu/year
COST SAVINGS			
Electric (Cost_e)	TOTe*Ecost	$1,334	/year
Natural Gas (Cost_ng)	TOTf*Ngcost	$1,450	/year
Total Savings	Cost_e + Cost_ng	$2,783	/year

Implementation Cost & Investment Metrics

We estimate that it would take 12 hours to program thermostat setbacks in Metasys at a rate of $150 per hour. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0.00	-
Labor Cost	$1,800	-
Total Implementation Cost	$1,800	-
COST SAVINGS		
Electric	$1,334	/year
Natural Gas	$1,450	/year
Total	$2,783	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$19,691	
IRR	155%	
Simple Payback	7.8	months

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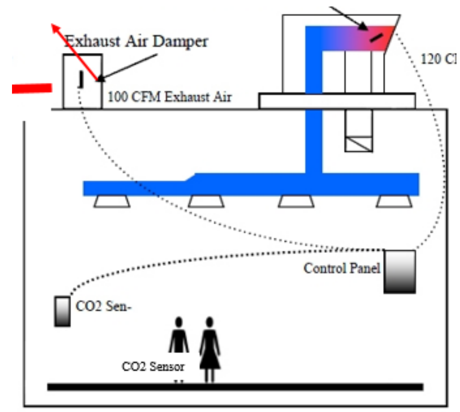
Miriam CER 4: Install Demand Control Ventilation

Implemenation Cost				Annual Savings					Economics		
Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$12,000	$5,680	$2,247	$15,433	22,471	0	847	61	$6,181	2.5 years	$32,294	39%

Analysis

Mechanically ventilated spaces in commercial buildings will set the minimum amount of outdoor air entering a building based upon the ventilation required at full occupancy. However, buildings are frequently only partially occupied. A demand ventilation system works by measuring the amount of carbon dioxide released by the building occupants, so it can maintain indoor air quality while reducing the amount of ventilation air during times of partial occupancy. Miriam Hall operates with a fixed fraction of outdoor ventilation air while not economizing. The building cooling capacity is 329 tons and nameplate 5.7 nameplate COP. The steam system efficiency is estimated to be 70% on average.



Recommendation

We recommend installing a CO2 sensor in the return ductwork to each air handling unit to measure the concentration of CO2 given off by occupants breathing and adjust the amount of ventilation air accordingly. This sensor should be incorporated into the Metasys building automation system for appropriate operation. This greatly reduces the amount of energy required to heat and cool spaces which are not constantly occupied. In schools, occupancy is typically very low during the summer months and allows this system to realize greater savings.

Expected Energy, Emissions and Cost Savings

To quantify the impact of reduced ventilation air, we simulated the energy use for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the amount of ventilation air brought into the school building currently as well as with the proposed CO2 sensor. The estimated occupancy and schedule are shown below as well as the energy calculations.

The cooling and heating temperature set-points are adjusted to include the thermostat setback recommendation to prevent double counting savings when combined with other CERs.

CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)*	53.3	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h)*	53.3	F
Building Cooling Slope (CS)	2,397	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	37.2	F
Heating Efficiency (eta_h)*	70%	
Nameplate Cooling Efficiency (neta_c)	5.7	COP
Average Cooling Efficiency (eta_c)	4.6	COP
Nameplate Total Cooling Capacity (nCap_c)	329	tons

ENGINEERING ASSUMPTIONS		
Sensible Heat Ratio (SHR)*	0.85	
Cooling Supply Air Temperature (SAT_c)*	57	F
Heating Supply Air Temperature (SAT_h)*	68	F
Economizer Low Limit (EconoLL)*	30	F
Economizer High Limit (EconoHL)*	70	F
Minimum Outdoor Air (MinOA)*	15%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

Building hourly occupancy rates are estimated, and AHU scheduling is incorporated to prevent double counting savings from the AHU scheduling or thermostat setbacks recommendation.

Hour of Day	Occupancy	Schedule (on/off)	Hour of Day	Occupancy	Schedule (on/off)
0:00	5%	0	12:00	50%	1
1:00	5%	0	13:00	80%	1
2:00	1%	0	14:00	80%	1
3:00	1%	0	15:00	80%	1
4:00	1%	0	16:00	50%	1
5:00	0%	0	17:00	20%	1
6:00	1%	0	18:00	20%	1
7:00	10%	1	19:00	10%	1
8:00	50%	1	20:00	5%	1
9:00	80%	1	21:00	0%	1
10:00	80%	1	22:00	0%	1
11:00	80%	1	23:00	0%	1

The building's hourly loads are calculated from the heating and cooling slopes found in the Lean Energy Analysis section. Savings from demand ventilation only occurs when the building is set to bring in the minimum amount of outdoor air. Therefore, the hours in the year corresponding to economizer operation are excluded. The current outdoor airflow is calculated based on the general HVAC design rule that a building should move 400 cfm of air per ton of cooling provided at design conditions. The minimum amount of outdoor air is expressed in HVAC designs is based on this value. In our calculation we propose reducing the amount of ventilation based on the estimated occupancy for each hour.

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This calculation does not consider the significantly lower summer occupancy and therefore represents a conservative estimate of cooling savings.

CALCULATIONS		
PARAMETER	**EQUATION**	**UNITS**
Hourly Building Heating Energy (BHE)	HS*(Tbal_h-Toa)$^+$/30.4/24	mmBtu
Hourly Building Cooling Energy (BCE)	CS*(Toa-Tbal_c)$^+$/30.4/24	kWh
Economizer Mode (EconoM)	IF(EconoHL>Toa>EconoLL,1,0)	0,1
Hourly Building Heating Load (BHL)	BHE/(HS*(Tbal_h-Tdesign_h)/30.4/24)	%
Hourly Building Cooling Load (BCL)	BCE/(CS*(Tdesign_c-Tbal_c)/30.4/24)	%
Current Outdoor Airflow (COA)	IF(Schedule=ON,MAX(BHL,CHL)*400*Cap_c*MinOA,0)	cfm
Current Hourly Heating Energy Use (C_BHE)	IF(Toa<Tbal_h,1.08*COA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	IF(Toa>SAT_c,1.08*COA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh
Proposed Outdoor Airflow (POA)	IF(EconoM=1,COA,COA*Occupancy)	cfm
Proposed Hourly Heating Energy Use (P_BHE)	IF(Toa<Tbal_h,1.08*POA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	IF(Toa>SAT_c,1.08*POA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh

RESULTS			
ENERGY REDUCTION			
Proposed Annual Fuel Savings (Sf)	ΣC_BHE-ΣP_BHE	847	mmBtu/yr
Proposed Annual Electricity Savings (Se)	ΣC_BCE-ΣP_BCE	22,471	kWh/yr
COST SAVINGS			
Electric (Cost_e)	Sf*Ngcost	$863	/year
Natural Gas (Cost_ng)	Se*Ecost	$5,318	/year
Total Savings	Cost_e + Cost_ng	$6,181	/year

Implementation Cost & Investment Metrics

We estimate that it would cost $1,500 per CO2 sensor for each AHU. It is also estimated to take 24 hours to program in Metasys (3 hours per sensor) at $150 per hour, and take two technicians, at $65 per hour, 4 hours to install each CO2 sensor per AHU. It has also been confirmed by DP&L that this would fall under a custom rebate, at $0.10/kWh saved, up to 50% of the total installed cost. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$12,000	-
Labor Cost	$5,680	-
Rebate	$2,247	-
Total Implementation Cost	$15,433	-
COST SAVINGS		
Energy	$6,181	/year
Demand	$0	/year
Total	$6,181	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$32,294	
IRR	39%	
Simple Payback	2.5	years

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Miriam CER 5: Relocate VFD Static Pressure Sensors on Supply Fans

Implementation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$1,400	$3,640	$5,040	100,913	0	71	$3,875	1.3 years	$24,882	77%

Analysis

Seven of eight AHU supply air fans in Miriam Hall are currently controlled by a static pressure sensor in the ductwork tied to a variable frequency drive (VFD) on the fan. At the time of the site visit, the VFDs were running at high speed in very mild weather. The static pressure sensors on the supply fans were also noted at the outlet of the supply fan in each AHU. This location for the static pressure sensor makes for simple installation. However, it requires a higher pressure set-point than if the sensor were in a remote location, thus limiting the potential energy savings from the VFD.

Static Pressure Sensor on Miriam AHU

Recommendation

We recommend reinstalling the static pressure sensors on each of the 7 AHU supply fans to a remote location 2/3 of the distance through the ductwork in accordance with industry best practice.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of supply fans in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in fan power required based on regression data from ASHRAE as well as performance equations found the Energy Efficiency Guidebook (Kissock, 2003). Heating slope was estimated based on the electricity use between Roesch and Miriam, and heating balance temperature is estimated at 55F.

CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)*	24.3	mmBtu/F-month
Building Heating Balance Temperature (Tbal_h)*	53.3	F
Building Cooling Slope (CS)	2397	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	37.2	F
Heating Design Temperature (Tdesign_h)	0	F
Cooling Design Temperature (Tdesign_c)	95	F

*Engineering Assumption

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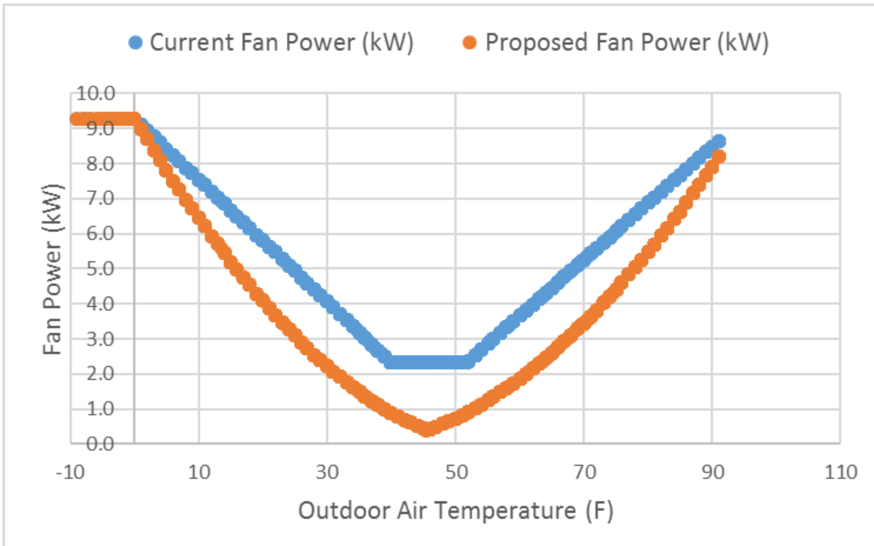
CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Total AHU Fan Power Rating (HP_all)	14	hp
Number of AHUs w/ supply VFDs (N_AHU)	7	
Fraction Loaded @100% (FL)*	80%	
Minimum damper position (VAVpercent_open)	25%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

*Engineering Assumption



CALCULATIONS			
PARAMETER	**HOURLY EQUATION**	**ANNUAL TOTALS**	
Current Hourly Heating Energy Use (C_BHE)	HS*(Tbal_h-Toa)+/30.4/24	2,794	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	CS*(Toa-Tbal_c)+/30.4/24	501,210	kWh
Building % Cooling Load (BFCL)	CCE/(CS*(Tdesign_c-Tbal_c)+/30.4/24)	30%	
Building % Heating Load (BFHL)	CHE/(HS*(Tbal_h-Tdesign_h)+/30.4/24)	18%	
Current AHU Energy Use (C_AHU)	FL*HP_all*MAX(BFCL,BFHL)/eta_m	230,857	kWh
Proposed AHU Energy Usage (P_AHU)	FL*HP_all*.746*(A+xB^2+xC^2+xD^3)	139,666	kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Annual AHU Savings (AHU_sav)	ΣCFP-ΣPFP	100,913	kWh/year
Electric Savings	AHU_sav*Ecost	$3,875	/year

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Implementation Cost & Investment Metrics

We estimate the changes to the controls would take two technicians, paid $65/hour, about 4 hours to completely reinstall each of the 7 sensors, with another $200 in cables and other distance infrastructure per sensor. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$1,400	-
Labor Cost	$3,640	-
Rebate	$0	-
Total Implementation Cost	$5,040	-
COST SAVINGS		
Energy	$3,875	/year
Demand	$0	/year
Total	$3,875	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$24,882	
IRR	77%	
Simple Payback	1.3	years

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Miriam CER 6: Install Primary Chiller Pump & Eliminate Bypass Chilled Water Pumping

Implemenation Cost				Annual Savings				Economics		
Material	Labor/ Overhead	Rebate	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$8,523	$4,054	$1,313	$11,265	81,228	0	57	$3,120	3.6 years	$12,827	25%

Analysis

Miriam CW Valves

The pumps which circulate chilled water through Miriam Hall were found to run at constant speed with 3-way bypass chilled water valves on each of the 8 AHUs. In this configuration, the chilled water pumps will run at full speed anytime chilled water is required. Significant energy savings can be realized by eliminating a bypass chilled water in favor of a variable speed chilled water system that has both primary and secondary chilled water pumps.

Recommendation

We recommend removing all 3-way bypass chilled water valves and piping and replacing them with 2-way control valves. Additionally, we recommend installing a variable frequency drive on the current 30-hp chilled water distribution pumps and installing a 7.5-hp primary chilled water pump to maintain adequate circulation through the chiller.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of chilled water pumps in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in pump power required based on regression data from ASHRAE as well as performance equations found the Energy Efficiency Guidebook (Kissock, 2003).

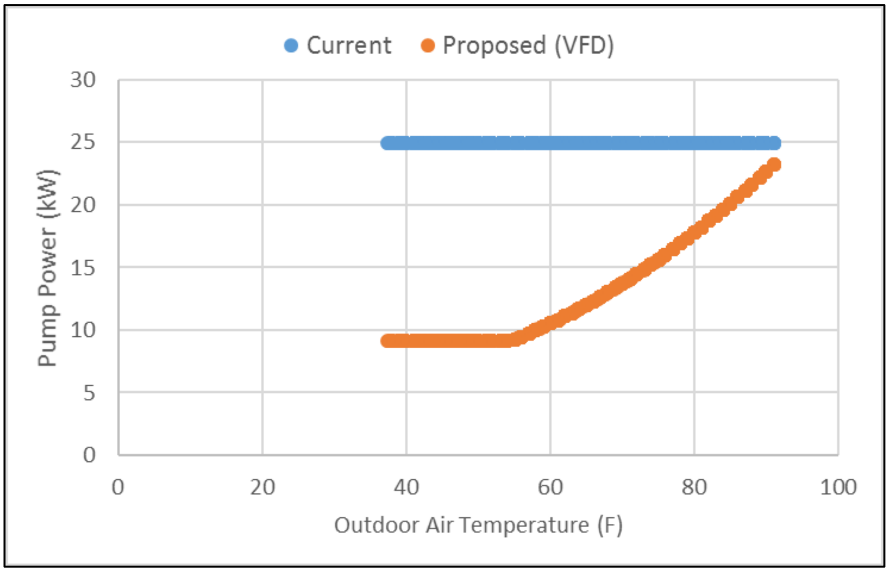
CURRENT BUILDING INFORMATION		
Building Cooling Slope (CS)	2,397	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	37.2	F
Cooling Design Temperature (Tdesign_c)	95	F

CURRENT PUMP INFORMATION		
Pump Motor Efficiency (eta_m)*	90%	
Supply Pump Nameplate (NFP)	30	hp
Fraction Loaded @100% (FL)*	75%	

PROPOSED INFORMATION		
Chilled Water Primary Pump Nameplate	7.5	hp
Chilled Water Secondary Pump Nameplate	30	hp
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

*Engineering Assumption

Utilizing the 30-hp pump as the secondary pump, pumping chilled water throughout the building, enables a VFD to reduce its energy usage based on the outdoor air temperature and corresponding cooling energy, as shown below.



CALCULATIONS			
PARAMETER	HOURLY EQUATION	ANNUAL TOTALS	
Current Hourly Cooling Energy Use (C_BCE)	CS*(Toa-Tbal_c)+/30.4/24	501,120	kWh
Building % Cooling Load (BFCL)	CCE/(CS*(Tdesign_c-Tbal_c)+/30.4/24)	30%	
Current Pump Energy Use (C_pump)	FL*NFP/eta_m	159,275	kWh
Proposed Pump Energy Usage (P_pump)	FL*NFP*.746*(A+xB^2+xC^2+xD^3)/eta_m	78,047	kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Annual AHU Savings (AHU_sav)	ΣCFP-ΣPFP	81,228	kWh/year
Electric Savings	AHU_sav*Ecost	$3,120	/year

Implementation Cost & Investment Metrics

Based on mechanical cost data from RS Means 2012, the VFD installation would cost $6,100, the primary chilled water pump would cost $5,365, and the replacement of control valves would cost $1,112. DP&L also offers rebates of $15/HP for premium efficiency pumps, and $40/HP for VFDs. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

IMPLEMENTATION COST BREAKDOWN					
	VFD (30-HP)	Pump (7.5-HP)	Control Valves $/Valve	Control Valves Valves	Total
Material	$3,850	$4,125	68.5	8	$8,523
Labor	$1,250	$490	40.5	8	$2,064
Overhead	$1,000	$750	30	8	$1,990
Rebate	$1,200	$113	-	-	$1,313

(RS Means Mechanical Cost Data, 2012)

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$8,523	-
Labor Cost	$4,054	-
Rebate	$1,313	-
Total Implementation Cost	$11,265	-
COST SAVINGS		
Energy	$3,120	/year
Demand	$0	/year
Total	$3,120	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$12,827	
IRR	25%	
Simple Payback	3.6	years

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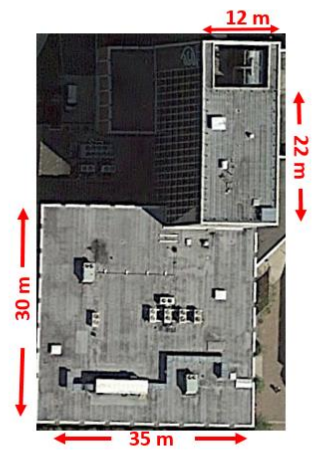
Miriam CER 7: Install 75 kW Rooftop Solar PV System

Implementation Cost			Annual Savings				Economics		
Capex	ITC	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback (years)	25 year NPV	25 year IRR
$131,250	$0	$131,250	99,060	13	70	$5,146	25.5	-$58,716	0%

Analysis



Rooftop Area

Miriam has an upper rooftop area of around 300 square meters, while the 2nd Floor roof has an area of around 1,050 square meters. Some of this area sees ample sunlight throughout the year. Parts of the roof's area is unobstructed from equipment or shade of nearby objects can be utilized for energy generation by installing solar PV panels.

Recommendation

We recommend installing a 75kW-DC solar PV array split between the 2nd floor and top floor rooftop.

Expected Energy, Emissions and Cost Savings

The total area unobstructed from equipment or shade of nearby objects, mainly the south half of the top roof, and south part of the 2nd floor roof, was determined to be around 800 m2. After factoring in spacing from arrays tilted at 30 degrees, it was determined that a total area of around 380 m2 could be utilized for solar PV. Assuming a system with generic 330 W, 1.67 m2 solar panels, this would be around 75 kW-DC. However, once inverter losses of 2.5% converting from DC to AC, and 10% losses from other factors such as soiling, mismatch, light-induced degradation, and partial shading are taken into account, the AC capacity would be around 66 kW (NREL, 2014).


Rooftop Area with solar PV

To quantify the potential energy generation from the 75- kW solar PV aray, the annual solar radiation was determined by using NASA average daily horizontal radiation for each month for Dayton Ohio, downloaded from https://eosweb.larc.nasa.gov/sse/RETScreen/. This yields annual solar radiation of 1384 kWh/m2 for a horizontal surface, and after calculating increases from tilting the panels 30 degrees south, 1534 kWh/m2. This results in a DC capacity factor of 17.5%.

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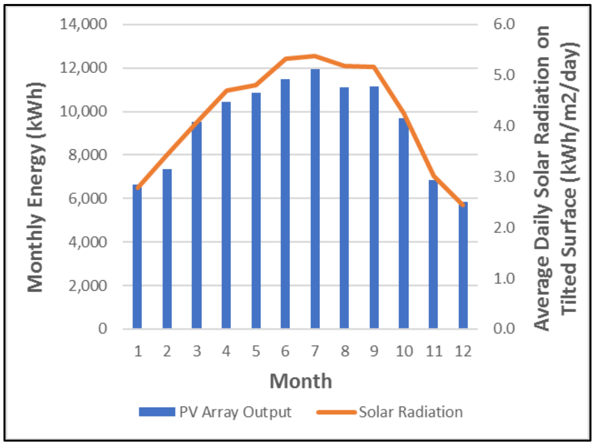

The system's annual generation can then be determined by multiplying the capacity factor by its AC capacity. Monthly demand savings are assumed to be 20% of the solar system's AC capacity. The corresponding cost savings are based on the marginal costs of energy and demand.

RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**13.2**	kW
Electrical Consumption	**99,060**	kWh/year
Electrical Demand Cost	**$1,343**	/year
Electrical Consumption Cost	**$3,804**	/year
Total Electricity Cost	**$5,146**	/year

Implementation Cost & Investment Metrics

The total cost is based on an assumption of $1.75/W-DC, assuming all solar PV recommendations is this report are done in tandem for a total system rate closer to 500 kW. The investment tax credit is not applicable to UD, as they are exempt from federal taxes under 501(c)(3). However, depending on the outcome of Congress' 2017 bill to tax endowment income, this may change.

ECONOMICS		
IMPLEMENTATION COST		
Total Cost	$131,250	-
Rebate	$0	-
Total Implementation	**$131,250**	-
COST SAVINGS		
Energy	$3,804	/year
Demand	$1,343	/year
Total	$5,146	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	($58,716)	
IRR	0%	
Simple Payback	25.5	years

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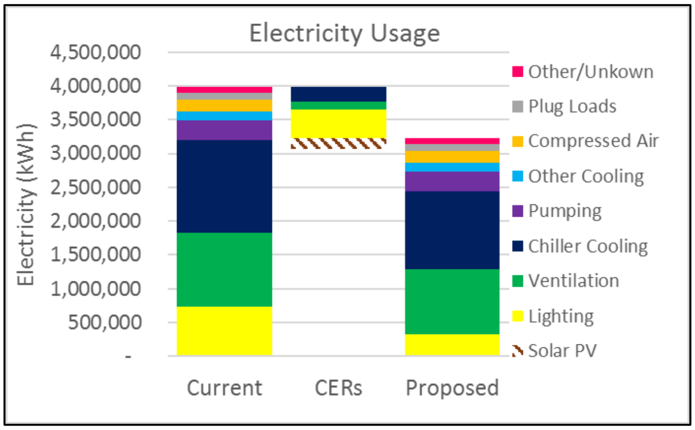
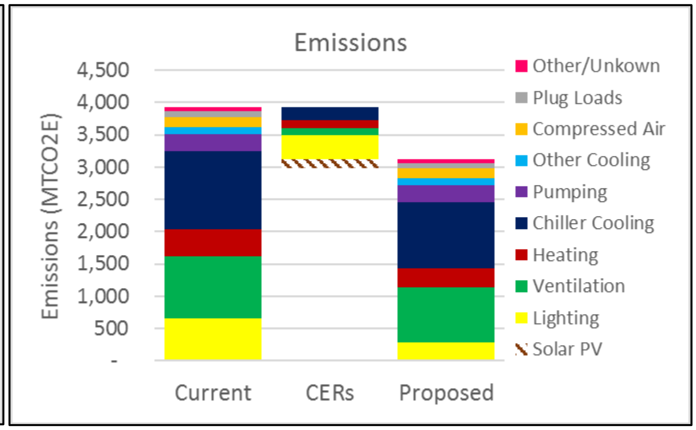
KETTERING LABS

Summary

A total of 6 clean energy recommendations for Kettering Labs are estimated to reduce electricity by 23% and natural gas by 31%. This is equivalent to reducing emissions by 24%, or 952 metric tons of CO2. These recommendations have a total simple payback of 4.7 years, and 10-year NPV of $245,399 with an 18% IRR.





	CLEAN ENERGY RECOMMENDATIONS	Annual Savings				Project Cost	Simple Payback (years)	NPV	IRR
		kWh	mmBTU	$MTCO_2$	$				
Lighting									
1	Replace all 4' & 2' FT8s & CFLs to LEDs with occ sensors	412,128		364	$25,035	$53,414	2.1	$139,898	46%
	Lighting Reduction	56%							
Building Cooling									
2	Reset chiller set point based on outdoor air temp.	124,801		110	$4,792	$4,080	0.9	$32,925	117%
3	Schedule AHUs and setback thermostats during unoccupied hours	36,687		32	$1,409	$2,400	0.3	$62,038	348%
4	Install Demand Control Ventilation	58,032		51	$2,228	$12,892	0.8	$108,691	174%
	Cooling Reduction	16%							
Building Heating									
3	Schedule AHUs and setback thermostats during unoccupied hours		339	18	$2,126	-*	-*	-*	-*
4	Install Demand Control Ventilation		2,068	110	$12,966	-*	-*	-*	-*
	Heating Reduction		31%						
Ventilation									
3	Schedule AHUs and setback thermostats during unoccupied hours	125,267		111	$4,810	-*	-*	-*	-*
	Ventilation Reduction	11%							
Compressed Air									
5	Reduce Compressed Air Setpoint from 120 to 100 psi	10,427		9	$522	$64	0.1	$3,028	626%
	Compressed Air Reduction	6%							
Renewable Energy									
6	Install 125 kW Rooftop Solar PV	165,100		146	$8,577	$218,750	26	-$97,859	0%
	Reduction in Building Energy/Emissions	4%		4%					
	Kettering Labs Clean Energy Recommendations Total	**932,442**	**2,407**	**952**	**$62,466**	**$291,600**	**4.7**	**$245,399**	**18%**
	Kettering Labs Energy & Emissions % Reduction Total	**23%**	**31%**	**24%**					

* Not applicable since CERs energy savings are broken down by equipment. Total costs and economics for these CERS are included under cooling savings

KL CER 1: Replace all 4ft-FT8, 2ft-FT8, & 2-pin CFLs with LEDs with occ. sensors

Bulb Type & Lighting Area		Implementation Cost				Annual Energy Savings		Annual Cost Savings				Simple Payback (years)
		Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Energy	Demand	Re-lamping	Total	
4ft-T8	Classrooms	$38,579	$4,012	$17,338	$25,253	153,453	37.9	$5,894	$3,869	-$560	$9,204	2.7
	Hallways / Stairwells	$4,313	$3,735	$2,645	$5,403	96,488	12.6	$3,706	$1,284	$228	$5,217	1.0
	Offices	$13,711	$12,451	$9,566	$16,595	85,554	26.2	$3,286	$2,671	$111	$6,068	2.7
	Mech Rooms / Storage	$942	$864	$662	$1,144	24,554	1.4	$943	$142	$203	$1,288	0.9
	Bathrooms	$1,708	$1,643	$1,008	$2,343	31,706	2.7	$1,218	$277	$107	$1,602	1.5
2'T8	Hallways / Stairwells	$69	$59	$24	$104	464	0.1	$18	$6	$1	$25	4.2
	Classrooms	$1,296	$36	$942	$390	5,207	1.3	$200	$131	$10	$341	1.1
	Bathrooms	$72	$64	$28	$108	931	0.1	$36	$7	$25	$68	1.6
CFL	Hallways / Stairwells	$1,025	$562	$299	$1,287	8,883	1.2	$341	$118	$288	$747	1.7
	Offices	$440	$235	$150	$525	1,786	0.6	$69	$58	$59	$185	2.8
	Bathrooms	$220	$117	$75	$263	3,102	0.3	$119	$29	$141	$289	0.9
	Total	**$ 62,374**	**$ 23,778**	**$ 32,737**	**$ 53,414**	**412,128**	**84**	**$15,830**	**$8,592**	**$613**	**$25,035**	**2.1**

Analysis

During our walk-through, our team counted a total of 7,191 4ft-T8 fluorescent lamps, 246 2ft-T8 fluorescent lamps, 158 CFLs, and 48 LEDs. For 4ft-T8s, 842 were in open areas, hallways, and stairwells, 3,824 in study rooms or classrooms, 2,157 in offices, 144 in mechanical rooms, and 224 in bathrooms. During the walk through, some of the lamps were identified as 32W and some 25 W, so their average is estimated to be 28W. All 2-ft-T8s and CFLs are estimated to be 17W and 26W respectively. One week of light logger data indicated that during the school year classroom lights are on 40% of the time, office lights 33%, hallways 85%, mechanical rooms 81%, and bathrooms 100%.

4ft T8 Lamps in Classrooms

Fluorescent T8s lamps can be directly replaced with direct-wire LED tubes after removing the ballast. LEDS offer several advantages, such as consuming around 50% less energy, a longer rated lifespan, and are directional, meaning that more of the light emitted from the lamp illuminates the work plane. They are also better suited for lighting control systems.

A few lighting control systems were identified during our walk-through, specifically in 11% of classrooms, 13% of offices, and 90% of hallways/stairwells. Occupancy sensors can provide energy savings by turning lights off when the area is unoccupied.

Recommendation

We recommend **replacing all 7,191 4ft-FT8 bulbs** and ballasts and installing **877 LED 12.5-W** tubes in hallways, stairwells, and bathrooms, and installing **6,125 LED 15-W** tubes in classrooms, offices, and mechanical rooms. We also recommend **replacing all 246 2ft-T8s** with **9W high lumen T8 LEDS** and **all 158 2-pin CFLs** with **10W high lumen 2-pin** LEDs in order to satisfy the required lighting levels.

We also recommend installing **ceiling occupancy sensors** in all hallways, open areas, and large classrooms, and installing **wall mounted occupancy sensors** at the doors of office rooms, bathrooms, mechanical rooms, and at each

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hallway door. The recommended time delay settings are 10 minutes for hallways, stairwells, and bathrooms, 15 minutes for classrooms and offices, and 1 hour in mechanical rooms.

Expected Energy, Emissions and Cost Savings

We estimate that retrofitting a 4ft-F8, 2ft-FT8, or CFL with a LED direct-wire tube and removing the ballast would take about 10 minutes per lamp. Installing a ceiling sensor is estimated to take 1 hour and a wall sensor 30 minutes. According to facilities management, the in-house labor rate is $32 per hour.

FACILITY DATA	
Marginal Demand charge	$8.50 /kW-mo
CO_2 emission factor	1.56 lb-CO_2/kWh
Energy Inflation Rate	3.3% -
Labor rate	$32 /hr
Relamping labor	0.17 hr/lamp
Occupancy Sensor Installation labor	1 hr/sensor

For each bulb replacement, the LED replacement was chosen based on the lowest wattage required to meet the area's recommended lighting levels, as noted in the Appendix. Ceiling mounted sensors are recommended in large open areas, and wall mounted sensors near the door are recommended for all smaller areas, as well as at each hallway door in order to trigger lights as soon as any door opens. The occupancy sensor costs for ceiling and wall mounted sensors are based off estimates from facilities management personnel.

Lighting energy and cost savings calculations were done separately for each area and each type of blub replacement due to varying input parameters on occupancy, required sensors, and required lighting levels for each area. Below is the process used for the lighting energy and cost savings of switching from 4ft-FT8s with sensors in classrooms. The same process was repeated for all other areas, and 2' T8s and CFLs replacements.

CURRENT LIGHTING DATA		
Light Type	4' 28 W T8	
Number of Fixtures	1,187	fixtures
Number of Lamps	3,824	lamps
% Area That Have Sensors	11%	
% Time On Without Sensors	40%	
% Time On with Sensors	35%	
PROPOSED LIGHTING DATA		
Lamp Type	1 Tube 15-W LED	
Type of Sensor	Ceiling Mounted	
# Rooms to have a sensor	79	rooms
Sensors per Room	2	sensors/room
% Fixtures Controlled by Sensor	100%	
Demand Saving Months	12	mo/yr
Occupancy Sensor Cost	$50	/sensor

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REBATES DATA		
Rebate Company	DP&L	
Light Rebate Type	Re-lamping	$/foot
Light Rebate Value	$4	4ft Lamp
Control Rebate Type	$/Connected Watt	
Control Rebate Value	$0.04	/Connected Watt
Maximum Rebate Type	No Cap	-

These lamp specifications and costs are based off 12W and 15W supplier specifications at 1000bulbs.com, specifics also included in the Appendix.

FIXTURE DATA				
	Present		Proposed	
Fixture Type	1 Lamp 28 W T8	-	1 Lamp 15 W LED T8	-
Number of Lamps	1	lamps	1	lamps
Lamp Power	28	W/lamp	15.0	W/lamp
Lamp Output	2,600	lumens/lamp	2,100	lumens/lamp
Lamp Life	40,000	hours	50,000	hours
Lamp CRI	0.85	-	0.83	-
Ballast Factor, BF	0.89	-	1.00	-
Lumen Degradation Factor, LDF**	0.93	-	0.85	-
Lamp Cost	$3.0	/lamp	$8.3	/lamp
**Lumen Degradation Factor = lumen output at lamp half-life/initial lumen output				

Energy use, energy costs, CO_2 emissions, re-lamping costs and total operating costs for the existing fluorescent fixtures and the proposed LED fixtures with sensors are shown in the following table.

CALCULATIONS				
LIGHTING LEVELS				
	Present		Proposed	
Number of Lamps	3,824	lamps	3,824	lamps
Lighting Levels	46	fc	38	fc
ANNUAL ELECTRICITY COSTS				
	Present		Proposed	
Electrical Demand	95.3	kW	57.4	kW
Electrical Consumption	329,319	kWh/year	175,866	kWh/year
Electrical Demand Cost	$9,720	/year	$5,851	/year
Electrical Consumption Cost	$12,649	/year	$6,755	/year
Total Electricity Cost	$22,369	/year	$12,606	/year
ADDITIONAL ANNUAL COSTS				
	Present		Proposed	
Relamping Material Cost	$991	/year	$1,935	/year
Relamping Labor Cost	$1,322	/year	$938	/year
Total Relamping Cost	$2,313	/year	$2,872	/year
TOTAL OPERATING COST				
	Present		Proposed	
Total Operating Cost	**$24,682**	/year	**$15,478**	

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RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**37.9**	kW
Electrical Consumption	**153,453**	kWh/year
CO_2 Emissions	**109**	tonnes/year
Electrical Demand Cost	**$3,869**	/year
Electrical Consumption Cost	**$5,894**	/year
Total Electricity Cost	**$9,763**	/year
ADDITIONAL ANNUAL COST SAVINGS		
Relamping Material Cost	-$943	/year
Relamping Labor Cost	$384	/year
Total Relamping Cost	**-$560**	/year
TOTAL OPERATING COST SAVINGS		
Total Operating Cost Savings	**$9,204**	/year

Economics

The cumulative economic viability for **all lighting recommendations** in this building are shown in the following table. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS	
IMPLEMENTATION COST	
Implementation Material Cost	$62,374
Implementation Labor Cost	$23,778
Rebate	$32,737
Total Implementation Cost	**$53,414**
INVESTMENT METRICS	
Simple Payback (yrs)	**2.1**
Net Present Value	**$139,898**
10 Year Internal Rate of Return	**46%**
Assumed Discount Rate	5%

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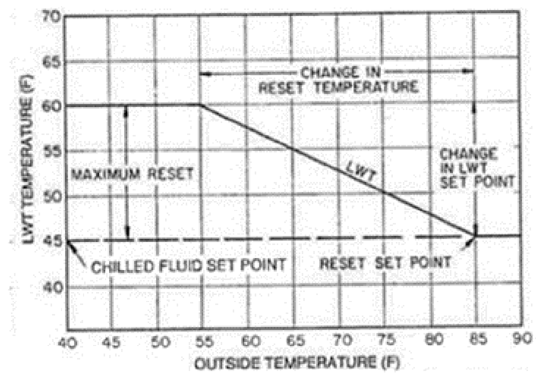
KL CER 2: Improve Chilled Water Temperature Control

Implemenation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$2,000	$2,080	$4,080	124,801	0	88	$4,792	10 months	$32,925	117%

Analysis

Two water-cooled chillers in this facility generate chilled water for space cooling. Currently the chillers are set to cool a closed-loop water system to a set-point of 42 F. During our investigation there appeared to be a form of chilled water reset control in Metasys already, but it is not aggressive enough to achieve any noticeable energy savings. By controlling the chilled water temperature to increase when it is cold outside and lower when it is warmer outside, the chillers will allow them to operate more efficiently.



Recommendation

We recommend changing implementing a control strategy which changes the set-point of chilled water in the building based on the outdoor air temperature. This can be done through the facility's building automation system (Metasys) or through Carrier and/or Trane HVAC technicians installing the controls in the built in chiller control system..

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of chillers in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in water-cooled chiller efficiency based on estimates found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT SYSTEM INFORMATION		
Chiller Rated Capacity (RC)	800	tons
Chiller Rated kW/ton (eta)	0.710	kW/ton
LCWT at Rated kW/ton (R_LCWT)*	45.0	F
Current Chilled Water Setpoint (CW_T_setpoint)	42.0	F
Current Condeser Water Setpoint (TW_T_setpoint)*	75.0	F
Cooling Slope (CS)	6.84	kWh/F-hr
Cooling Balance Temperature (Tbal)	43.7	F

PROPOSED SYSTEM INFORMATION		
Maximum Temperature Reset (Tmax)	60	F
Outdoor Air Temperature at Maximum Reset (ToaMax)	60	F
Minimum Temperature Reset (Tmin)	45	F
Outdoor Air Temperature at Minimum Reset (ToaMin)	85	F

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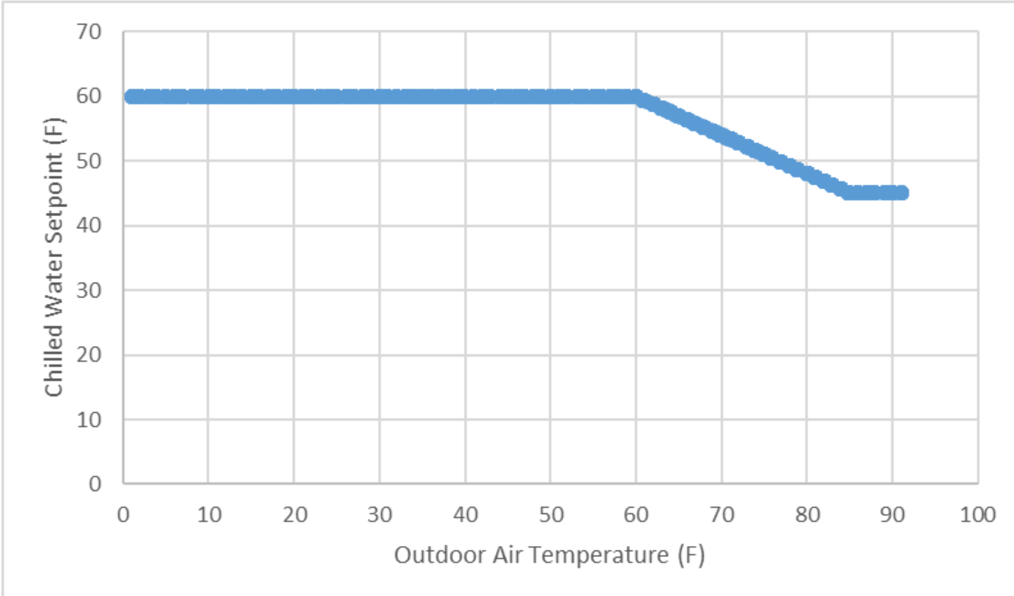

CALCULATIONS			
PARAMETER	**EQUATION**	**VALUE**	**UNITS**
Chilled Water Reset Curve Slope (Rslope)	=(Tmax-Tmin)/(ToaMin-ToaMax)	-0.6	F/F
Chilled Water Reset Curve Intercept (Rint)	=Tmax-Rslope*ToaMax	60	F
	HOURLY EQUATION		**UNITS**
Current Building Energy Use (CCEU)	=CS*(Toa-Tbal)$^+$		kWh
Building Load (BL)	=CCEU/eta		tons
Chiller % Load (CL)	=BL/RC		%
Standard Chiller Efficiency (eta_S)	=0.57341 - 1.2023*CL + 0.79481*CL^2 + 0.0051964*TW_T_setpoint + 0.000022926*TW_T_setpoint^2 - 0.000805732*TW_T_setpoint*CL		kW/ton
Current Chiller Efficiency (eta_C)	=eta_S+0.015*eta_S*(RLCWT-CW_T_setpoint)		kW/ton
Proposed Chilled Water Setpoint (P_setpoint)	=IF(Toa<ToaMax, Tmax, IF(Toa>ToaMin, Tmin, Rslope*Toa + Rint))		F
Proposed Chiller Efficiency (eta_P)	=eta_S+0.015*eta_S*(RLCWT-P_setpoint)		kW/ton
Proposed Chiller Energy Use (PCEU)	=CCEU*eta_C/eta_P		kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Proposed Annual Electricity Savings (Se)	ΣC_CCEU-ΣP_PCEU	124,801	kWh/year
Proposed Annual Cost Savings (Sc)	Se*Ecost	$4,792	/year

Implementation Cost & Investment Metrics

We estimate the changes to the controls would take two Chiller Technicians, paid $65/hour, about 8 hours to complete in the Chiller Control System with another $2,000 in parts and sensors. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

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ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$2,000	-
Labor Cost	$2,080	-
Rebate	$0	-
Total Implementation Cost	**$4,080**	-
COST SAVINGS		
Energy	$4,792	/year
Demand	$0	/year
Total	$4,792	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$32,925	
IRR	117%	
Simple Payback	10.2	months

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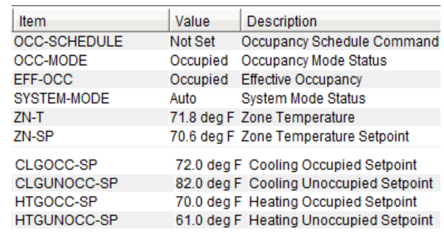
KL CER 3: Schedule AHUs 4, 5, & 6 off and Setback Thermostats during Unoccupied Hours

Breakdown by Equipment	Implemenation Cost		Annual Savings					Economics		
	Material	Labor	Electric (kWh)	Demand (kW)	Nat Gas (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
Boilers				-	339	18	$2,126	N/A		
Chiller	$0	$2,400	36,687	-		26	$1,409	N/A		
AHUs			125,267	-		89	$4,810	N/A		
Total	$2,400		161,954	-	339	133	$8,345	3 months	$62,038	348%

Analysis

Kettering Labs has areas that are unoccupied during a significant number of hours each evening throughout the year. During these unoccupied hours, AHUs that serve floors that are entirely unoccupied for consecutive hours, such as the Basement and Floors 4 and 5, can be scheduled to turn off, as is currently done in Miriam Hall. This can significantly reduce AHU energy usage. On floors where AHUs serve both classrooms and offices with different occupancy schedules, such as Floors 1-3, thermostats can be programmed to reduce their set-point during the winter months, and increase the set-point during summer months. This will decrease heating loads during winter months, and decrease cooling loads during summer months. A lower temperature difference between the inside and outside air results in reduced heat transfer and infiltration losses. Although it requires some additional energy to reheat the plant in the morning, it is significantly less than the energy saved by reducing the temperature during un-occupied hours.



Item	Value	Description
OCC-SCHEDULE	Not Set	Occupancy Schedule Command
OCC-MODE	Occupied	Occupancy Mode Status
EFF-OCC	Occupied	Effective Occupancy
SYSTEM-MODE	Auto	System Mode Status
ZN-T	71.8 deg F	Zone Temperature
ZN-SP	70.6 deg F	Zone Temperature Setpoint
CLGOCC-SP	72.0 deg F	Cooling Occupied Setpoint
CLGUNOCC-SP	82.0 deg F	Cooling Unoccupied Setpoint
HTGOCC-SP	70.0 deg F	Heating Occupied Setpoint
HTGUNOCC-SP	61.0 deg F	Heating Unoccupied Setpoint

Example Metasys Zone Temperature Setback Controls

Recommendation

We recommend utilizing UD's Metasys system to schedule AHUs 4, 5, and 6 to turn off between midnight and 7 AM. Metasys can also be utilized to control the office thermostats on floors 1-3 from 7 PM – 7 AM, and classroom thermostats from midnight to 7 AM, to reduce set-points from 70F to 60F during heating days and increase its set-point from 72 to 80F during cooling days.

Expected Energy, Emissions and Cost Savings

During the school year and summer, classrooms in this building is estimated to be occupied from 7 AM to midnight during the week, 9 AM – 7 PM on weekends, and unoccupied during breaks. Offices are estimated to be occupied 7 AM – 7 PM during school year and summer weekdays, 9 AM – 5 PM on weekends, and 8 AM – 5 PM on weekdays and unoccupied weekends during breaks. Therefore, thermostat setbacks can occur during the hours that areas are not occupied. The setbacks should not include finals week in the Spring and Fall semester.

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	Classrooms					
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	0	0	1	0
9:00	1	0	0	0	1	0
10:00	1	0	0	0	1	0
11:00	1	1	0	0	1	1
12:00	1	1	0	0	1	1
13:00	1	1	0	0	1	1
14:00	1	1	0	0	1	1
15:00	1	1	0	0	1	1
16:00	1	1	0	0	1	1
17:00	1	1	0	0	1	1
18:00	1	1	0	0	1	1
19:00	1	1	0	0	1	1
20:00	1	0	0	0	1	1
21:00	1	0	0	0	1	1
22:00	1	0	0	0	0	1
23:00	1	0	0	0	0	0

	Offices					
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	1	0	1	0
9:00	1	1	1	0	1	1
10:00	1	1	1	0	1	1
11:00	1	1	1	0	1	1
12:00	1	1	1	0	1	1
13:00	1	1	1	0	1	1
14:00	1	1	1	0	1	1
15:00	1	1	1	0	1	1
16:00	1	1	1	0	1	1
17:00	1	0	0	0	1	0
18:00	1	0	0	0	1	0
19:00	1	0	0	0	1	0
20:00	0	0	0	0	0	0
21:00	0	0	0	0	0	0
22:00	0	0	0	0	0	0
23:00	0	0	0	0	0	0

To calculate savings, the building's heating and cooling baseline information was determined. The thermostat set-points were based off typical campus buildings, as its specific set-points were not found in Metasys. The heating efficiency is assumed to be 70%, factoring in losses going from the main steam plant to heating applications, and its chiller COP is taken from its nameplate. The building's cooling slope and cooling balance temperature was identified in the lean energy analysis from annual electrical bills, as noted in Section 1D. Heating slope was estimated based on the electricity use between Roesch and Miriam, and heating balance temperature is estimated at 55F.

CURRENT BUILDING INFORMATION		
Heating Indoor Temperature Setpoint (Tia_h)	70	F
Cooling Indoor Temperature Setpoint (Tia_c)	72	F
Heating Efficiency (eta_h)*	70%	
Cooling Efficiency (eta_c)	5.1	
Building Heating Slope (HS)*	33.9	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h)*	55	F
Building Cooling Slope (CS)	4987	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	42.2	F
% Building Area for Classrooms/Hallways	60%	
% Building Area for Offices	40%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

*Engineering Assumption

The building has eight AHUs, one of which, AHU7, is already scheduled off during unoccupied periods so its savings are not considered for AHU scheduling or thermostat setbacks. It is assumed that AHU VFDs operate at ASHRAE standards.

CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Supply Fan Nameplate (NFP)	250	hp
Return Fan Nameplate (RFP)	53	hp
Total AHU Fan Power Rating (HP_all)	303	hp
Total AHU Fan Power Current Scheduled Off (HP_offnow)	22.5	hp
Scheduled Start Time Off (Sch_time1)	20	:00
Scheduled End Time Off (Sch_time2)	7	:00
Fraction Loaded @100% (FL)*	80%	
Minimum damper position (VAVpercent_open)	30%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

The proposed setback temperatures are indicated below, and are only for 50% of the building since only Floors 1-3 are to get thermostat setbacks. The total horsepower of AHUs serving areas with thermostat setbacks is 163 HP. AHUs on Floors 4-6 total 141 HP and are proposed to be off during scheduled hours. It is also recommended to set the minimum damper positions from 30% to 5% in Metasys in order to see all potential savings.

PROPOSED INFORMATION		
% Building Area to get Therm Setbacks	50%	
Heating Setback Temperature (Tsetbk_h)	60	F
Cooling Setback Temperature (Tsetbk_c)	80	F
AHU Fan Power for Therm Setback (HP_therm)	163	hp
New AHU Fan Power to Schedule Off (HP_off-new)	118	hp
Total AHU Fan Power to Schedule Off (HP_off-prop)	141	hp
Minimum damper position (VAVperc_open_prop)	5%	

The new balance temperatures for areas with thermostat setbacks is calculated below, and used to calculate proposed heating and cooling energy in areas of thermostat setbacks. Reduced heating and cooling corresponds to reduced AHU energy.

CALCULATIONS			
PARAMETER	**EQUATION**	**Results**	
Building UA (UA)	(HS/30.4/24*10^6*eta_h+CS/30.4/24*3412*eta_c)/2	80,362	Btu/hr-F
Internal Load (IL_h)	UA*(Tia_h-Tbal_h)	1,205,427	Btu/hr
Internal Load (IL_c)	UA*(Tia_c-Tbal_c)	2,394,781	Btu/hr
Heating Setback Balance Temperature (Tbal_setback_h)	Tsetbk_h*perc_setbk+T_iah*(1-perc_setbk)-IL_h/UA	50.0	F
Cooling Setback Balance Temperature (Tbal_setback_c)	Tsetbk_c*perc_setbk+T_iac*(1-perc_setbk)-IL_c/UA	46.2	F
PARAMETER	**HOURLY EQUATION**	**Annual Totals**	
Current Hourly Heating Energy Use (C_BHE)	$HS*(Tbal\_h-Toa)^{+}/30.4/24$	4,254	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	$CS*(Toa-Tbal\_c)^{+}/30.4/24$	835,628	kWh
Current AHU Energy Use (C_AHU)	FL*(HP_all-HP_offnow)*.746*(A+xB^2+xC^2+xD^3)	498,551	kWh
Proposed Hourly Heating Energy Use (P_BHE)	$HS*(Tbal\_[none,night,wkend]\_h-Toa)^{+}/30.4/24$	3,689	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	$CS*(Toa-Tbal\_[none,night,wkend]\_c)^{+}/30.4/24$	774,482	kWh
Proposed AHU Energy Usage (P_AHU)	FL*(HP_all-HP_offprop)*.746*(A+xB^2+xC^2+xD^3)	341,967	kWh

A steady state analysis uses the difference in indoor and outdoor temperature to calculate savings. However, in practice the thermal mass of the building reduced temperature swings. To correct for this, actual savings are assumed to be 60% of steady state savings (Kissock, 2003).

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RESULTS		
ENERGY REDUCTION		
Steady State Annual Fuel Savings (SSf)	ΣC_BHE-ΣP_BHE	565 mmBtu/year
Steady State Annual Cooling Electricity Savings (SSe_c)	ΣC_BCE-ΣP_BCE	61,146 kWh/year
Steady State Annual AHU Electricity Savings (SSe_ahu)	ΣC_BCE-ΣP_BCE	156,583 kWh/year
Actual Annual Cooling Savings (ACTe_c)	SSe_c*0.6	36,687 kWh/year
Actual Annual AHU Savings (ACTe_ahu)	SSe_ahu*perc_setbk*0.6 +SSe_ahu*(1-perc_setbk)	125,267 kWh/year
Total Annual Electric Savings (TOTe)	ACTe_c + ACTe_ahu	161,954 /year
Actual Annual Fuel Savings (TOTf)	SSf*0.6	339 mmBtu/year
COST SAVINGS		
Electric (Cost_e)	TOTe*Ecost	$6,219 /year
Natural Gas (Cost_ng)	TOTf*Ngcost	$2,126 /year
Total Savings	Cost_e + Cost_ng	$8,345 /year

Implementation Cost & Investment Metrics

We estimate that it would take 16 hours to program AHU scheduling and thermostat setbacks in Metasys at a rate of $150 per hour. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS	
IMPLEMENTATION COST	
Material Cost	$0 -
Labor Cost	$2,400 -
Total Implementation Cost	**$2,400** -
COST SAVINGS	
Electric	$6,219 /year
Natural Gas	$2,126 /year
Total	$8,345 /year
INVESTMENT METRICS	
Discount Rate	5%
Net Present Value	$62,038
IRR	348%
Simple Payback	3.5 months

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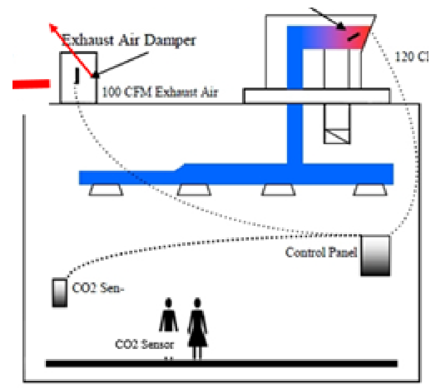
KL CER 4: Install Demand Control Ventilation

Implemenation Cost				Annual Savings					Economics		
Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$10,500	$4,046	$5,803	$8,743	58,032	0	2068	151	$15,208	7 months	$108,691	174%

Analysis

Mechanically ventilated spaces in commercial buildings will set the minimum amount of outdoor air entering a building based upon the ventilation required at full occupancy. However, buildings are frequently only partially occupied. A demand ventilation system works by measuring the amount of carbon dioxide released by the building occupants, so it can maintain indoor air quality while reducing the amount of ventilation air during times of partial occupancy. Kettering Labs operates with a fixed fraction of outdoor ventilation air while not economizing. The building's nameplate cooling capacity is 800 tons and 5.1 COP. The steam system efficiency is estimated to be 70% on average.



Recommendation

We recommend installing a CO2 sensor in the return ductwork to each air handling unit to measure the concentration of CO2 given off by occupants breathing and adjust the amount of ventilation air accordingly. This sensor should be incorporated into the Metasys building automation system for appropriate operation. This greatly reduces the amount of energy required to heat and cool spaces which are not constantly occupied. In schools, occupancy is typically very low during the summer months and allows this system to realize greater savings.

Expected Energy, Emissions and Cost Savings

To quantify the impact of reduced ventilation air, we simulated the energy use for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the amount of ventilation air brought into the school building currently as well as with the proposed CO2 sensor. The estimated occupancy and schedule are shown below as well as the energy calculations.

The cooling and heating temperature set-points are adjusted to include thermostat setback recommendation to prevent double counting savings when combined with other CERs.

CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)*	33.9	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h)*	53.3	F
Building Cooling Slope (CS)	4,987	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	43.7	F
Heating Efficiency (eta_h)*	70%	
Nameplate Cooling Efficiency (neta_c)	5.1	COP
Average Cooling Efficiency (eta_c)	4.1	COP
Nameplate Total Cooling Capacity (nCap_c)	803	tons

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ENGINEERING ASSUMPTIONS		
Sensible Heat Ratio (SHR)*	0.85	
Cooling Supply Air Temperature (SAT_c)*	57	F
Heating Supply Air Temperature (SAT_h)*	68	F
Economizer Low Limit (EconoLL)*	30	F
Economizer High Limit (EconoHL)*	70	F
Minimum Outdoor Air (MinOA)*	15%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

Building hourly occupancy rates are estimated, and AHU scheduling is incorporated to prevent double counting savings from the AHU scheduling or thermostat setbacks recommendation.

Hour of Day	Occupancy	Schedule (on/off)	Hour of Day	Occupancy	Schedule (on/off)
0:00	5%	0	12:00	50%	1
1:00	5%	0	13:00	80%	1
2:00	1%	0	14:00	80%	1
3:00	1%	0	15:00	80%	1
4:00	1%	0	16:00	50%	1
5:00	0%	0	17:00	20%	1
6:00	1%	0	18:00	20%	1
7:00	10%	1	19:00	10%	1
8:00	50%	1	20:00	5%	1
9:00	80%	1	21:00	0%	1
10:00	80%	1	22:00	0%	1
11:00	80%	1	23:00	0%	1

The building's hourly loads are calculated from the heating and cooling slopes found in the Lean Energy Analysis section. Savings from demand ventilation only occurs when the building is set to bring in the minimum amount of outdoor air. Therefore, the hours in the year corresponding to economizer operation are excluded. The current outdoor airflow is calculated based on the general HVAC design rule that a building should move 400 cfm of air per ton of cooling provided at design conditions. The minimum amount of outdoor air is expressed in HVAC designs is based on this value. In our calculation we propose reducing the amount of ventilation based on the estimated occupancy for each hour.

This calculation does not consider the significantly lower summer occupancy and therefore represents a conservative estimate of cooling savings.

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CALCULATIONS		
PARAMETER	EQUATION	UNITS
Hourly Building Heating Energy (BHE)	$HS*(Tbal\_h-Toa)^+/30.4/24$	mmBtu
Hourly Building Cooling Energy (BCE)	$CS*(Toa-Tbal\_c)^+/30.4/24$	kWh
Economizer Mode (EconoM)	IF(EconoHL>Toa>EconoLL,1,0)	0,1
Hourly Building Heating Load (BHL)	BHE/(HS*(Tbal_h-Tdesign_h)/30.4/24)	%
Hourly Building Cooling Load (BCL)	BCE/(CS*(Tdesign_c-Tbal_c)/30.4/24)	%
Current Outdoor Airflow (COA)	IF(Schedule=ON,MAX(BHL,CHL)*400*Cap_c*MinOA,0)	cfm
Current Hourly Heating Energy Use (C_BHE)	IF(Toa<Tbal_h,1.08*COA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	IF(Toa>SAT_c,1.08*COA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh
Proposed Outdoor Airflow (POA)	IF(EconoM=1,COA,COA*Occupancy)	cfm
Proposed Hourly Heating Energy Use (P_BHE)	IF(Toa<Tbal_h,1.08*POA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	IF(Toa>SAT_c,1.08*POA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh

RESULTS			
ENERGY REDUCTION			
Proposed Annual Fuel Savings (Sf)	ΣC_BHE-ΣP_BHE	2,068	mmBtu/yr
Proposed Annual Electricity Savings (Se)	ΣC_BCE-ΣP_BCE	58,032	kWh/yr
COST SAVINGS			
Electric (Cost_e)	Sf*Ngcost	$12,980	/year
Natural Gas (Cost_ng)	Se*Ecost	$2,228	/year
Total Savings	Cost_e + Cost_ng	$15,208	/year

Implementation Cost & Investment Metrics

We estimate that it would cost $1,500 per CO_2 sensor for each AHU. It is also estimated to take 21 hours to program in Metasys (3 hours per CO_2 sensor) at $150 per hour, and take two technicians, at $65 per hour, 4 hours to install each CO_2 sensor per AHU. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$10,500	-
Labor Cost	$4,046	-
Rebate	$5,803	-
Total Implementation Cost	$8,743	-
COST SAVINGS		
Energy	$15,208	/year
Demand	$0	/year
Total	$15,208	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$108,691	
IRR	174%	
Simple Payback	7	months

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KL CER 5: Lower Operating Set-point Pressure of 25-hp Compressors from 120 psig to 100 psig

Implemenation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year
$0	$64	$64	10,427	1.2	7	$400	2 months	$3,028	626%

Analysis

The highest compressed air pressure required in this building is likely around 90 psig. Typically, a 10 psig difference between set-point pressure and end-use pressure is more than sufficient to account for pressures losses across the dryer, filters, and pipes. Therefore, the current operating set-point and lower activation pressure of 120 psig is uneccessarily high. As a rule of thumb, each 2 psig decrease in operating pressure reduces compressor power draw by about 1%. Thus, lowering the operating set-point pressure of both 25-hp compressors would reduce the compressor power draw, resulting in energy, CO_2 emission, and cost savings.

25-hp Air Compressor

Recommendation

We recommend lowering the operating pressure set-point of the 25-hp compressors from 120 psig to 100 psig.

Expected Energy, Emissions and Cost Savings

To quantify the savings in power draw from the proposed reduction in compressor set-point pressure, we used a compressed air excel model, part of the UD IAC Energy Efficiency Guidebook, which is available free of charge at: http://academic.udayton.edu/kissock/http/RESEARCH/EnergySoftware.htm (Kissock 2003). The inputs are shown below:

COMPRESSOR INFORMATION (INPUT)		
Term	Value	Units
Current Average Compressor Operating Pressure ($P2_{high}$)	120	psig
Proposed Average Compressor Operating Pressure ($P2_{low}$)	100	psig
Inlet Air Pressure (P1)*	14.7	psi
Average Fraction Power (FP)*	0.6	-
Motor Efficiency (Em)	0.9	-
Compressor Size (HP)	25	hp
Operating Hours per Year (HPY)	8,760	hours/year

*Engineering Assumption

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The equations listed below were used to calculate fractional energy savings by lower the pressure set-point.

CALCULATIONS AND SAVINGS		
Term	**Value**	**Units**
Fractional Savings (FS) = $[(P2_{high}/P1)^{0.286} - (P2_{low}/P1)^{0.286}] / [(P2_{high}/P1)^{0.286} - 1]$	10%	
Demand Savings (DS) = (FP x HP x [0.746 kW/hp]/Em) x FS	1.2	kW
Electricity Savings (ES) = DS x HPY	10,427	kWh/year

Implementation Cost & Investment Metrics

Marginal energy and demand costs are used to calculate cost savings. It is estimated to take one facilities management staff two hours to lower the pressure set-points of both 25-hp compressors, with an in house labor rate of $32 per hour. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0	-
Labor Cost	$64	-
Total Implementation Cost	**$64**	-
COST SAVINGS		
Energy	$401	/year
Demand	$122	/year
Total	$522	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$3,028	
IRR	626%	
Simple Payback	1.5	months

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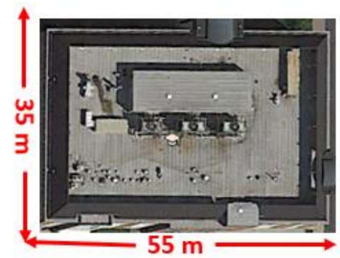
KL CER 6: Install 125 kW Rooftop Solar PV System

Implementation Cost			Annual Savings				Economics		
Capex	ITC	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback (years)	25 year NPV	25 year IRR
$218,750	$0	$218,750	165,100	22	117	$8,577	25.5	-$97,859	0%

Analysis

Kettering Labs has an upper rooftop area of around 2,000 square meters. However, only some of this area sees ample sunlight throughout the year due to shading from black wind guards at each side and the penthouse. However, parts of the roof's area is still unobstructed from shade of nearby objects, and can be utilized for energy generation by installing solar PV panels and elevating the panels a meter or two. And while the south facing wind deflector guard could be utilized to install solar panels on, its 45 degrees is greater than the 30 degree tilt for maximum solar radiation, and could create aesthetic concerns so it will not be recommended to utilize for solar PV.



Rooftop Area

Recommendation

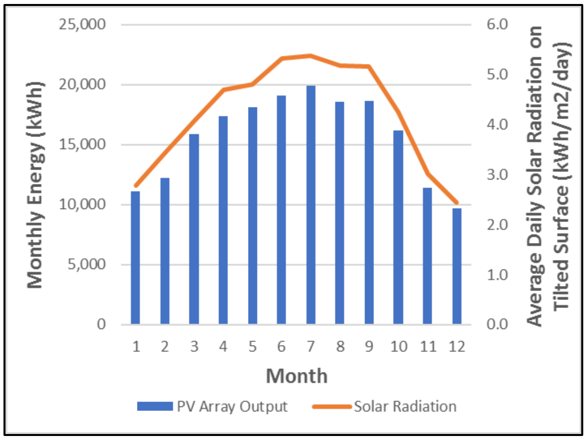
We recommend installing a 125 kW-DC solar PV array on the Kettering Labs rooftop. The array on the main roof would likely have to be elevated one to two meters to prevent shading from the bordering wind guards.

Expected Energy, Emissions and Cost Savings

The total area unobstructed from shade of nearby objects, mainly the south half of the main roof and all of the penthouse roof, was determined to be around 1,100 m2. After factoring in spacing from arrays tilted at 30 degrees, it was determined that a total area of around 630 m2 could be utilized for solar PV. Assuming a system with generic 330 W, 1.67 m2 solar panels, this would be around 125 kW-DC. However, once inverter losses of 2.5% converting from DC to AC, and 10% losses from other factors such as soiling, mismatch, light-induced degradation, and partial shading are taken into account, the AC capacity would be around 110 kW (NREL, 2014).


Rooftop Area with solar PV

To quantify the potential energy generation from the 8- kW solar PV aray, the annual solar radiation was determined by using NASA average daily horizontal radiation for each month for Dayton Ohio, downloaded from https://eosweb.larc.nasa.gov/sse/RETScreen/. This yields annual solar radiation of 1384 kWh/m2 for a horizontal surface, and after calculating increases from tilting the panels 30 degrees south, 1534 kWh/m2. This results in a DC capacity factor of 17.5%.



The system's annual generation can then be determined by multiplying the capacity factor by its AC capacity. Monthly demand savings are assumed to be 20% of the solar system's AC capacity. The corresponding cost savings are based on the marginal costs of energy and demand.

RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**21.9**	kW
Electrical Consumption	**165,100**	kWh/year
Electrical Demand Cost	**$2,238**	/year
Electrical Consumption Cost	**$6,340**	/year
Total Electricity Cost	**$8,577**	/year

Implementation Cost & Investment Metrics

The total cost is based on an assumption of $1.75/W-DC, assuming all solar PV recommendations is this report are done in tandem for a total system rate closer to 500 kW. The investment tax credit is not applicable to UD, as they are exempt from federal taxes under 501(c)(3). However, depending on the outcome of Congress' 2017 bill to tax endowment income, this may change.

ECONOMICS		
IMPLEMENTATION COST		
Total Cost	$218,750	-
Rebate	$0	-
Total Implementation	**$218,750**	-
COST SAVINGS		
Energy	$6,340	/year
Demand	$2,238	/year
Total	$8,577	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	($97,859)	
IRR	0%	
Simple Payback	25.5	years

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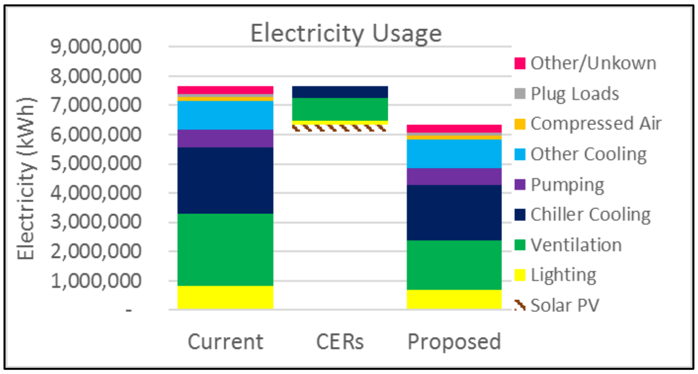
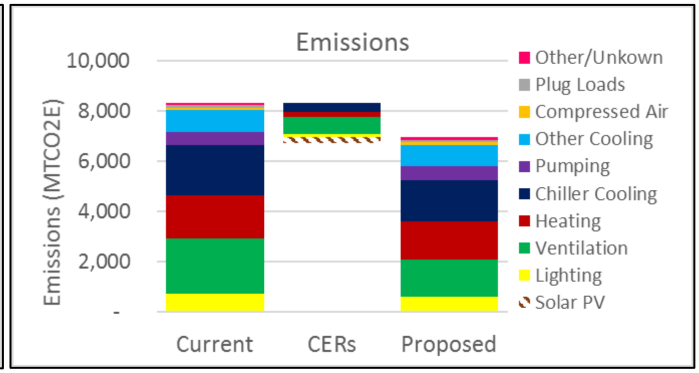
FITZ HALL

Summary

A total of 8 clean energy recommendations for Fitz Hall are estimated to reduce electricity by 20% and natural gas by 12%. This is equivalent to reducing emissions by 18%, or 1,580 metric tons of CO2. These recommendations have a total simple payback of 4.9 years, and 10-year NPV of $325,461 with a 16% IRR.





CLEAN ENERGY RECOMMENDATIONS		Annual Savings				Project Cost	Simple Payback (years)	NPV	IRR
		kWh	mmBTU	MTCO2	$				
Lighting									
1	Replace FT8s with LEDs on the entire 3rd Floor	141,873		125	$6,857	$10,054	1.5	$42,897	68%
	Lighting Reduction	17%							
Building Cooling									
2	Reset chiller set point based on outdoor air temp.	261,103		231	$10,026	$6,120	0.6	$73,301	164%
3	Schedule AHUs and set back thermostats	83,407		74	$3,203	$6,000	0.4	$118,572	269%
4	Install Demand Control Ventilation	52,682		47	$2,023	$57,072	3.3	$76,169	28%
	Cooling Reduction	18%							
Building Heating									
3	Schedule AHUs and set back thermostats		659	35	$4,136	-*	-*	-*	-*
4	Install Demand Control Ventilation		2,427	129	$15,232	-*	-*	-*	-*
5	Reduce Excess Air in Steam Boilers		885	47	$5,554	$260	0.0	42,607	2135%
	Heating Reduction		12%						
Ventilation									
3	Schedule AHUs and set back thermostats	228,968		202	$8,792	-*	-*	-*	-*
6	Relocate AHU VFD static pressure sensors	401,677		355	$15,424	$15,840	1.0	$103,263	97%
7	Install VFDs on AHU Supply Fan Motors	148,050		131	$5,685	$36,240	6.4	7,659	9%
	Ventilation Reduction	32%							
Renewable Energy									
8	Install 175 kW Rooftop Solar PV	231,141		204	$12,008	$306,250	25.5	-$137,003	0%
	Reduction in Building Energy/Emissions	3%		2%					
	Fitz Hall Clean Energy Recommendations Total	**1,548,901**	**3,971**	**1,580**	**$88,941**	**$437,836**	**4.9**	**$325,461**	**16%**
	Fitz Hall Energy & Emissions % Reduction Total	**21%**	**12%**	**19%**					

* Not applicable since CERs energy savings are broken down by equipment. Total costs and economics for these CERS are included under cooling savings

FH CER 1: Replace all 4ft and 2ft-FT8 with corresponding LED replacement on 3rd Floor

Bulb Type & Lighting Area		Implementation Cost				Annual Energy Savings		Annual Cost Savings				Simple Payback (years)
		Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Energy	Demand	Re-lamping	Total	
4ft-T8	Open Areas	$15,213	$307	$7,376	$8,144	128,194	18.3	$4,924	$1,866	-$818	$5,971	1.4
	Enclosed Areas	$3,234	$65	$1,568	$1,731	11,241	3.9	$432	$397	-$72	$757	2.3
	Bathrooms	$96	$85	$64	$117	1,531	0.2	$59	$20	-$2	$76	1.5
2ft-T8	Hallways	$168	$5	$112	$61	906	0.2	$35	$17	$1	$53	1.1
	Total	**$ 18,711**	**$ 463**	**$ 9,120**	**$ 10,054**	**141,873**	**23**	**$5,449**	**$2,299**	**-$891**	**$6,857**	**1.5**

Analysis

During our walk-through, our team counted a total of 2,252 4ft-T8 fluorescent lamps and 28 2ft-T8 fluorescent lamps. For 4ft-T8s, 2,122 were in large 'open areas' that utilize 8ft dividers for offices and classrooms, 130 were in enclosed classrooms or offices, and 16 in bathrooms. During the walk through, some of the lamps were identified as 32W and some 25 W, so their average is estimated to be 28W. All 2-ft-T8s are estimated to be 17W.

3rd Floor Lighting still on around 10 PM

Fluorescent T8s lamps can be directly replaced with direct-wire LED tubes after removing the ballast. LEDS offer several advantages, such as consuming around 50% less energy, a longer rated lifespan, and are directional, meaning that more of the light emitted from the lamp illuminates the work plane. They are also better suited for lighting control systems.

Recommendation

We recommend replacing all 2,252 4ft-FT8 bulbs with LED 15-W tubes, and all 28 2ft-T8s with 9W high lumen T8 LEDS in order to satisfy the required lighting levels. It is also recommended to use a light meter to measure the area's foot-candles to see if lumen output of 12.5W LEDs would be sufficient.

Expected Energy, Emissions and Cost Savings

We estimate that retrofitting 4ft-F8 and 2ft-FT8s with a LED direct-wire tube and removing the ballast would take about 10 minutes per lamp. According to facilities management, the in-house labor rate is $32 per hour.

BUILDING DATA	
Marginal Demand charge	$8.50 /kW-mo
Marginal Energy charge	$0.03841 /kWh
Labor rate	$32 /hr
Relamping labor	0.167 hr/lamp

A 15-W LED replacement was chosen in order to meet the areas' recommended lighting levels, as noted in the Appendix. Lighting hours are based on 1-week trended light logger data. Lighting energy and cost savings calculations were done separately for each area due to varying light hours for each area. Below is the process used for the lighting energy and cost savings of switching from 4ft-FT8s in all open areas and the same process was repeated for enclosed rooms and bathrooms.

CURRENT LIGHTING DATA		
Light Type	4' 28 W T8	
Number of Fixtures	916	fixtures
Number of Lamps	1,844	lamps
% Area That Have Sensors	0%	
% Time On	80%	

PROPOSED LIGHTING DATA		
Lamp Type	1 Tube 15-W LED	
Demand Saving Months	12	mo/yr

REBATES DATA		
Rebate Company	DP&L	
Light Rebate Type	Re-lamping	$/foot
Light Rebate Value	$4	4ft Lamp
Control Rebate Type	$/Connected Watt	
Control Rebate Value	$0.04	/Connected Watt
Maximum Rebate Type	No Cap	-

These lamp specifications and costs are based off 15W supplier specifications at 1000bulbs.com, specifics also included in the Appendix.

FIXTURE DATA				
	Present		Proposed	
Lamp Power	28	W/lamp	15.0	W/lamp
Lamp Output	2,600	lumens/lamp	2,100	lumens/lamp
Lamp Life	40,000	hours	50,000	hours
Lamp CRI	0.85	-	0.83	-
Ballast Factor, BF	0.89	-	1.00	-
Lumen Degradation Factor, LDF**	0.93	-	0.85	-
Lamp Cost	$3.0	/lamp	$8.3	/lamp
****Lumen Degradation Factor = lumen output at lamp half-life/initial lumen output**				

Energy use, energy costs, CO_2 emissions, re-lamping costs and total operating costs for the existing fluorescent fixtures and the proposed LED fixtures with sensors are shown in the following table.

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CALCULATIONS		
ANNUAL ELECTRICITY COSTS		
	Present	Proposed
Electrical Demand	46.0 kW	27.7 kW
Electrical Consumption	322,035 kWh/year	193,841 kWh/year
Electrical Demand Cost	$4,687 /year	$2,821 /year
Electrical Consumption Cost	$12,369 /year	$7,445 /year
Total Electricity Cost	$17,057 /year	$10,267 /year
ADDITIONAL ANNUAL COSTS		
	Present	Proposed
Relamping Material Cost	$969 /year	$2,132 /year
Relamping Labor Cost	$1,723 /year	$1,378 /year
Total Relamping Cost	$2,692 /year	$3,511 /year
TOTAL OPERATING COST		
	Present	Proposed
Total Operating Cost	**$19,749** /year	**$13,777**

RESULTS	
ENERGY REDUCTION AND COST SAVINGS	
Electrical Demand	**18.3** kW
Electrical Consumption	**128,194** kWh/year
CO_2 Emissions	**91** tonnes/year
Electrical Demand Cost	**$1,866** /year
Electrical Consumption Cost	**$4,924** /year
Total Electricity Cost	**$6,790** /year
ADDITIONAL ANNUAL COST SAVINGS	
Relamping Material Cost	-$1,163 /year
Relamping Labor Cost	$345 /year
Total Relamping Cost	**-$818** /year
TOTAL OPERATING COST SAVINGS	
Total Operating Cost Savings	**$5,971** /year

Implementation Cost and Investment Metrics

The cumulative economic viability for **all lighting recommendations** in open areas, enclosed rooms, hallways, and bathrooms are shown in the following table. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS	
IMPLEMENTATION COST	
Implementation Material Cost	$18,711
Implementation Labor Cost	$463
Rebate	$9,120
Total Implementation Cost	**$10,054**
INVESTMENT METRICS	
Simple Payback (yrs)	**1.5**
Net Present Value	**$42,897**
10 Year Internal Rate of Return	**68%**
Assumed Discount Rate	5%

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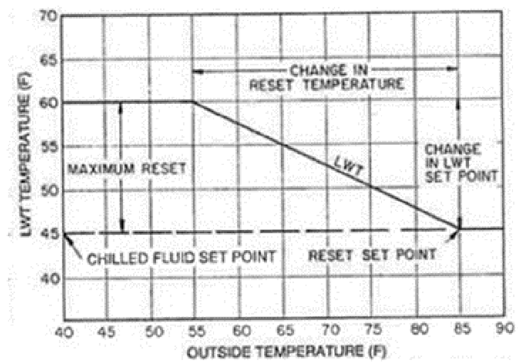
FH CER 2: Improve Chilled Water Temperature Control

Implemenation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$3,000	$3,120	$6,120	261,103	0	185	$10,026	7 months	$71,301	164%

Analysis

Three water-cooled chillers in this facility generate chilled water for space cooling. Currently the chillers are set to cool a closed-loop water system to a set-point of 42 F. During our investigation there appeared to be a form of chilled water reset control in Metasys already, but it is not aggressive enough to achieve any noticeable energy savings. By controlling the chilled water temperature to increase when it is cold outside and lower when it is warmer outside, the chillers will allow them to operate more efficiently.



Recommendation

We recommend implementing a control strategy which changes the set-point of chilled water in the building based on the outdoor air temperature. This can be done through the facility's building automation system (Metasys) or through Trane HVAC technicians installing the controls in the built in chiller control system.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of chillers in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in water-cooled chiller efficiency based on estimates found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT SYSTEM INFORMATION		
Chiller Rated Capacity (RC)	1200	tons
Chiller Rated kW/ton (eta)	0.459	kW/ton
LCWT at Rated kW/ton (R_LCWT)*	45.0	F
Current Chilled Water Setpoint (CW_T_setpoint)	42.0	F
Current Condeser Water Setpoint (TW_T_setpoint)*	75.0	F
Cooling Slope (CS)	7.74	kWh/F-hr
Cooling Balance Temperature (Tbal)	31.7	F

*Engineering Assumption

PROPOSED SYSTEM INFORMATION		
Maximum Temperature Reset (Tmax)	60	F
Outdoor Air Temperature at Maximum Reset (ToaMax)	60	F
Minimum Temperature Reset (Tmin)	45	F
Outdoor Air Temperature at Minimum Reset (ToaMin)	85	F

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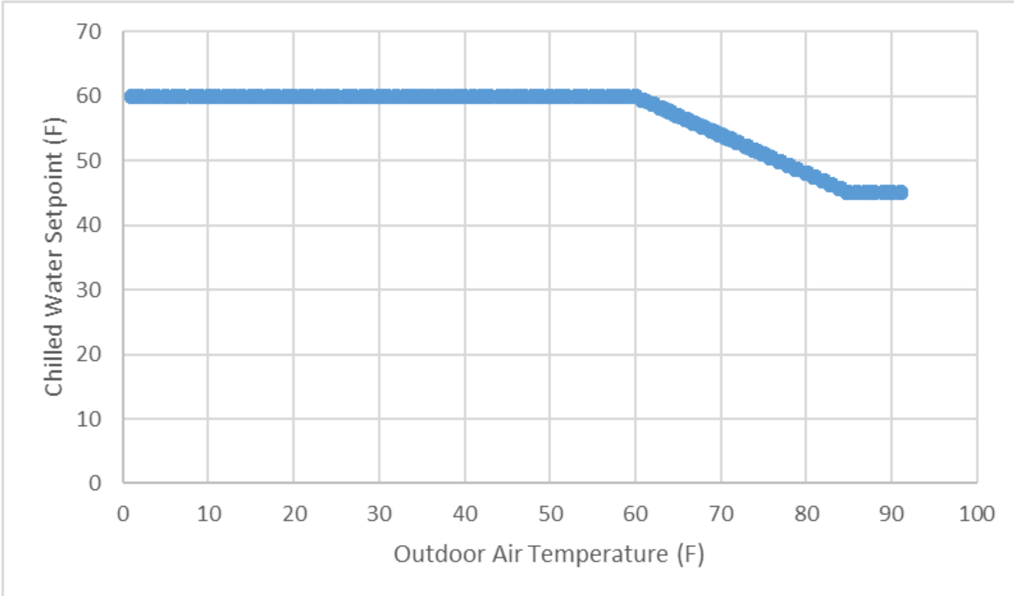

CALCULATIONS			
PARAMETER	**EQUATION**	**VALUE**	**UNITS**
Chilled Water Reset Curve Slope (Rslope)	=(Tmax-Tmin)/(ToaMin-ToaMax)	-0.6	F/F
Chilled Water Reset Curve Intercept (Rint)	=Tmax-Rslope*ToaMax	60	F
	HOURLY EQUATION		**UNITS**
Current Building Energy Use (CCEU)	=CS*(Toa-Tbal)$^{+}$		kWh
Building Load (BL)	=CCEU/eta		tons
Chiller % Load (CL)	=BL/RC		%
Standard Chiller Efficiency (eta_S)	=0.57341 - 1.2023*CL + 0.79481*CL^2 + 0.0051964*TW_T_setpoint + 0.000022926*TW_T_setpoint^2 - 0.000805732*TW_T_setpoint*CL		kW/ton
Current Chiller Efficiency (eta_C)	=eta_S+0.015*eta_S*(RLCWT-CW_T_setpoint)		kW/ton
Proposed Chilled Water Setpoint (P_setpoint)	=IF(Toa<ToaMax, Tmax, IF(Toa>ToaMin, Tmin, Rslope*Toa + Rint))		F
Proposed Chiller Efficiency (eta_P)	=eta_S+0.015*eta_S*(RLCWT-P_setpoint)		kW/ton
Proposed Chiller Energy Use (PCEU)	=CCEU*eta_C/eta_P		kWh

RESULTS			
ENERGY REDUCTION & COST SAVINGS			
Proposed Annual Electricity Savings (Se)	ΣC_CCEU-ΣP_PCEU	261,103	kWh/year
Proposed Annual Cost Savings (Sc)	Se*Ecost	$10,026	/year

Implementation Cost & Investment Metrics

We estimate the changes to the controls would take two Chiller Technicians, paid $65/hour, about 8 hours to complete control changes in each of the three Chiller Control System, with another $1,000 in parts and sensors per chiller. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$3,000	-
Labor Cost	$3,120	-
Rebate	$0	-
Total Implementation Cost	**$6,120**	-
COST SAVINGS		
Energy	$10,026	/year
Demand	$0	/year
Total	$10,026	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$71,301	
IRR	164%	
Simple Payback	7.3	months

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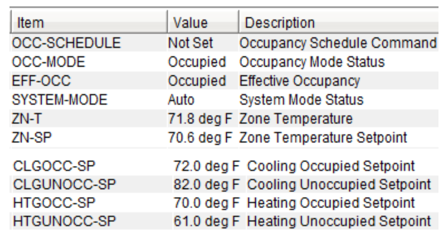
FH CER 5: Schedule AHUs and Setback Thermostats during Unoccupied Hours

Implemenation Cost		Annual Savings					Economics		
Material	Labor	Electric (kWh)	Demand (kW)	Nat Gas (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$0	$6,000		-	659	35	$4,137	N/A		
		83,407	-		59	$3,203	N/A		
		228,968	-		162	$8,792	N/A		
$6,000		312,375	-	659	256	$16,133	4 months	$118,572	269%

Analysis

Fitz Hall has areas that are unoccupied during a significant number of hours each evening throughout the year. During these unoccupied hours, AHUs that serve regions that are entirely unoccupied for consecutive hours, such as the office regions and Floor 3, can be scheduled to turn off, as is currently done in Miriam Hall. This can significantly reduce AHU energy usage. In regions where AHUs serve both classrooms and offices with different occupancy schedules, thermostats can be programmed during unoccupied hours to reduce their set-point during the winter months, and increase the set-point during summer months. This will decrease heating loads during winter months, and decrease cooling loads during summer months. A lower temperature difference between the inside and outside air results in reduced heat transfer and infiltration losses. Although it requires some additional energy to reheat the plant in the morning, it is significantly less than the energy saved by reducing the temperature during unoccupied hours.



Item	Value	Description
OCC-SCHEDULE	Not Set	Occupancy Schedule Command
OCC-MODE	Occupied	Occupancy Mode Status
EFF-OCC	Occupied	Effective Occupancy
SYSTEM-MODE	Auto	System Mode Status
ZN-T	71.8 deg F	Zone Temperature
ZN-SP	70.6 deg F	Zone Temperature Setpoint
CLGOCC-SP	72.0 deg F	Cooling Occupied Setpoint
CLGUNOCC-SP	82.0 deg F	Cooling Unoccupied Setpoint
HTGOCC-SP	70.0 deg F	Heating Occupied Setpoint
HTGUNOCC-SP	61.0 deg F	Heating Unoccupied Setpoint

Example Metasys Zone Temperature Setback Controls

Recommendation

We recommend utilizing UD's Metasys system to schedule to turn AHUs 7, 9-16, 17E 18, 19, & 23 off between 8 PM and 7 AM. For AHUs that serve offices and class rooms, metasys can also be utilized to control the office thermostats from 8 PM – 7 AM, and classroom thermostats from midnight to 7 AM, to reduce set-points from 70F to 60F during heating days and increase its set-point from 72 to 80F during cooling days.

Expected Energy, Emissions and Cost Savings

During the school year and summer, classrooms in this building is estimated to be occupied from 7 AM to midnight during the week, 9 AM – 7 PM on weekends, and unoccupied during breaks. Offices are estimated to be occupied 7 AM – 7 PM during school year and summer weekdays, 9 AM – 5 PM on weekends, and 8 AM – 5 PM on weekdays and unoccupied weekends during breaks. Therefore, thermostat setbacks can occur during the hours that areas are not occupied. The setbacks should not include finals week in the Spring and Fall semester.

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Classrooms						
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	0	0	1	0
9:00	1	0	0	0	1	0
10:00	1	0	0	0	1	0
11:00	1	1	0	0	1	1
12:00	1	1	0	0	1	1
13:00	1	1	0	0	1	1
14:00	1	1	0	0	1	1
15:00	1	1	0	0	1	1
16:00	1	1	0	0	1	1
17:00	1	1	0	0	1	1
18:00	1	1	0	0	1	1
19:00	1	1	0	0	1	1
20:00	1	0	0	0	1	1
21:00	1	0	0	0	1	1
22:00	1	0	0	0	0	1
23:00	1	0	0	0	0	0

Offices						
	School Year		Breaks		Summer	
	weekday	weekend	weekday	weekend	weekday	weekend
Time	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)	(on/off)
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	0	0
7:00	1	0	0	0	1	0
8:00	1	0	1	0	1	0
9:00	1	1	1	0	1	1
10:00	1	1	1	0	1	1
11:00	1	1	1	0	1	1
12:00	1	1	1	0	1	1
13:00	1	1	1	0	1	1
14:00	1	1	1	0	1	1
15:00	1	1	1	0	1	1
16:00	1	1	1	0	1	1
17:00	1	0	0	0	1	0
18:00	1	0	0	0	1	0
19:00	1	0	0	0	1	0
20:00	0	0	0	0	0	0
21:00	0	0	0	0	0	0
22:00	0	0	0	0	0	0
23:00	0	0	0	0	0	0

To calculate savings, the building's heating and cooling baseline information was determined. The thermostat set-points were based off typical campus buildings, as its specific set-points were not found in Metasys. The heating efficiency is around 86% based on the steam boiler analysis results. The building's cooling slope, heating slope, cooling balance temperature, and heating balance temperature was identified in the lean energy analysis from annual electrical bills, as noted in Section 1D.

CURRENT BUILDING INFORMATION		
Heating Indoor Temperature Setpoint (Tia_h)	70	F
Cooling Indoor Temperature Setpoint (Tia_c)	72	F
Heating Efficiency (eta_h)	86%	
Cooling Efficiency (eta_c)	8.0	
Building Heating Slope (HS)	37.2	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h)*	63.8	F
Building Cooling Slope (CS)	5647	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	30.5	F
% Building Area for Classrooms/Hallways	60%	
% Building Area for Offices	40%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

*Engineering Assumption

The building has 39 AHUs, where AH 7, 18, 19, and 44 are scheduled off during unoccupied periods so its savings are not considered for AHU scheduling or thermostat setbacks. It is assumed that AHU VFDs operate at ASHRAE standards.

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CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Supply Fan Nameplate (NFP)	482	hp
Return Fan Nameplate (RFP)	201	hp
Total AHU Fan Power Rating (HP_all)	683	hp
Total AHU Fan Power Current Scheduled Off (HP_offnow)	115.0	hp
Scheduled Start Time Off (Sch_time1)	20	:00
Scheduled End Time Off (Sch_time2)	7	:00
Fraction Loaded @100% (FL)*	80%	
Minimum damper position (VAVpercent_open)	30%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

The proposed setback temperatures are indicated below, and are only for 75% of the building since only certain regions of the building are to get thermostat setbacks. The total horsepower of AHUs serving areas with thermostat setbacks is 495 HP. The AHUs proposed to be scheduled have a total of 188 HP. It is also recommended to set the minimum damper positions from 30% to 5% in Metasys in order to see all potential savings.

PROPOSED INFORMATION		
% Building Area to get Therm Setbacks	75%	
Heating Setback Temperature (Tsetbk_h)	60	F
Cooling Setback Temperature (Tsetbk_c)	80	F
AHU Fan Power for Therm Setback (HP_therm)	495	hp
New AHU Fan Power to Schedule Off (HP_off-new)	188	hp
Total AHU Fan Power to Schedule Off (HP_off-prop)	303	hp
Minimum damper position (VAVperc_open_prop)	5%	

The new balance temperatures for areas with thermostat setbacks is calculated below, and used to calculate proposed heating and cooling energy in areas of thermostat setbacks. Reduced heating and cooling corresponds to reduced AHU energy.

CALCULATIONS			
PARAMETER	**EQUATION**	**Results**	
Building UA (UA)	(HS/30.4/24*10^6*eta_h+CS/30.4/24*3412*eta_c)/2	127,581	Btu/hr-F
Internal Load (IL_h)	UA*(Tia_h-Tbal_h)	791,002	Btu/hr
Internal Load (IL_c)	UA*(Tia_c-Tbal_c)	5,294,608	Btu/hr
Heating Setback Balance Temperature (Tbal_setback_h)	Tsetbk_h*perc_setbk+T_iah*(1-perc_setbk)-IL_h/UA	56.3	F
Cooling Setback Balance Temperature (Tbal_setback_c)	Tsetbk_c*perc_setbk+T_iac*(1-perc_setbk)-IL_c/UA	36.5	F
PARAMETER	**HOURLY EQUATION**	**Annual Totals**	
Current Hourly Heating Energy Use (C_BHE)	$HS*(Tbal\_h-Toa)^{+}/30.4/24$	7,039	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	$CS*(Toa-Tbal\_c)^{+}/30.4/24$	1,535,395	kWh
Current AHU Energy Use (C_AHU)	FL*(HP_all-HP_offnow)*.746*(A+xB^2+xC^2+xD^3)	1,313,251	kWh
Proposed Hourly Heating Energy Use (P_BHE)	$HS*(Tbal\_[none,night,wkend]\_h-Toa)^{+}/30.4/24$	5,940	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	$CS*(Toa-Tbal\_[none,night,wkend]\_c)^{+}/30.4/24$	1,396,384	kWh
Proposed AHU Energy Usage (P_AHU)	FL*(HP_all-HP_offprop)*.746*(A+xB^2+xC^2+xD^3)	986,154	kWh

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A steady state analysis uses the difference in indoor and outdoor temperature to calculate savings. However, in practice the thermal mass of the building reduced temperature swings. To correct for this, actual savings are assumed to be 60% of steady state savings (Kissock, 2003).

RESULTS			
ENERGY REDUCTION			
Steady State Annual Fuel Savings (SSf)	ΣC_BHE-ΣP_BHE	1,099	mmBtu/year
Steady State Annual Cooling Electricity Savings (SSe_c)	ΣC_BCE-ΣP_BCE	139,011	kWh/year
Steady State Annual AHU Electricity Savings (SSe_ahu)	ΣC_BCE-ΣP_BCE	327,098	kWh/year
Actual Annual Cooling Savings (ACTe_c)	SSe_c*0.6	83,407	kWh/year
Actual Annual AHU Savings (ACTe_ahu)	SSe_ahu*perc_setbk*0.6 +SSe_ahu*(1-perc_setbk)	228,968	kWh/year
Total Annual Electric Savings (TOTe)	ACTe_c + ACTe_ahu	312,375	/year
Actual Annual Fuel Savings (TOTf)	SSf*0.6	659	mmBtu/year
COST SAVINGS			
Electric (Cost_e)	TOTe*Ecost	$11,995	/year
Natural Gas (Cost_ng)	TOTf*Ngcost	$4,137	/year
Total Savings	Cost_e + Cost_ng	$16,133	/year

Implementation Cost and Investment Metrics

We estimate that it would take 40 hours to program AHU scheduling and thermostat setbacks in Metasys at a rate of $150 per hour. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0	-
Labor Cost	$6,000	-
Rebate	$0	-
Total Implementation Cost	**$6,000**	-
COST SAVINGS		
Electric	$11,995	/year
Natural Gas	$4,137	/year
Total	$16,133	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$118,572	
IRR	269%	
Simple Payback	4.5	months

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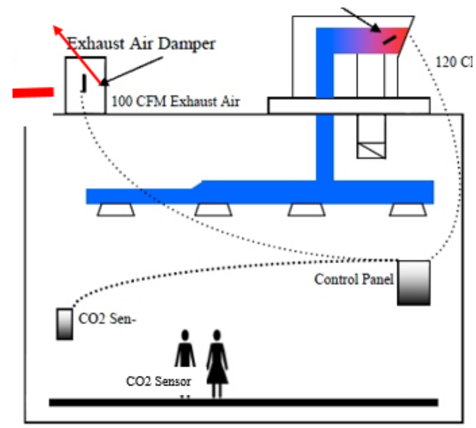
FH CER 4: Install Demand Control Ventilation

Implementation Cost				Annual Savings					Economics		
Material	Labor	Rebate	Total	Energy (kWh)	Demand (kW)	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$45,000	$17,340	$5,268	$57,072	52,682	0	2427	166	$17,255	3.3 years	$76,169	28%

Analysis

Mechanically ventilated spaces in commercial buildings will set the minimum amount of outdoor air entering a building based upon the ventilation required at full occupancy. However, buildings are frequently only partially occupied. A demand ventilation system works by measuring the amount of carbon dioxide released by the building occupants, so it can maintain indoor air quality while reducing the amount of ventilation air during times of partial occupancy. Fitz Hall operates with a fixed fraction of outdoor ventilation air while not economizing. The building cooling capacity related to occupant loads in AHUs with supply fan nameplate horsepower greater than 7.5 is 800 tons with an average COP of 6.4. The boiler system efficiency is 88% on average.



Recommendation

We recommend installing a CO2 sensor in the return ductwork to each air handling unit with a supply fan nameplate horsepower greater than 7.5 to measure the concentration of CO2 given off by occupants breathing and adjust the amount of ventilation air accordingly. This sensor should be incorporated into the Metasys building automation system for appropriate operation. This greatly reduces the amount of energy required to heat and cool spaces which are not constantly occupied. In schools, occupancy is typically very low during the summer months and allows this system to realize greater savings.

Expected Energy, Emissions and Cost Savings

To quantify the impact of reduced ventilation air, we simulated the energy use for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the amount of ventilation air brought into the school building currently as well as with the proposed CO2 sensor. The estimated occupancy and schedule are shown below as well as the energy calculations.

The cooling and heating temperature set-points are adjusted to include thermostat setback recommendation to prevent double counting savings when combined with other CERs.

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CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)	37	mmBtu/F-mo
Building Heating Balance Temperature (Tbal_h)	62.3	F
Building Cooling Slope (CS)	5,647	kWh/F-mo
Building Cooling Balance Temperature (Tbal_c)	31.7	F
Heating Efficiency (eta_h)*	88%	
Nameplate Cooling Efficiency (neta_c)	8.0	COP
Average Cooling Efficiency (eta_c)	6.4	COP
Nameplate Total Cooling Capacity (nCap_c)	1200	tons

ENGINEERING ASSUMPTIONS		
Sensible Heat Ratio (SHR)*	0.85	
Cooling Supply Air Temperature (SAT_c)*	57	F
Heating Supply Air Temperature (SAT_h)*	68	F
Economizer Low Limit (EconoLL)*	30	F
Economizer High Limit (EconoHL)*	70	F
Minimum Outdoor Air (MinOA)*	15%	
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

Occupancy rates are estimated, and AHUs are scheduled to be on 24/7 to prevent book degradation.

Hour of Day	Occupancy	Schedule (on/off)	Hour of Day	Occupancy	Schedule (on/off)
0:00	0%	0	12:00	80%	1
1:00	0%	0	13:00	80%	1
2:00	0%	0	14:00	80%	1
3:00	0%	0	15:00	80%	1
4:00	0%	0	16:00	50%	1
5:00	5%	0	17:00	20%	1
6:00	10%	0	18:00	20%	1
7:00	20%	1	19:00	10%	1
8:00	40%	1	20:00	10%	1
9:00	80%	1	21:00	5%	1
10:00	80%	1	22:00	0%	1
11:00	80%	1	23:00	0%	1

The building's hourly loads are calculated from the heating and cooling slopes found in the Lean Energy Analysis section. Savings from demand ventilation only occurs when the building is set to bring in the minimum amount of outdoor air. Therefore, the hours in the year corresponding to economizer operation are excluded. The current outdoor airflow is calculated based on the general HVAC design rule that a building should move 400 cfm of air per ton of cooling provided at design conditions. The minimum amount of outdoor air is expressed in HVAC designs is based on this value. In our calculation we propose reducing the amount of ventilation based on the estimated occupancy for each hour.

This calculation does not consider the significantly lower summer occupancy and therefore represents a conservative estimate of cooling savings.

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CALCULATIONS		
PARAMETER	EQUATION	UNITS
Hourly Building Heating Energy (BHE)	$HS*(Tbal\_h-Toa)^{+}/30.4/24$	mmBtu
Hourly Building Cooling Energy (BCE)	$CS*(Toa-Tbal\_c)^{+}/30.4/24$	kWh
Economizer Mode (EconoM)	IF(EconoHL>Toa>EconoLL,1,0)	0,1
Hourly Building Heating Load (BHL)	BHE/(HS*(Tbal_h-Tdesign_h)/30.4/24)	%
Hourly Building Cooling Load (BCL)	BCE/(CS*(Tdesign_c-Tbal_c)/30.4/24)	%
Current Outdoor Airflow (COA)	IF(Schedule=ON,MAX(BHL,CHL)*400*Cap_c*MinOA,0)	cfm
Current Hourly Heating Energy Use (C_BHE)	IF(Toa<Tbal_h,1.08*COA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Current Hourly Cooling Energy Use (C_BCE)	IF(Toa>SAT_c,1.08*COA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh
Proposed Outdoor Airflow (POA)	IF(EconoM=1,COA,COA*Occupancy)	cfm
Proposed Hourly Heating Energy Use (P_BHE)	IF(Toa<Tbal_h,1.08*POA*(SAT_h-Toa)/1000000/eta_h,0)	mmBtu
Proposed Hourly Cooling Energy Use (P_BCE)	IF(Toa>SAT_c,1.08*POA*(Toa-SAT_c)/3412/SHR/eta_c,0)	kWh

RESULTS			
ENERGY REDUCTION			
Proposed Annual Fuel Savings (Sf)	ΣC_BHE-ΣP_BHE	2,427	mmBtu/yr
Proposed Annual Electricity Savings (Se)	ΣC_BCE-ΣP_BCE	52,682	kWh/yr
COST SAVINGS			
Electric (Cost_e)	Sf*Ngcost	$15,232	/year
Natural Gas (Cost_ng)	Se*Ecost	$2,023	/year
Total Savings	Cost_e + Cost_ng	$17,255	/year

Implementation Cost and Investment Metrics

We estimate that it would cost $1,500 per CO_2 sensor for each AHU. It is also estimated to take 14 hours to program in Metasys at $150 per hour, and take two technicians, at $65 per hour, 4 hours to install each CO_2 sensor per AHU. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$45,000	-
Labor Cost	$17,340	-
Rebate	$5,268	-
Total Implementation Cost	**$57,072**	-
COST SAVINGS		
Energy	$17,255	/year
Demand	$0	/year
Total	$17,255	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$76,169	
IRR	28%	
Simple Payback	3.3	years

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FH CER 5: Reduce Excess Air to 10% in Steam Boilers

Implementation Cost			Savings			Economics		
Material	Labor	Total	Fuel (mmBTU)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$0	$260	$260	885	47	$5,552	1 months	$42,607	2135%

Analysis

Two 5,040 MBH rated output Bryan Steam Boilers provide steam to serve space heating equipment for the building. The boilers use linkages that connect natural gas supply valves with combustion air inlet dampers. In this configuration, combustion air intake is controlled based on natural gas input to the boiler. Excess air is not constant over the firing range, but increases as firing rate decreases, as shown below. It is estimated that these boilers operate 6,000 hours per year.

Bryan Boiler #1 in Fitz Hall

	Boiler #1			Boiler #2		
Firing Rate	low	medium	high	low	medium	high
Excess Air	46.7%	25.9%	31.7%	31.0%	25.1%	49.7%
Stack Temp (F)	379.2	413.9	496.5	364.2	399	463.5
Combustion Efficiency	83.3%	83.7%	81.5%	85.9%	85.8%	85.6%

The optimal excess combustion air in a gas heating system for energy efficiency and pollution prevention is about 10% ("Guide to Industrial Assessments for Pollution Prevention and Energy Efficiency", EPA/625/R-99/003), which yields an O_2 content of 1.7% in the exhaust gasses. Higher levels of excess air dilute the combustion stream and decrease the quantity of useful heat available to the process. Tuning the boiler's mechanical linkages to maintain a proper excess air ratio of 10% can improve efficiency and yield substantial natural gas savings.

Recommendation

We recommend tuning the two steam boilers to 10% excess air at high fire when regular boiler maintenance occurs. Since the modulating boilers are much smaller and not analyzed each season, they are not recommended to tune.

Expected Energy, Emissions and Cost Savings

The existing and proposed steam systems were modeled using SteamSim software (Kissock,2008). SteamSim is part of the UD-IAC Energy Efficiency Guidebook and is available free of charge at: http://academic.udayton.edu/kissock/http/research/EnergySoftware.htm.

Mechanical linkages must be tuned at high fire to prevent dropping below 10% excess air at lower firing rates. The inputs and outputs for both the current and proposed cases are shown in the following figures.

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CONSTANTS FOR NATURAL GAS		
Term	**Value**	**Unit**
LHV = lower heating value	21,500	Btu/lb
HHV = higher heating value	23,900	Btu/lb
cpp = specific heat of products of exhaust	0.300	Btu/lb-F
Tdpp = dew point temp of H20 in exhaust	140	F
AFs = air/fuel mass ratio at stochiometric conditions	17.2	

INPUTS			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Excess Air (EA) (0.1 = optimum, 0=stochiometric point)	0.348	0.353	
Combustion Air Temperature (Tca) (Before Burner)	70		F
Exhaust Gas Temperature (Tex)	429.8	408.9	F
Rated Output (RO)	5.04		mmBtu/hr
Fraction Loaded (FL)	0.5		
Operating Hours (HPY)	6,000		hr
Natural Gas Cost (Ncost)	6.27		$/mmBtu
PROPOSED			
Excess Air (EA) (0.1 = optimum, 0=stochiometric point)	0.1		

CALCULATIONS: CURRENT			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Temp combustion (Tc) = Tca+LHV/[(1+(1+EA)(Afs))cpp]	3034	3023	F
Water vapor latent energy (hfg) = (if Tex<140 then hfg=HHV-LHV else hfg = 0)	0	0	Btu/lb
Efficiency (E) = {hfg+[1 + (1+EA)(AFs)]*cpp*(Tc-Tex)}/HHV	0.790	0.796	
Heating Load (HL)= RO*FL	2.52	2.52	mmBtu/hr
Annual Fuel Consumption (NG1) = HPY*HL/E	19130	18987	mmBtu/yr
CALCULATIONS: PROPOSED			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Temp combustion (Tc) = Tca+LHV/[(1+(1+EA)(Afs))cpp]	3668	3668	F
Water vapor latent energy (hfg) = (if Tex<140 then hfg=HHV-LHV else hfg = 0)	0	0	Btu/lb
Efficiency (E) = {hfg+[1 + (1+EA)(AFs)]*cpp*(Tc-Tex)}/HHV	0.810	0.815	
Heating Load (HL)= RO*FL	2.52	2.52	mmBtu/hr
Annual Fuel Consumption (NG1) = HPY*HL/E	18676	18556	mmBtu/yr

By reducing the excess air in the boilers, their efficiency increases and corresponds to energy savings. Using the marginal cost of natural cost, annual cost savings can also be determined, as shown below.

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CALCULATIONS: SAVINGS			
Term	**Boiler 1**	**Boiler 2**	**Unit**
Total Fuel Savings (NG_save) = NG1-NG2	**455**	**431**	mmBtu/yr
Cost Savings (Csav) = NG_save*Ncost	**2,851**	**2,701**	$/yr
Carbon Dioxide Reduction = NG_save*[117 lb CO2/mmBtu]/[2205 lb/tonne]	**24**	**23**	tonnes CO2

Implementation Cost & Investment Metrics

Facilities management indicated that regular boiler maintenance already occurs, thus there is only a labor cost of $260 for two technicians to spend about an hour to tune the linkage on each boiler. The relative investment metrics are listed below, assuming a project lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$0	-
Labor Cost	$260	-
Rebate	$0	-
Total Implementation Cost	$260	-
COST SAVINGS		
Energy	$5,552	/year
Demand	$0	/year
Total	$5,552	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$42,607	
IRR	2135%	
Simple Payback	0.6	months

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FH CER 6: Relocate VFD Static Pressure Sensors on Supply Fans

Implementation Cost			Annual Savings				Economics		
Material	Labor	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$4,400	$11,440	$15,840	401,677	0	284	$15,424	1.0 years	$103,263	97%

Analysis

Fitz Hall SP Sensor

Of the 33 AHUs in Fitz Hall, 22 supply air fans are currently controlled by a static pressure sensor in the ductwork tied to a variable frequency drive (VFD) on the fan. At the time of the site visit, the VFD was running at high speed in very mild weather, and the static pressure sensors on the supply fans are located at the outlet of the supply fan in each AHU. This location for the static pressure sensor makes for simple installation. However, it requires a higher pressure set-point than if the sensor were in a remote location.

Recommendation

We recommend reinstalling the static pressure sensors on each of the 22 AHU supply fans to a remote location 2/3 of the distance through the ductwork in accordance with industry best practice.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of supply fans in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in fan power required based on regression data from ASHRAE as well as performance equations found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)	37.2	mmBtu/F-month
Building Heating Balance Temperature (Tbal_h)	62.1	F
Building Cooling Slope (CS)	5647	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	32.2	F
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

*Engineering Assumption

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CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Average AHU Fan Power Rating (HP_ave_all)	17.6	hp
Number of AHUs (N_AHU)	22	
Fraction Loaded @100% (FL)*	80%	
Minimum damper position (VAVpercent_open)	30%	
ASHRAE Fan Coefficient A	0.0013	
ASHRAE Fan Coefficient B	0.147	
ASHRAE Fan Coefficient C	0.9506	
ASHRAE Fan Coefficient D	0.0998	

CALCULATIONS			
PARAMETER	**HOURLY EQUATION**	**ANNUAL TOTALS**	
Current Hourly Cooling Energy Use (C_BCE)	CS*(Toa-Tbal_c)+/30.4/24	1,442,732	kWh
Building % Cooling Load (BFCL)	CCE/(CS*(Tdesign_c-Tbal_c)+/30.4/24)	34%	
Building % Heating Load (BFHL)	CHE/(HS*(Tbal_h-Tdesign_h)+/30.4/24)	24%	
Current AHU Energy Use (C_AHU)	FL*NFP*MAX(BFCL,BFHL)/eta_m	1,181,154	kWh
Proposed AHU Energy Usage (P_AHU)	FL*HP_all*.746*(A+xB^2+xC^2+xD^3)	779,478	kWh

RESULTS		
ENERGY REDUCTION & COST SAVINGS		
Annual AHU Savings (AHU_sav)	ΣCFP-ΣPFP	401,677 kWh/year
Electric Savings	AHU_sav*Ecost	$15,424 /year

Implementation Cost & Investment Metrics

We estimate the changes to the controls would take two technicians, paid $65/hour, about 124 hours to complete reinstall the sensors with another $6,200 in cables and other distance infrastructure. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$4,400	-
Labor Cost	$11,440	-
Rebate	$0	-
Total Implementation Cost	$15,840	-
COST SAVINGS		
Energy	$15,424	/year
Demand	$0	/year
Total	$15,424	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$103,263	
IRR	97%	
Simple Payback	1.0	years

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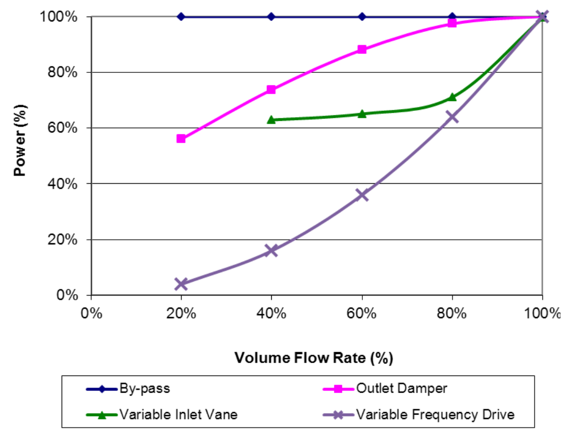
FH CER 7: Install VFDs on 7.5-HP AHU Supply Fans

Implementation Cost				Annual Savings				Economics		
Material	Labor / Overhead	Rebate	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback	10 year NPV	10 year IRR
$24,000	$17,040	$4,800	$36,240	148,050	0	105	$5,685	6.4 years	$7,659	9%

Analysis

Sixteen AHU supply fan motors were found without variable frequency drives (VFDs), therefore running based on the outlet damper. Significant energy savings can be realized by installing VFDs to more efficiently vary the motor power based on the required flow rates. These motors likely did not have VFDs installed because they were figured to be uneconomic due to their smaller size, 7.5-HP, however with rebates and lower VFD costs these can be economic today.



Fan Power & Flow Under Different Configurations

Recommendation

We recommend installing VFDs on all AHU supply motors with a nameplate power rating of 7.5-HP and above.

Estimated Energy, Emissions, and Cost Savings

To quantify the impact of better operational efficiency during different times of the year, we simulated the energy use of the AHUs in the facility for each hour in the year using Typical Meteorological Year data (TMY3) from Dayton, OH. Using the facility information and engineering assumptions shown in the table below, we calculated the change in AHU power based on regression data from ASHRAE as well as performance equations found the Energy Efficiency Guidebook (Kissock, 2003).

CURRENT BUILDING INFORMATION		
Building Heating Slope (HS)	37.2	mmBtu/F-month
Building Heating Balance Temperature (Tbal_h)	62.1	F
Building Cooling Slope (CS)	5647	kWh/F-month
Building Cooling Balance Temperature (Tbal_c)	32.2	F
Heating Design Temperature (Tdesign_h)*	0	F
Cooling Design Temperature (Tdesign_c)*	95	F

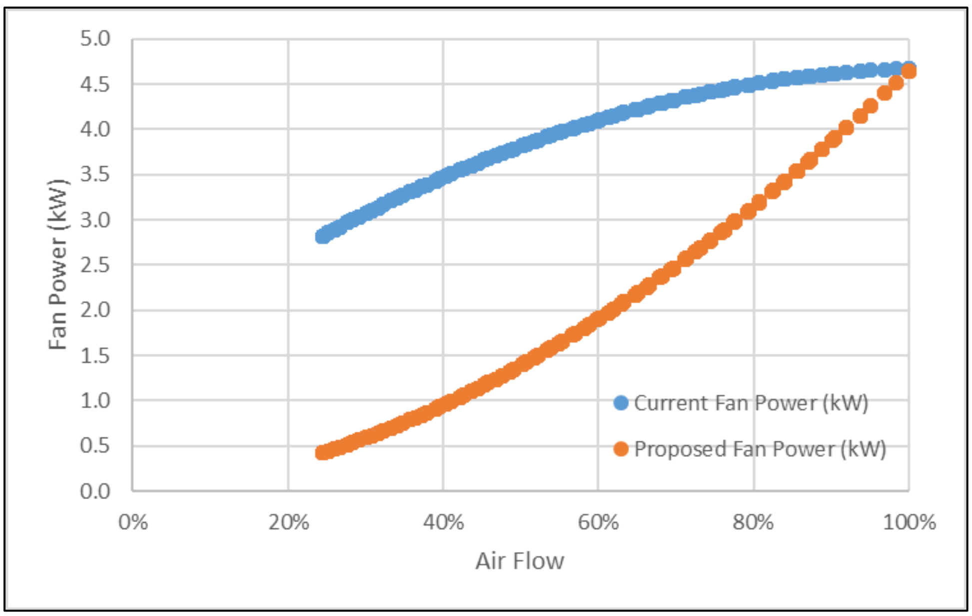
*Engineering Assumption

CURRENT AHU INFORMATION		
Fan Motor Efficiency (eta_m)	90%	
Average AHU Fan Power Rating (HP_ave_all)	7.5	hp
Number of AHUs w/out vfd (N_AHU)	16	
Fraction Loaded @100% (FL)*	75%	
Minimum damper position (VAVpercent_open)	5%	
Outlet Damper Fan Coefficient A	0.3282	
Outlet Damper Fan Coefficient B	1.2923	
Outlet Damper Fan Coefficient C	-0.6163	

*Engineering Assumption

PROPOSED INFORMATION		
AHU Fan Power w/ VFD (HP_vfd)	7.5	hp
ASHRAE VFD Fan Coefficient A	0.0013	
ASHRAE VFD Fan Coefficient B	0.147	
ASHRAE VFD Fan Coefficient C	0.9506	
ASHRAE VFD Fan Coefficient D	0.0998	
Minimum damper position (VAVperc_open_prop)	5%	

Utilizing the VFDs reduces the fan motor power draw significantly during low flow requirements, as shown below.



CALCULATIONS			
PARAMETER	**HOURLY EQUATION**	**ANNUAL TOTALS**	
Current Hourly Cooling Energy Use (C_BCE)	CS*(Toa-Tbal_c)+/30.4/24	1,442,732	kWh
Building % Cooling Load (BFCL)	CCE/(CS*(Tdesign_c-Tbal_c)+/30.4/24)	34%	
Building % Heating Load (BFHL)	CHE/(HS*(Tbal_h-Tdesign_h)+/30.4/24)	24%	
Current AHU Energy Use (C_AHU)	FL*HP_ave_all*.746*(A+xB+xC^2)/eta_m	271,724	kWh
Proposed AHU Energy Usage (P_AHU)	FL*HP_ave_all*.746*(A+xB+xC^2+xD^3)/eta_m	123,674	kWh

RESULTS		
ENERGY REDUCTION & COST SAVINGS		
Annual AHU Savings (AHU_sav)	ΣCFP-ΣPFP	148,050 kWh/year
Electric Savings	AHU_sav*Ecost	$5,685 /year

Implementation Cost & Investment Metrics

Based on mechanical cost data from RS Means 2012, each VFD installation would cost $1,500 in material, $615 in labor (only requiring 1 installer), and $450 in overhead. DP&L also offers rebates of $40/HP for VFDs, or $300 per 7.5-HP motor. For 16 VFDs, this results in a total implementation cost of $36,240. In calculating NPV and IRR, energy and cost savings are assumed to have a lifespan of 10 years.

ECONOMICS		
IMPLEMENTATION COST		
Material Cost	$24,000	-
Labor Cost	$17,040	-
Rebate	$4,800	-
Total Implementation Cost	$36,240	-
COST SAVINGS		
Energy	$5,685	/year
Demand	$0	/year
Total	$5,685	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	$7,659	
IRR	9%	
Simple Payback	6.4	years

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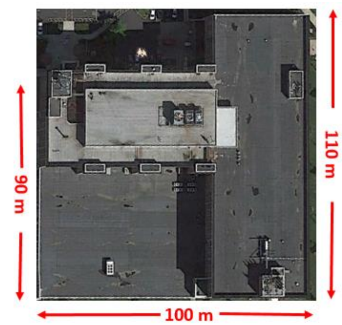
FH CER 8: Install 175 kW Rooftop Solar PV System

Implementation Cost			Annual Savings				Economics		
Capex	ITC	Total	Energy (kWh)	Demand (kW)	MTCO2	US Dollars	Simple Payback (years)	25 year NPV	25 year IRR
$306,250	$0	$306,250	231,141	31	164	$12,008	25.5	-$137,003	0%

Analysis

Fitz Hall has an upper east-rooftop area of around 3,630 square meters, penthouse top rooftop of around 1,000 square meters, and 2nd Floor rooftop of around 3,250 square meters. The rooftop of the penthouse sees ample sunlight throughout the year, as well as the south half of the east-upper rooftop. The 2nd Floor roof has significant shading on its east half throughout the year. The rooftop areas unobstructed by equipment and shade can be utilized for energy generation with solar PV panels. Facilities Management is currently negotiating around a 600 kW solar PV rooftop array on Fitz Hall but the project has stalled, potentially due to financing. By consolidating energy efficiency recommendations in this report for Fitz Hall with solar PV, partial financing for the project could be provided through the Green Revolving Fund.



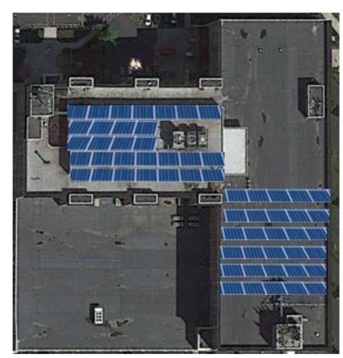
Rooftop Area

Recommendation

We recommend installing a 175 kW-DC solar PV array on the Fitz Hall upper-east rooftop and penthouse roof. While a larger capacity system is potential by utilizing more of the upper-east and 2nd Floor rooftop, its capital investment would bring the overall simple payback for Fitz Hall CERs above the maximum 5 year payback for Green Revolving Fund projects.

Expected Energy, Emissions and Cost Savings

The total area entirely unobstructed from shade of nearby objects, mainly the south half of the main roof and all of the penthouse roof, was determined to be around 2,000 m2. After factoring in spacing from arrays tilted at 30 degrees, it was determined that a total area of around 900 m2 could be utilized for solar PV. Assuming a system with generic 330 W, 1.67 m2 solar panels, this would be around 175 kW-DC. However, once inverter losses of 2.5% converting from DC to AC, and 10% losses from other factors such as soiling, mismatch, light-induced degradation, and partial shading are taken into account, the AC capacity would be around 154 kW (NREL, 2014).


Rooftop Area with solar PV

To quantify the potential energy generation from the 8- kW solar PV aray, the annual solar radiation was determined by using NASA average daily horizontal radiation for each month for Dayton Ohio, downloaded from https://eosweb.larc.nasa.gov/sse/RETScreen/. This yields annual solar radiation of 1384 kWh/m2 for a horizontal surface, and after calculating increases from tilting the panels 30 degrees south, 1534 kWh/m2. This results in a DC capacity factor of 17.5%.

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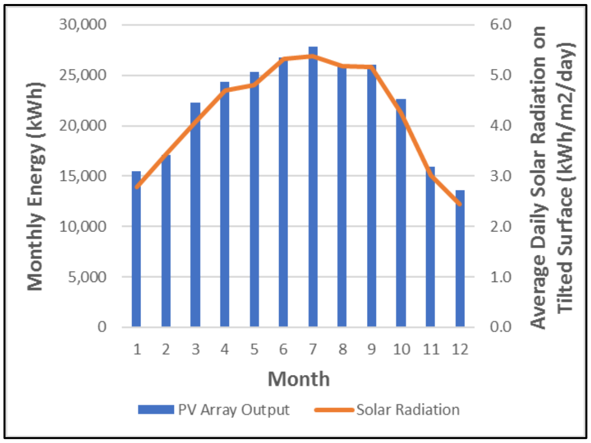

The system's annual generation can then be determined by multiplying the capacity factor by its AC capacity. Monthly demand savings are assumed to be 20% of the solar system's AC capacity. The corresponding cost savings are based on the marginal costs of energy and demand.

RESULTS		
ENERGY REDUCTION AND COST SAVINGS		
Electrical Demand	**30.7**	kW
Electrical Consumption	**231,141**	kWh/year
Electrical Demand Cost	**$3,133**	/year
Electrical Consumption Cost	**$8,876**	/year
Total Electricity Cost	**$12,008**	/year

Implementation Cost & Investment Metrics

The total cost is based on an assumption of $1.75/W-DC, assuming all solar PV recommendations is this report are done in tandem for a total system rate closer to 500 kW. The investment tax credit is not applicable to UD, as they are exempt from federal taxes under 501(c)(3). However, depending on the outcome of Congress' 2017 bill to tax endowment income, this may change.

ECONOMICS		
IMPLEMENTATION COST		
Total Cost	$306,250	-
Rebate	$0	-
Total Implementation	**$306,250**	-
COST SAVINGS		
Energy	$8,876	/year
Demand	$3,133	/year
Total	$12,008	/year
INVESTMENT METRICS		
Discount Rate	5%	
Net Present Value	($137,003)	
IRR	0%	
Simple Payback	25.5	years

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APPENDIX

CO_2 Emission Factors

1.95 lb. CO_2/kWh is the 2017 RFC West regional average from EPA Year 2016 eGRID

4.08 x 10-4 metric tons CO2E/vehicle-mile defined as 2-axle 4-tire vehicles, including passenger cars, vans, pickup trucks, and sport/utility vehicles (EPA, 2017)

117 lb. CO_2/MMBtu natural gas is from "Benchmarking Air Emissions Largest Electrical Producers in the U.S.", National Resources Defense Council, www.nrdc.org, 2006.

Financing and Incentives

Several options are available for implementing the recommendations in this report. Simple recommendations can be implemented in-house; more complex and costly recommendations may require additional engineering, financing or management services. The following list offers a few options; it is not, however, meant to be comprehensive.

Overview of Federal, State and Utility Energy Efficiency Incentive Programs

An up-to-date overview of federal, state and utility energy-efficiency incentive programs is available at: http://www.dsireusa.org/.

Electric Utility Rebate Programs

Ohio's electric utilities provide rebates for energy efficiency projects ranging from lighting upgrades and VFD motor controls to custom incentives based on energy savings. The rebate programs for each utility are listed below.

AEP Ohio - https://www.aepohio.com/save/business/programs/
Dayton Power & Light - http://www.dpandl.com/save-money/business-government/

Ohio Financing Programs

Ohio Development Services Agency

The Ohio Development Services Agency's Advanced Energy and Efficiency Programs provides funding through the Energy Efficiency Program for Manufacturers and the Energy Loan Fund.

The Energy Efficiency Program for Manufacturers is a multi-phase energy efficiency program that helps Ohio manufacturers to reduce their costs through facilitation services and financial assistance that diagnose, plan, and implement cost-effective energy improvements at their facilities:

https://development.ohio.gov/summary_07energyefficiencyprogram.htm.

The Energy Loan Fund is a program that provides low-cost financing to small businesses, manufacturers, nonprofits, and public entities for energy improvements that reduce energy usage and associated costs, reduce fossil fuel emissions, and/or create or retain jobs: http://development.ohio.gov/bs/bs_energyloanfund.htm.

Ohio Environmental Protection Agency

The Ohio Environmental Protection Agency's Office of Compliance Assistance and Pollution Prevention (OCAPP) is a non-regulatory program that provides information and resources to help small businesses comply with environmental regulations. OCAPP also helps customers identify and implement pollution prevention (P2) measures that can save money, increase business performance and benefit the environment. Services of the office include a toll-free hotline, on-site compliance and P2 assessments, workshops/training, plain-English publications library and assistance in completing permit application forms: http://epa.ohio.gov/ocapp/ComplianceAssistanceandPollutionPrevention.aspx.

Furthermore, the Ohio Environmental Protection Agency provides financing information for environmental projects including grant, loan and tax incentive programs: http://epa.ohio.gov/ocapp/funding.aspx.

Lighting Information

Building Area & Task	Average Maintained Footcandles (Horizontal) (FC)	Range of Maintained Footcandles (Horizontal) (FC)
WAREHOUSING & STORAGE		
Bulky Items—Large Labels	10	
Small Items—Small Labels	30	
Cold Storage	20	10 - 30
Open Warehouse	20	10 - 30
Warehouse w/Aisles	20	10 - 30
COMMERCIAL OFFICE		
Open Office	40	30 - 50
Private Office	40	30 - 50
Conference Room	30	
Restroom	18	7.5 - 30
Lunch & Break Room	15	5 - 20
EDUCATIONAL (SCHOOLS)		
Classroom	40	30 - 50
Gymnasium		
Class I (Pro or Div. 1 College)	125	
Class II (Div. 2 or 3 College)	80	
Class III (High School)	50	
Class IV (Elementary)	30	
Auditorium	7.5	3 - 10
Corridor	25	10 - 40

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LED 4-ft FT8 replacement specifications

View Specifications

(37)

5000 Kelvin - 2100 Lumens - 15W - LED - F32T8/F40T12 Replacement - 120-277V - Ballast Must Be Removed

Brand: LifeBulb
MPN (Part No.): LBP8F2150B
Dimmable: No
Color Temperature: 5000 Kelvin
Life Hours: 50,000
Wattage: 15 Watt
Lumens: 2,100
Voltage: 120, 208, 240, 277
Fluorescent Equal: 32 Watt
Operation: Ballast Bypass
Length: 48 in.
Diameter: 1 in.

$8.25 ea.

Quantity

1

Add to Cart

PLT-10852

View Specifications

(48)

5000 Kelvin - 1800 Lumens - 12.5W - LED- F32T8 Replacement - 120-277V - Ballast Must Be Removed - Case of 16

Brand: LifeBulb
MPN (Part No.): LBP8F1750B-CS
Dimmable: No
Color Temperature: 5000 Kelvin
Life Hours: 50,000
Wattage: 12.5 Watt
Lumens: 1,800
Voltage: 120, 208, 240, 277
Fluorescent Equal: 32 Watt
Operation: Ballast Bypass
Length: 48 in.
Diameter: 1 in.

4.0

$5.99 ea.
Sold only by the Case of 16 for $95.84

Quantity

1

Add to Cart

LEDT-10025CS

2-ft FT8 specifications

View Specifications

USHIO (5)

Ushio 3000261 - F17T8/841 - 2 ft. - 17 Watt - T8 - 1400 Lumens - 4100K - 800 Series Tri-Phosphors

Brand: Ushio
Safety Rating: Not Applicable
Color Temperature: 4100 Kelvin
Bulb Type: F17T8
Life Hours: 30,000
Wattage: 17 Watt
Lumens: 1,400
Base Type: Bi-Pin
Diameter: 1 in.
Case Quantity: 25

$1.65 ea.

Quantity

1

Add to Cart

USH-3000261

LED 2-ft FT8 Replacement specifications

View Specifications

(6)

4100 Kelvin - 1100 Lumens - 9W - LED - F17T8 Replacement - 120-277V - Ballast Must Be Removed

Brand: LifeBulb
MPN (Part No.): LBP8F1241B
Dimmable: No
Color Temperature: 4100 Kelvin
Life Hours: 50,000
Wattage: 9 Watt
Lumens: 1,150
Voltage: 120, 208, 240, 277
Fluorescent Equal: 17 Watt
Operation: Ballast Bypass
Length: 24 in.
Diameter: 1 in.

4.0

$5.99 ea.

Quantity

1

Add to Cart

LEDT-10020

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CFL specifications

(3)

GE 97608 - F26DBX/835/ECO - 26 Watt - 2 Pin G24d-3 Base - 3500K - CFL

Brand: GE
CRI: 82
Color Temperature: 3500 Kelvin
Life Hours: 10,000
Wattage: 26 Watt
Lumens: 1,710
Base Type: G24d-3
TCLP: Compliant
Case Quantity: 10

View Specifications

$2.14 ea.

Quantity

1

Add to Cart

FC26-G26059

LED - CFL replacement specifications

Light Efficient Design

LED PL Lamp - 10 Watt - 2-Pin G24d - 26W CFL Equal - 1043 Lumens - 3500 Kelvin - Vertical Mount - 120-277V - Ballast Must Be Removed

Brand: Light Efficient Design
MPN (Part No.): LED-7306-35A
UPC: 844006073077
Life Hours: 50,000
Wattage: 10 Watt
Lumens: 1,043
Voltage: 120, 208, 240, 277
Base Type: 2-Pin, G24d
CFL Equivalent: 26 Watt
Burn Position: Vertical
Operation: Ballast Bypass, Plug and Play

View Specifications

$10.20 ea.

Quantity

1

Add to Cart

LED-730635A

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