Green Gauges

A design methodology at Williams College

At the conclusion of this session, participants will be able to:

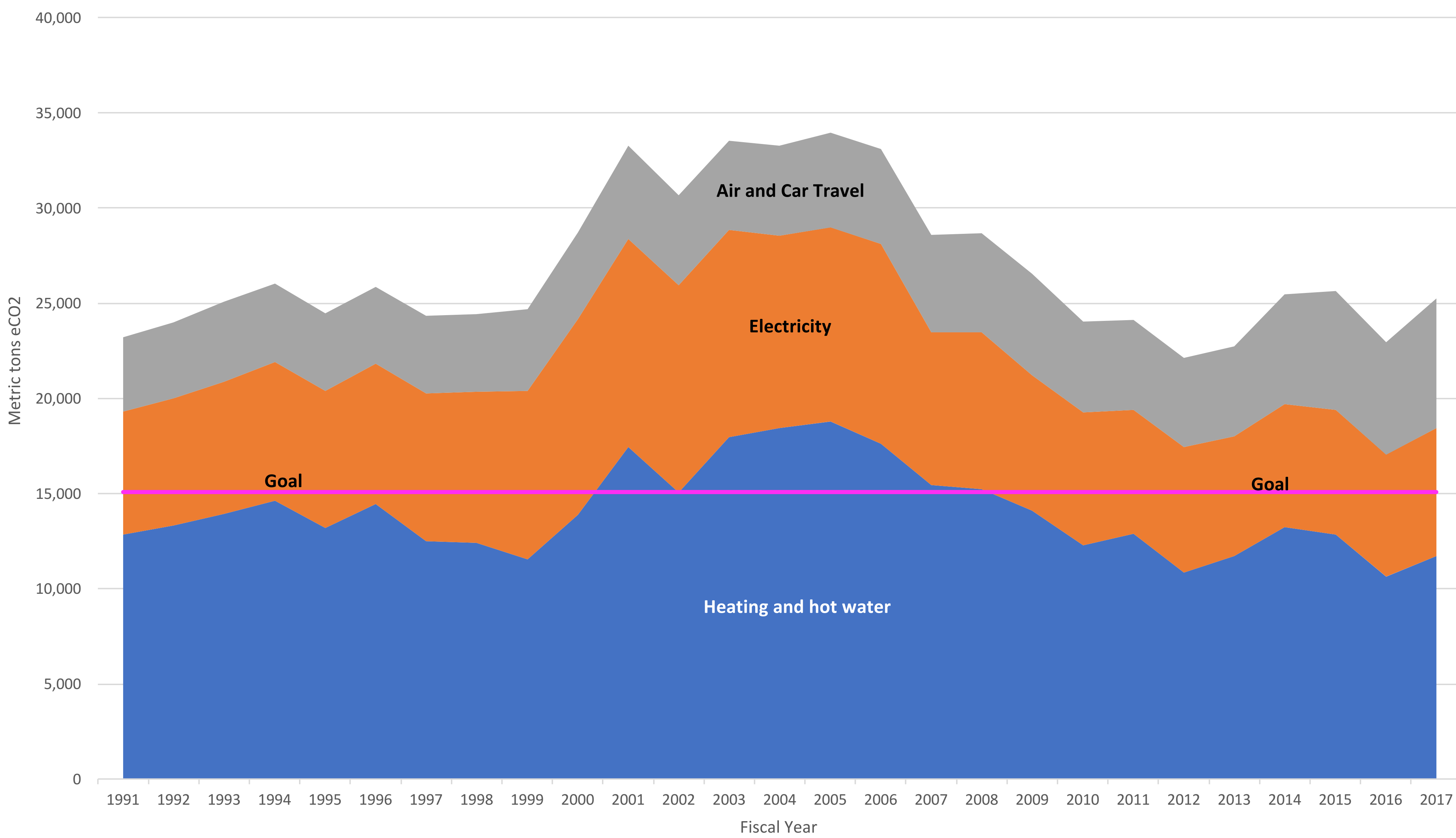
- understand the value of systems thinking and early design communication
- calculate and compare *operational* carbon benefits of specific design strategies
- define and contrast site energy and source energy and CO2 equivalent greenhouse gas emissions
- critique the Green Gauges approach based on their own experience

Schedule:

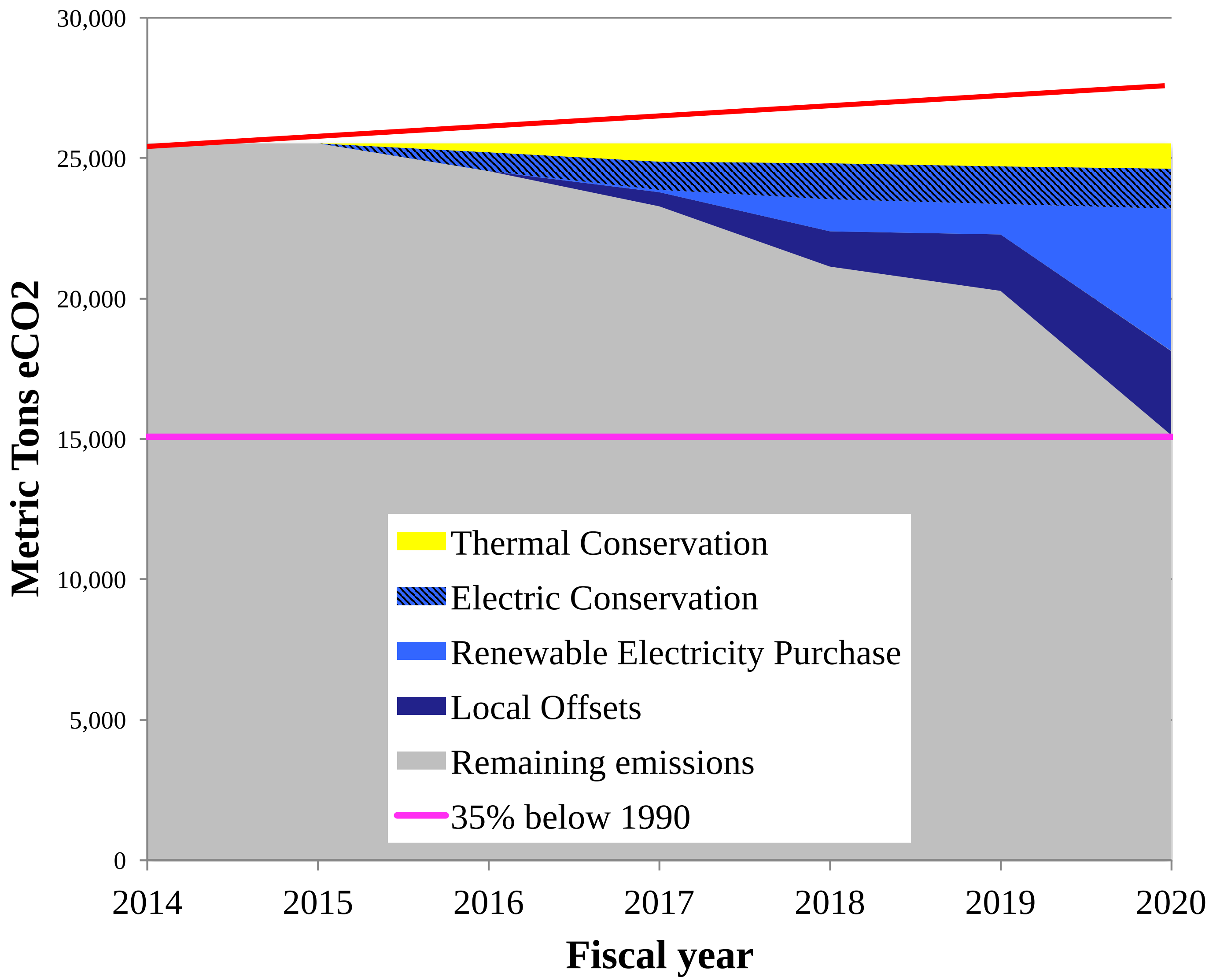
10 min	Amy	Introduction and Goals
5 min	Tom	Looking back- past projects
10 min	Amy/Tom	Green Gauges framework
10 min	Tom	Current projects
15 min	Andy	What's next? site EUI vs source? eCO2 per sf…
10 min		Questions and Discussion

Williams College

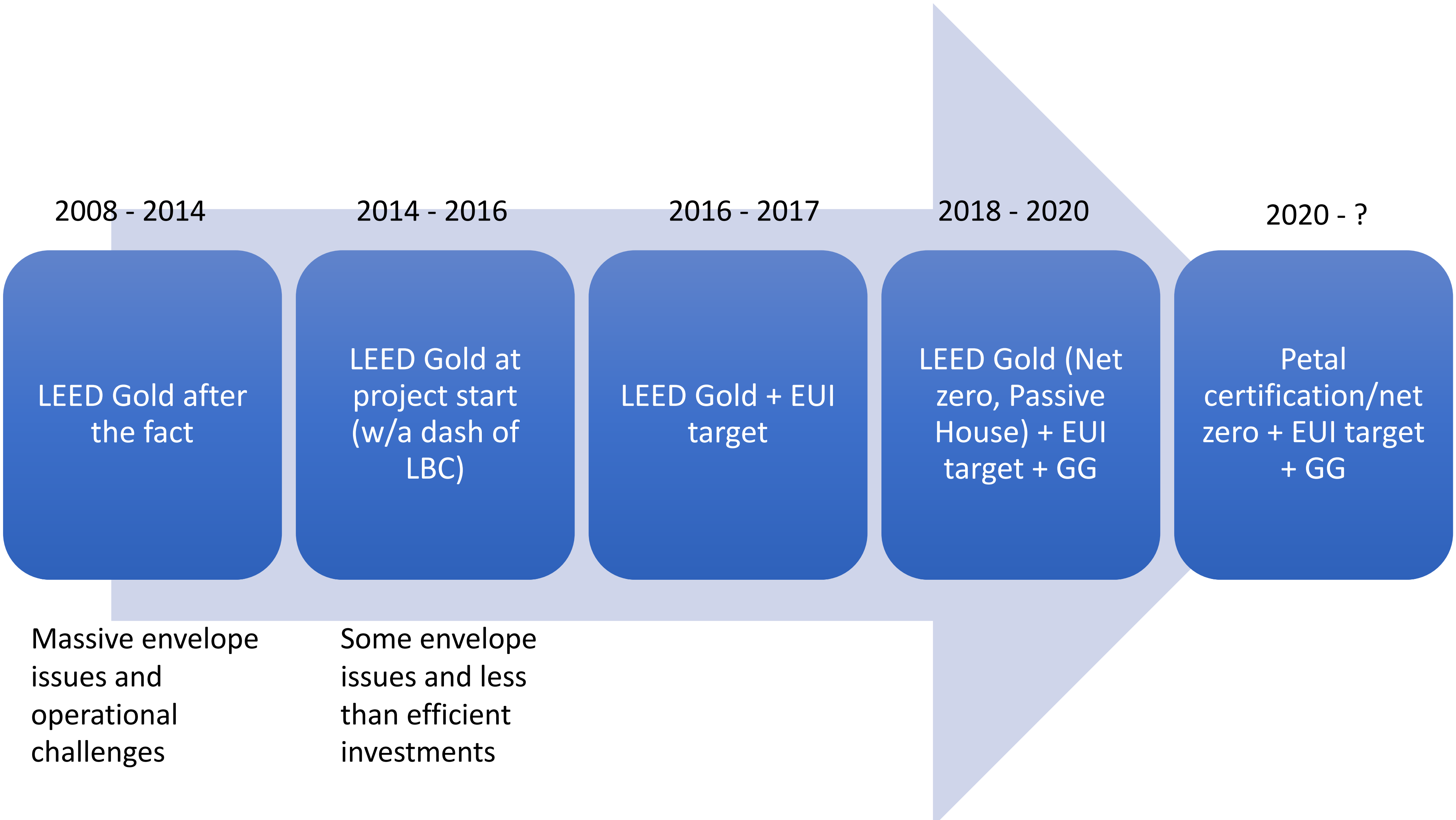
- Founded 1793
- 2000 undergraduates
- 110 buildings
- $2 billion endowment
- First GHG reduction goals in 2007
- Additional goals in 2010



Williams College Emissions by Scope


30,000
25,000
20,000
15,000
10,000
5,000
0
Metric Tons eCO2
Thermal Conservation
Electric Conservation
Renewable Electricity Purchase
Local Offsets
Remaining emissions
35% below 1990
2014
2015
2016
2017
2018
2019
2020
Fiscal year

High performance buildings are important – but what are we getting for our investment?



Historical & Future Building Standards

What to measure?

- Incremental cost of high performance — What's the baseline?
- Benefit: carbon reduction — Site? Source? Lifetime? Annual?
- Benefit: Energy cost savings
- Benefit: Operational cost savings

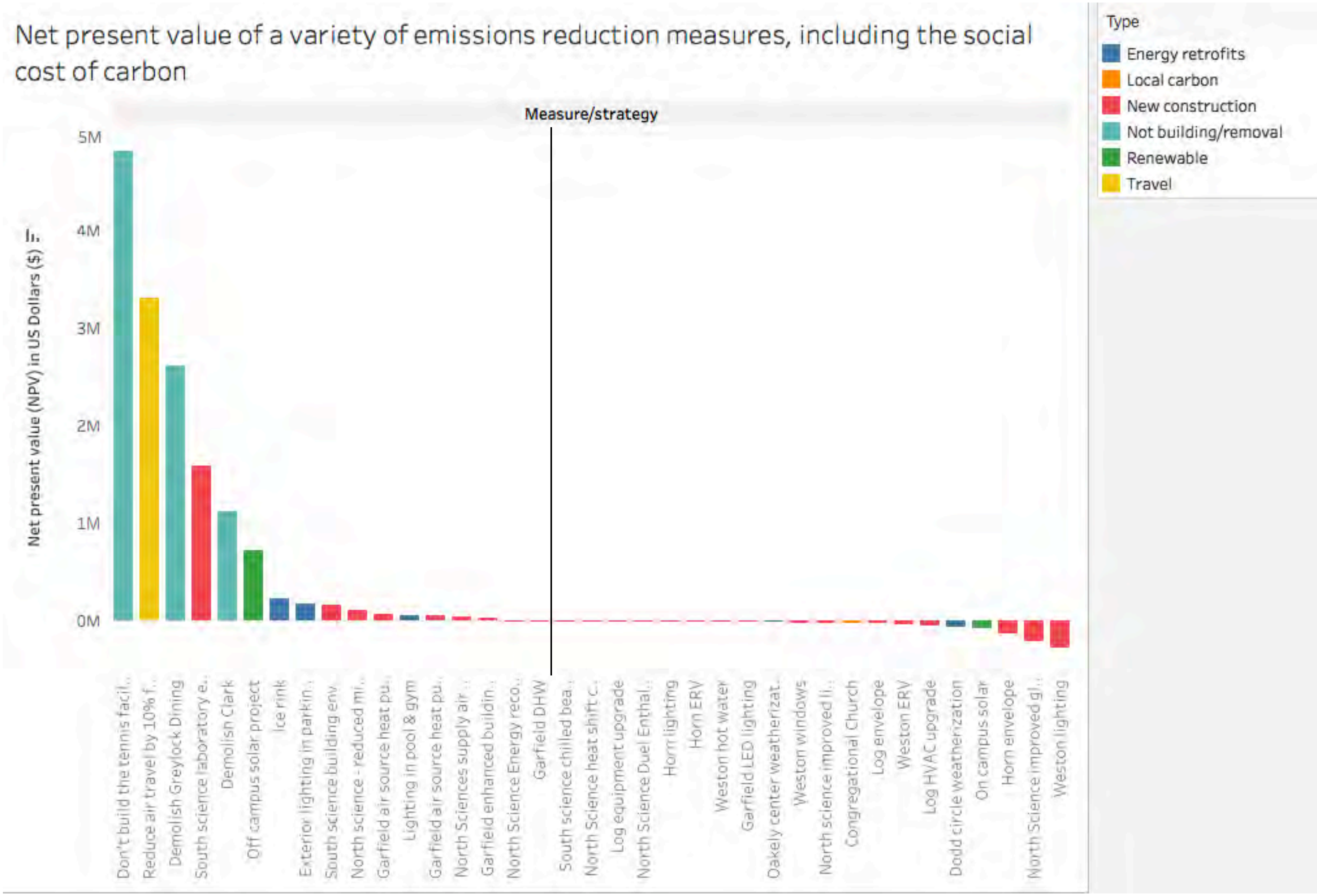
See above – what's the baseline?

- Then combine somehow into a unified metric!

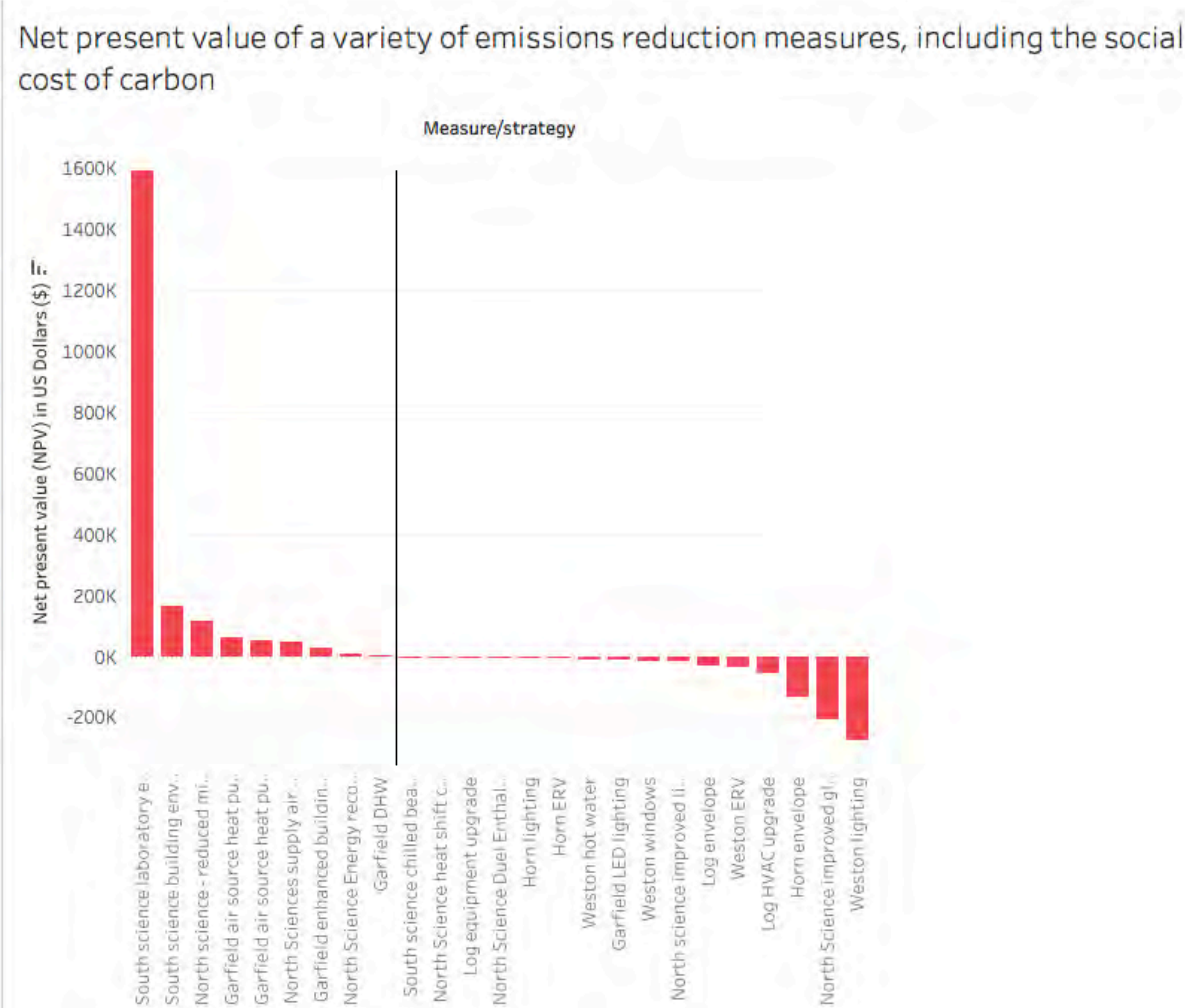
Annual carbon/incremental cost?
Lifetime carbon/incremental cost?
Net present value/incremental cost?
??????

- ~~Easy, right~~?

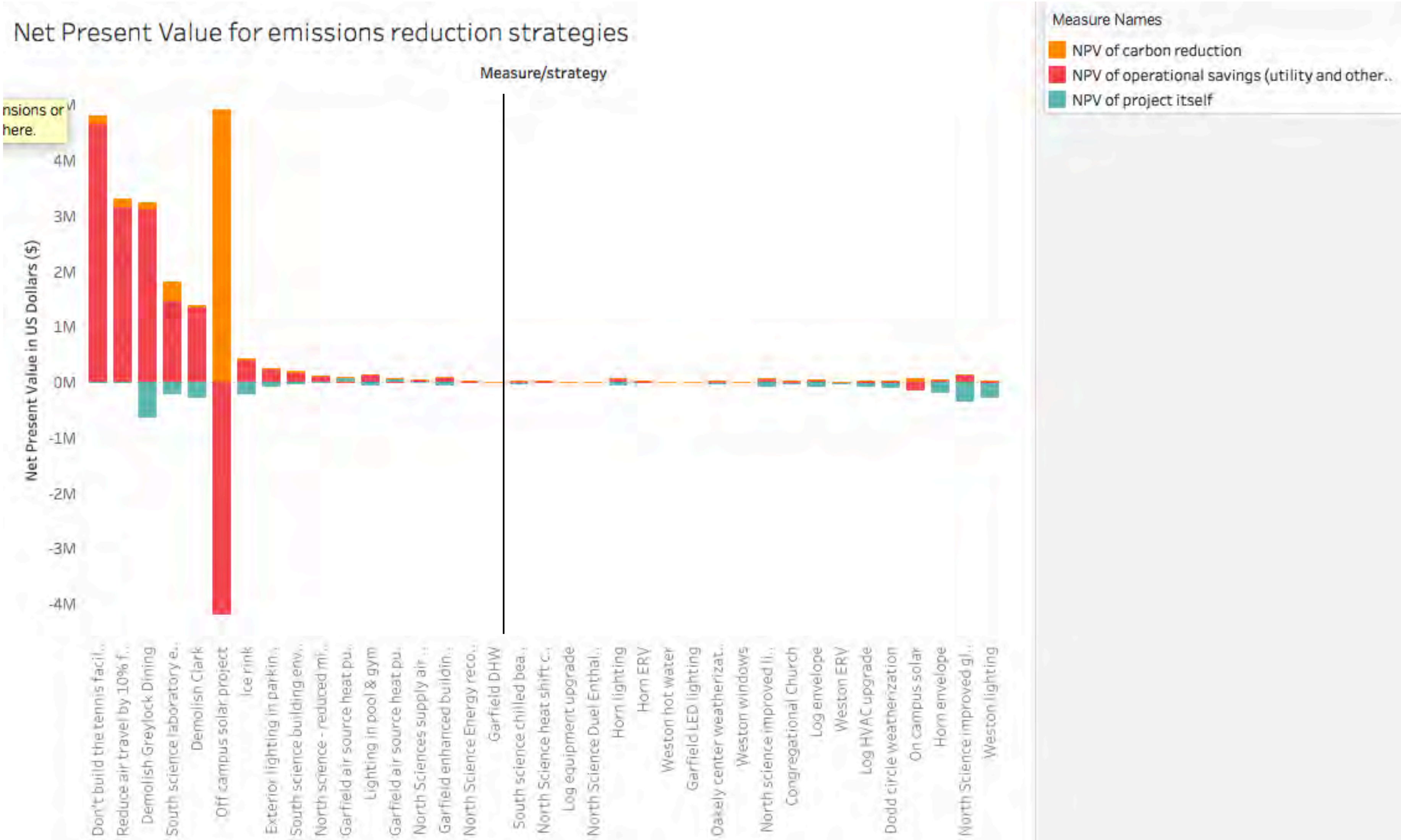
Fun, though.

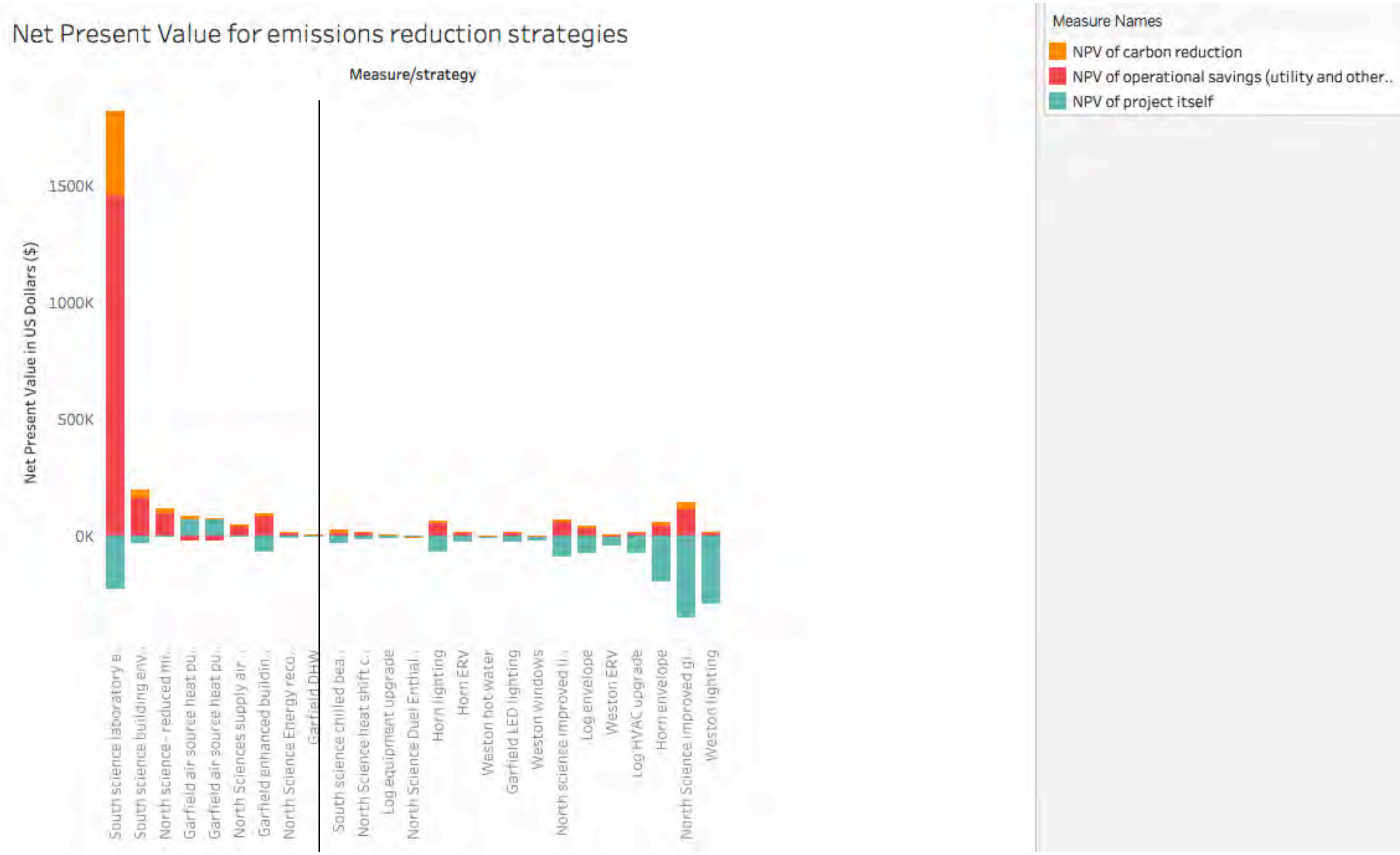


NPV including avoided social costs



NPV including avoided social costs


Net Present Value for emissions reduction strategies
Measure/strategy
Net Present Value in US Dollars ($)
4M
3M
2M
1M
0M
-1M
-2M
-3M
-4M
Don't build the tennis facil..
Reduce air travel by 10% f..
Demolish Greylock Dining
South science laboratory e..
Demolish Clark
Off campus solar project
Ice rink
Exterior lighting in parkin..
South science building env..
North science - reduced mi..
Garfield air source heat pu..
Lighting in pool & gym
Garfield air source heat pu..
North Sciences supply air ..
Garfield enhanced buildin..
North Science Energy reco..
Garfield DHW
South science chilled bea..
North Science heat shift c..
Log equipment upgrade
North Science Duel Enthal..
Horn lighting
Horn ERV
Weston hot water
Garfield LED lighting
Oakely center weatherizat..
Weston windows
North science improved li..
Congregational Church
Log envelope
Weston ERV
Log HVAC upgrade
Dodd circle weatherization
On campus solar
Horn envelope
North Science improved gl..
Weston lighting
Measure Names
NPV of carbon reduction
NPV of operational savings (utility and other..
NPV of project itself


Net Present Value for emissions reduction strategies
Measure/strategy
Net Present Value in US Dollars ($)
1500K
1000K
500K
0K
South science laboratory e..
South science building env..
North science - reduced mi..
Garfield air source heat pu..
Garfield air source heat pu..
North Sciences supply air ..
Garfield enhanced buildin..
North Science Energy reco..
Garfield DHW
South science chilled bea..
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Log equipment upgrade
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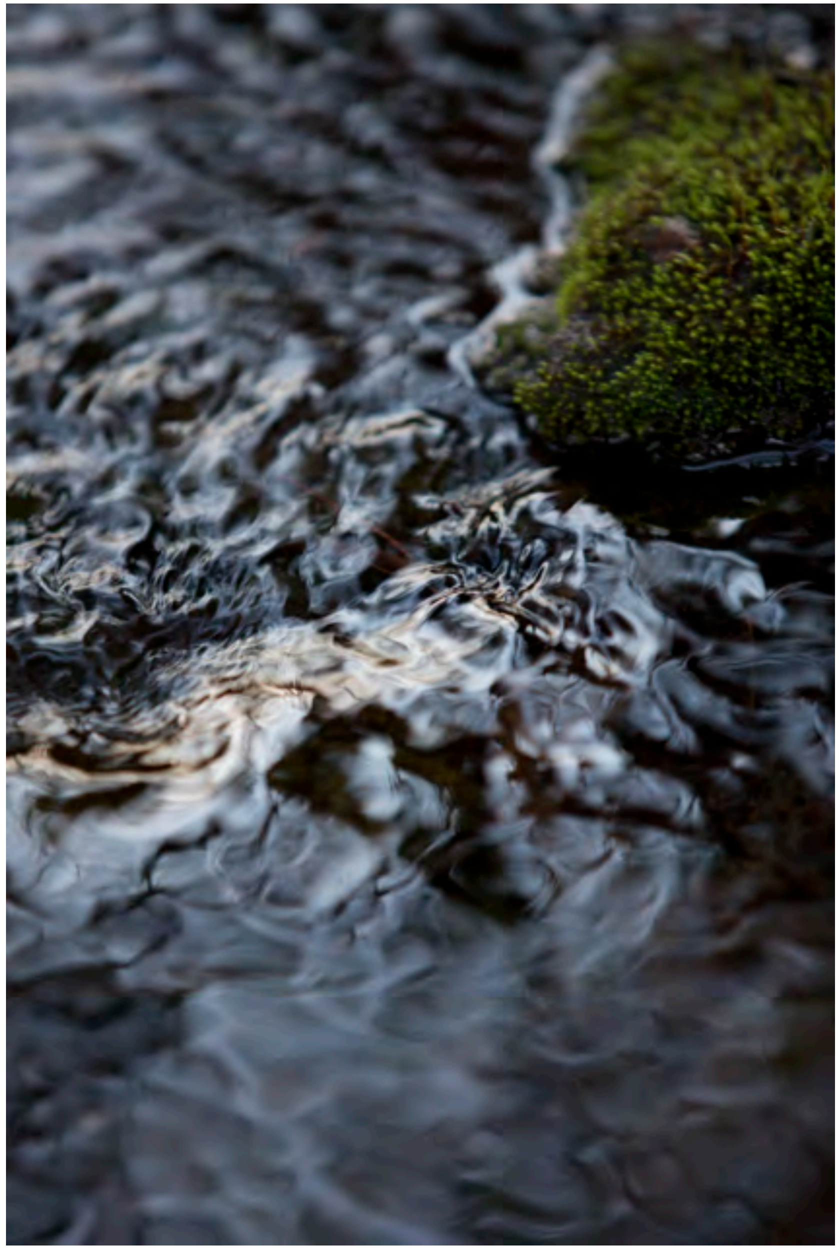


Biophilic moment- *all photos courtesy of Ethan Drinker Photography*

In the context of carbon reductions,

three questions are being asked:

1. What specifically is the College doing?
2. What does it cost?
3. What are the savings?

We were asked to:

develop a methodology to track this effort in new projects and retroactively evaluate past projects

The effort has been named Green Gauges:

gauge *|gāj| - an instrument or device for measuring the magnitude, amount, or contents of something, typically with a visual display of such information*

Measure #	Measure Name	kWh	Therms	Steam MMBtu	Utility Energy Cost ($)	Incremental Savings ($)	Increm %	Cumulative Savings ($)	Cum.%
Base	Baseline Design (0.4 CFM/SF infiltration)	309,843	620	994	66,048				
1	Base + Energy recovery units + fin-tube	374,837	626	458	58,590	7,458	11.3%	7,458	11%
2	1 + R-40 exterior walls	375,706	626	397	56,960	1,629	2.5%	9,088	14%
3	2 + R-60 roof	377,136	626	350	55,801	1,159	1.8%	10,247	16%
4	3 + R-20 below-grade walls	379,003	626	338	55,671	130	0.2%	10,377	16%
5	4 + R-10 under-slab insulation	380,099	626	332	55,623	48	0.1%	10,425	16%
6	5 + Improved Fenestration	379,855	626	258	53,497	2,126	3.2%	12,551	19%
7	6 + Reducing infiltration to 0.25 CFM/SF	383,741	626	238	53,397	100	0.2%	12,651	19%
8	7 + Reducing infiltration to 0.11 CFM/SF	387,433	626	227	53,509	(112)	-0.2%	12,539	19%
9	8 + Exterior Lighting	378,822	626	227	52,485	1,024	1.9%	13,563	21%
10	9 + Reduced LPD	299,180	626	248	43,624	8,862	16.9%	22,425	34%
11	10 + Occupancy sensors	296,341	626	249	43,312	311	0.7%	22,736	34%
12	11 + Daylighting controls	295,811	626	249	43,249	63	0.1%	22,799	35%
13	12 + DHW Heater	295,811	516	249	43,079	170	0.4%	22,969	35%
14	13 + Low flow fixtures	295,811	273	196	41,189	1,891	4.4%	24,860	38%
15	14 + ES washer & dishwasher DHW savings	295,811	273	196	41,189	-	0.0%	24,860	38%
16	15 + Pump VFD	291,218	273	204	40,874	314	0.8%	25,174	38%
17	16 + ERU VAV	291,130	273	204	40,866	8	0.0%	25,182	38%
18	17 + ERU-2 DCV	255,797	273	196	36,435	4,431	10.8%	29,613	45%
19	18 + Thermostat OS	255,673	273	191	36,275	160	0.4%	29,773	45%
20	19 + Window Shades	252,491	273	180	35,584	691	2%	30,465	46%
21	20 + Removing Cooling	219,594	272	177	31,581	4,003	11%	34,468	52%
22	21 + Roof Solar Panels (116.4 MWh annually)	103,188	272	177	17,728	13,853	44%	48,320	73%

Horn Hall-
designed by Centerline Architects, analysis by Karpman Associates

Past Projects- Typical Energy Conservation Measures (ECM)

The Log

Construction - Occupancy 2015

Total Project Cost $4,500,000

Area (square feet) 7,890

Modeled Annual Energy Savings from Existing Baseline (185,000 kWh per year)

Strategy	Cost	% Total Project	kWh saved	% Base Total	By Component	Comments
Additional Design	$35,000	0.8%	-	0		MEP, Energy Consultant, Arch- blower door testing, LEED evaluation, but not Certified
Enhanced Commissioning	$7,200	0.2%	-	0		
Enhanced Envelope	$75,000	1.7%	50,000	27%		Triple glazed windows, exterior insulation, air tightness
Photovoltaic Panels	$79,390	1.8%	18,000	10%		
Upgrade Equipment	$10,000	0.2%	4,000	2%		Modulating Kitchen Hood and Efficient Coolers
HVAC	$75,000	1.7%	30,000	16%		ERV and VFD's multiple zones
Total	**$281,590**	**6.3%**				EUI 69 kbtu/sf/year (NIC pv)

Note: Saving on **existing consumption**- NOT CODE

Designed by c&h architects, analysis by Energy Balance

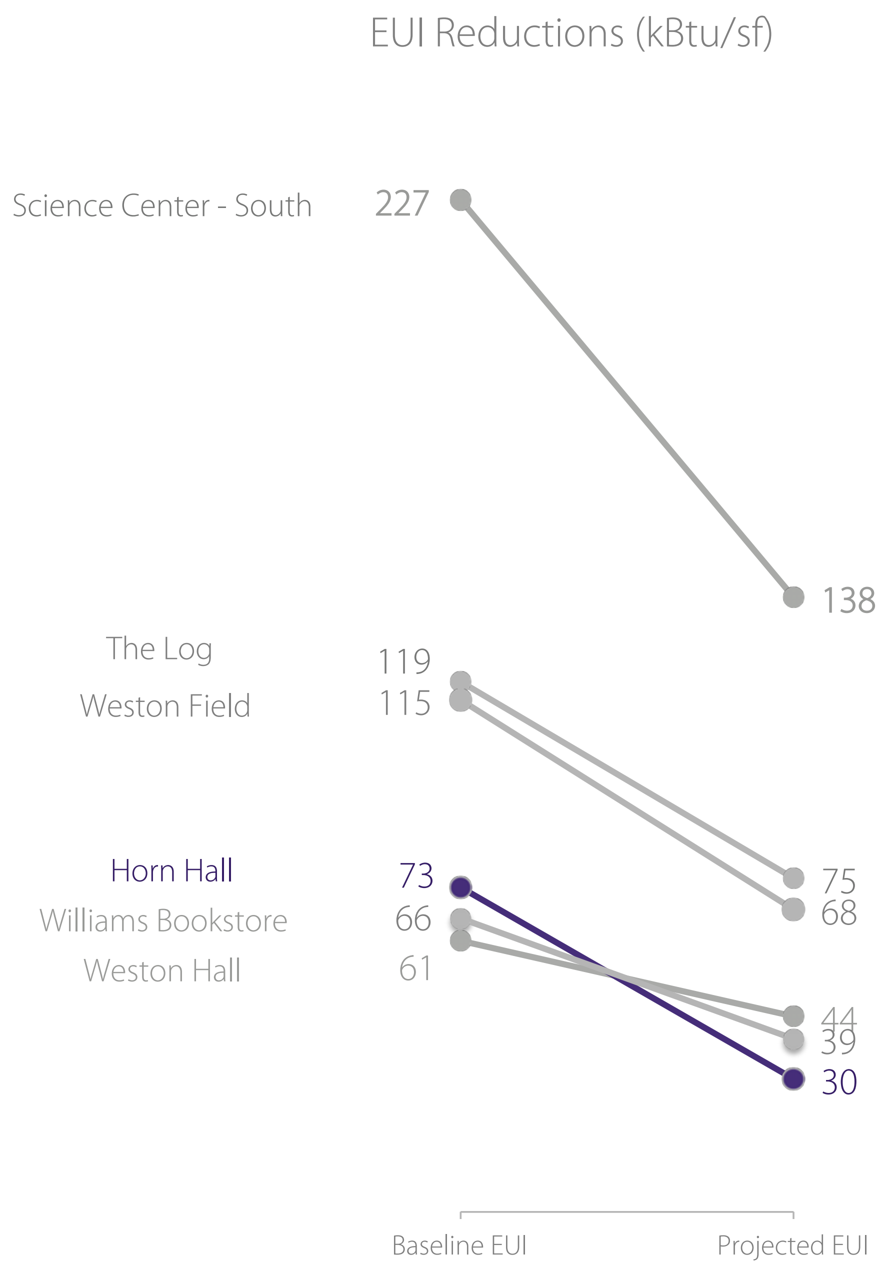
Past Projects- Pulling out data afterwards

December 2016

Project	*Baseline modeling standard*	*% better than baseline*	*% better than Stretch code*	*Energy Use Intensity (EUI) Kbtu/sf/year Not including pv*	
				DESIGN	BASELINE
Williams Inn	Appendix G- 2013 Appendix G- 2007	26% 37%	16% (new code)	60 Design	95 Weighted CBECS 109 Existing Inn
CDE Residence Hall	N/A as not LEED after schematic			23 Design 20 with EEM1 + EEM2	
Science Center- South	Appendix G- 2007	31.6%	11.6% (old code)	138 Design	227 Baseline
Science Center- North	Appendix G- 2007	25%	5% (old code)	89 Design	120 Baseline
Williams Bookstore	Appendix G- 2007	41%	21%	39 Design	66 Baseline
Horn Hall	Appendix G- 2007 With modifications	52%	32%	30 Design	73 Baseline
Weston Hall	Appendix G- 2007	18%		44 Design	61 Baseline
The Log	Exempt	34%	N/A	75 Design	119 Existing and unoccupied.
Weston Field	Appendix G- 2007	38.9%	18.9%	68 Design	115 Baseline
Kellogg				19 Design	

- Appendix G is the Building Performance Rating Method of ASHRAE Standard 90.1.
- The past stretch code required commercial building over 100,000 sf to be 20% better than the 2007 version of Appendix G.A building between 5,000 and 100,000 sf may either be 20% better than Appendix G, or comply with the prescriptive requirements of the code.
- The new stretch code (effective Jan 1, 2017) requires 100,000 sf buildings to be 10% better than Appendix G- 2013 (which is more stringent than 2007). Smaller buildings must comply with the International Energy Conservation Code (IECC) 2015 or ASHRAE 90.1.
- LEED V3 requires all new buildings to be 10% better than the equivalent Appendix G-2007 building on a cost of energy basis.
- CBECS is the U.S. Energy Information Administration’s Commercial Buildings Energy Consumption Survey.

Project EUI summary sheet



Project EUI- Code verses design

Key Green Gauges deliverables from the design team

10% Schematic Design –
Goals and Feasibility are established (A).
Energy metrics and comparisons.

30% Schematic Design-
Systems & Metering Narrative (B)
Simple descriptions of various design elements.

25% Design Development-
Updated Narratives & **Value Assessments (C)**
Cost, energy savings, and carbon reduction.

70% Design Development-
Metering Diagram(D)
Show the components of multiple systems in one diagram.

Then follow up during and after Construction **(E & F)**.

Most decisions are made in Schematic Design

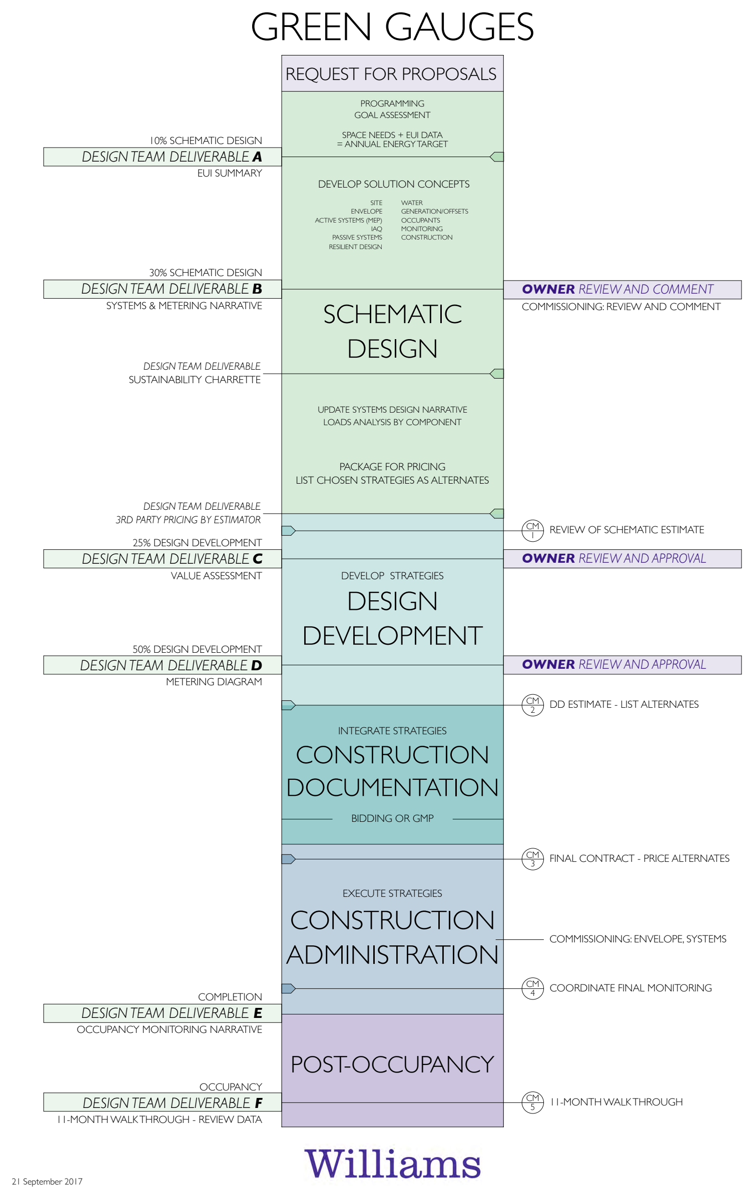


Diagram- overall

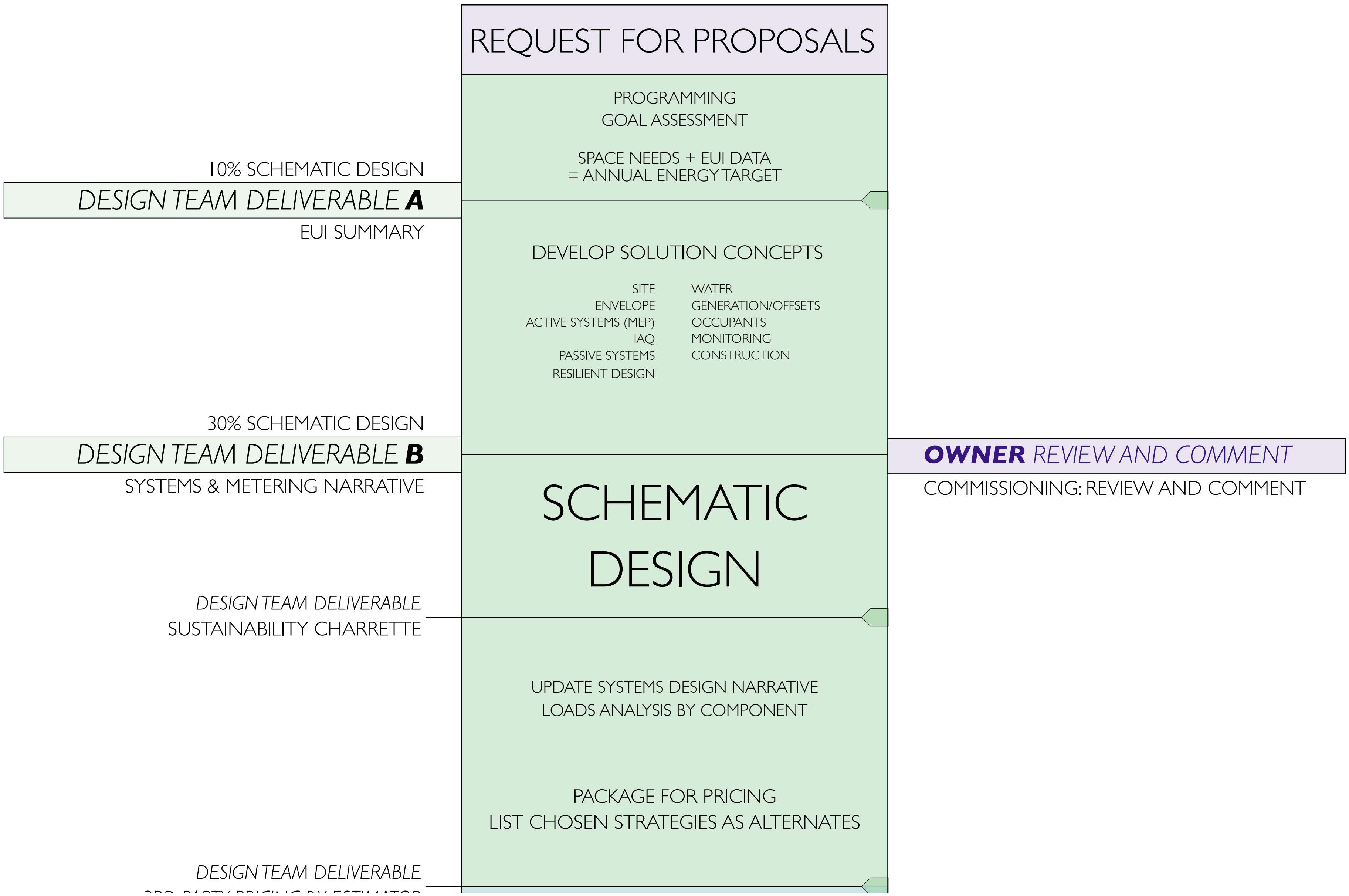


Diagram - Schematic

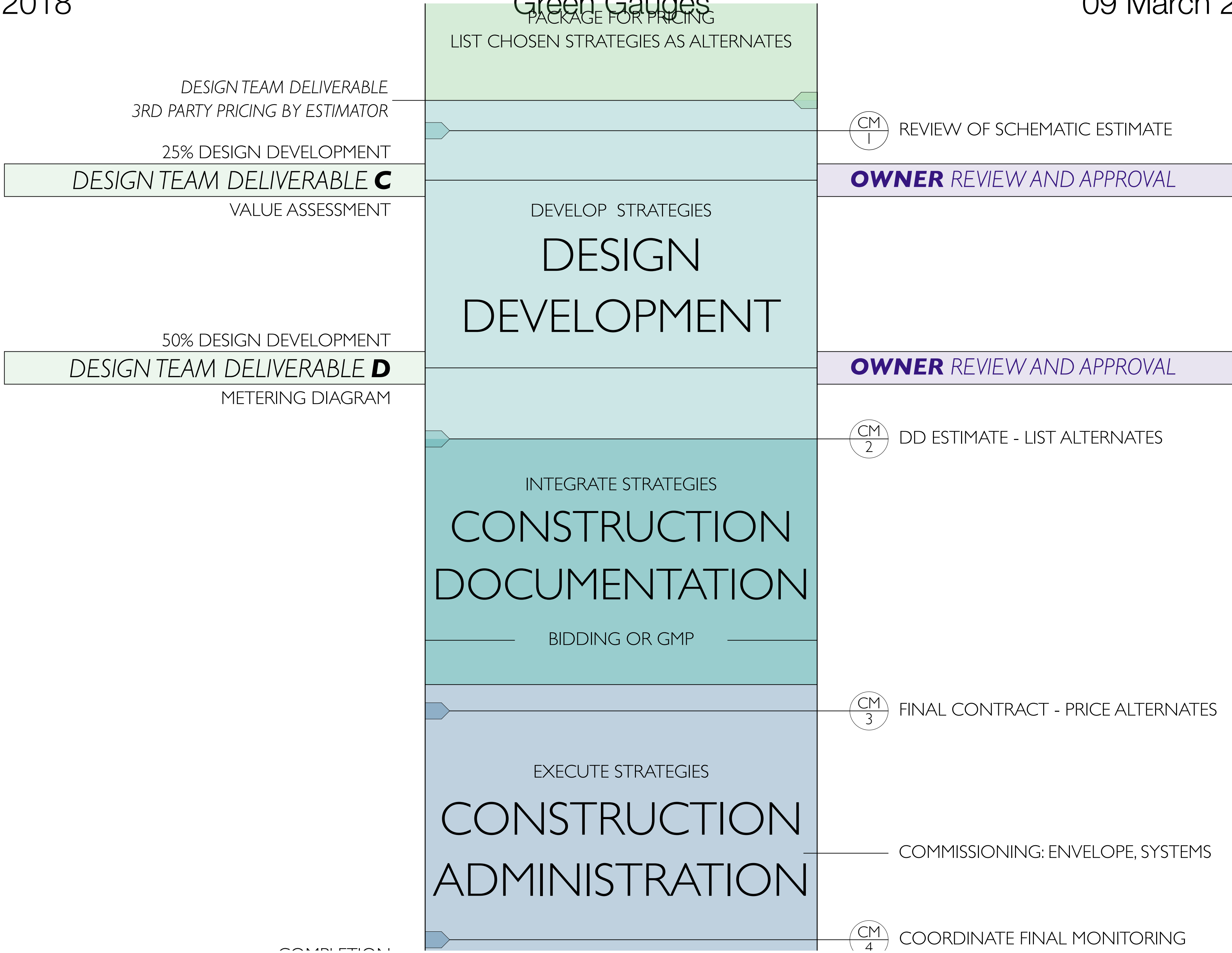


Diagram – Design Development

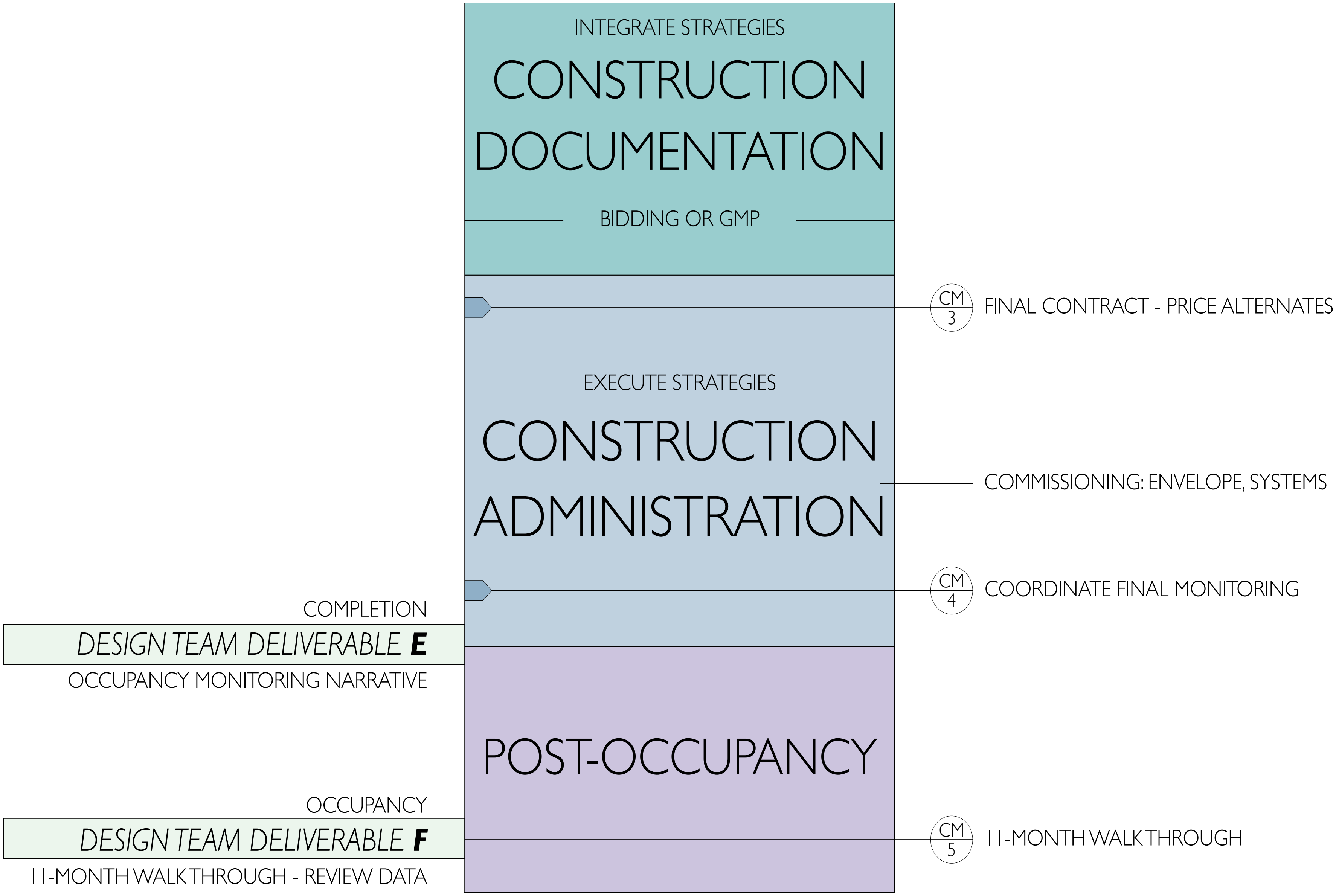


Diagram – At completion

Biophilic moment

What is the BASELINE and What is the GOAL?

BASELINE

Peer group Baseline is LEED Silver (not energy specific)

Energy Baseline is MA Stretch Code

GOAL

LEED GOLD or better

15-20% better than the Stretch Code (now IECC – 2015)

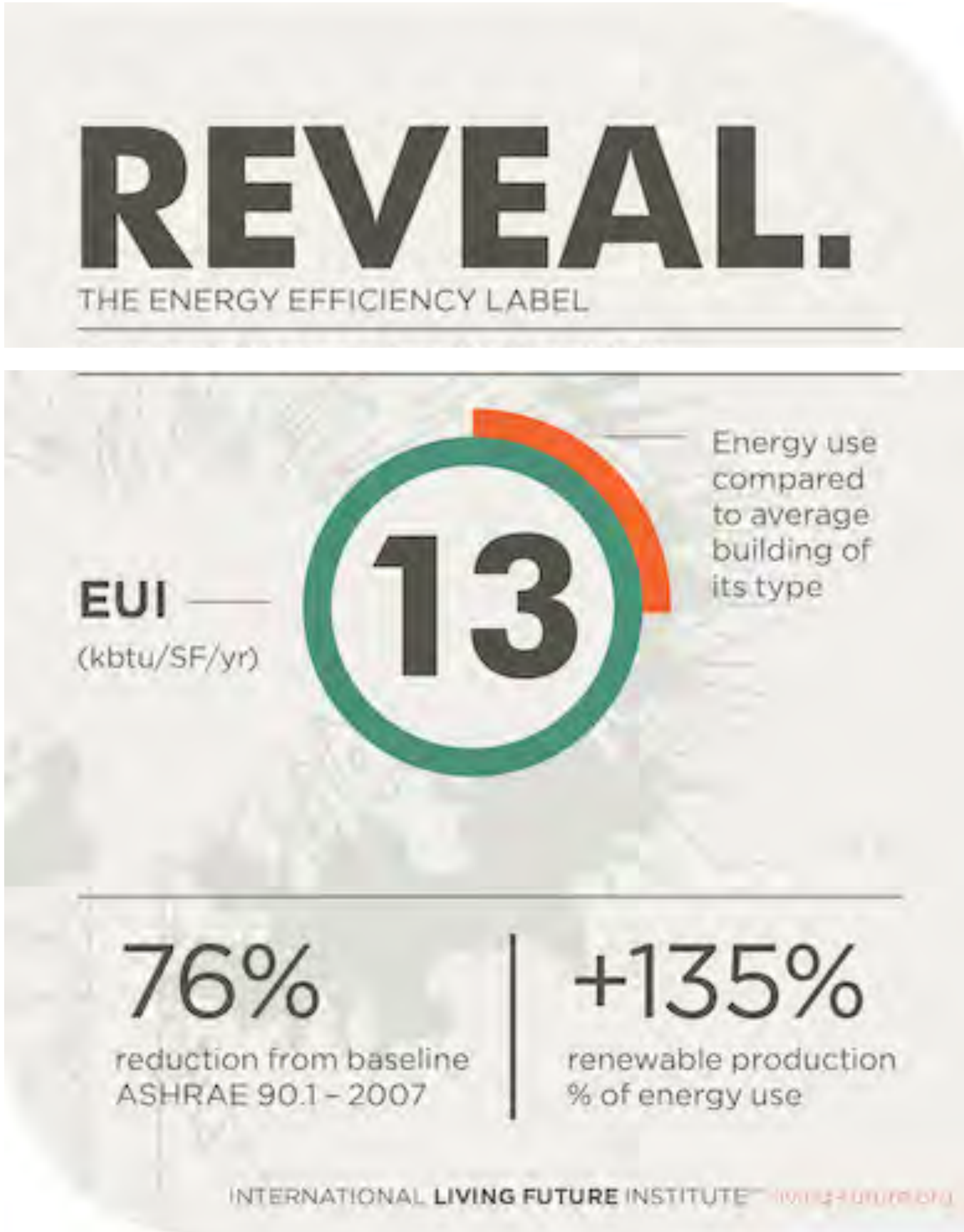
Stated goal- 35% campus wide carbon emission reduction of 1990 levels by 2020

ENERGY USE INTENSITY or EUI

The total amount of energy used in the course of a year expressed in kbtu/sf.

For either source or site energy.

at Williams, this value is NOT offset by renewables



(EUI)- as reported by LBC, not 2030 Challenge

WILLIAMS INN SCHEMATIC DESIGN | BENCHMARKING | BENCHMARKS AND TARGETS

BENCHMARK TARGETS

These graphs show how the Benchmarking Analysis described on the previous pages compares against other industry values.

The source of information for the existing Williams Inn in based on 2013 Utilities provided by Williams College.

The Benchmarking analysis shows that the current target of 60 kbtu/sf for the project is roughly 45% better than the existing Inn and about 37% better than existing buildings of comparable program.

For comparison, LEED and Architecture 2030 Targets are also shown. Since LEED uses energy costs instead of EUI, some approximation is necessary to provide a comparable target. Since LEED does not have a specific energy target, what is shown is the likely range of energy performance that will be required in order to achieve the desired level of LEED Gold (using the 2009 version of the Rating System).

Architecture 2030 uses the CBECS baseline and seeks to achieve Carbon Neutral design relative to 2003 CBECS data by the year 2030 though increasing savings year over year. The current goal is 70% reduction, or an EUI of approximately 29 relative to the program-weighted EUI.

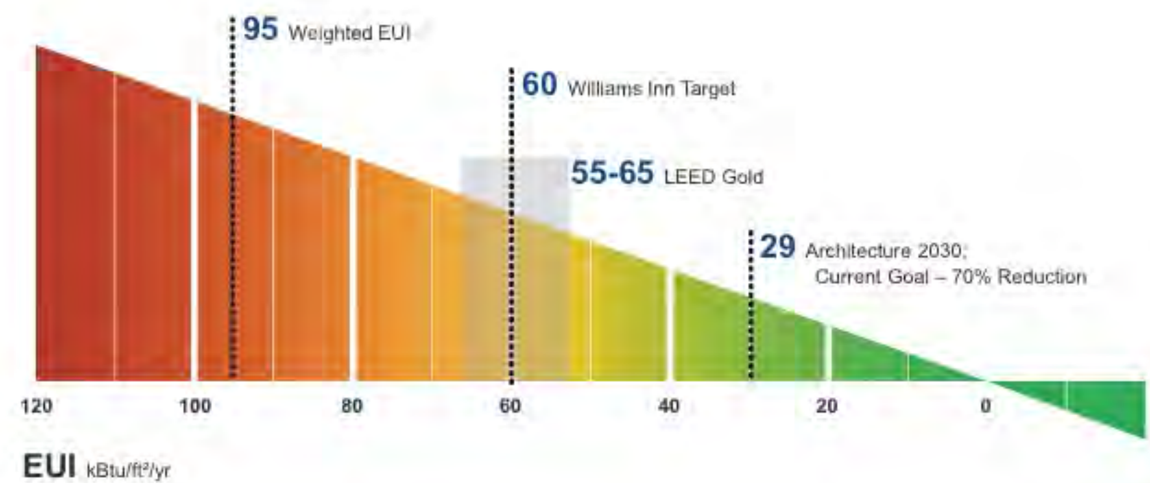
The above Benchmarking exercise therefore suggests that the current target of 60 kbtu/sf represents a moderately aggressive, yet realistic target.

In addition to the EUI target and LEED Gold, the project is also required to meet the MA Stretch Energy Code.

The next sections of the report outlines strategies to achieve these targets.

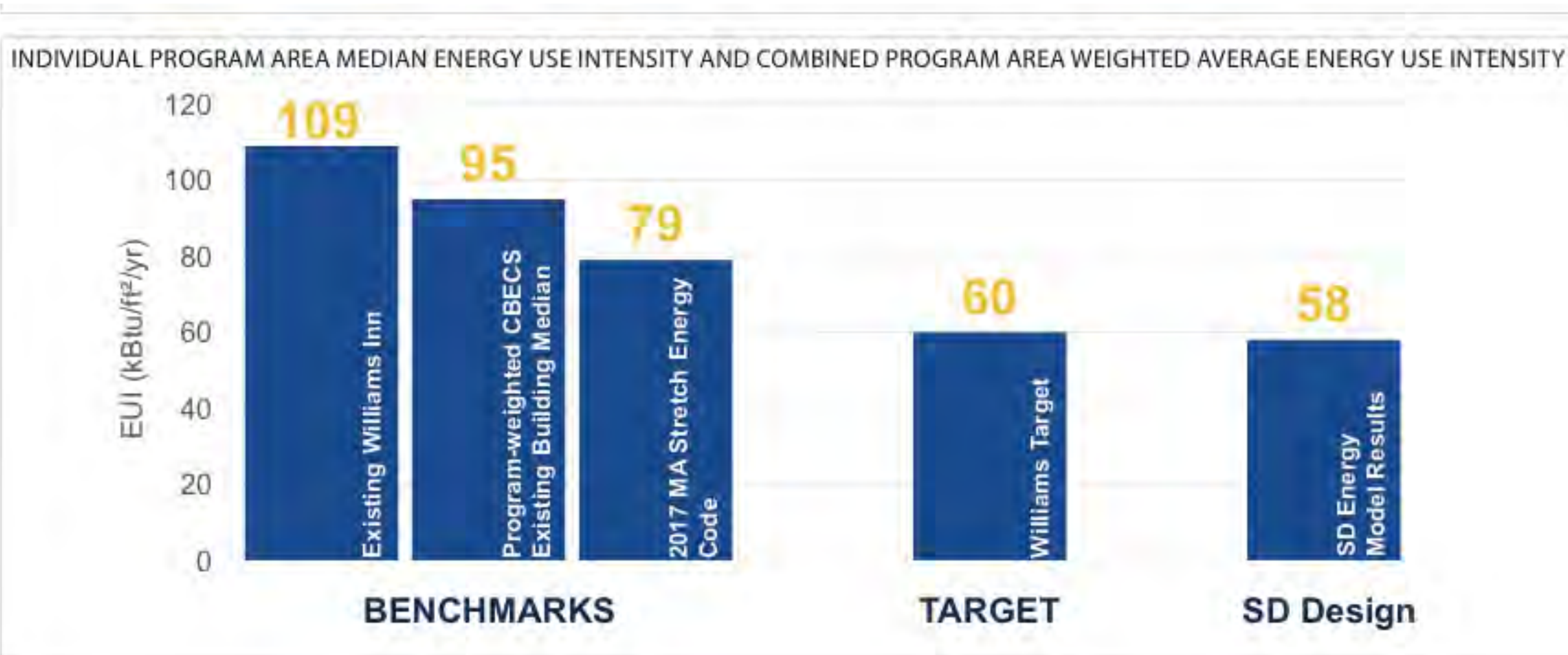
EUI BENCHMARKING EXISTING WILLIAMS INN, MEDIANS AND CURRENT TARGET

EUI BENCHMARKING COMPARISON, LEED GOLD AND ARCHITECTURE 2030



Williams Inn- Energy Use Intensity- EXAMPLE

Designed by Cambridge Seven, Analysis by WSP



Williams Inn- Energy Use Intensity- EXAMPLE

Designed by Cambridge Seven, Analysis by WSP

A simple narrative that is organized to communicate with all members of the Project team.

B1	Site
B2	Envelope
B3	Mechanical, Electrical & Plumbing
B4	Indoor Air Quality
B5	Passive Strategies
B6	Resilient Strategies
B7	Water
B8	Generation & Offsets
B9	Occupant engagement
B10	Monitoring

To be reviewed and approved with the Owner at 30% of Schematic Design ***before*** the design is fully documented.

A consistent format for Project Managers working with numerous design teams. If an integrated design process, this is easy.

Systems and Metering Narrative- Appendix B

B2- Envelope	System Description	Pros / Cons	Target / Goal	Owner Review & Comments
Sub-Slab	2" XPS Foam Board continuous beneath slab.	Adequate, continuous sub-slab insulation and air/moisture control provides thermal stability, moisture mitigation, reduced heat loss. Areas of discontinuity can provide regions for condensation, mold formation.	Reduce heatloss through foundation walls and condensation at slab. Continuous sub-slab insulation. Consider R-15 to R-20 for Net Zero Projects	
Foundation	4" XPS continuous foam board in ground contact to exterior of poured concrete foundation walls. AAC block grade where insulation ends.	Continuous insulation at the foundation – whether inside or outside – provides thermal comfort. Air control and moisture control below grade are critical to maintaining internal comfort throughout building. basement. Some ground-contact foam products have high Global Warming Potential – subtracting from the climate-benefits their insulation provides.	Durable, low-impact insulation continuous to the exterior of the foundation to R-20.	
Walls - Wood	Insulation: 2x8 Walls with batt insulation, 4" Rigid Insulation outboard of sheathing. Outline spec indicates wall insulation to be mineral fiber and rigid insulation to be rock-wool-fiber. Air Sealing: Continuous and verified air barrier assembly.	Insulation: Batt insulation affordable but difficult to install to Grade I standards. Outboard insulation is good strategy for protection of structural members and sheathing. Air Sealing: Provides thermal comfort, energy savings, and durability by preventing movement of heat and moisture through wall assembly and avoiding future condensation/mold/rot.	Insulation: R-40 wall with continuous insulation to the exterior of structural members. Air Sealing standard: 0.25 cfm75/square foot of shell – all six sides.	
Walls – Masonry	8" CMU. Brick veneer. Insulated to the outside.	Exterior insulation allows for protection of the structural assemblies from hot/cold/wet conditions.	Continuous insulation on all segments of the thermal boundary.	
Walls – Curtain	High performance curtain wall. U-0.2 or lower whole unit value specified.	Low U-value windows typically provide greater energy savings, higher thermal comfort, esp. in spaces dominated by curtain wall assemblies. Prices typically higher than lower performance units.	Avoid cold spots, uncomfortable spaces	
Windows / Doors	Doors: U-0.24 Exterior Doors specified. Windows: Single hung, triple-glazed wood clad windows with multi-layer low-E coating and Argon fill	Low U-value windows provide greater thermal comfort, energy savings. Prices typically higher than double glazed units.	U-0.2 or better all windows.	
Roof	Insulation: 4" Batt insulation in attic floor. 8" rigid insulation at underside of roof sheathing. Air Sealing: Continuous, verifiable air barrier assembly.	High R-value roof will reduce energy losses in winter (and gains in summer). Carefully detailed air sealing prevents migration of warm moist air into assemblies during winter, preventing condensation, protecting structure.	R-50 or better. All mechanicals fully within insulated space. Air Sealing standard: 0.25 cfm75/square foot of shell – all six sides.	
Air-Tightness	Continuous, verifiable air barrier assembly, traceable from roof to basement. Testing protocols established early. Full-scale mockup provided and tested with fog.	Careful detailing and established testing protocols provide for low heat loss and high durability in low-infiltration buidings. Testing of mockup can diagnose possible issues in construction sequence.	0.25cfm75/shell square foot, all six sides	

B2- Envelope	System Description	Pros / Cons
Sub-Slab	2″ XPS Foam Board continuous beneath slab.	Adequate, continuous sub-slab insulation and air/moisture control provides thermal stability, moisture mitigation, reduced heat loss. Areas of discontinuity can provide regions for condensation, mold formation.
Foundation	4″ XPS continuous foam board in ground contact to exterior of poured concrete foundation walls. AAC block grade where insulation ends.	Continuous insulation at the foundation – whether inside or outside – provides thermal comfort. Air control and moisture control below grade are critical to maintaining internal comfort throughout building. basement. Some ground-contact foam products have high Global Warming Potential – subtracting from the climate-benefits their insulation provides.
Walls - Wood	Insulation: 2x8 Walls with batt insulation, 4″ Rigid Insulation outboard of sheathing. Outline spec indicates wall insulation to be mineral fiber and rigid insulation to be rock-wool-fiber. Air Sealing: Continuous and verified air barrier assembly.	Insulation: Batt insulation affordable but difficult to install to Grade I standards. Outboard insulation is good strategy for protection of structural members and sheathing. Air Sealing: Provides thermal comfort, energy savings, and durability by preventing movement of heat and moisture through wall assembly and avoiding future condensation/mold/rot.

SUSTAINABLE STRATEGIES: MEP (MECHANICAL, ELECTRICAL, PLUMBING)

SYSTEM	DESCRIPTION	PROS/CONS	MEASURED BENEFITS
HEATING	Option #1: Campus Steam	(+) no site fossil fuel (-) higher EUI	Utilizes existing heating source
	Option #2: Air Source VRF Heat Pump with supplemental steam heating	(+) no site fossil fuel – could be offset by PV/GEC (+) lower EUI (-) requires supplemental heat for extreme cold	Reduced EUI and reduce Carbon footprint when coupled with PV/GECs
COOLING	Option #1: Air Cooled Chiller	(+) High Efficiency (-) High First Cost	Less equipment to support AC.
	Option #2: Air Source VRF Heat Pump	(+) High Efficiency (-) Distributed refrigerant	Reduced EUI and reduce Carbon footprint when coupled with PV/GECs
VENTILATION	Energy Recovery Units (ERUs)	(+) Provide Code required ventilation (-) Space in existing building for ductwork (-) High First Cost	Comfort Air Quality Reduce Energy
	Occupancy Based Control	(+) High Efficiency	
	Single room recovery ventilation unit	(+) Low energy (+) Eliminate the need for ductwork	
	Operable windows (see passive section)		
FILTRATION	MERV 13 Filters in ERUs Comply with LEED	(+) Air Quality (-) Fan Power (-) Filter Cost	Air Quality

Designed by Centerline Architects

System		First Cost	Operating Cost	Source EUI*	Architectural Requirements	Thermostats	notes
Heating Only	Hot-Water Radiant Panels	$$$	Low	Medium	Basement Mechanical Room; Recessed Ceiling Panels	Individual Control	**Horn Hall** is designed with this off campus steam plant – primary campus standard
	Air-Source Heat Pumps	$$	Medium	Low	Mechanical Closets with Ducting	Shared Control	
	Electric Baseboard	$	High	Medium	Recessed Wall or Ceiling Panels	Individual Control	
Heating & Cooling	VRF Heat Pumps	$$	Medium	Medium	Mechanical Closets with Ducting	Shared Control	Installed at Kellogg Center
	Ground Source Heat Pumps (Water-to-Air)	$$$	Low	Low	Mechanical Closets with Ducting	Shared Control	
	Ground Source Heat Pumps (Water-to-Water)	$$$($)	Low	Low	Mechanical Room; Recessed Terminal Units	Individual Control	Current design for the CDE
Domestic Hot Water	Natural Gas	$$	Medium	Medium	Mechanical Room	N/A	
	Air-Source Heat Pump	$$	Medium	Medium	Mechanical Room	N/A	

***Source EUI:**

In comparing the projected energy performance of the Garfield House to other new construction at Williams College, it is important to make an apples to apple comparison of heating energy sources. Buildings such as Horn Hall rely on district steam, so the efficiency of the district heating plant must be taken into consideration when comparing it to the efficiency of Garfield's proposed heating systems (local boilers, etc.).

Designed by SGA, Vanderweil and Thorton Tomasetti

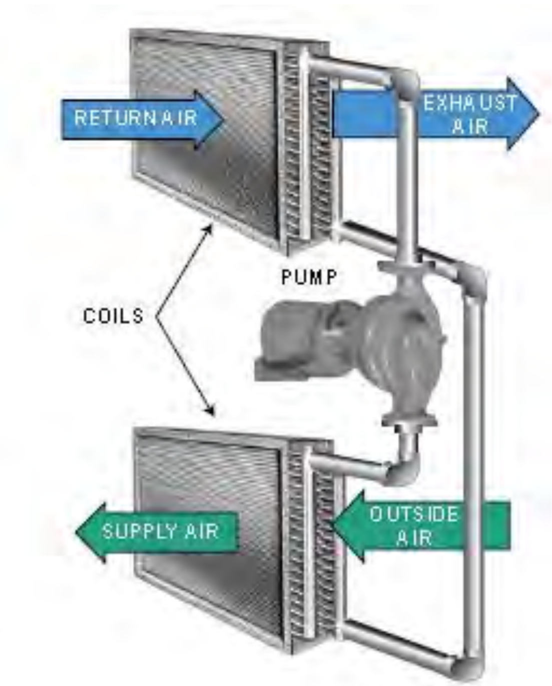
Biophilic moment

	Strategies for Assessment (ref Appendix B)	Incremental Cost of Measure over Baseline ($ initial cost)	Energy Savings (units per fuel type- not $) over Baseline	Avoided carbon Metric Tons-eCO2	System life (years)	$/Metric Ton of eCO2 per year over the system life	Comments
C1- Site							
C2- Envelope							
C3- Mechanical							
C3- Electrical							
C3- Plumbing							
C4- Materials & IAQ							
C5- Passive Strategies							
C6- Resilient Design							
C7- Water							
C8- Generation							
C8- Offsets							
C9- Occupant Engagement							
C10- Metering							

Value Assessment- Appendix C

	SCIENCE CENTER SOUTH	Incremental costs from Nat. Grid study	KWH savings	Equ. Carbon avoided in metric tons	THERMS savings	Equ. Carbon avoided in metric tons	Total metric tons avoided eCO2		cost per avoided metric ton	System Life	cost per metric ton of eCO2 avoided over system life
C2	Envelope Enhancements	$ 33,204	17,726	5.9	6,297	33.3	39.3		$ 846	40	$ 21
C3	High Efficiency Lighting	$ 38,785	137,486	45.9	- 3,561	-18.9	27.0		$ 1,435	20	$ 72
C3	Enhanced Lighting controls	$ 122,707	22,755	7.6	- 223	-1.2	6.4		$ 19,136	10	$ 1,914
C3	Chilled beams at offices	$ 29,700	- 15,590	-5.2	2,857	15.1	9.9		$ 2,993	25	$ 120
C3	Lab exhaust enhancements	$ 226,039	103,282	34.5	96,122	508.9	543.4		$ 416	25	$ 17
C8	Photovoltaics (147.9 kv 123.6	$ 494,500	148,350	49.5	-	0.0	49.5		$ 9,990	20	$ 499
								TOTAL 675.5			

Data by Payette- analysis to cost/aCO2e/year by c&h
Carbon equivalent values from Clean Air Cool planet



ECM #5: Exhaust Air Enhancements

Measure Name	Electric Energy Savings and NEBs				Total Cost Reduction	Installed Incremental Cost	Simple Payback w/o incentive	
	Electricity		Natural Gas				Elec Only	Total
ECM 5	kWh	$	Therms	$	$	$	years	years
Laboratory Exhaust	103,282	$ 15,161	96,122	$ 117,942	$133,103	$226,039	14.9	1.7

Designed by Payette and Vanderweil, analysis by Andelman and Lelek

Science Center- Lab Exhaust

BE 2018 — Green Gauges — 09 March 2018

ID	GARFIELD	Incremental costs over code	Savings KWH	metric tons Equ. Carbon	Savings THERMS	metric tons Equ. Carbon	Total metric tons eCO2	cost per metric ton	System Life	cost per metric ton over system life
C2	Passive Haus Envelope	$ 69,800.00	33,980	11.34	0	0.0	11.3	$ 6,156	50	$ 123
C3a	DHW- drain water recovery	$ 4,500.00	0	0.00	359	1.9	1.9	$ 2,368	50	$ 47
C3b	LED Lighting	$ 25,000.00	11,679	3.90	0	0.0	3.9	$ 6,415	20	$ 321
C3c	Electric heating vs. gas boiler (No cooling)	-$ 71,814.00	- 24,300	-8.11	2129	11.3	3.2	-$ 22,704	30	$ (757)

reviewed by TRCH

WILLIAMS INN

ID	Measure	Incremental costs	Savings KWH	metric tons Equ. Carbon	Savings THERMS	metric tons Equ. Carbon	Total metric tons eCO2	cost per metric ton	System Life	cost per metric ton over the system life
C2	Exterior Envelop upgrades	$ 38,000	-	0.0	3,560	18.8	18.8	$ 2,016	50	$ 40
C3a	Mechanical Upgrades	$ 378,000	-	0.0	14,250	75.4	75.4	$ 5,010	20	$ 251
C3b	Electrical Upgrades	$ 82,000	45,122	15.1		0.0	15.1	$ 5,446	10	$ 545
C3c	High Efficiency DHW	$ 67,000		0.0	2,530	13.4	13.4	$ 5,002	20	$ 250
C8	30 kw pv array	$ 86,000	36,000	12.0	-	0.0	12.0	$ 7,159	20	$ 358

ID	SCIENCE CENTER SOUTH	Incremental costs From Nat. Grid study	Savings KWH	metric tons Equ. Carbon	Savings THERMS	metric tons Equ. Carbon	Total metric tons eCO2	cost per metric ton	System Life	cost per metric tc over system life
C2	Envelope Enhancements	$ 33,204	17,726	5.9	6,297	33.3	39.3	$ 846	40	$ 21
C3	High Efficiency Lighting	$ 38,785	137,486	45.9	- 3,561	-18.9	27.0	$ 1,435	20	$ 72
C3	Enhanced Lighting controls	$ 122,707	22,755	7.6	- 223	-1.2	6.4	$ 19,136	10	$ 1,914
C3	Chilled beams at offices	$ 29,700	- 15,590	-5.2	2,857	15.1	9.9	$ 2,993	25	$ 120
C3	Lab exhaust enhancements	$ 226,039	103,282	34.5	96,122	508.9	543.4	$ 416	25	$ 17
C8	Photovoltaics (147.9 kw) #	$ 494,500	148,350	49.5	-	0.0	49.5	$ 9,990	20	$ 499

12-Dec-17

Input by TRCH from 04 Dec Memo from ARC/RFS

ID	BOAT HOUSE		Incremental costs of Measure over baseline	Savings KWH	calculated per WC values metric tons Equ. Carbon	Savings THERMS	metric tons Equ. Carbon	Total metric tons eCO2	1st year cost per metric ton	System Life	Lifetime cost per metric ton
C2a	Wall insulation	U-0.04 vs 0.051	$ 24,000	5,121	1.7	-	0.0	1.71	$ 14,045	40	$ 351
C2b	Roof insulation	U-0.025 vs 0.032	in above	in above		-					
C2c	Triple pane glazing	U 0.24 vs 0.3	$ 20,000	1,691	0.6	-	0.0	0.56	$ 35,445	20	$ 1,772
C3	Heat pumps (over propane boiler)		?		0.0	-	0.0	0.00	#VALUE!	20	#VALUE!
C3	Increase ERV Efficiency		$ 5,000	1,061	0.4	-	0.0	0.35	$ 14,123	20	$ 706
C4	LED Lighting		$ 40,500	8,062	2.7	-	0.0	2.69	$ 15,055	20	$ 753
C7	PV's	131.98	$ 527,910	158,373	52.8	-	0.0	52.85	$ 9,990	20	$ 499
		1200 kwh per kw	$4,000								
C8	Network lighting control		$ 20,250	5,254	1.8	-	0.0	1.75	$ 11,551	20	$ 578

Value Assessment- Appendix C- more examples

SCIENCE CENTER SOUTH

		Incremental Cost	Total Metric Tons of eCO2 saved per year	System Life	Cost per metric ton over system life
C2	Envelope Enhancements	$33,204	39.3	40	$21
C3	High Efficiency Lighting	$38,785	27.0	20	$72
C3	Enhanced Lighting Controls	$122,707	6.4	10	$1,914
C3	Chilled Beams at Offices	$29,700	9.9	25	$120
C3	Lab Exhaust Enhancements	$226,039	534.4	25	$17
C8	Photovoltaics- 148 kw @$3.57 per watt	$494,500 (PPA)	49.5	20	$499

BOAT HOUSE

		Incremental Cost	Total Metric Tons of eCO2 saved per year	System Life	Cost per metric ton over system life
C2a	Wall and Roof insulation	$24,000	1.7	40	$351
C2b	Triple glazed windows	$20,000	0.5	20	$1,772
C3	Heat pumps (over propane boiler)	??			
C3	Increase ERV Efficiency	$5,000	0.4	20	$706
C4	LED Lighting	$40,500	2.7	20	$753
C7	Photovoltaics- 132 kw @ $4 per watt	$527,910 (PPA)	52.8	20	$499
C8	Network Lighting Control	$20,250	1.75	20	$578

WILLIAMS INN

		Incremental Cost	Total Metric Tons of eCO2 saved per year	System Life	Cost per metric ton over system life
C2	Exterior Envelope Upgrades	$38,000	18.8	50	$40
C3a	Mechanical Upgrades	$378,000	75.4	20	$251
C3b	Electrical and Lighting Upgrades	$82,000	15.1	10	$545
C3c	High Efficiency DHW	$67,000	13.4	20	$250
C8	Photovoltaics- 30 kw @ $2.86 per watt	$86,000 (low) (PPA)	12	20	$358

GARFIELD

		Incremental Cost	Total Metric Tons of eCO2 saved per year	System Life	Cost per metric ton over system life
C2	Passive Haus Envelope	$69,800	11.3	50	$123
C3a	DHW- drain water recovery	$4,500	1.9	50	$47
C3b	LED Lighting	$25,000	3.9	20	$321
C3c	Electric heat vs. gas boiler (no cooling)	($24,300) savings	3.2	30	-$757 but positive
	Phase change material? Little heating benefit				

Summary Tables

SCIENCE CENTER NORTH

		Incremental Cost	Total Metric Tons of eCO2 saved per year	System Life	Cost per metric ton over system life
C2	Envelope Enhancements	$348,600	27.3	40	$319
C3a	Improved Lighting	$89,200	12	20	$371
C3b	Dual Enthalpy Economizers	$3,000	-0.4 (yes, more)	25	-$329
C3c	Supply air temperature reset	$2,200	15.4	60	$2
C3d	Energy Recovery enthalpy wheel	$10,000	4.1	25	$97
C3e	Reduced Minium flow	$2,200	23.4	60	$2

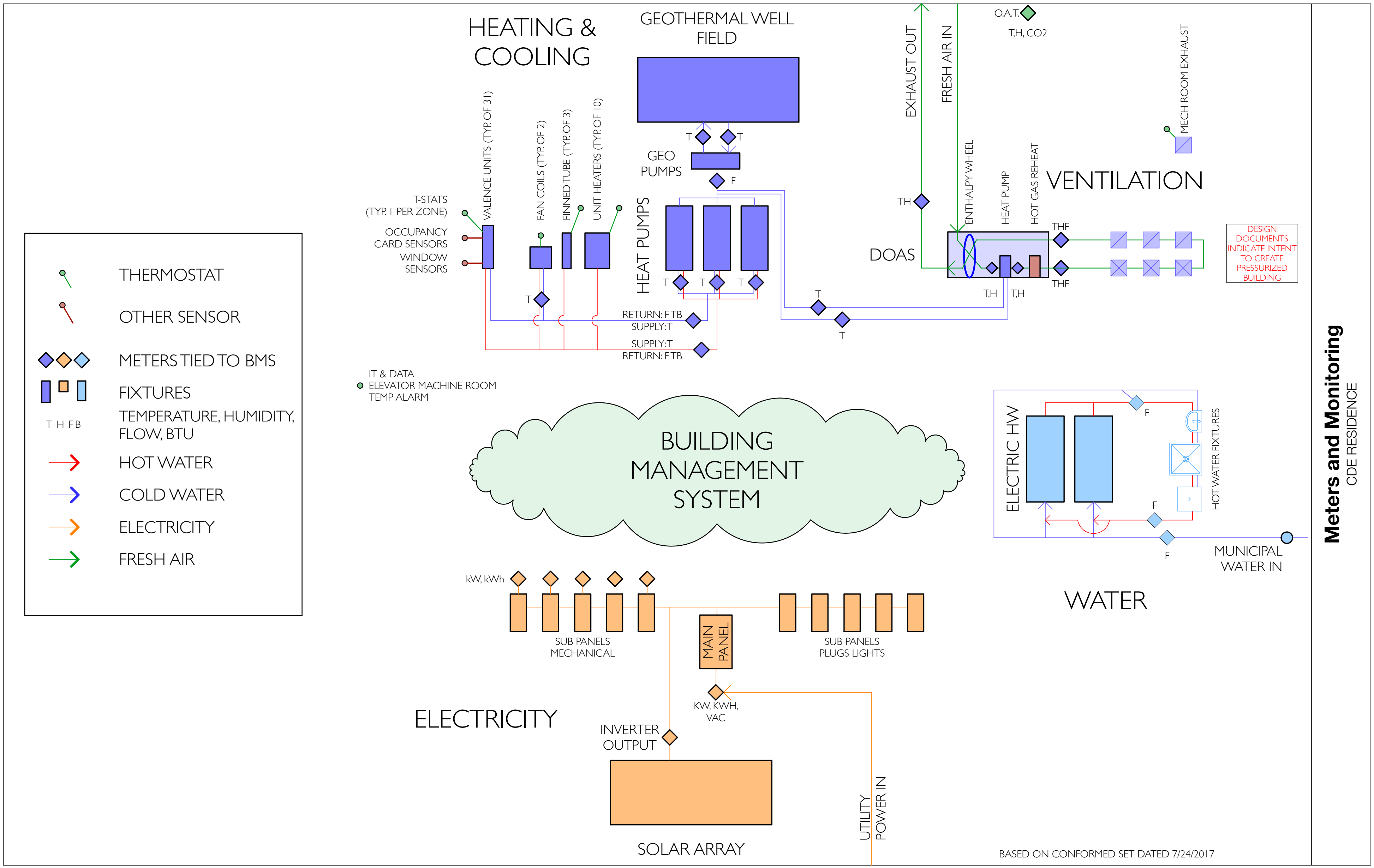
Williams College Measurement and Verification of Performance Process

% EFFORT	ACTION	DELIVERABLE	TEAM MEMBERS	COMMENTS
		SCHEMATIC DESIGN (SD)		
5%	**Identify target systems and metrics.** Identify systems to monitor (e.g., water system) and metrics for monitoring (e.g., amount of potable water use)	List of systems and metrics to be monitored	Project Owner; Design Team (i.e., Architect, M+V Consultant, MEP Designer, Water System Designer, PV System Designer); General Contractor; Building Manager	
5%	**Create schematic metering plan.** Create a schematic metering plan that identifies which systems will be monitored and where equipment will be located	Schematic metering plan for each metered system	Design Team (i.e., Architect, M+V Consultant, MEP Designer, Water System Designer, PV System Designer); General Contractor; Building Manager	
		DESIGN DEVELOPMENT (DD)		
15%	**Develop metering plan.** Develop a more detailed metering plan that includes descriptions of variables, metering equipment, and data collection frequencies, as well as diagrams depicting where metering equipment will be located	Metering plan	Design Team (i.e., Architect, M+V Consultant, MEP Designer, Water System Designer, PV System Designer); General Contractor; Building Manager	
5%	**Confirm metering plan.** Confirm metering plan with all project team members, including those involved in design, construction, and day-to-day operations of the project	Sign-off on metering plan	Project Owner; Design Team (i.e., Architect, M+V Consultant, MEP Designer, Water System Designer, Electrical Consultant, PV System Designer); General Contractor; Building Manager	
		CONSTRUCTION DOCUMENTS (CD)		
5%	**Confirm constructability.** Review metering plan with the construction team to verify constructability of the metering plan	Sign-off on metering plan, with respect to construction and construction documents	Design Team (i.e., M+V Consultant); Construction Team (i.e., Electrical Consultant, HVAC Consultant, Plumbing Consultant, IT Consultant); General Contractor	

Metering Diagram- Appendix D - RFP

RFP scope developed with Linnean Solutions on behalf of c&h architects

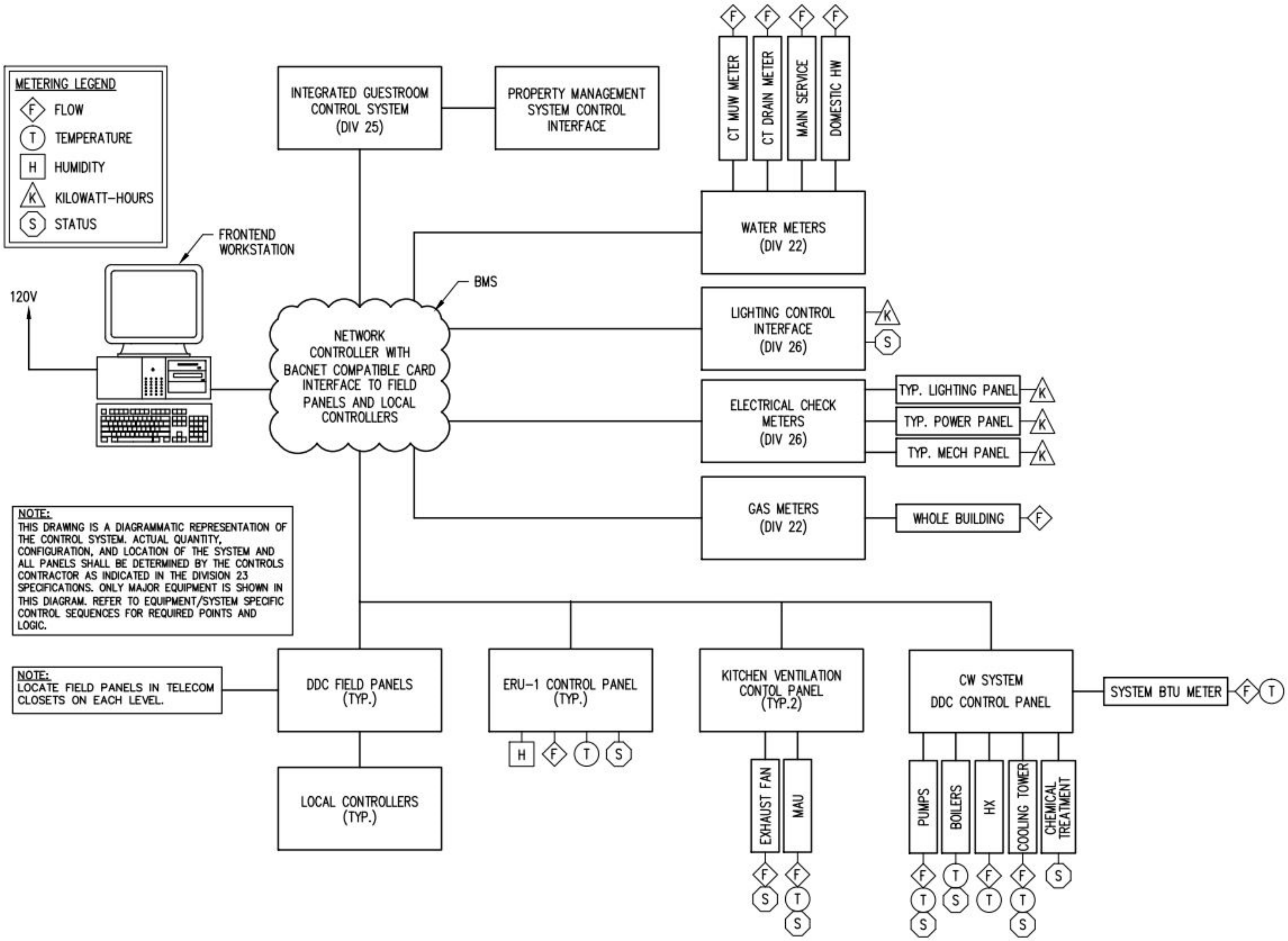
		CONSTRUCTION	
5%	**Install metering equipment.** Communicate with sub-consultants and participate in the installation process to verify that equipment is installed properly	Installation of metering equipment	Design Team (i.e., M+V Consultant); Construction Team (i.e., Electrical Consultant, HVAC Consultant, Plumbing Consultant, IT Consultant); General Contractor
5%	**Install metering displays.** Communicate with sub-consultants and participate in the installation process to verify that equipment displays are installed properly	Installation of metering displays	Design Team (i.e., M+V Consultant); Construction Team (i.e., Electrical Consultant, HVAC Consultant, Plumbing Consultant, IT Consultant); General Contractor
		COMMISSIONING (Cx)	
5%	**Support Cx process.** Communicate regularly with the commissioning team	N/A	Design Team (i.e., M+V Consultant); Commissioning Team
5%	**Confirm installation.** Confirm equipment has been installed properly and metering system has been connected to proper data storage system	Documentation that systems have been properly installed	Design Team (i.e., M+V Consultant); Commissioning Team; Construction Team as needed (i.e., Electrical Consultant, HVAC Consultant, Plumbing Consultant, IT Consultant); General Contractor
20%	**Verify metering system.** Verify that data collected is complete and accurate (to best of knowledge), and that systems are performing as designed or expected	Documentation that data has been reviewed and systems are operating as planned; Adjustments to the system as needed	Design Team (i.e., M+V Consultant); Commissioning Team; Construction Team as needed (i.e., Electrical Consultant, HVAC Consultant, Plumbing Consultant, IT Consultant); General Contractor
		ONGOING MONITORING	
25%	**Periodic Analysis.** Periodic analysis of load profiles, seasonal variations, equipment functionality, performance, etc.	Quarterly assessments of collected data compiled in reports to owner	M+V Consultant; Building Manager; Project Owner



Metering Diagram- Appendix D

Designed by PBDW, diagrammed by c&h

METERING DIAGRAM



Designed by C7A and WSP. Diagram by WSP.

Metering Diagram- Appendix D

Biophilic moment

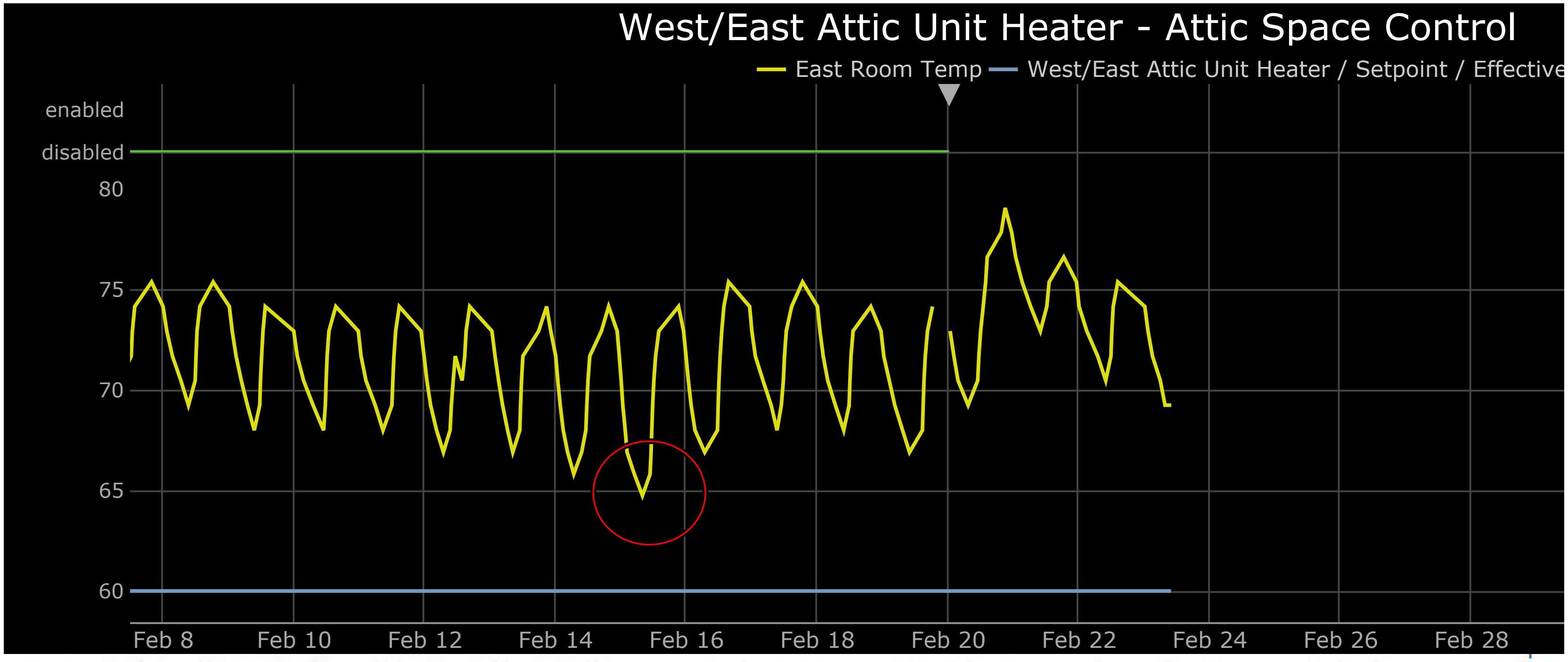
c&h architects

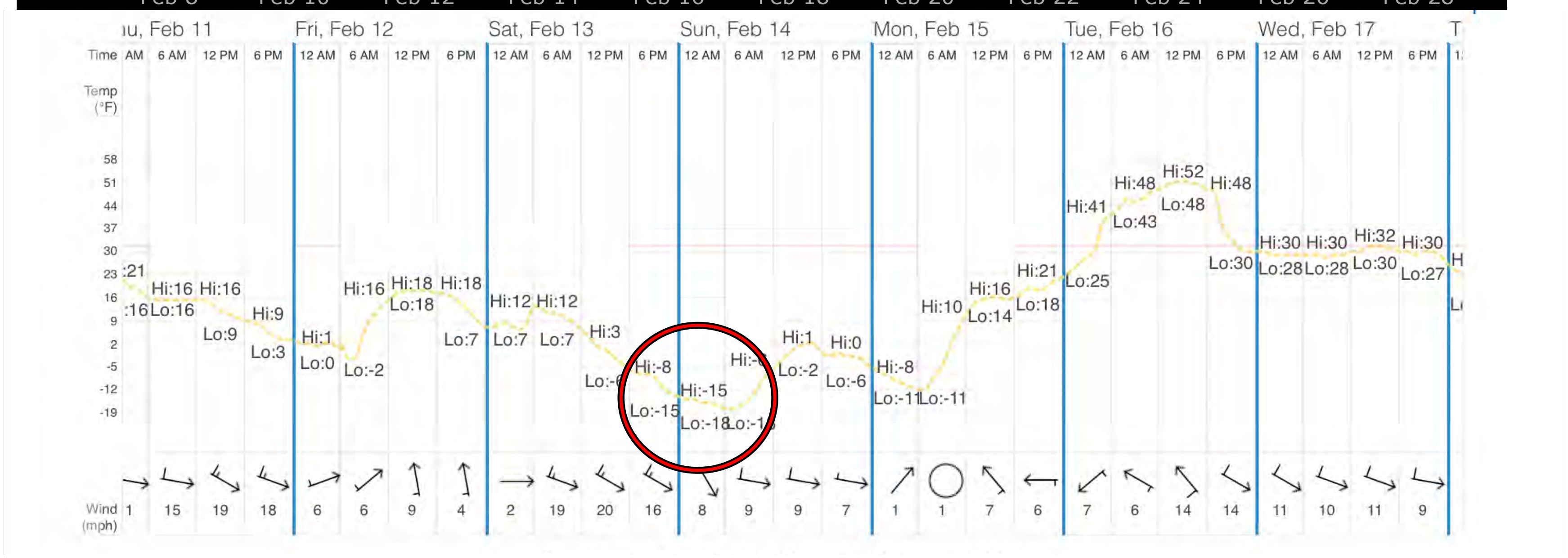
APPENDIX D

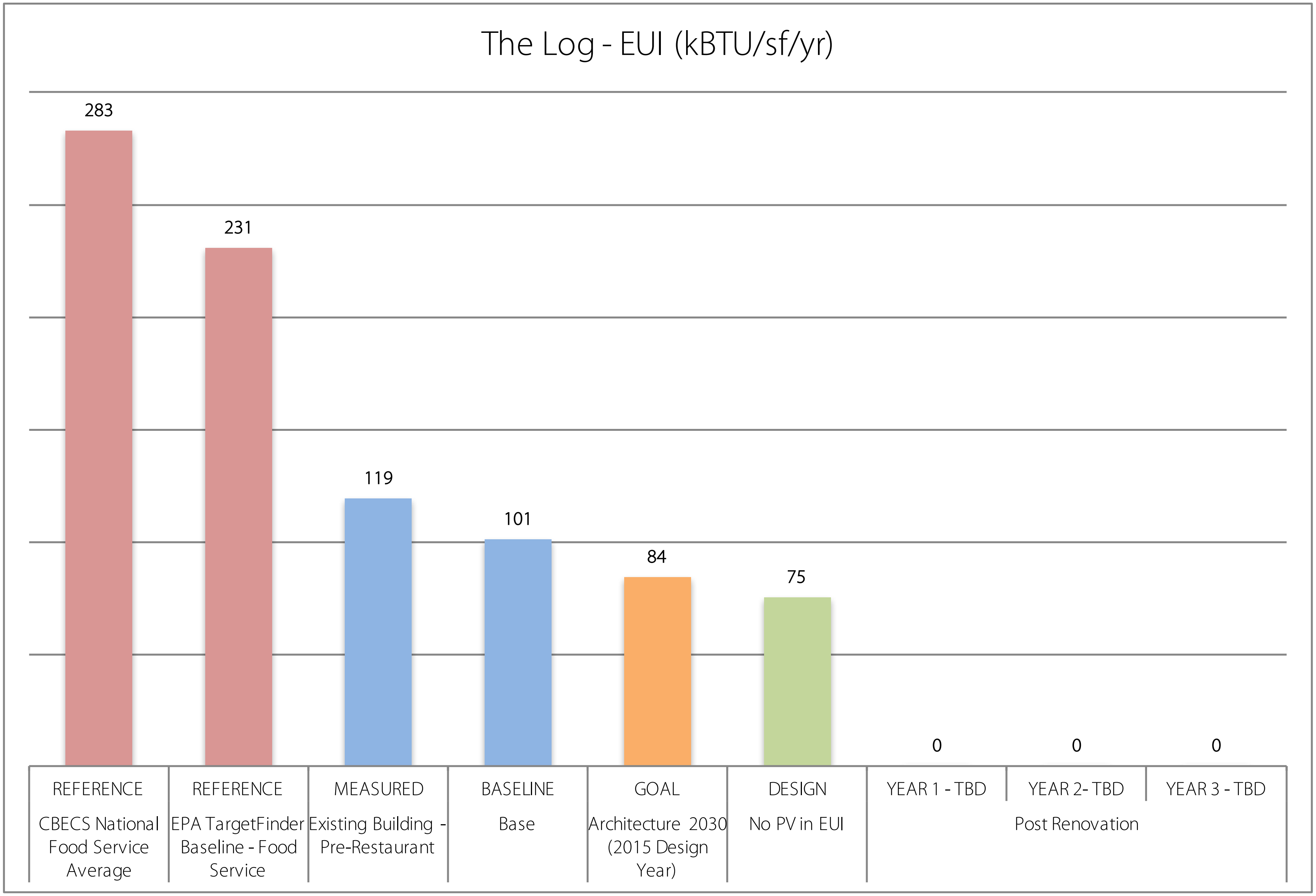
Project Name: The Log
Date: 5/16/16
Appendix D: **Monitoring**

Component	EXPECTED RANGE	ACTUAL:	NOTES:
Kitchen Hood			Review data with actual occupancy trends. Ensure staff is not turning on hood before cooking starts as a habit.
Hot Water			Review summer gas loads with flow meters.
Attic	60-80 degrees	Checked when -10 degrees and 20 mph winds- ok	Attic contains freeze sensitive equipment – sprinklers. Attic is within envelope, but has no dedicated full time heat source. Attic is provided with emergency electric fan coil connected to T-Stat to prevent freezing.
Fireplace Gas			Fireplace consumption trends should be logged in concert with occupancy and cooling equipment to confirm they are not driving unnecessary space conditioning. Ensure staff is not turning on the fireplaces in the summer when unoccupied.

Occupancy Monitoring Narrative - Appendix E


West/East Attic Unit Heater - Attic Space Control
East Room Temp
West/East Attic Unit Heater / Setpoint / Effective
enabled
disabled
80
75
70
65
60
Feb 8
Feb 10
Feb 12
Feb 14
Feb 16
Feb 18
Feb 20
Feb 22
Feb 24
Feb 26
Feb 28


Fri, Feb 12
Sat, Feb 13
Sun, Feb 14
Mon, Feb 15
Tue, Feb 16
Wed, Feb 17
Time
Temp (°F)
Wind (mph)


The Log - EUI (kBTU/sf/yr)
283
231
119
101
84
75
0
0
0
REFERENCE
CBECS National Food Service Average
REFERENCE
EPA TargetFinder Baseline - Food Service
MEASURED
Existing Building - Pre-Restaurant
BASELINE
Base
GOAL
Architecture 2030 (2015 Design Year)
DESIGN
No PV in EUI
YEAR 1 - TBD
YEAR 2- TBD
YEAR 3 - TBD
Post Renovation

The following is based upon information from Automated Logic Dashboard and School Dude from July 1, 2016 to June 30th, 2017.

EUI (kbtu/sf/year)	Proposed at Schematic	Actual	Notes
Total	75	142	EPA Target finder for Food Service is 231 This total does not include the pv production.
Cooking (Nat Gas)	12 (16%)	69 (51%)	Was induction electric cooking at SD with far fewer meals and no catering.
Building (Steam & Elec)	63	57	
PV offset	nic	(8)	Estimated pv production

Total Energy 989,145 kbtu + 58,021 kbtu of pv offset = 1,047,175
Area 7,816 sf (only including portion of the basement)
EUI 134

Energy Mix	Electric- 43%	125,168 Kwh (we think this is net of pv production)
	Steam- 4%	11,195 Kwh
	Natural Gas- 53%	5,136 CCF
	PV Production	Meter not reading on Automated Logic at the moment 15.6kw should produce ±17,000 kwh annually (or 58,021 kbtu)

Comment & Suggestions:

1. If the vendor is not paying the gas bill, consider it, especially if they are servicing their catering business from this kitchen. The initial projection for cooking was 100-120 meals a day for 260 days per year. Based on a call to the Log, they estimate 300-400 meals per day all year, not including the catering function.

2. We have observed the two gas fireplaces are on frequently. They each are rated 31,500 btu/hr Max, 17,100 btu/hr Min. This load is within the Natural Gas allocation and included within Actual cooking above. Their use could be one reason the steam load in so low.

Biophilic moment

Andy was working on one of the projects, and as usual…

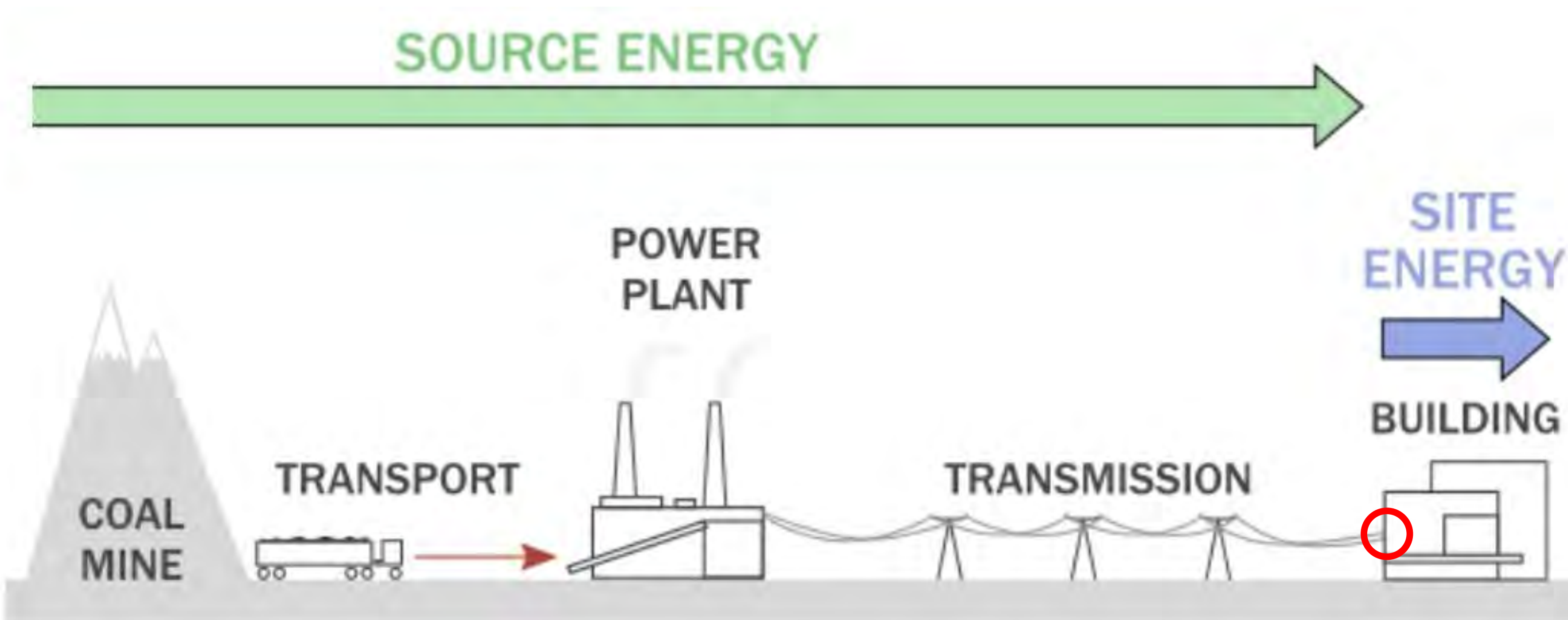
he had an opinion...

... about using source EUI rather than site EUI, and what this means for greenhouse gas emissions.

So we hired him to think about that, here's what happened.

Williams was asking for site EUI – energy use at the meter at the building.

But what they care about is the environmental impact – meaning greenhouse gas emissions, soooo…



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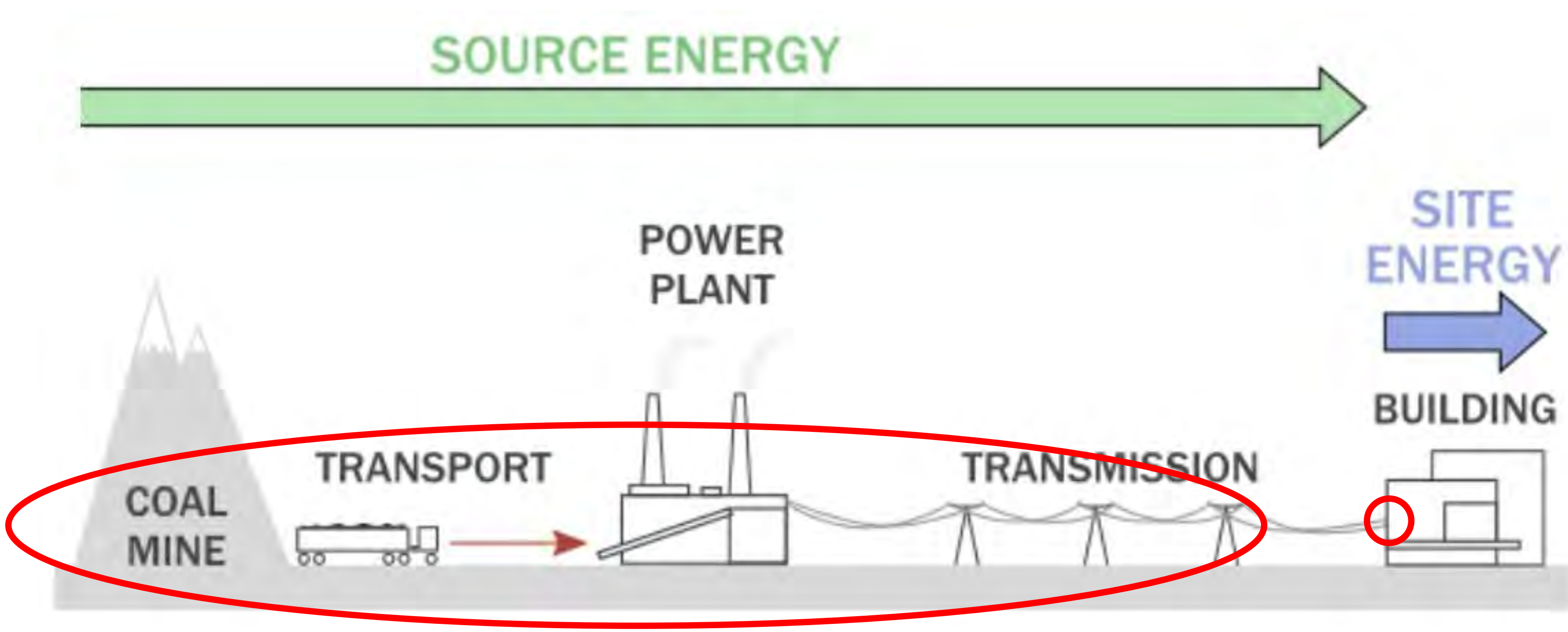

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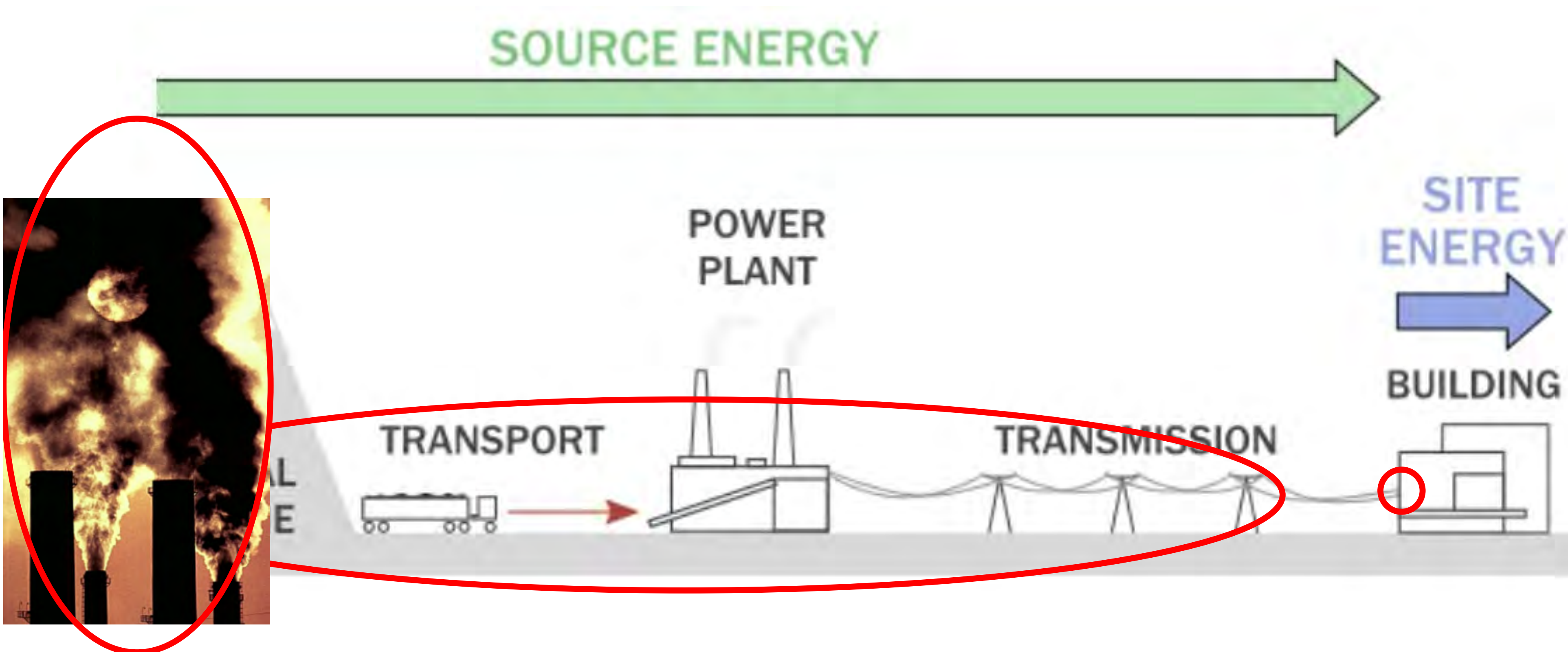
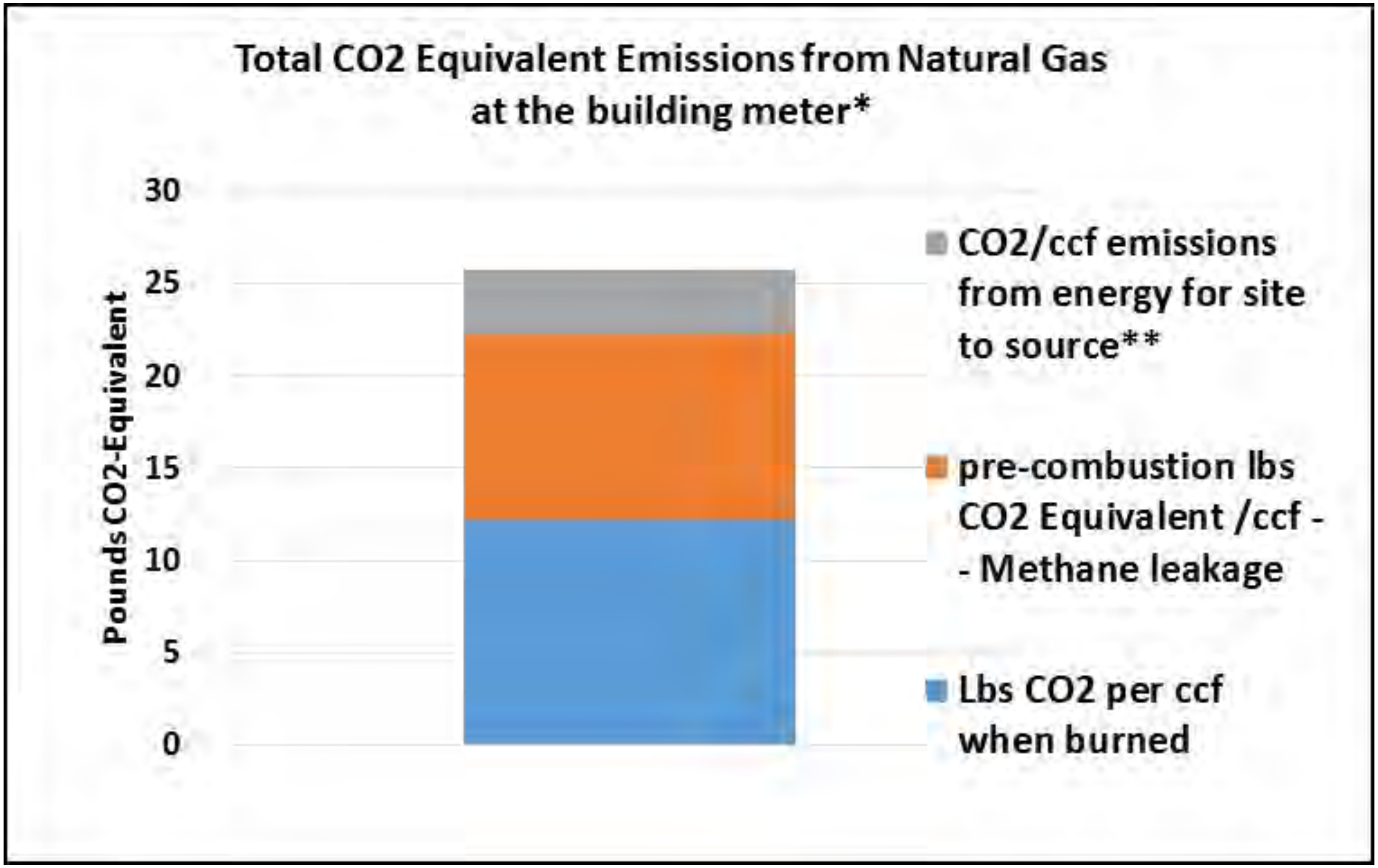
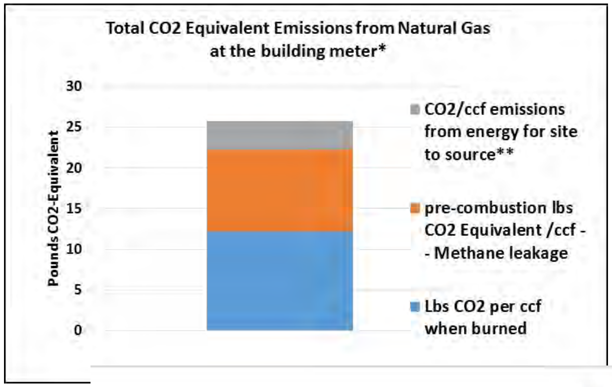
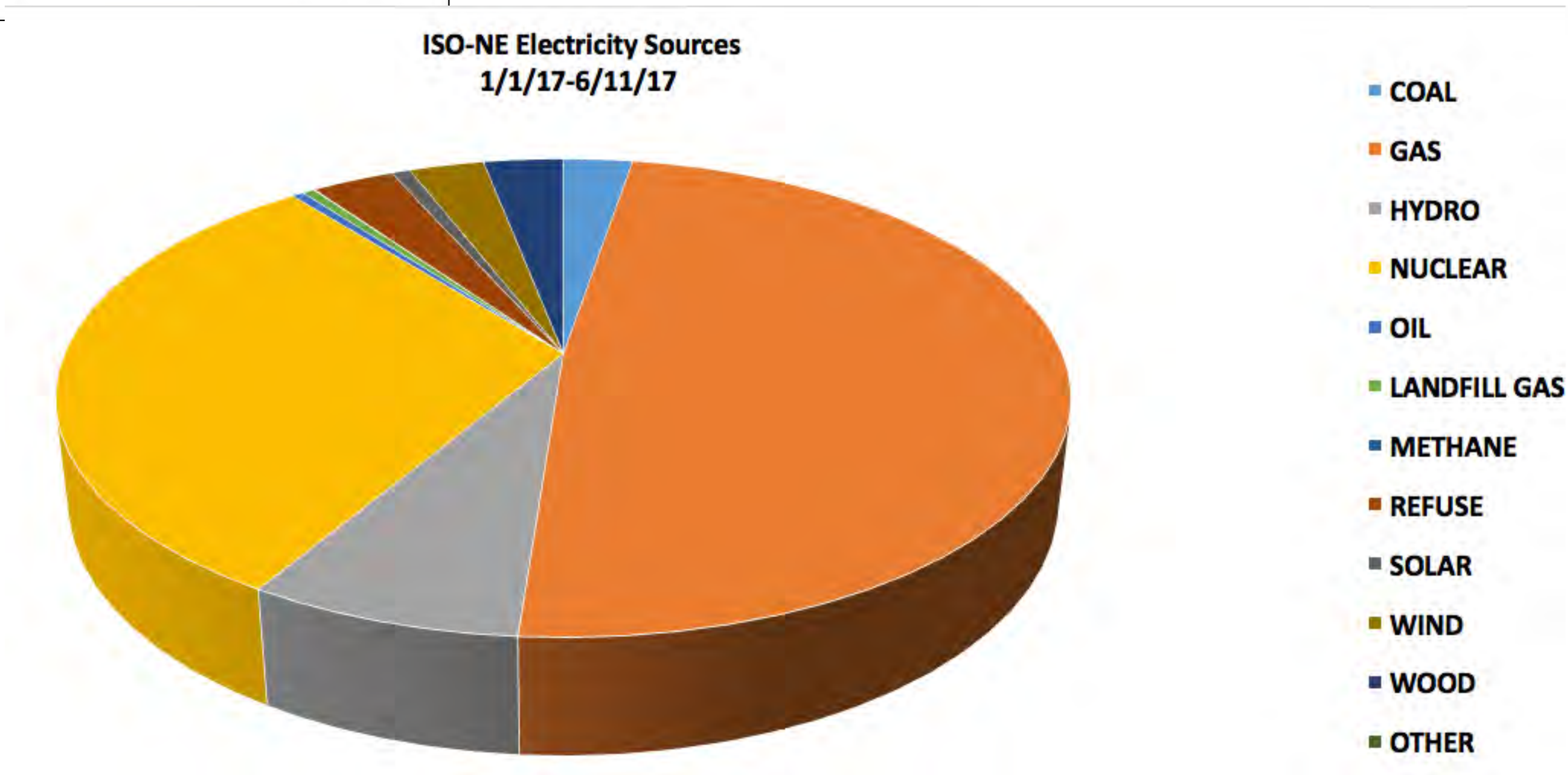



Total CO2 Equivalent Emissions from Natural Gas at the building meter*
Pounds CO2-Equivalent
30
25
20
15
10
5
0
CO2/ccf emissions from energy for site to source**
pre-combustion lbs CO2 Equivalent /ccf - - Methane leakage
Lbs CO2 per ccf when burned


Total CO2 Equivalent Emissions from Natural Gas at the building meter*
Pounds CO2-Equivalent
30
25
20
15
10
5
0
CO2/ccf emissions from energy for site to source**
pre-combustion lbs CO2 Equivalent /ccf - - Methane leakage
Lbs CO2 per ccf when burned


ISO-NE Electricity Sources
1/1/17-6/11/17
COAL
GAS
HYDRO
NUCLEAR
OIL
LANDFILL GAS
METHANE
REFUSE
SOLAR
WIND
WOOD
OTHER

Williams College								180214
CO2-equivalent Emissions by Fuel Type								
Fuel Source	**unit**	**Btu/unit**	**source/ site factor [1]**	**precombustion emissions [2] lb CH4/unit**	**precombustion emissions [2] lbs CO2e/unit**	**combustion emissions [3] lb CO2/unit**	**total lbs CO2e/unit [4]**	**total lbs CO2e/MMBtu [4]**
Oil #2	gallon	139,600	1.2	0.035	3.0	22	29	207
Natural Gas	**therm**	**100,000**	**1.1**	**0.070**	**10**	**12**	**23**	**234**
Propane	gallon	91,330	1.2	0.035	3.0	13	18	193
Grid electricity	**kWh**	**3,413**	**1.7**				**1.23**	**361**
WC CoGen electricity	**kWh**	**3,413**	**1.0**				**0.84**	**245**
Average non-PV electricity [6	kWh	3,413	1.6				**1.2**	340
PV generated electricity	kWh	3,413	1.0				0.064	19
WC Steam	MMBtu	1,000,000					344	344
WC Chilled Water	kBtu	1,000					0.083	83

CO2/kWh for Photovoltaic Systems	
2.3	Energy input into production, kWh energy input/ peak watt panels only (kWh-in/Wp [1]
1.1	50% increase for balance of system, including racking, inverter, installation, estimate
3.4	Total system kWh input/Wp
1.4	Avg US lbs CO2/kWh [3]
3.1	Avg China lbs CO2/kWh estimated for 2017 [4] at 25% reduction from 2015
2.2	Avg PV production CO2/kWh, assuming half of PV system is made in China [2]
1.29	Albany kWh/yr-Wp
35	Albany lifetime kWh/Wp, accounting for 0.7% decrease in putput per year [5]
0.064	**lbCO2/kWh- lifetime, for PV in Albany NY**

Figure of interest only

2.6	energy payback, years, in Albany

[1] implied in data from * PHOTOVOLTAICS REPORT Prepared by FraunhoferInstitute for Solar Energy Systems, ISE with support of PSE AG Freiburg, 11 March 2016 www.ise.fraunhofer.de

[2] Both the production and installation location of PV influence its environmental impact. The production location mainly because the environmental impact of the electricity used in production is very locationally dependent, and as a result, production of PV in China has, for example, almost twice the GHG footprint compared to production in Europe -- from [1]

[3] https://www.quora.com/How-much-CO2-is-produced-per-KWH-of-electricity

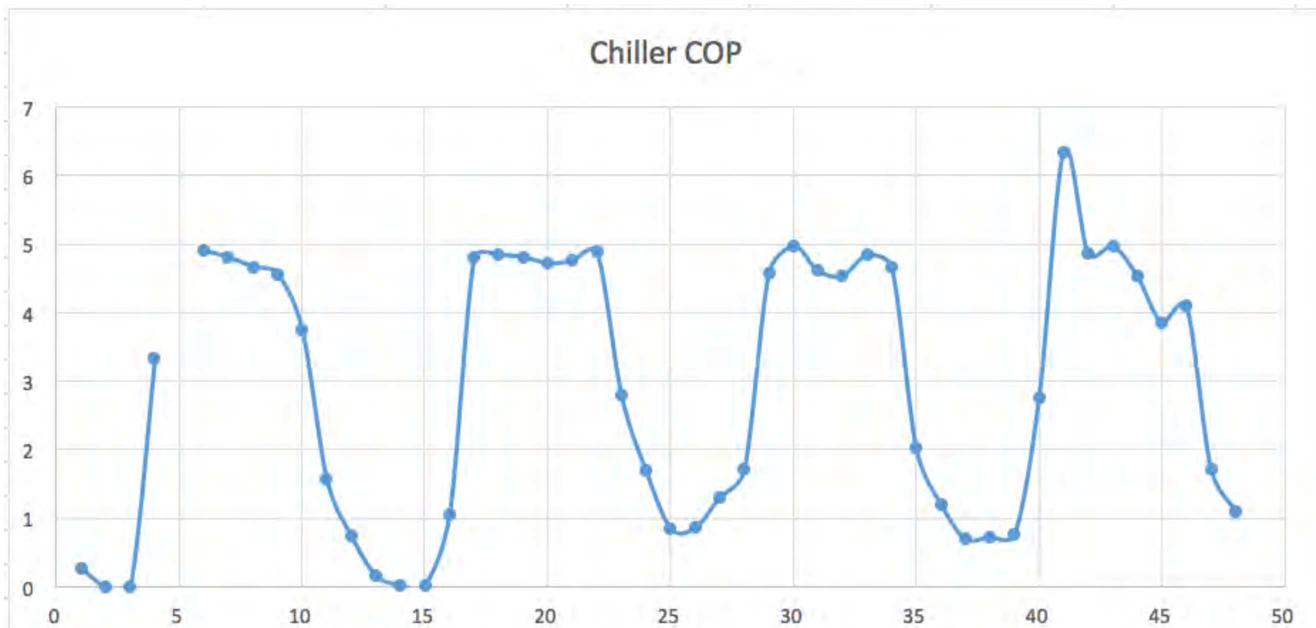
[4] http://energypost.eu/chinas-electricity-mix-changing-fast-co2-emissions-may-peaked/

Louwen, A. *et al* . Re-assessment of net energy production and greenhouse gas emissions a development. *Nat. Commun.* **7,** 13728 doi: 10.1038/ncomms13728 (2016).

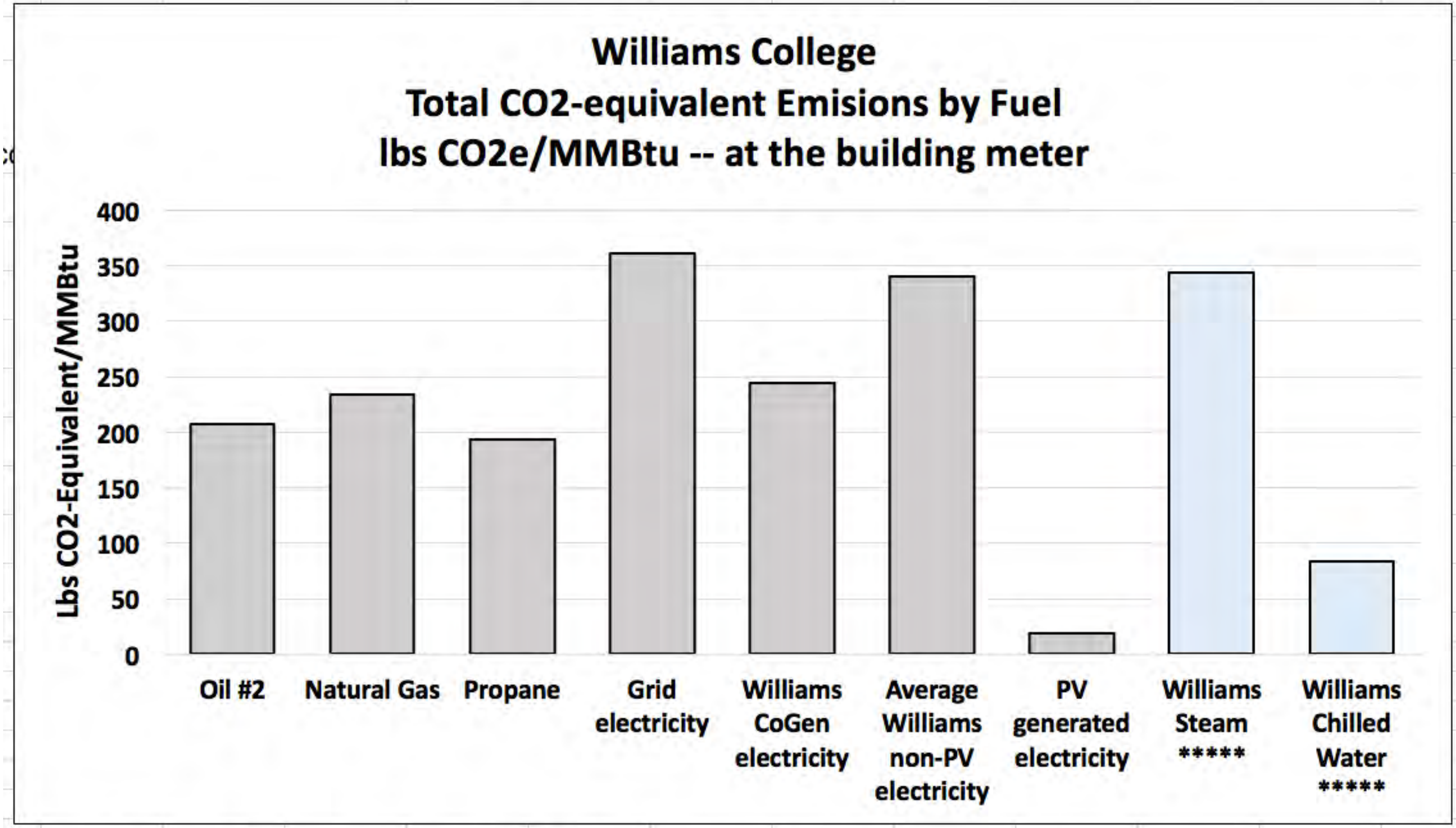
What is the CO2e for PV’s?

	Chiller Output	Building Usage				
	Plant data from portal	From Building Data				
	kWh output	kWh Usage	Building Usage/ plant output			kBtu Usage
2,014	3,272,885	6,009,365	1.84			20,503,954
2,015	3,322,383	8,213,904	2.47			28,025,839
2,016	3,305,784	7,706,023	2.33			26,292,951
2,017	3,155,202	8,108,556	2.57			27,666,395
May 2014 from avg of three later years						
			3.89	**Last 3 Years Wtd Average COP**		
			3.90	**4-Year Average COP**		
Data from portal			Calculated		**4 year average COP**	**avg May-Oct COP**
					3.90	**4.68**

Williams has developed a fabulous data base of energy usage on campus, which is measured monthly at central plant and at each building by fuel type.



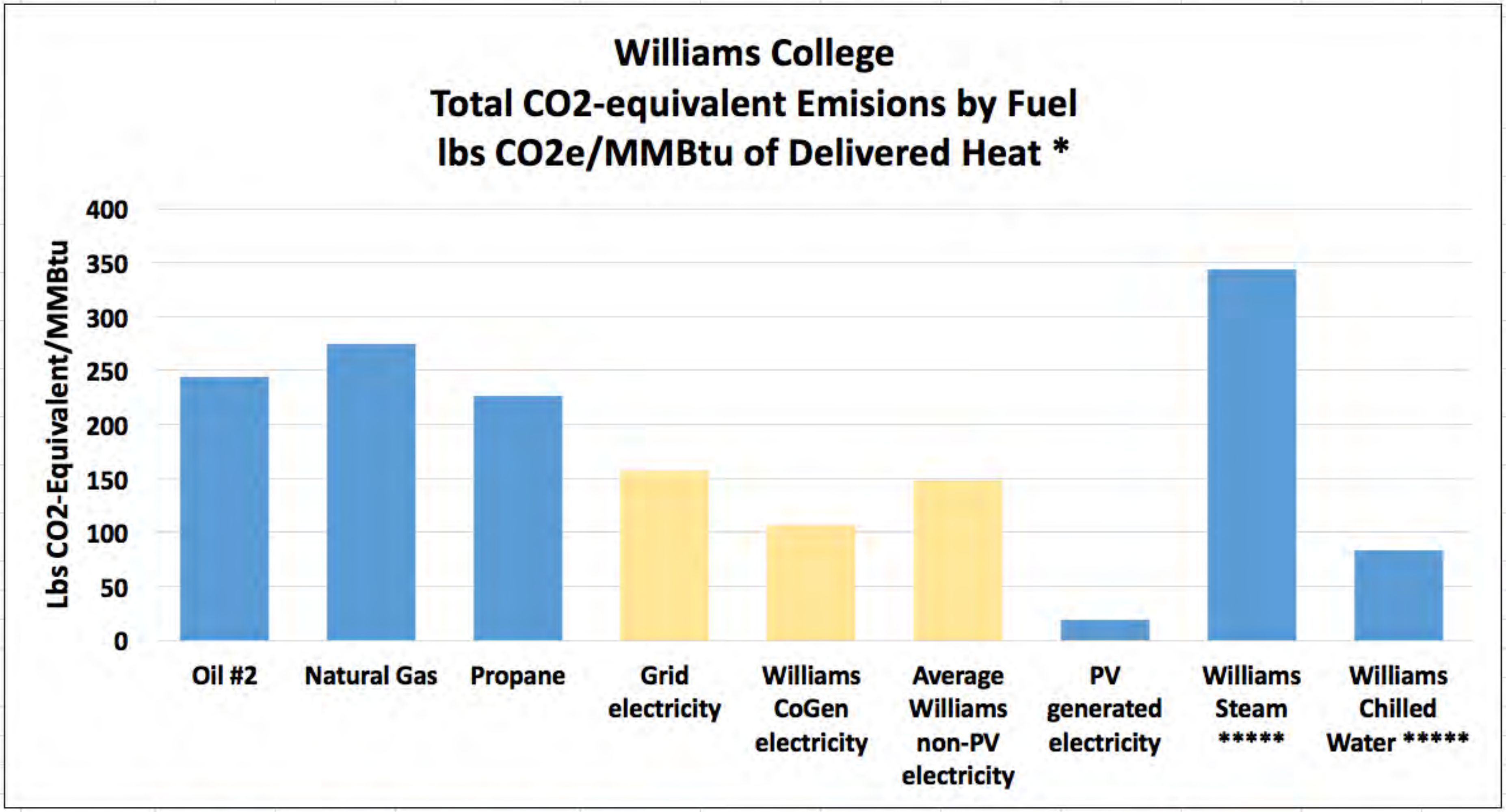
What is the Chiller COP?



***** Delivered heating or cooling CO2e/MMBtu from other fuels requires dividing by efficiency

None of the values include distribution losses within the building, or steam/chilled water converter losses

Quantifying Williams' carbon emissions



With combustion efficiency of 85% With heat pump at COP of 2.3

* Does not include distribution losses within the building or steam-to-hot-water or chilled water heat exchange losses

With heat pumps

Williams College	Enter data in highlighted cells only	180214
Building Emissions Calculator		
Building Name		
Building Area [2]		
Name of person entering data		
Company of person entering data		
Date data entered		
Design phase [3]		

Energy Consumption

Fuel Source	unit	Btu/unit	Site Energy -- Units per year at the building	Source Energy/Site Energy - ratio	Source Energy -- Units per year (calculated)	total lbs CO2e/unit	Total lbs CO2e /year (calculated)	Metric tons CO2e /year (calculated)
WC Steam	MMBtu	1,000,000		-	-	344	-	-
WC Chilled Water	kBtu	1,000		-	-	83	-	-
Natural Gas	therm	100,000		1.09	-	23	-	-
Propane	gallon	91,330		1.15	-	18	-	-
Oil #2	gallon	139,600		1.16	-	29	-	-
Electricity [1]	kWh	3,413		1.7	-	1.16	-	-
PV generated electricity	kWh	3,413		1.0	-	0.064	-	-

Building Metrics

Peak Heating Load [4]	kBtu/hr.	
Peak Cooling Load [4]	kBtu/hr.	
Annual Heating Load [5]	MMBtu/yr	
Annual Cooling Load [5]	MMBtu/yr	
Lighting Power Density [6]	watts/sq.ft.	
Building air tightness [7]	cfm75/sq.ft. shell	
Building air tightness units used in energy model [8]		
Building air tightness value used in energy model [9]		

Updated Calculator for the next round of projects with $/CO2e/year

Williams College 1/22/18

Site Energy EUI -- Goals by Building Type

kbtu/sf/year

make a footnote

Building Type	Existing EUI from 2016 campus EUI chart	Goal EUI	Dartmouth 2016 goals	Sources of Site Energy Goals
Dormitory [1]	77	30	40	College of the Atlantic Dorm village, EUI=27, 50 beds 20,500 sq.ft.
Dormitory with AC		35	50	Putney School Gray Dorm DER modeling EUI=20, same building modeled to code EUI=48, 2 floors 30 occupants wood frame bldg
Houses (small dorms under 15 beds)	58	20		Waterfront Apartmens, 4 floors, 42 units, 45k sq.ft. EUI measured = 24 Houses range of 20 to 35
Administrative	84	35	50	South Village small office project, EUI=33 and Mcalay offices EUI=29, very small office
Classrooms		50	70	Oakes Hall, Vt Law School, EUI=35 (22 if had ASHP)
Science [3]	235	138	100	138 based on model for Williams South Building
Sports	62	30	70	Putney School, Field House (14k sq.ft., light occupancy, sport facility, 60--ish avg temp) EUI=14
Dining Halls	151	120	130	Proctor Academy first year 88 kBtu/sq.ft.-yr

Exemplar EUI

Exemplar Buildings CO2e Emissions	
Project	Project Site EUI kBtu/ sq.ft.-yr
CoA dorms	27
Putney Gray Dorm	20
Waterfront Apts	39
South village offices	33
Oakes Hall	35
Putney Field House	14
Proctor Dinning Hall	88

Exemplar Buildings
CO2e Emissions

Project	Project Site EUI kBtu/ sq.ft.-yr		Oil gallons/yr	electricity kWh/yr	natural gas ccf/yr	propane gallons/yr	wood pellets tons/yr
		lbs Co2-e/unit>>>>	29	1.23	23	18	3,649
			Annual usage				
		Sq.ft. conditioned					
CoA dorms	27	20,552		62,625			21
Putney Gray Dorm	20	10,457		61,277			
Waterfront Apts	39	45,000		202,000	10,545		
South village offices	33	17,000	1,508	101,960			
Oakes Hall	35	23,000	3,450	96,039			
Putney Field House	14	14,000		57,000			
Proctor Dinning Hall	88	16,642		400,000		948	

Exemplar Buildings
CO2e Emissions

Project	Project Site EUI kBtu/ sq.ft.-yr		Oil	electricity	natural gas	propane	wood pellets	CO2-e emitted
			gallons/yr	kWh/yr	ccf/yr	gallons/yr	tons/yr	Metric tonnes CO2e/yr
		lbs Co2-e/unit>>>>	29	1.23	23	18	3,740	
			Annual usage					
		Sq.ft. conditioned						
CoA dorms	27	20,552		62,625			21	71
Putney Gray Dorm	20	10,457		61,277				34
Waterfront Apts	39	45,000		202,000	10,545			225
South village offices	33	17,000	1,508	101,960				77
Oakes Hall	35	23,000	3,450	96,039				99
Putney Field House	14	14,000		57,000				32
Proctor Dinning Hall	88	16,642		400,000		948		231

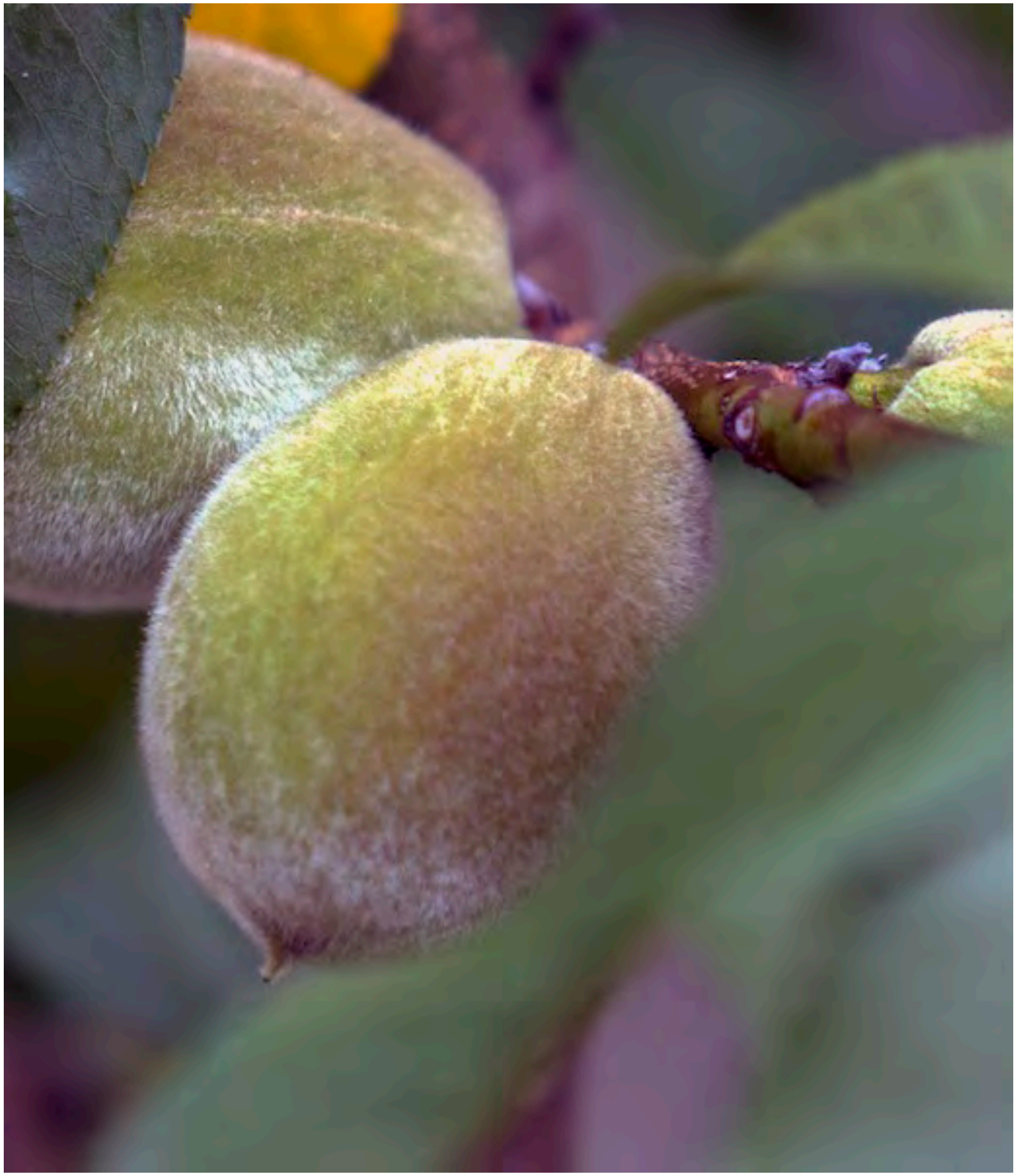
Exemplar Buildings
CO2e Emissions

Project	Project Site EUI kBtu/ sq.ft.-yr	lbs Co2-e/unit>>>>	**Total pounds CO2e/sq.ft.-yr** With no PV	With PV on Project
		Sq.ft. conditioned		
CoA dorms	27	20,552	**7.6**	7.6
Putney Gray Dorm	20	10,457	7.2	**0.38**
Waterfront Apts	39	45,000	**11**	11
South village offices	33	17,000	**10**	10
Oakes Hall	35	23,000	**9.5**	9.5
Putney Field House	14	14,000	5.0	**0.26**
Proctor Dinning Hall	88	16,642	31	***1.5***

"All building projects at Williams College must meet energy efficiency and greenhouse gas emissions targets."

Further discussions

- Should the metric be lbs CO2e/sq.ft.-year by building type, in addition to or instead of EUI at the meter?
- Dig into details of assumptions: how much methane is "really" emitted by natural gas use?
- Tabulate embodied carbon in buildings – develop guidelines?
- Tabulate construction process energy – develop guidelines?
- Is the goal net zero? Minimum total carbon?
- What is the path to reach the goal?



Biophilic moment

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Questions?

Thank you.

Williams

Amy Johns
ajohns@williams.edu

c&h architects

Thomas RC Hartman, AIA
tom@candharchitects.com

Energy Balance, Inc.

Andy Shapiro
andy@energybalance.us

Contact information