

Calvin
COLLEGE



1876

Operational Efficiency Project

Engineering 333 - Thermal Systems Design

Professor Heun

Fall 2015

The Problem

\$124,514,962 in total operating expenses (2014)

~ \$90 million in debt

\$3,151,413.57

Utilities 2014-2015

The Proposal (2014-2015)

Offer - \$600,000 savings

Challenges – Measurement and verification

Opt to pursue savings internally

The Project

What would it take for Calvin College to save

\$600,000 per year

on campus operations?



SE



CFAC



Science Complex



Spoelhof Complex



KHvR

Lighting

HVAC

Water and
Extra Buildings

Executive



Presentation Outline

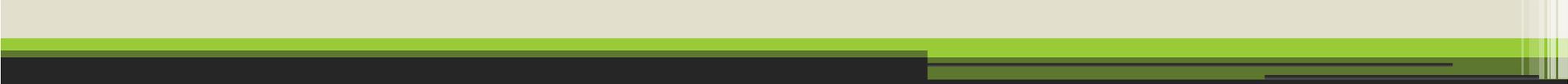
Cost-Saving Models and Project Initiatives

Building Teams

Major Project Implementation

Special Projects

Project Totals and Summary



Major Cost-Saving Project Initiatives

Major Cost-Saving Project Initiatives

Lighting LED conversion

Thermostat adjustments

Window improvements

Heat recovery ventilators

Water savings

LED Conversion

<http://www.thejewelrylightingexperts.com/store/wp-content/uploads/2012/01/t8LED.jpg>



http://image.dhgate.com/albu_485628563_00-1.0x0/t8-1-2m-double-lighting-fixture-brackets.jpg



SB 120 (Current)
3 bulbs per fixture
30 watts/bulb
90 Watts

De-lamp and replace with LED's
2 bulbs per fixture
18 watts/bulb
36 Watts

New LED fixtures
2 bulbs per fixture
As low as 12 watts/bulb
24 Watts

Lighting Model

B	C	D	E	F	G	AA	AD	AE	AF
Room Number	Room Type	Number of Fixtures	Type of Fixture	New # of Fixtures	New Type of Fixture	total fixture costs	Rebate	Steady-State Savings	Payback period (Years)
Science Stairwells	Hallway	64	4' - 2 bulb T8	32	4' - 2 bulb LED	\$ 6,576.00	\$ 1,075.20	\$ 882.77	6.23
SB Hallways (Cove)	Hallway	438	4' - 2 bulb T8	200	4' - 1 bulb LED	\$ 23,300.00	\$ 9,232.00	\$ 7,667.28	1.83
SB 120	ENGR Labs	17	4' - 3 bulb T8	17	2' - 2 bulb LED	\$ 2,813.50	\$ 448.80	\$ 623.08	3.80
SB 103	Classroom	14	4' - 3 bulb T8	14	2' - 2 bulb LED	\$ 2,317.00	\$ 369.60	\$ 196.50	9.91

Lighting: Measurement and Verification

Hours of operation

HOBO sensors

data from CERF

(Calvin Energy Recovery Fund)



Thermostat Adjustment Initiative

Summer

72°F

Winter

70°F



75°F

69°F

<http://blog.doctoroz.com/wp-content/uploads/2014/01/thermostat.jpg>

\$0 Implementation

Thermostat Adjustment Model

Square Footage



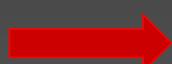
Outside Temp



Thermostat Setting



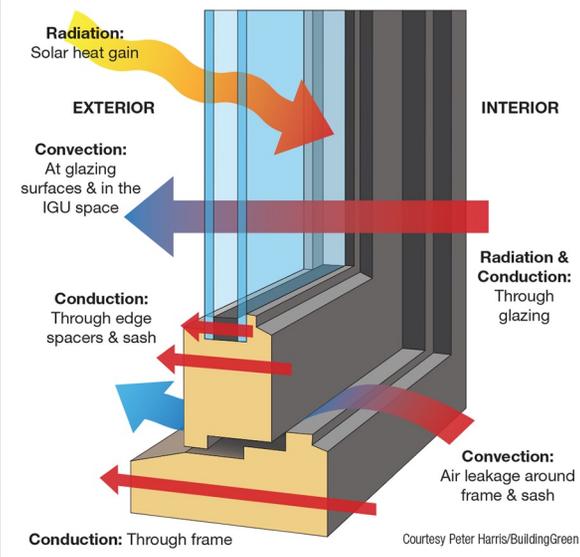
Energy Costs



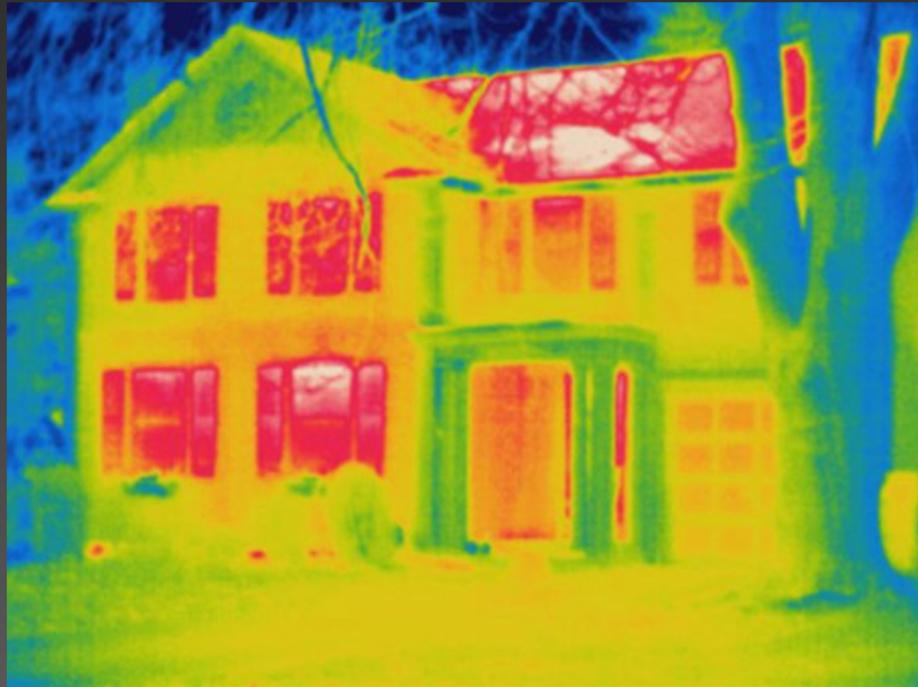
Cost Savings

Heat Loss Through Windows

Heat Transfer Through a Window



<http://www.homepower.com>



<http://www.bbc.co.uk>

Windows Model Savings

Low-E Coatings



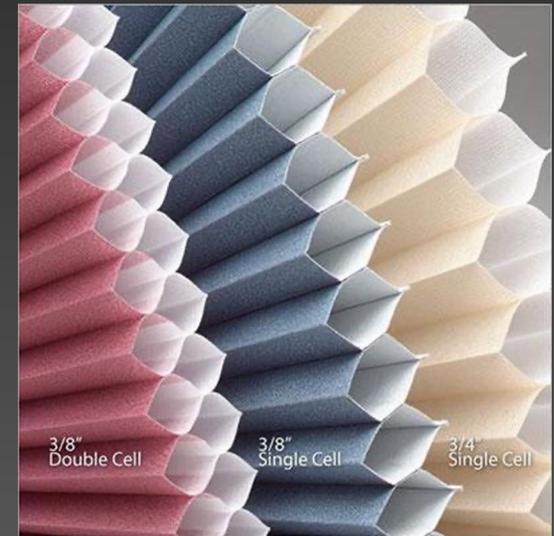
<http://www.delathomes.net>

Double Pane Windows



<http://www.nachi.org>

Cell Shades



<http://www.colorwiseandmore.com>

Windows Model

of Single Panes



of Windows



Area of Windows



Directional Window sets (SE, NW, etc.)



Seasonal Outdoor Temperatures



EES



Heat Flux out



Solar Heat Gain



Cost Savings

Effectiveness of Cost Savings



<http://www.lushome.com>

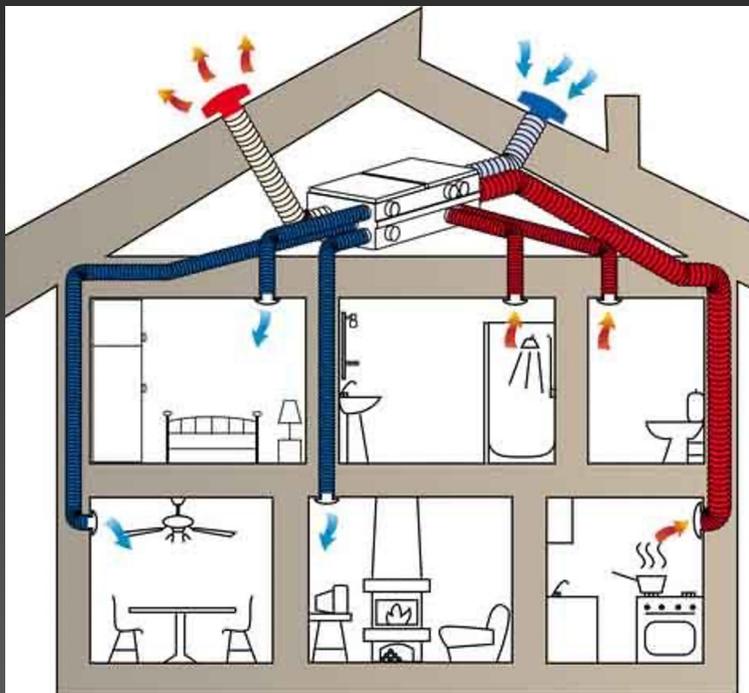


<http://innumerablegoods.typepad.com>

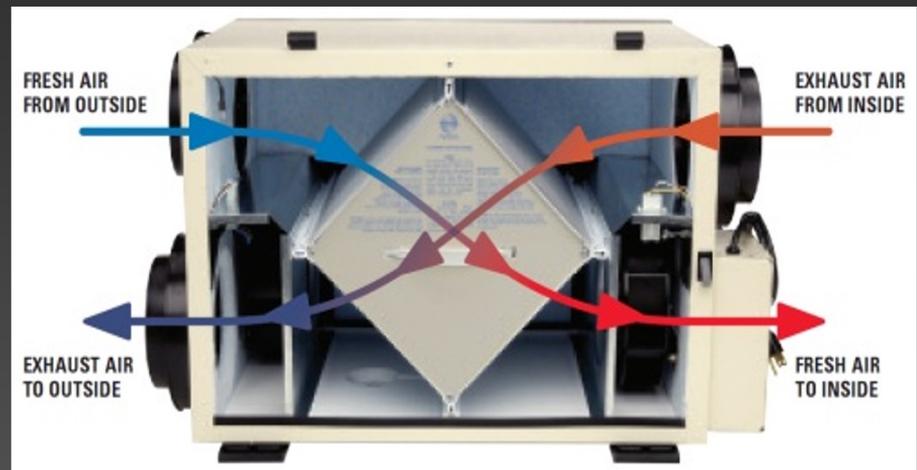
Window Improvements: Implementation Suggestion

Recommend low E-coatings only.

Heat Recovery Process



www.carnationconstruction.com



www.sustainablehomes.ie

Heat Recovery Model

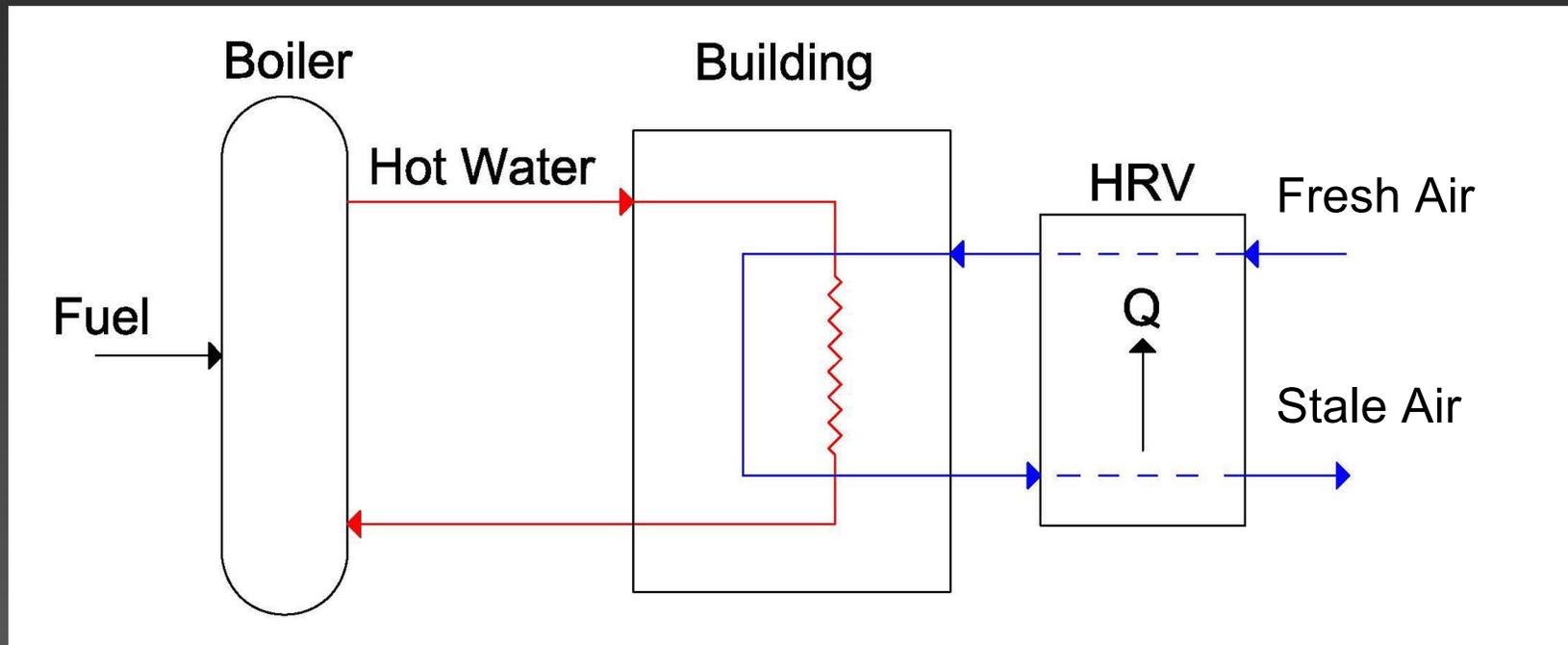


Figure 1. Building Model

Heat Recovery Ventilator Model

Air Flow Rate



*Interior and
Exterior Temps*



Boiler Effectiveness



HRV Effectiveness



EE_S



Q, heat transfer



Cost Savings

Heating Recovery: Measurement and Implementation

- 1. Temperature sensors at inlet and outlet of fresh air flow through HRV*
- 2. Flow meter in the fresh air flow*

Heat Recovery Ventilation: Implementation Suggestion

Recommend for new building constructions on campus and existing large buildings, such as SFC and CFAC.

Water: Reduce Shower Times



http://www.macdonaldindustries.co.nz/Cache/Pictures/1177197/6_DE711000-Image.jpg



https://www.inkhead.com/eco-water-saver-shower-timer/14729/?refypeid=11&adpos=1o2&creative=58961566743&device=c&matchtype=&network=g&gclid=CITVv6ezmckCFYM_aQodg_AMAQ

Shower Time Reduction Model

Number of Students



Student Utilization



Initial Shower Time



Water Heating Cost



EES



Cost Savings

Extra Buildings



Extra Buildings: Hekman Library



<http://www.calvin.edu/chimes/wp-content/uploads/2014/09/hekman-564x272.jpg>

Extra Buildings: KDH Steam Boiler Replacement



<http://www.burnhamcommercial.com/assets/images/product-high-eff-steam.jpg>

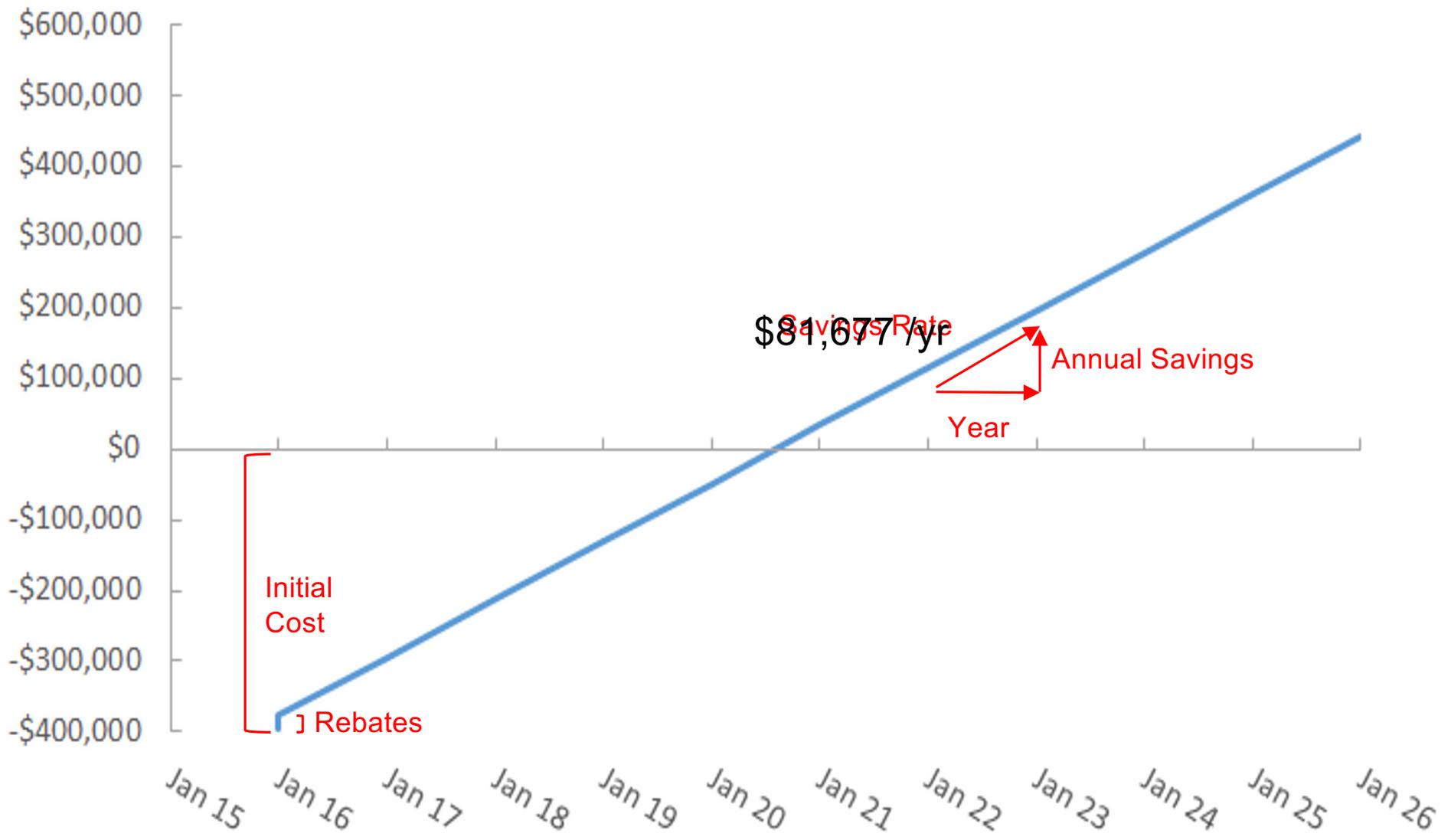
Extra Buildings: Parking Lot Lighting



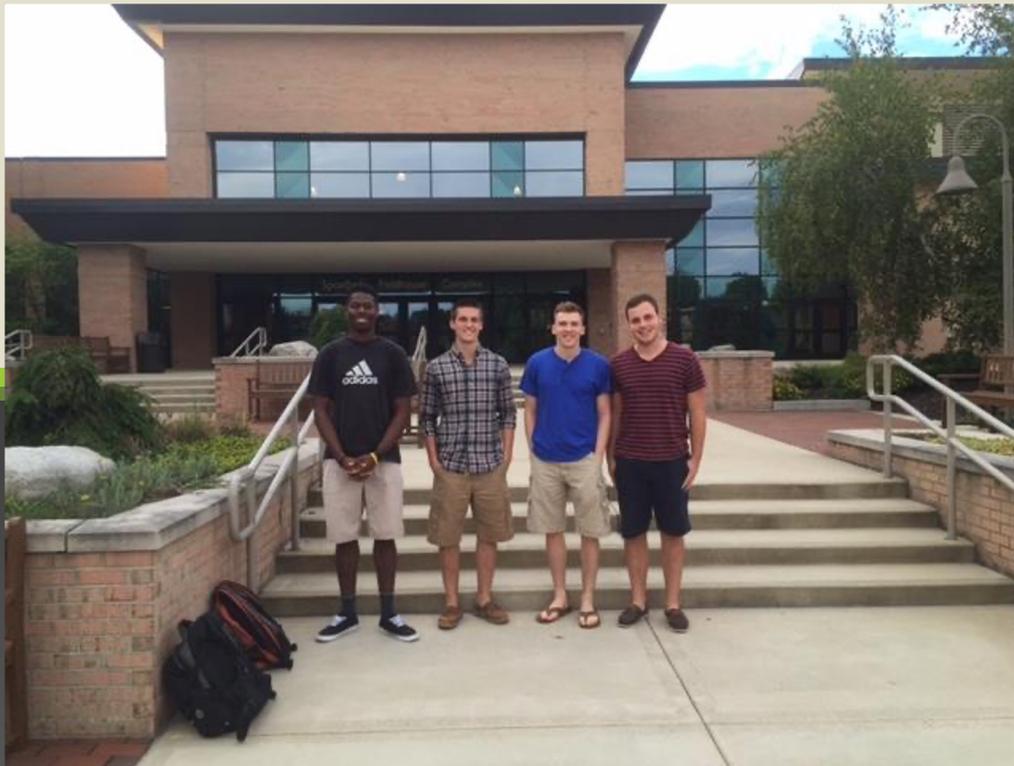
<http://www.wayfair.com/150w-MHPS-MT-Roadway-Cobra-Post-Head-with-Flat-Glass-in-Gray-DEK1853.html?>



http://cms.ipressroom.com.s3.amazonaws.com/149/files/20131/512258e629371a50fe000cd1_GE_EvolveScalableAreaLight/GE_EvolveScalableAreaLight_88028037-55d3-4446-9641-a668cb51f827-prv.jpg



Building Team Summaries



Spoelhof Fieldhouse Complex

Team Members:

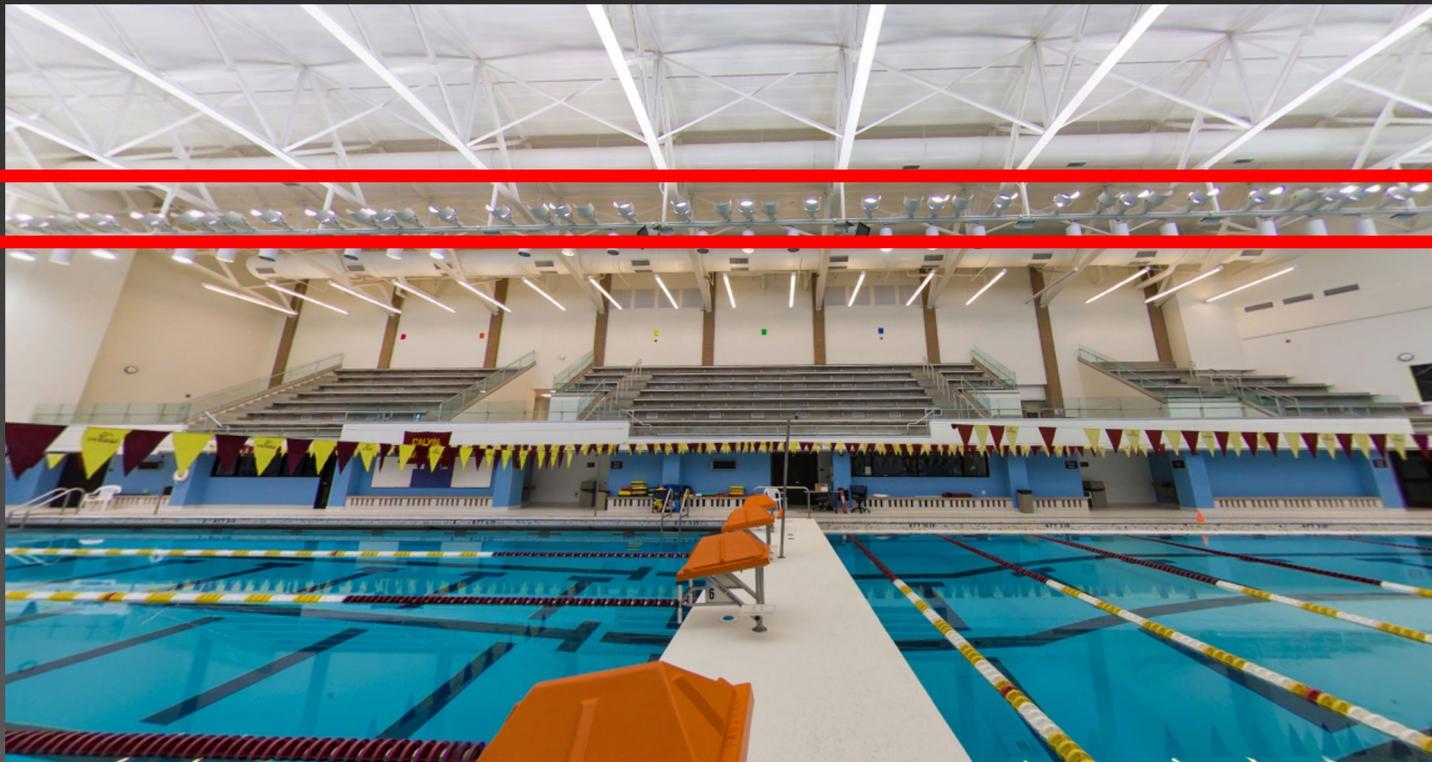
Justin Cooper

Ross Tenney

Philip Van Strien

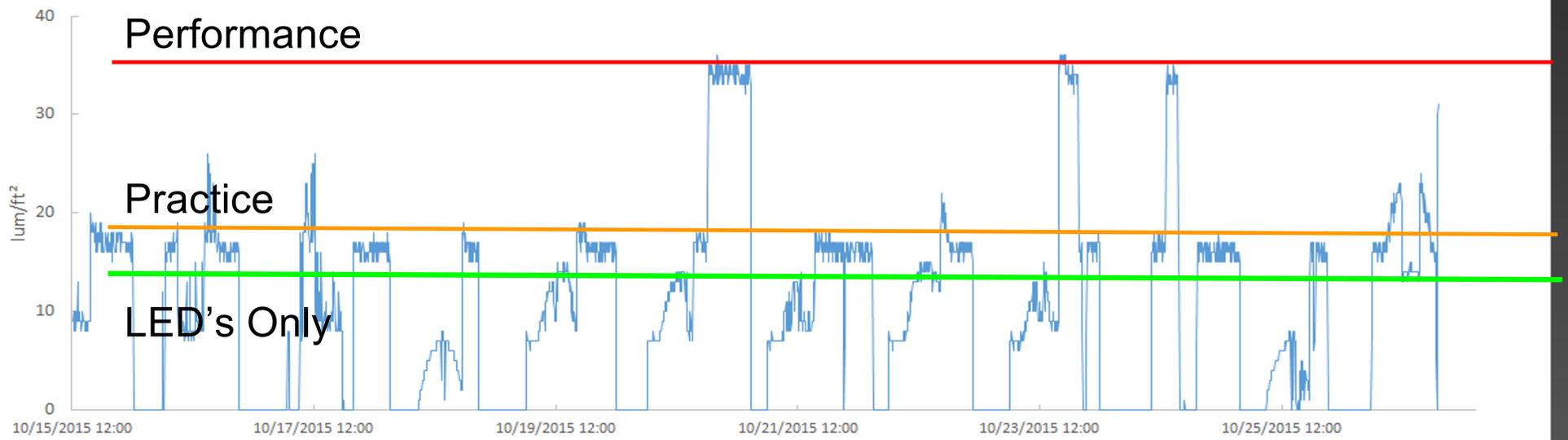
Zach Veenstra

Performance Lights

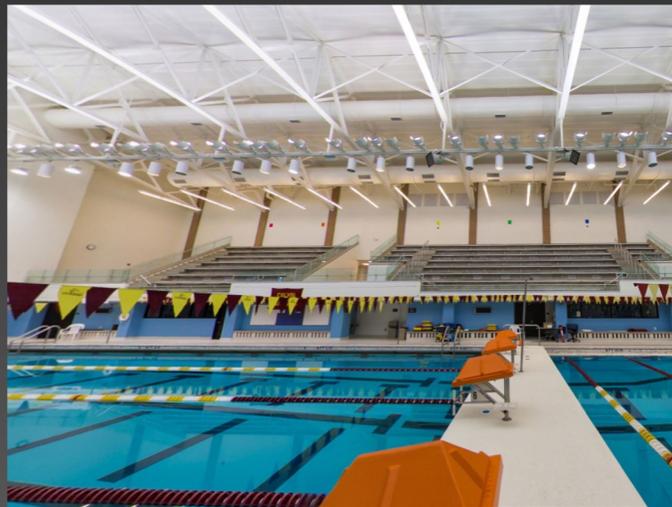


Performance Lights

Performance Light Usage in Aquatic Center (10/15 - 10/26)



Lighting - Sporting Event Lights



<http://www.youvisit.com/tour/panoramas/calvin/80759?id=24455>



Pool Cover

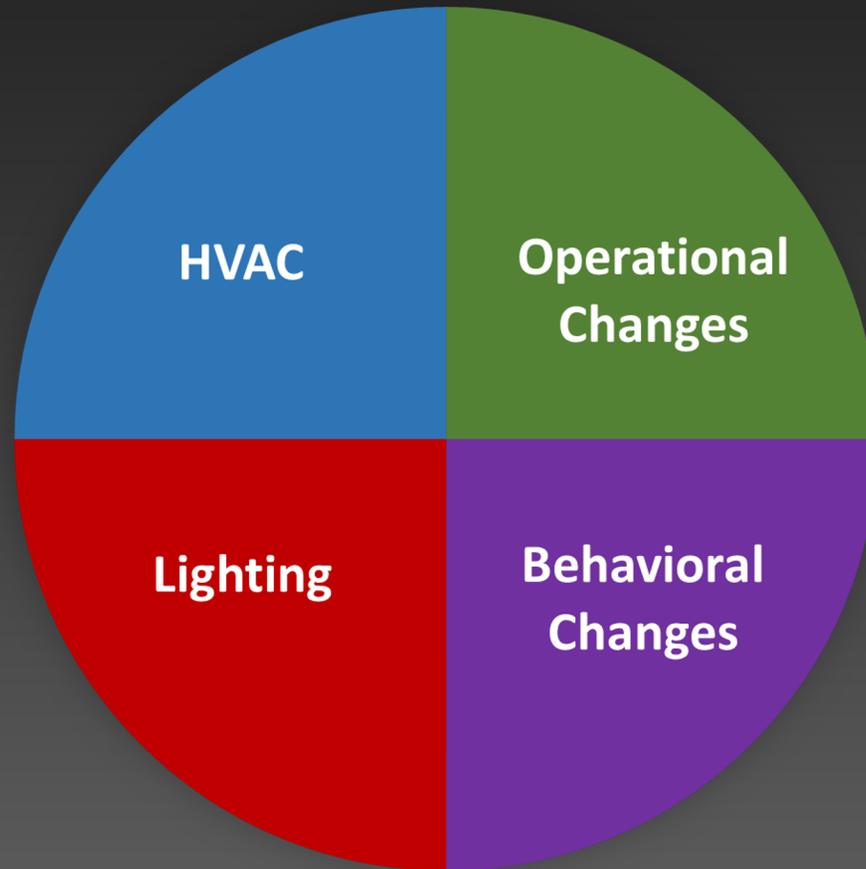


<http://www.calvin.edu/academic/pe/facilities/venema.htm>

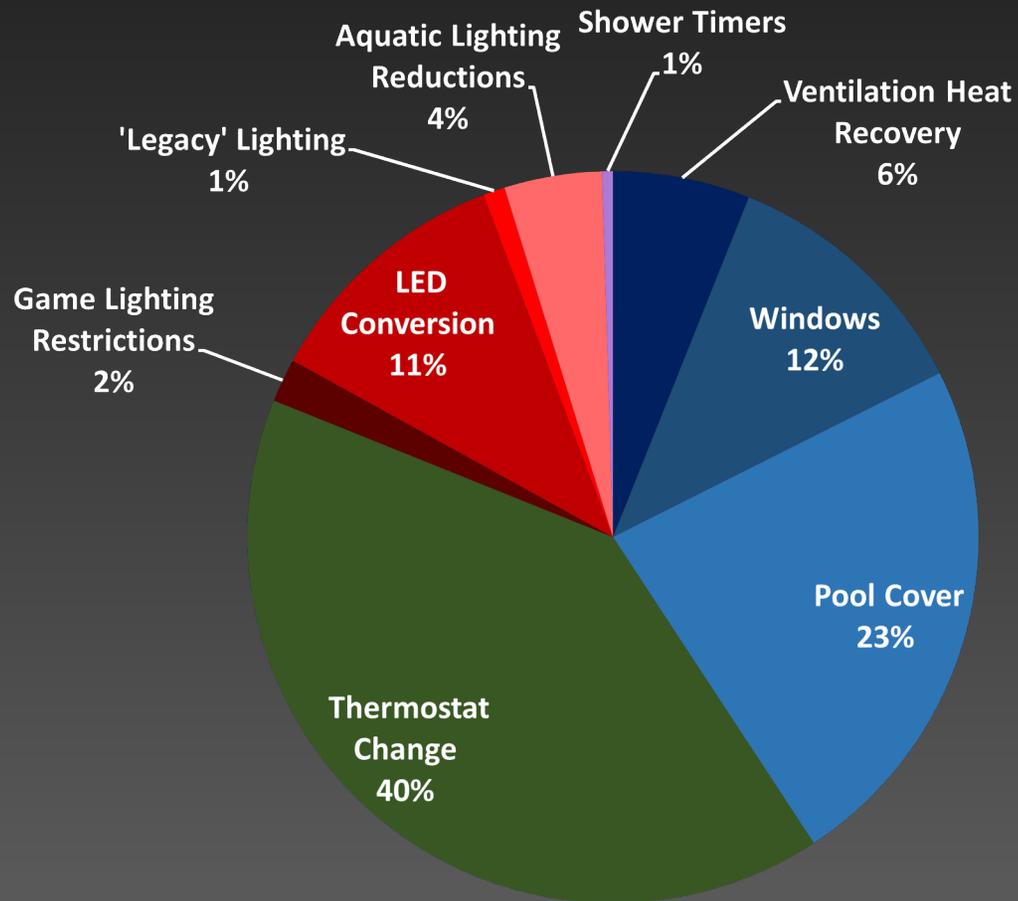
Fieldhouse Savings Opportunities

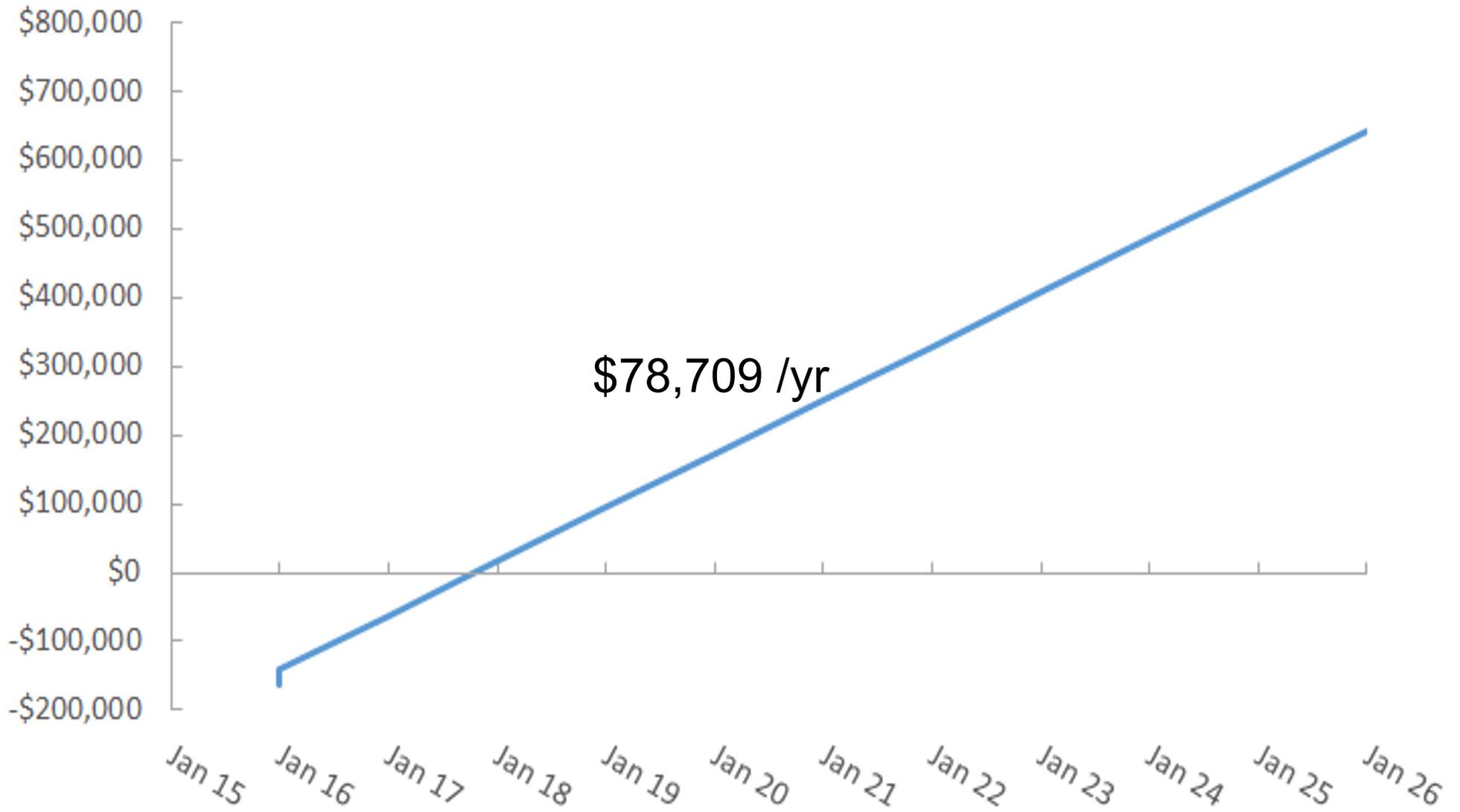
Project	Initial Cost	Rebate	Annual Savings	Payback Period
LED Lighting Conversion	\$ 94,120	\$ 14,620	\$ 8,768	9.07 years
Windows - Reflective Coating	\$ 7,740	\$ 1,461	\$ 9,009	0.70 years
Heat Recovery	\$ 33,195	\$ 0	\$ 4,732	7.02 years
Thermostat Change	\$ 0	\$ 0	\$ 31,500	0 years
Behavioral- Shower Time Reduction	\$ 482	\$ 0	\$ 373	1.29 years
Legacy Lighting	\$ 0	\$ 0	\$ 750	0 years
Game Lighting Restrictions	\$ 0	\$ 0	\$ 1,500	0 years
Aquatic Center Practice Lighting Reduction	\$ 0	\$ 0	\$ 3,374	0 years
Pool Cover	\$ 27,000	\$ 6,728	\$ 18,073	1.12 years
Totals	\$ 162,537	\$ 22,809	\$ 78,079	1.79 years

Project Breakdown Chart



Fieldhouse Savings Opportunities







KHvR

Team Members:

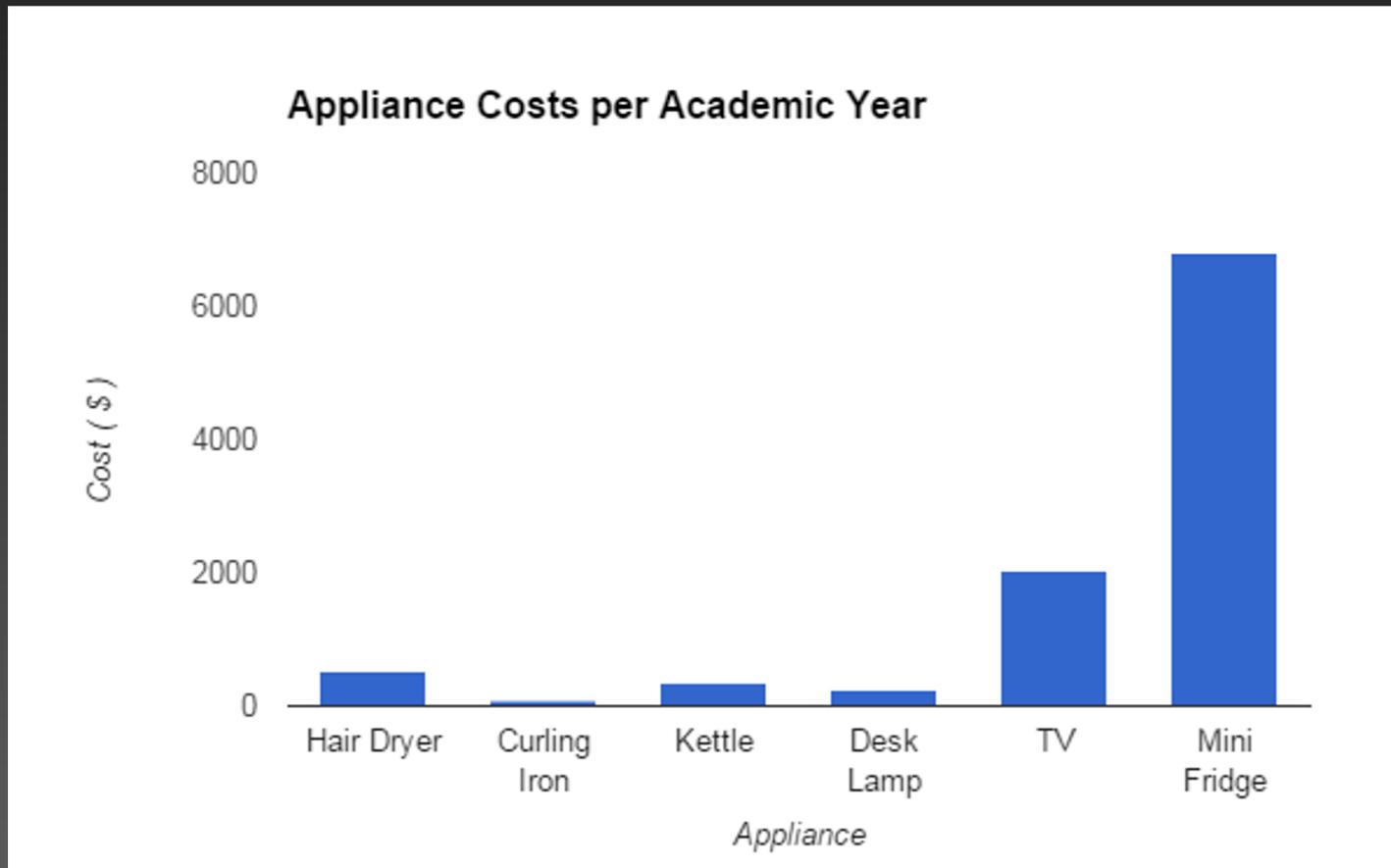
Ayo Ayoola

Hanfei Niu

Kemal Talen

Dalton Veurink

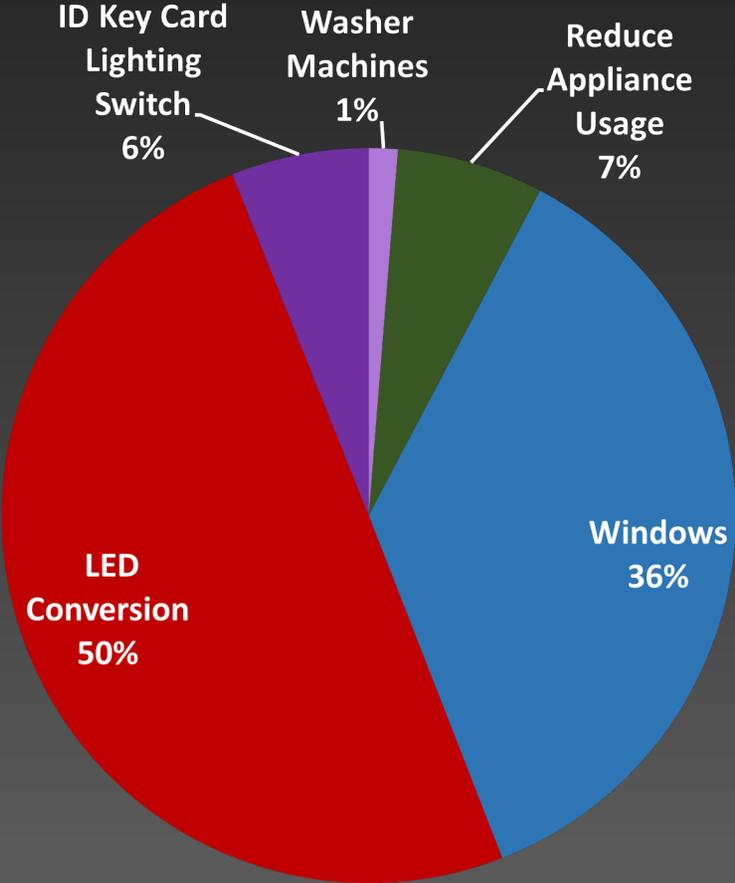
Appliance Costs

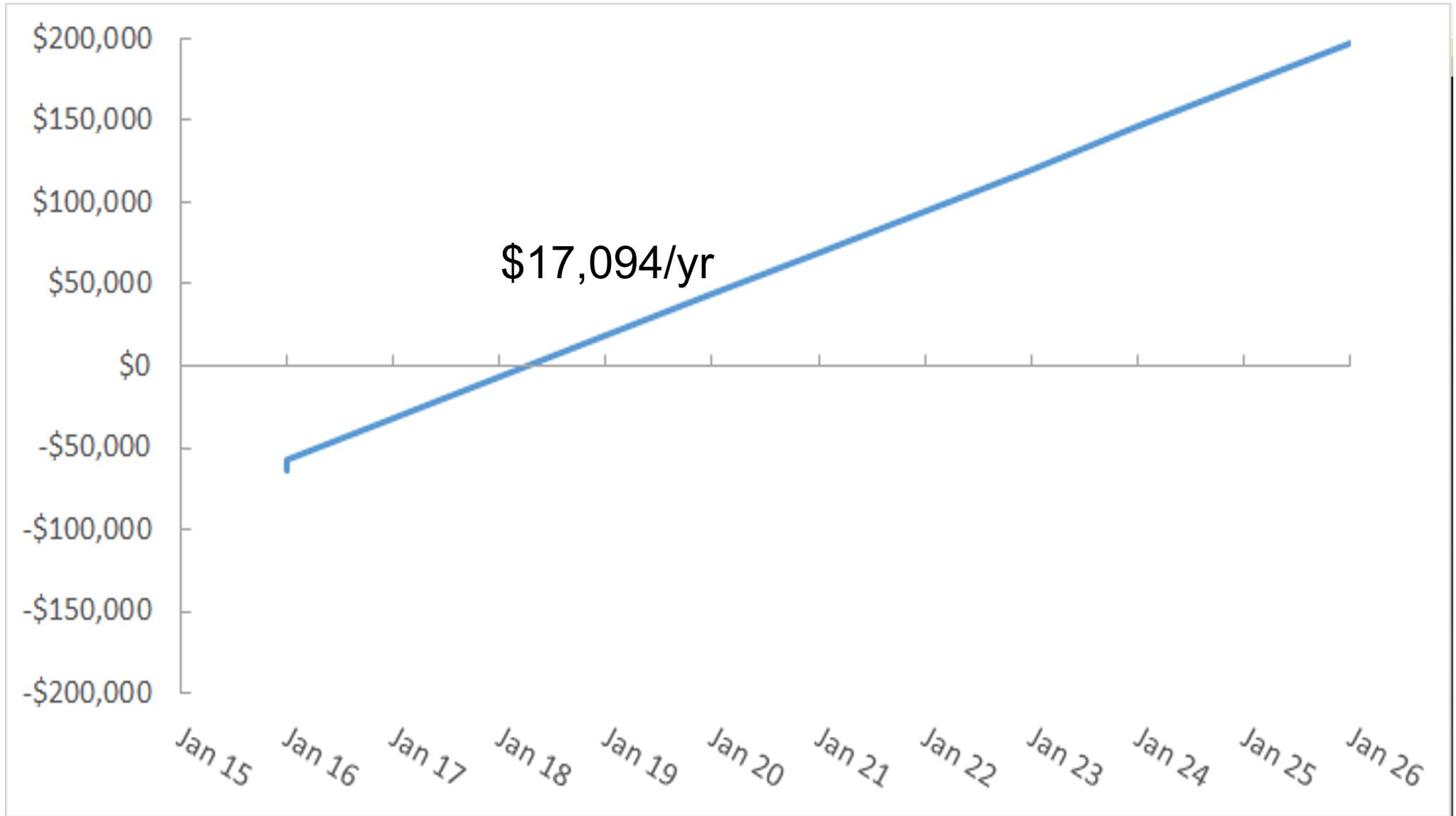


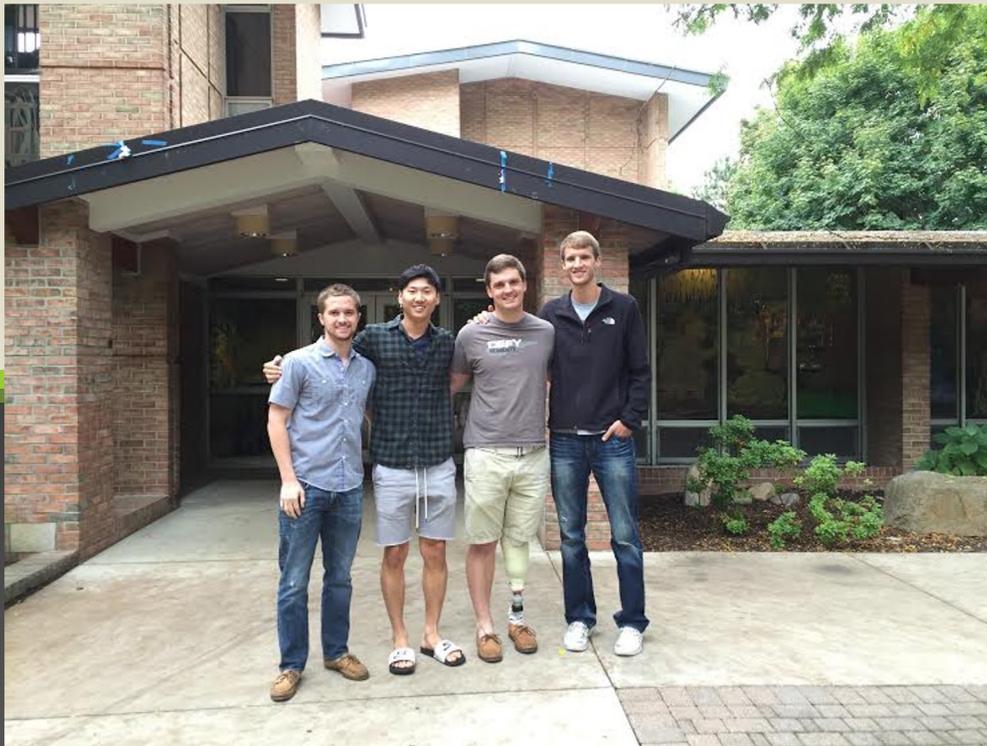
KHvR Savings Opportunities

Project	Initial Cost	Rebate	Annual Savings	Payback Period
Lighting - Delamping	\$ 33,600	\$ 3,565	\$ 8,522	3.52 years
Windows - Reflective Coatings	\$ 15,163	\$ 1,859	\$ 6,210	2.14 years
Appliances	\$ 270	\$ 0	\$ 1,107	0.24 years
ID Card Basement Lighting Switch	\$ 280	\$ 175	\$ 1,036	0.1 years
Washing Machines	\$ 0	\$ 0	\$ 219	0 years
Totals	\$ 49,313	\$ 5,599	\$ 17,094	2.56 years

KHvR Savings Opportunities







Schultze-Eldersveld

Team Members:

Lance Jensen

Se Ge Jung

Alex Karr

Stephen Lander

Behavioral - Basement Key Card



<http://www.capitalelectricalsupply.com/WATT-STOPPER-HS-150-W-HS-Series-Card>



<https://www.calvin.edu/dotAsset/e93efeff-3daf-4848-8c98-461368e36c18.jpg>

Revolving Door – MIT Study



http://www.smalldisruptions.com/images/revolvingdoors/4_door_signs

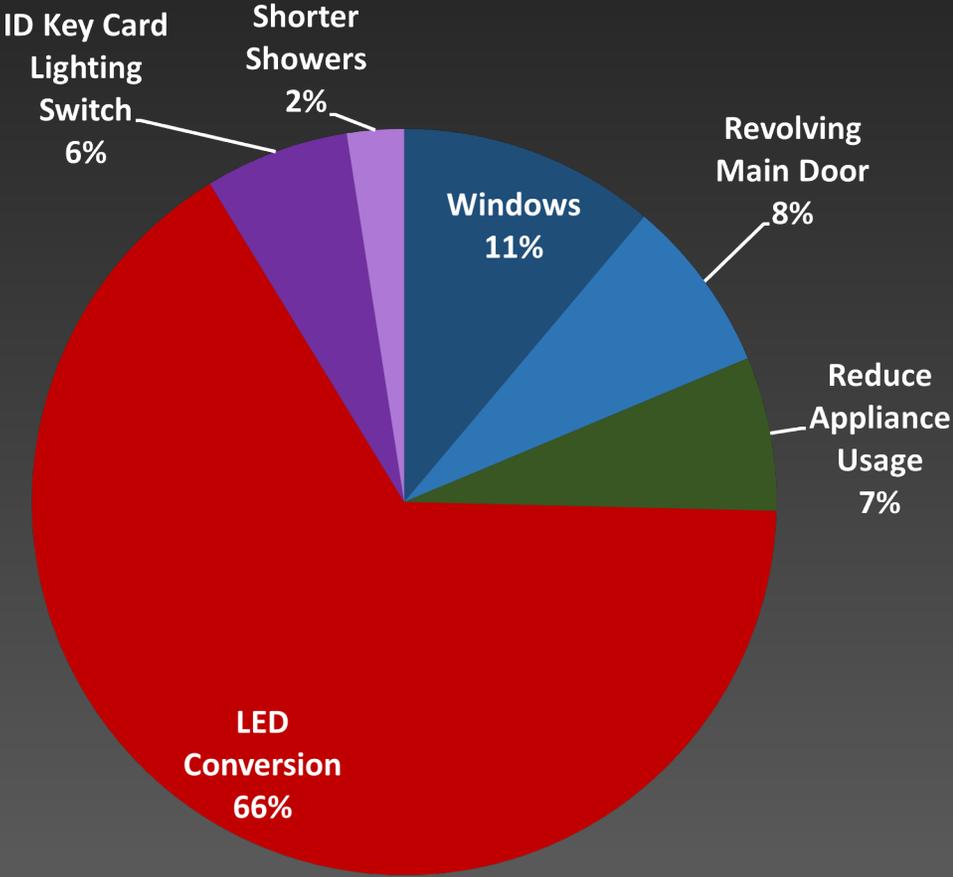


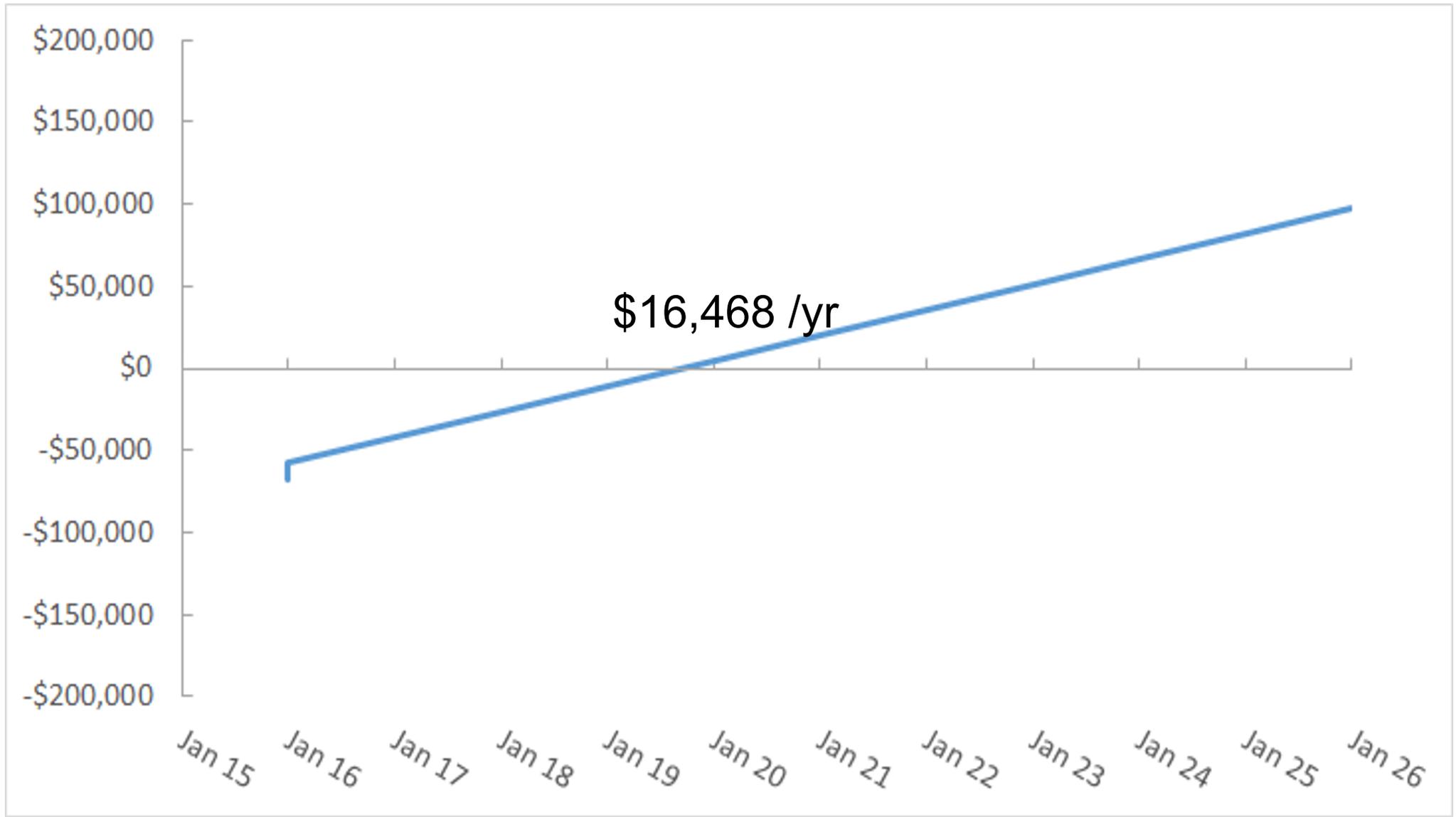
<http://jnewtonenterprises.com/projects>

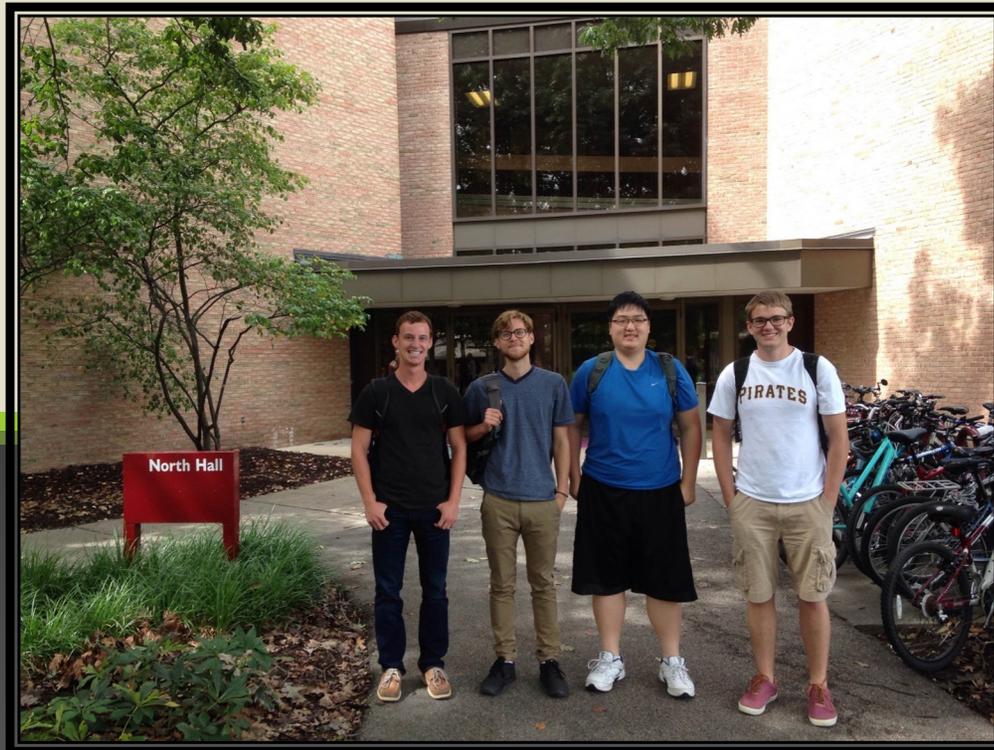
SE Savings Opportunities

Project	Initial Cost	Rebate	Annual Savings	Payback Period
Lighting - Delamping	\$ 56,835	\$ 8,870	\$ 10,894	4.40 years
Windows - Reflective Coating	\$ 4,746	\$ 896	\$ 1,843	2.09 years
Behavioral - Shower Time Reduction	\$ 320	\$ 0	\$ 409	0.78 years
ID Card Basement Lighting Switch	\$ 280	\$ 175	\$ 1,036	0.10 years
Revolving Main Door	\$ 5,000	\$ 210	\$ 1,250	3.83 years
Behavioral - Appliances	\$ 0	\$ 0	\$ 1,036	0.1 years
Totals	\$ 67,181	\$ 10,151	\$ 16,468	3.46 years

SE Savings Opportunities







Science Complex

Team Members:

Andrew Bouma

Joseph Cha

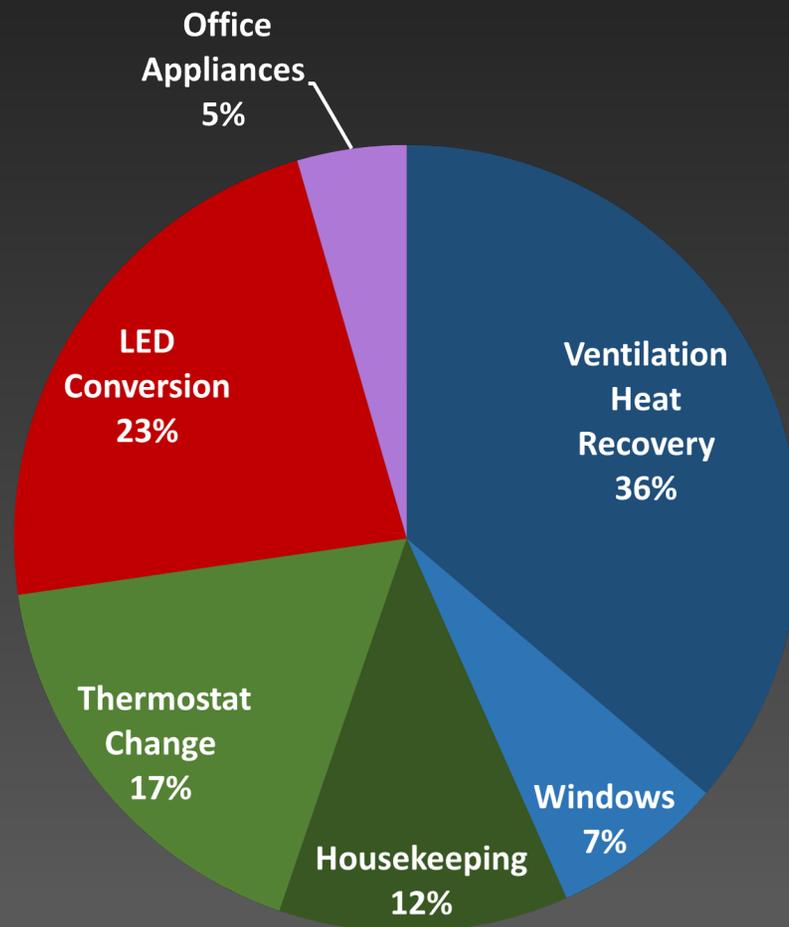
Mitch DuBois

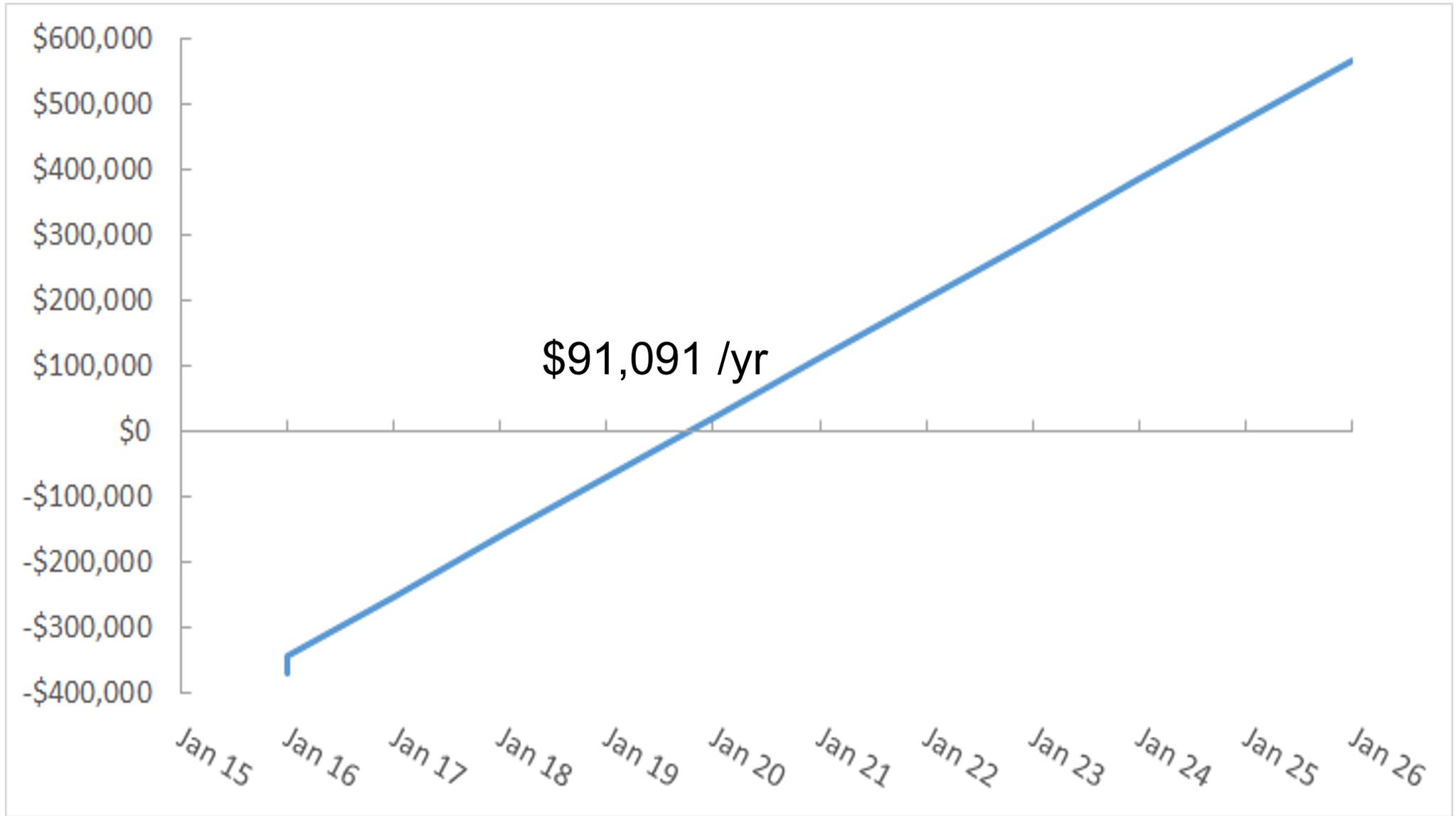
Jacob Milhorn

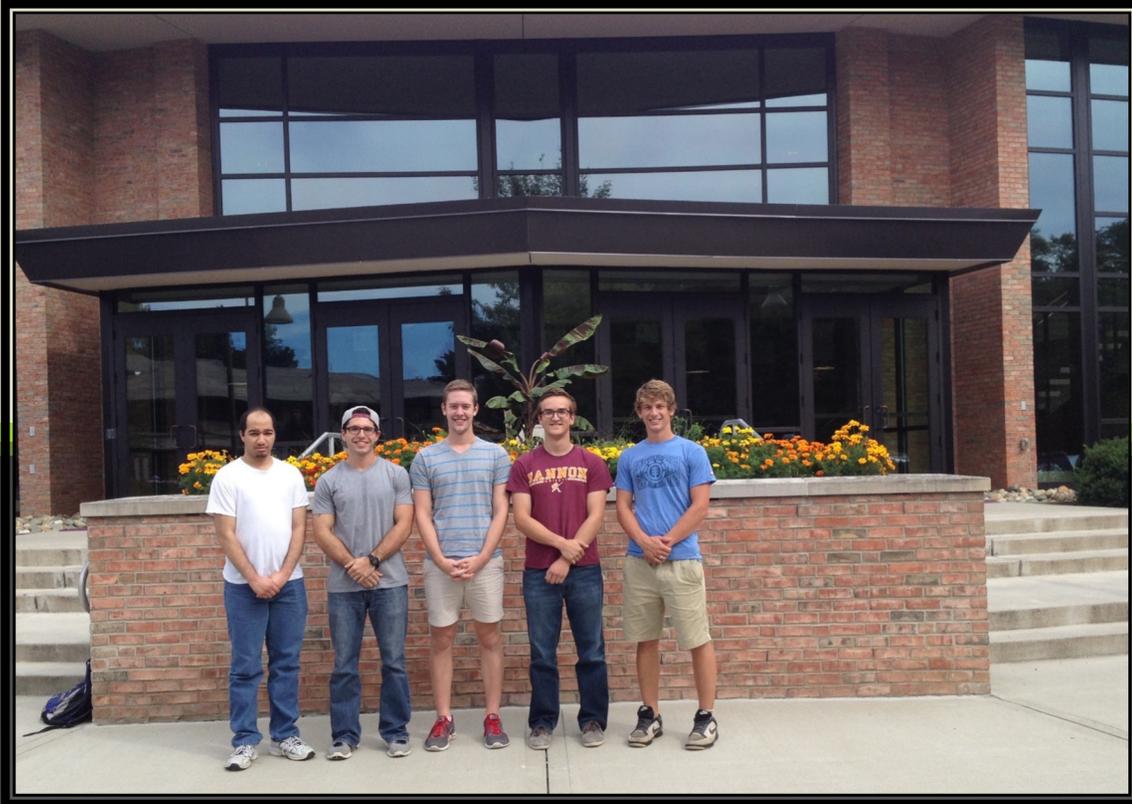
Science Complex Savings Opportunities

Project	Initial Cost	Rebate	Annual Savings	Payback Period
Lighting	\$ 156,654	\$ 22,523	\$ 20,759	6.46 years
Windows - Reflective Coating	\$ 14,223	\$ 3,311	\$ 6,495	1.68 years
Heat Recovery	\$ 200,190	\$ 2,275	\$ 32,974	6 years
Thermostat Change	\$ 0	\$ 0	\$ 15,896	0 years
Housekeeping Reduction	\$ 0	\$ 0	\$ 10,867	0 years
Office Appliances	\$ 0	\$ 0	\$ 4,100	0 years
Totals	\$ 371,067	\$ 28,109	\$ 91,091	3.76 years

Science Complex Savings Opportunities







CFAC

Team Members:

Caleb Meindersma

Dan DeVries

Tobin Tarantowski

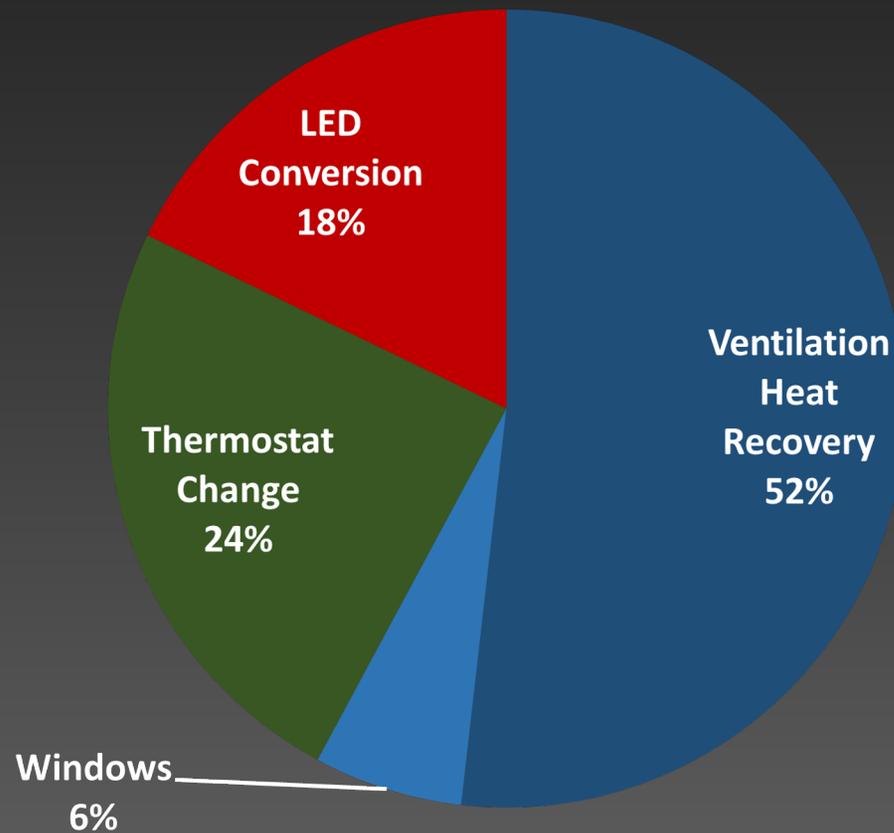
Zach Carney

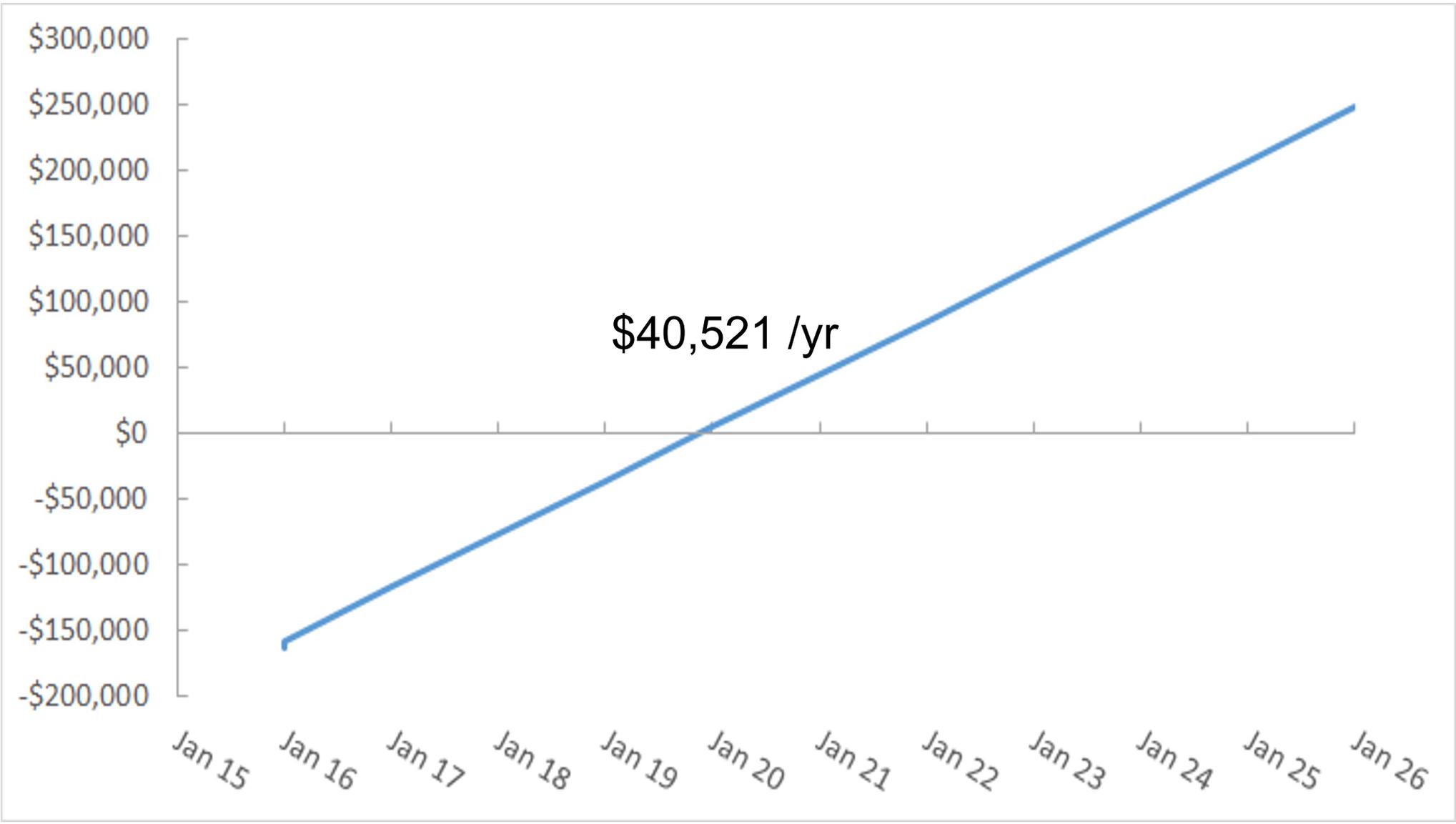
Vincent Rovedatti

CFAC Savings Opportunities

Project	Initial Cost	Rebate	Annual Savings	Payback Period
Lighting	\$ 54,038	\$ 5,035	\$ 7,233	6.77 years
Windows - Reflective Coating	\$ 6,354	\$ 1,200	\$ 2,488	2.11 years
Heat Recovery	\$ 103,522	\$ 0	\$ 20,997	4.93 years
Thermostat Change	\$ 0	\$ 0	\$ 9,843	0 years
Totals	\$ 163,914	\$ 6,235	\$ 40,521	3.93 years

CFAC Savings Opportunities





Project Totals and Summary

Collective Results

CFAC  \$40,521/yr

KHVR  \$17,094/yr

Science Complex  \$91,091/yr

SE  \$16,468/yr

SFC  \$78,079/yr

Extra Buildings  \$81,677/yr



\$324,930/yr

Extrapolating Savings

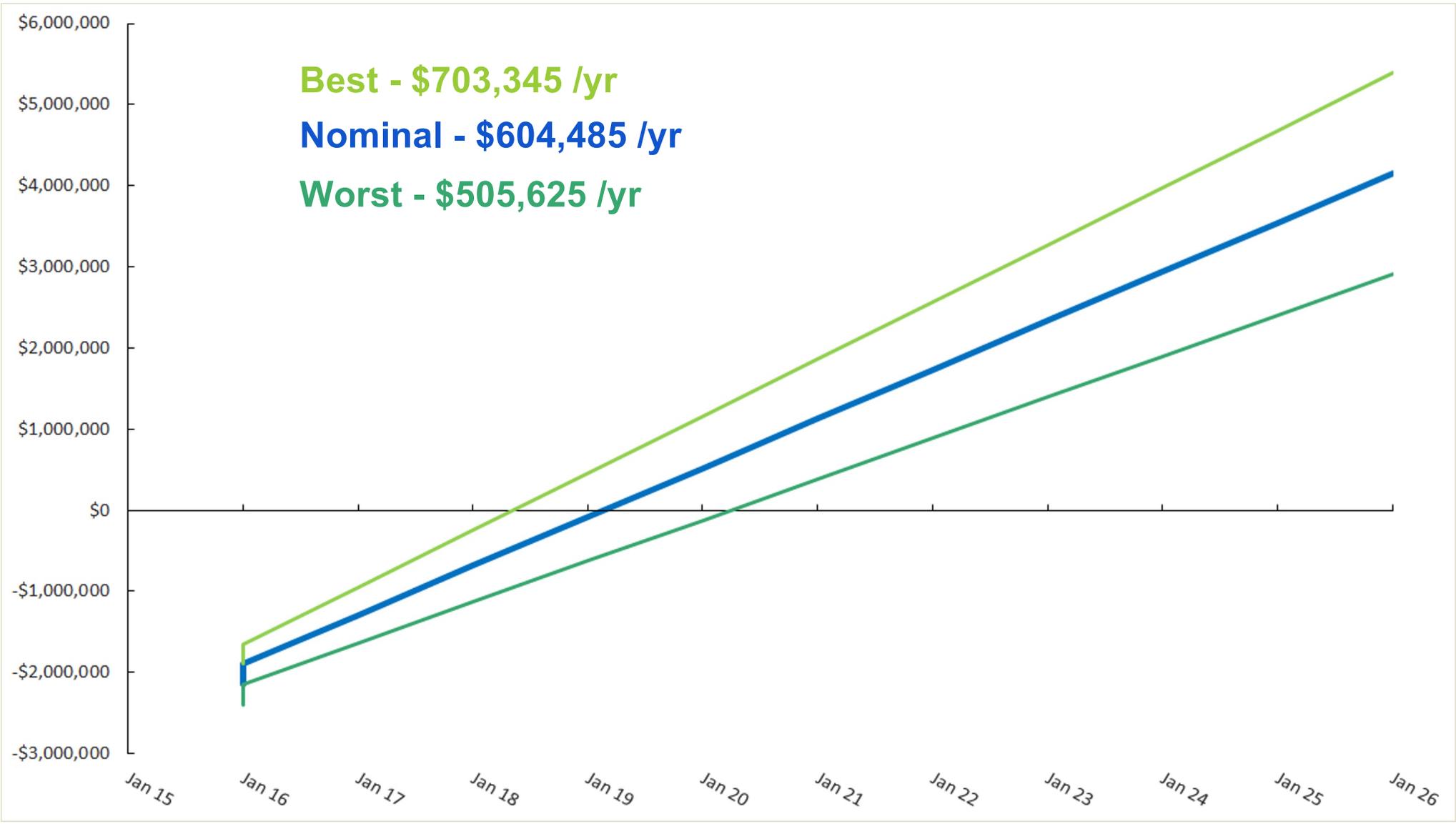
Covenant Fine Arts Center
Science Complex
Spoelhof Complex
SE and KHvR Dorms
Extra Opportunities



Prince Conference Center
Spoelhof Center
Hiemenga Hall
Engineering Building
Devos Communications Center
Knollcrest East Apartments
Chapel
Commons and Commons Annex
Knollcrest
Mail and Print Service Buildings



\$ 604,485 /yr



Best - \$703,345 /yr
Nominal - \$604,485 /yr
Worst - \$505,625 /yr

What would it take for Calvin College to save

\$600,000 per year

on campus operations?

Final Recommendation

\$2,144,634

Investment

\$250,445 Rebate

\$604,485 Annual Savings

3.13 Years Payback Period

Special Thanks

Professor Heun

Phil Beezhold

Jack Phillips

Lauren Grimley - CERF

ENGR-333 class for all the hard work!

Additional Thanks

Adam Tozer

Ashley Kelper

Caroline Chadderdon

Donald Levy

Jay Wise

John Witte

Justin Tebrake

Larry Van Hoe

Peter Ye

Sandy Palmatter

Tim Bakelaar

Tom Diepstra

Questions



Appendices

Non-Recommended Projects

Hair Dryers

Computer shutdown instead of sleep

HRV's in Dorms

Two-stage flushing toilets

Manual (non-electric) treadmills

Motion Sensors

Human powered machines - harvesting electricity from gym

Key card lights in dorm rooms

Housekeeping vacuum reduction

Future Work

Power Plant

Shutting down buildings on Sundays

Optimizing class schedules and shutting down buildings earlier

Motion sensors in hallways

Energy and efficiency live-updating website to educate and inform students

More performance readings for systems

Heat Recovery Savings

$$\frac{\dot{Q}}{\epsilon_{boiler}} = \dot{m}_{fuel} LHV_{fuel}$$

"!Fan Properties"

fan_1_hp = 0.5 [hp]

fan_1_CFM = 1545 [ft^3/min]

"!INPUT"

"!INPUT"

$$\dot{Q} = f(\epsilon_{HRV}, T_{inlet,air}, \dot{m}_{exhaust,air})$$

"!Heat Recovery Ventilator (HRV)"

epsilon_air_heater = 0.55

T_c_i = 24.5 [F]

T_h_i = 72 [F]

C_a_h = (m_dot_air_fan_1) * Cp(air, T = T_h_i)

C_a_c = (m_dot_air_fan_1) * Cp(air, T = T_c_i)

C_min = min(C_a_c, C_a_h)

T_c_i_R = ConvertTemp('F','R',T_c_i)

T_h_i_R = ConvertTemp('F','R',T_h_i)

q_max = C_min * (T_h_i_R - T_c_i_R)

epsilon_air_heater = q / q_max

q = C_a_h * (T_h_i - T_h_e)

q = C_a_c * (T_c_e - T_c_i)

"Heat capacity stale exhaust stream"

"Heat capacity inlet air"

"Whole dorm side" "!INPUT"

"!PARAMETRIC VAR"

"Room temperature"

"Minimum heat capacity"

"Rankine conversion"

"Rankine conversion"

Reduce Shower Times Model

"Behavioral Change of Reducing Shower Time to 5 Minutes"

"Inputs"

students = 240
utilization = 0.75
time_old_shower = 7.33 [min]
T_1 = convertTemp(F, C, 104.28)
flow_rate = 1.03*convert(gal/min, m^3/min)

"Students in dorm"
"Shower usage in a year assuming 1 shower per day per student"
"CERF data"
"CERF data"
"CERF data"

"Heated Water for Showers"

"GIVENS"

Cost_heating_water = 2.31 [\$/mmBTU]
year = 365
time_shower = (time_old_shower - 5 [min])
T_0 = convertTemp(F,C, 47) "<http://www.thetankless.com/uploads/Average%20water%20temp%20map2.pdf>"
P_1 = 101.325 [kPa]

"Behavioral change to reduce shower time"

"Calculations"

cp_water = SpecHeat(Water, T = T_1, P = P_1)
rho_water = Density(Water, T = T_1, P = P_1)
m_water_per_shower = rho_water * flow_rate * time_shower
q_water_per_shower = m_water_per_shower * cp_water * (T_1 - T_0) * convert(kJ, BTU)
Q_total_day = q_water_per_shower * students
Q_total_year = Q_total_day * utilization * year * convert(BTU, MMBTU)
Savings_heat_year = Q_total_year * Cost_heating_water



Savings _{heat,year} = 172.6 [\$]
Savings _{water,year} = 236.5 [\$]
Savings _{total} = 409.1 [\$]
Cost _{initial} = 320 [\$]
Payback = 0.7823 [years]

LED Conversion Implementation

Biggest savings first

Heavy usage classrooms and labs

Library

Hallways

Smaller savings in phase II

Bathrooms

Closets

Basement labs

Operational Changes - Science Complex

- Recommendation: Reduce hours cleaning crew work by 1/6th
- Issues
 - Required student employment
 - Dirtier buildings
- Proposed solution
 - Add an energy efficiency projects coordinator position

Behavioral Changes

- Limiting Usage of Appliances in Faculty Office Space
- Recommendation: Restrict faculty appliance usage to faculty lounges except when absolutely necessary.
- Rebound Effects
 - Complaints when HVAC is not evenly distributed
 - More faculty communication