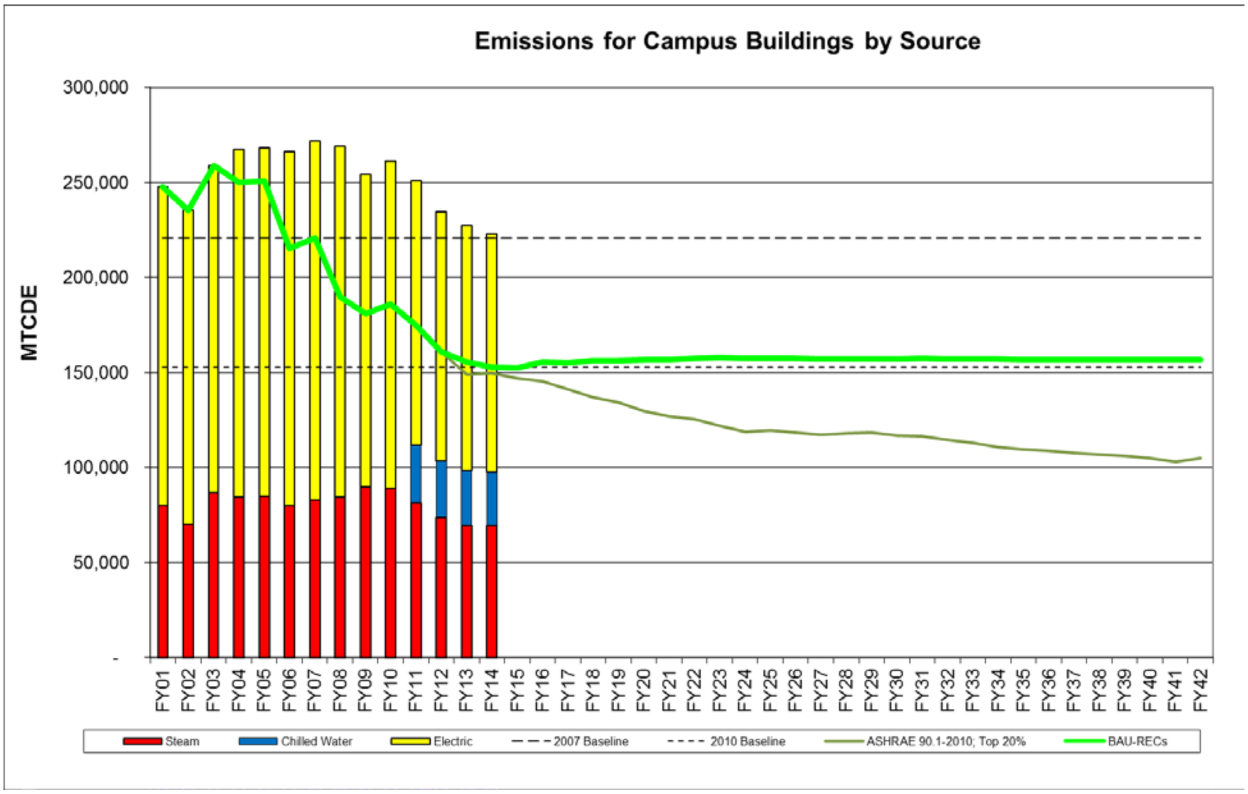
University of Pennsylvania Climate Action Plan 2.0

Energy, Carbon, and Financial Analysis of Climate Action Plan Scenarios for Buildings



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T. C. CHAN CENTER
FOR BUILDING SIMULATION AND ENERGY STUDIES

PennPraxis

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1.0-Introduction

1.1- Climate Action Plan 1.0 to 2.0

In 2009, the first Action Plan for Carbon Reduction was adopted by the University to meet the American College and University President's Climate Commitment (ACUPCC), with an initial five year period established for initial reduction targets and evaluation. The renewal of the action plan in 2014 has provided the opportunity to revisit and refine the reduction targets. The first five years have revealed a great deal about effecting change at this level and many of the initial assumptions about strategies and rates of change can now be reformulated with greater precision. We are calling this Action Plan 2.0, though the basic goals and approach remain the same.

The most fundamental change has been the recognition that any action plan of this scope will have to be adjusted and revised continuously, and many of the initial tools, strategies, and assumptions have been reformulated to make them more granular and adaptable. Building related utility usage remains the largest source of carbon emissions (~85%), and the largest refinement in method has been the development of tools to track and project the usage of individual buildings. The accuracy of those projections is dramatically improving as the buildings on campus are individually metered for steam and chilled water, and once a body of recorded data has accrued, it will become possible to much more accurately evaluate buildings for improvement.

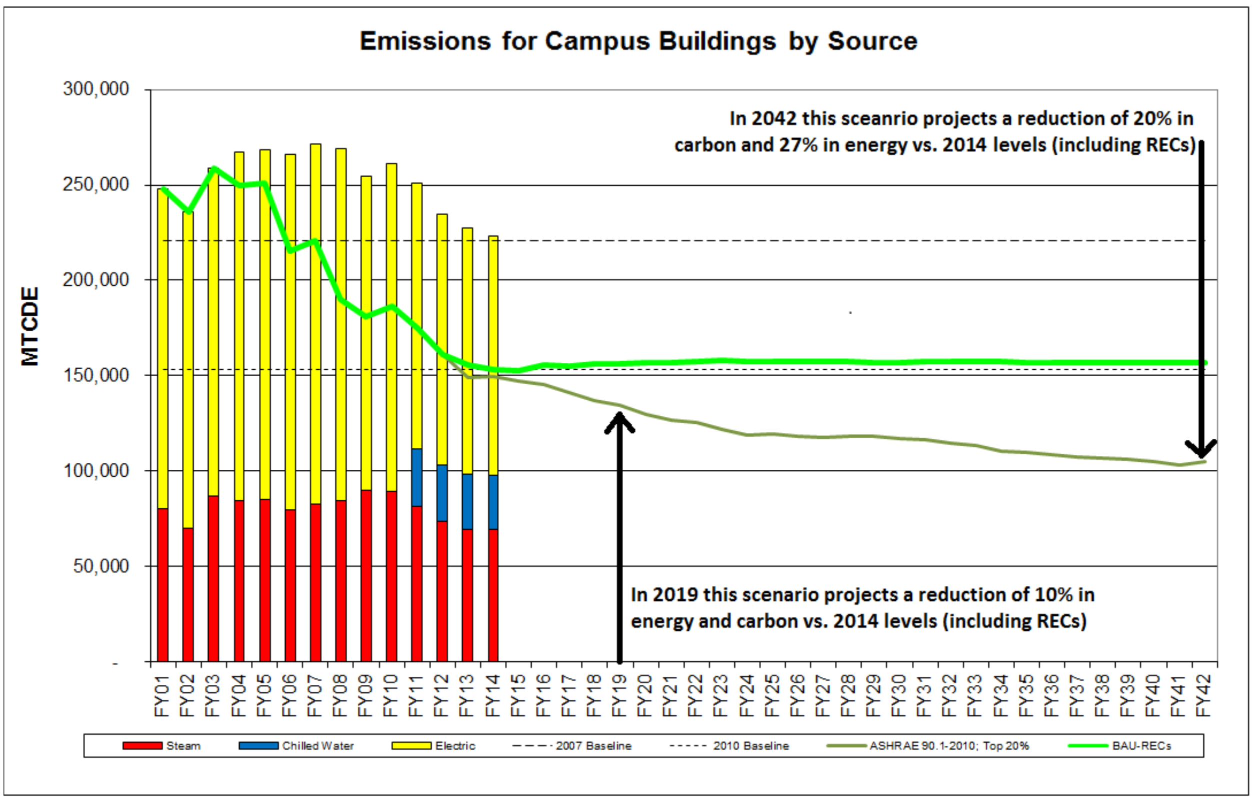


Figure 1- Projected Reductions to Carbon Emissions via CAP 2.0

The most optimistic aspect of the initial plan was the assumption that the regular renovations of campus buildings were deep enough to involve energy systems and frequent enough to achieve the reduction goals. Both points were recognized early in the five year period and one immediate response was the use of Century Bond funds to effect deeper, energy reduction renovations of 9 campus buildings and less intensive renovations of lighting systems on many more. Those projects represent the depth of work that will have to be sustained over the next few decades and also form the core of the work necessary to achieve the five year targets of Action Plan 2.0.

The TC Chan Center was commissioned to prepare and provide the technical analysis of the building renovation and recommissioning for the revised plan. The effort was headed by the Penn Department of Facilities and Real Estate Services (FRES) and the worked was closely coordinated with the Utilities and Operations sub-committee of the Environmental Sustainability Advisory Committee (ESAC) to develop recommendations for carbon reductions.

Total Carbon Reduction in Buildings (absolute reduction relative to a 2014 baseline)

7.2% reduction by 2019
18.8% reduction by 2042

Energy Reduction in Buildings (absolute reduction relative to a 2014 baseline)

10.2% reduction by 2019
27.1% by 2042

1.2- T.C. Chan Research

The T.C. Chan Center has been centrally involved in the University of Pennsylvania effort to achieve carbon neutrality since 2007 and provided much of the data analysis and research that was used as the basis for the Climate Action Plan 1.0. While this analysis has followed many different paths, the primary service provided by the T.C. Chan Center has been the calculation of the current carbon footprint for the campus and the projection of that footprint into the future under a variety of envisioned scenarios. This section will briefly describe those efforts and their importance.

The initial effort by the T.C. Chan Center was directly related to the formation of the Climate Action Plan 1.0. In addition to calculating the current carbon footprint from the campus using the UPenn Carbon Calculator, it was also necessary to make an estimation of the potential reductions that might be made to reduce that footprint and a schedule for how quickly those improvements could be made. Many sources for carbon reductions were identified including: reducing consumption in buildings, improving the efficiency of steam and chilled water distribution systems, greening the sources of energy carriers, changes to the transportation used by commuters, and other lesser impacts. In this initial effort the campus was only examined as an aggregated whole and the reductions possible from each category were estimated over the course of a 30 year scenario. This method was acknowledged to be imprecise and was used as a guidepost to set initial targets for reductions in the 5 year timeframe following the enacting of the plan and to estimate the scale of reductions that would be possible before 2042.

After the creation of the Climate Action Plan 1.0, the research conducted on behalf of FRES by the T.C. Chan Center began to explore the question in greater depth by breaking down the aggregated campus into individual buildings as facilities. Examining the collection of individual buildings rather than the aggregated campus carries several benefits. The built environment of the University of Pennsylvania accounts for approximately 85% of the carbon produced by activities stemming from the main campus in western Philadelphia through the use of electricity, steam, and chilled water so this presents a concentrated target for any effort to reduce greenhouse gas emissions from the campus in addition to being one of the primary areas over which the University has direct control. The focus on individual facilities does little to improve the accuracy of the current carbon footprint, which may be very accurately calculated from the campus total consumption of energy and other aggregated university activities, but it does create a significant improvement in the ability to identify current problem buildings which use more energy than similar buildings on campus and it also creates the beginnings of a framework for a more accurate projection of the potential carbon reductions which could be gained through a program of building renovations and recommissioning.

In 2011 the Individual Building Worksheet was created to work with the original UPenn Carbon Calculator by extracting the historical consumption of electricity, steam, and chilled water at the campus level and attributing as much of that consumption as possible to specific facilities. This is optimally done through the use of meters at the facility level and as most campus buildings were metered only some gaps were filled using low order normative energy models, such as BPAT+. In theory the summation of the facility level consumption of these energy carriers should equal the consumption reported for the entire campus, but line losses, inefficient energy transfers, and a number of small consumers of energy unassociated with a specific facility mean that in actuality there is a small gap between the consumption at the campus level and the sum of the individual metered buildings.

The creation of the Individual Building Worksheet opened the door for much more detailed scenario projections of the carbon footprint as well as allowing for the creation of specific plans of action for renovation that could more accurately calculate the carbon reductions possible through, and the cost associated with, each plan. While the Individual Building Worksheet determines the initial consumption of energy for each facility from meters and energy models, giving a more accurate presentation of current consumption, its real power derives from its ability to create specific scenarios for each individual building. The scenarios and projections created for each building can then be summed together, adding back in the difference created by line losses and inefficient distribution, to create a projection for the build environment of the entire campus.

While the original UPenn Carbon Calculator could make assumptions such as “there will be a 1% reduction in energy use in the built environment each year due to energy efficient renovations”, this is an estimate and is difficult to link to specific actions that the University should take to achieve that reduction, which also limits the ability to estimate the costs of those actions. The Individual Building Worksheet allows for the creation of scenarios based on an actable plan, calling for the specific renovations to select buildings with estimable costs and effects. This projection is used to replace the cruder projection made by the original UPenn Carbon Calculator for the consumption from the built environment, retaining only the less sophisticated projections for the remaining 15% of campus carbon emissions (commuting, air travel, solid waste, fertilizers, etc.). By crafting a scenario in the Individual Building Worksheet that assumes a specific schedule of renovations to a certain standard the carbon footprint of the university can be more accurately calculated for any given plan of action.

In 2012 another addition to the UPenn Carbon Calculator was created which built on the process established with the Individual Building Worksheet. The UPenn Carbon Financial Calculator determines the NPV of a scenario by considering the effects of the renovation of specific buildings on a predetermined schedule. Estimates of the cost and effectiveness of each renovation planned within a scenario can be calculated and the net present value of the costs and the growing energy savings from each project can be estimated. By combining these individual projects the overall NPV of any given scenario can be established and compared against a business as usual scenario to determine the incremental costs of that course of action.

The combination of these two new calculators allows for a much more detailed examination of the potential for carbon reductions in the built environment. In addition to estimating the overall potential reduction, it also allows for the creation of a specific plan of action that would be implemented to achieve that goal along with the estimates of its cost. This will allow for the most cost effective plan that meet the University's carbon reduction goals to be developed, and is the first time that goals, a plan for achieving those goals, and the costs of carrying out that plan could all be accurately determined using the same input information based on real figures rather than vague estimates.

All three tools were used together in 2013 to examine the effects and costs of several different scenarios. These scenarios considered a range of options for the renovation of campus buildings focused around the Century Bond projects and the potential improvements that could be achieved by bringing the worst performing facilities up to a modern level of ASHRAE 90.1 standard. Different scenarios were crafted by assuming that either the top 20% or top 30% of poorly performing buildings would be renovated and that they would be brought to current or next generation code. The results for each of these scenarios were compared against the consumption and costs that would accrue if the campus adopted no significant building renovations beyond the already approved Century Bond projects.

2.0- Current and Potential Energy Consumption by the Built Environment

The formation of the Climate Action Plan 2.0 is based on the development of scenarios detailing specific sets of renovations that could be conducted across the campus. The scenarios selected as the basis for the plan all revolve around identifying the buildings in which the greatest reduction of energy use could be gained if the building were to be brought to next-gen ASHRAE 90.1 code and choosing a set of these to renovate over a 25 year time span ending in 2042. In order to identify the buildings which show the greatest potential for reduction two pieces of information are required: 1) the current energy consumption of the building and 2) the potential energy consumption of the building if it were renovated to next gen-code. The absolute savings to be found in a building by renovation to code may be determined by subtracting potential consumption from the current consumption. All of the buildings on campus may then be ordered by the magnitude of this reduction, or by other metrics if desired, and the optimal set selected to fulfil the goals laid out in Climate Action Plan 2.0.

2.1- Assessing Current Energy Consumption

Prior to 2011 little effort was made to assess the carbon production by the campus at any finer level of detail than the aggregated campus. Basing carbon footprint calculations for campuses on the total consumption of the campus yields very accurate estimates of carbon production for current and historical years but since few individual buildings were metered for the consumption of steam or chilled water, examining carbon production at this level would require significant use of energy simulation models, which are time intensive to create and calibrate; feasible but ultimately impractical. However the recent initiative to introduce steam and chilled water metering to the majority of the buildings served by these loops has dramatically changed that situation and for the first time has begun to make it practical to consider scenarios that track individual buildings and renovations rather than campus totals and broad assumptions for growth and change.

For buildings that have had meters installed for electricity, steam, and chilled water determining their annual consumption is a simple matter of aggregating the meter readings for the most recent year. However, some buildings have not yet been metered of steam and/or chilled water, were metered relatively recently and have not yet collected a year of data, or suffered from unit or calibration issues causing a portion of the data to be unusable. Approximately 20% of the required metered data was unavailable for one of these reasons, typically affecting either the steam or chilled water consumption of a building while electrical metered data tended to be reliable and accurate. Rather than exclude this buildings from consideration, these gaps were filled with approximate values for consumption that were derived from the BPAT+ normative energy consumption model, developed by at the T.C. Chan Center.

By using a combination of metered data and simulated estimates, sufficient information was collected to generate annual energy consumption estimates for the largest 132 of the 170 buildings in the main campus, including all buildings larger than 15,000gsf. While this is not a complete picture of the campus, it encompasses the largest energy consumers on campus and all of the buildings that were considered for major renovations. A summary of this information may be found in Appendix A. This data was used as the baseline condition for these buildings and was compared against estimates of annual consumption modeled on the building receiving a renovation to next-gen ASHRAE 90.1 code. As anticipated there was a large range in the absolute as well as the normalized consumption of the buildings, with laboratories accounting for the largest consumers, both in terms of absolute and normalized consumption, followed by residential halls. This list will form the basis of the renovation plans discussed in Sections 3 and 4.

2.1.1- Normalization for Weather and Other Effects

In addition to using the metered data to establish a baseline to calculate the potential for improvement by renovation, this new level of information has allowed more accurate assessment of the effects of weather, variability in the schedules caused by the academic calendar, sunlight and other variables on the consumption of energy by buildings. The meters which have been installed allow statistical techniques to be used to determine the effect that each of these variables has on the consumption of electricity, steam, and chilled water within each building as well as at the aggregated campus level. This information is important because different variables have different impact on consumption and can help evaluate different forms of renovation. Due to the natural variability caused by these factors, their effects must be accounted for before the impact of any change to the building or its operation can be accurately gauged. This information is also useful in determining if something unusual or unexpected is occurring in a building that is causing more or less consumption than would be expected given the current conditions.

Efforts this year have focused on two levels of normalization for variable conditions. First an examination was made of the potential for the weather normalization of individual buildings based on monthly aggregations of steam and chilled water consumption. These monthly consumption figures were normalized using linear regression against the number of heating or cooling degree days in that same span of time. The linear regression produced a simple equation in the form of $y= m*x + b$, where y is the amount of energy expected to be consumed, x is the number of HDD or CDD in the span of time being considered, and m and b are the slope and y intercept of the line representing the level of impact temperature has on consumption and the amount of consumption unrelated to the weather, respectively.

The metered data from 20 buildings was examined and statistically analyzed using linear regression techniques. These efforts saw some success, particularly in determining the impact of heating degree days on the consumption of steam. For steam 18 of the 20 buildings examined found linear relationships between HDD and kbtu of steam consumed with R^2-values greater than 0.7.When considering the electrical consumption used directly by the buildings combined with the electricity used to generate the chilled water for cooling it was considerably more difficult to find a strong linear relationship between CDD and kWhs of electricity consumed. Only 11 of the 20 buildings examined yielded linear relationships with R^2-values of greater than 0.7. (Figure 2) This was expected due to the many different uses for electricity within buildings, many of which are unrelated to temperature or are strongly affected by additional variables.

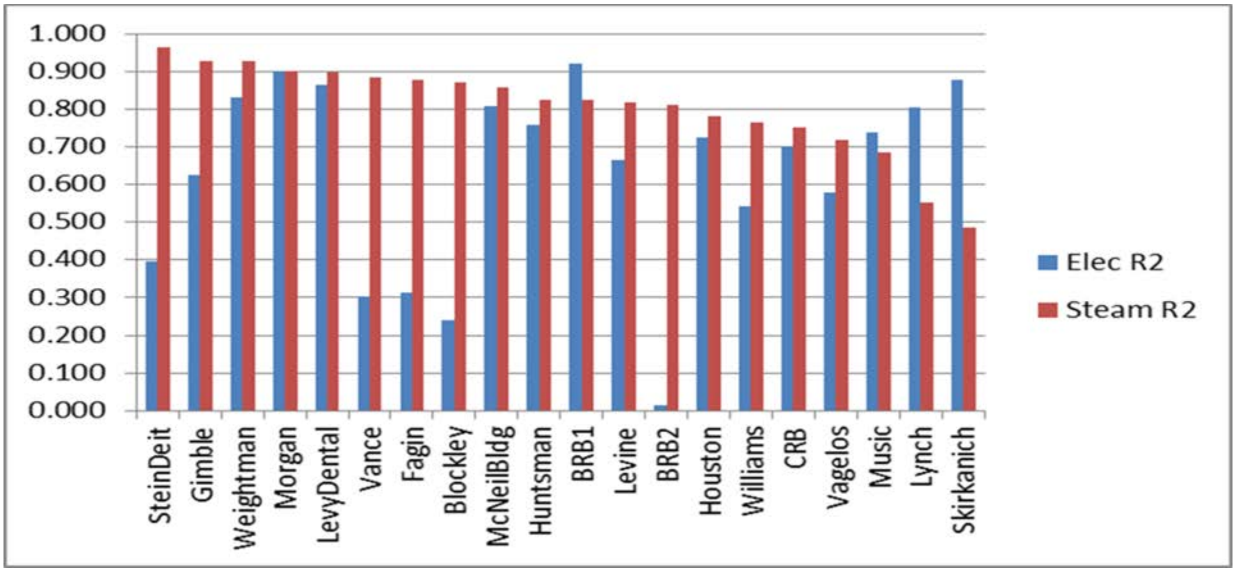


Figure 2- R^2-values showing correlation between HDD - Steam Consumption and CDD - Electricity Consumption for 20 University buildings

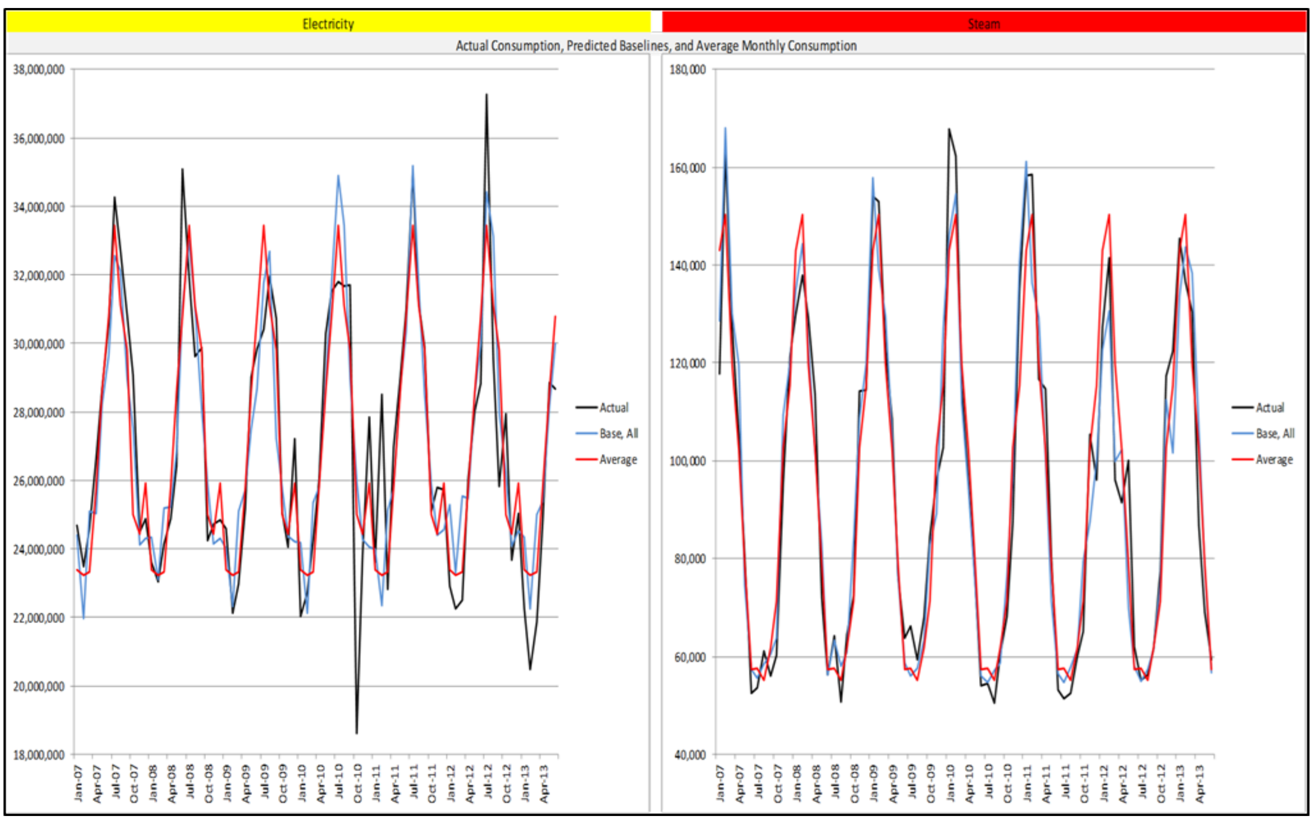


Figure 3- Baselines derived from Regression and Historical Average vs. Actual Campus Consumption

The second level of analysis focused on the campus as a whole and examined the consumption of electricity, steam, and chilled water, also at the monthly level of aggregation. This study was focused on developing a technique that would reduce the level of error that could be expected when calculating a baseline estimate for a month of consumption against which the actual consumption can be compared. One of the primary arguments against weather normalization is that the baselines generated have a larger margin of error than the magnitude of change they are attempting to detect in consumption. (Figure 3)

This margin of error is calculated by using the equation generated by the regression analysis to create a baseline that covers the historical period of time for which there is actual metered data. If the generated formula were 100% accurate than the baseline would precisely match the actual consumption in each month, but in reality some variables will always go unaccounted for a simple human intervention will introduce a random element regardless. The absolute value of the % difference between the baseline and the actual consumption, averaged across all the months for which there is historical data, provides a measure for comparison of the overall accuracy of any formula generated by the regression analysis relating consumption to one or more variables.

Table 1- Coefficients, R^2-values, and Average Absolute Monthly % Deviation for 4 Regression Baselines vs. the Average

		CDD	CDD/Occ	CDD/Occ/Sun	All	Average
Electricity	Intercept	810,093	771,074	658,361	770,363	n/a
	CDD/Day	19,616	20,866	17,711	16,318	n/a
	Occ Rate		46,002	39,463	19,647	n/a
	Sun Hour			10,625	4,628	n/a
	HDD/Day				-1,508	n/a
	R2	0.699	0.703	0.716	0.721	n/a
Ave Abs Diff		***5.83%***	***5.79%***	***5.61%***	***5.47%***	***4.56%***

		HDD	HDD/Occ	HDD/Occ/Sun	All	Average
Steam	Intercept	1,983	1,379	-2,800	-2,748	n/a
	HDD/Day	92	86	121	120	n/a
	Occ Rate		897	1,402	1,338	n/a
	Sun Hour			276	279	n/a
	CDD/Day				-6	n/a
	R2	0.853	0.877	0.930	0.930	n/a
Ave Abs Diff		***10.89%***	***10.63%***	***7.72%***	***7.59%***	***8.26%***

		CDD	CDD/Occ	CDD/Occ/Sun	All	Average
CHW	Intercept	79,965	55,651	-145,838	139,733	n/a
	CDD/Day	21,764	22,540	15,970	12,960	n/a
	Occ Rate		28,582	2,858	-44,401	n/a
	Sun Hour			20,533	4,798	n/a
	HDD/Day				-4,032	n/a
	R2	0.891	0.893	0.929	0.964	n/a
Ave Abs Diff		***38.25%***	***37.25%***	***30.48%***	***13.45%***	***14.05%***

In previous attempts to utilize regression analysis to create a baseline of consumption for comparison the efforts were abandoned after it was determined that the average percentage deviance of the generated baseline consumption from the actual consumption was significantly greater than simple creating a baseline from the average historical consumption in each month, rather than trying to relate it to weather. In this effort the goal was to achieve an average monthly deviance using regression with multiple variables that was better than simple using the historical average. In addition to temperature (HDD or CDD) the number of sunlight hours and the occupancy schedule for the campus was considered. Each additional variable considered improved the accuracy of the baseline generated and for steam and chilled water managed to achieve a higher accuracy than the baseline generated from the average. The results of this analysis can be seen in Table 1, above.

This demonstrated that it is possible to use regression analysis to calculate more accurate baselines of consumption than simply utilizing the historical average and shows the potential of future research in this area using more accurate and detailed occupancy schedules and incident solar radiation taking into account weather in addition to the time of year. Additional tables, figures, and information about the techniques used to achieve these results can be found in Appendix B.

2.2- Calculating Potential Energy Consumption

This year the project including last year ASHARE 90.1 2007 base energy model to 2010 version. Purpose of this section is not just updating energy model to more latest but also shares more in-depth knowledge that can be further investigate in this project, i.e. which building or building type requires more energy consumption to meet the standard or customized strategies to reduce energy consumption

First process was to increase the accuracy of the energy model previously developed. For that reason, as shown in Figure 4, additional information were used to update ASHRAE 90.1 2007 energy model. Building geometry information from BPAT+, Building system information from previous survey data and Occupancy densities were updated for ASHRAE 90.1 2007 energy model for whole campus buildings. This updated whole campus building energy models were transfer to ASHRAE 90.1.2010 energy model.

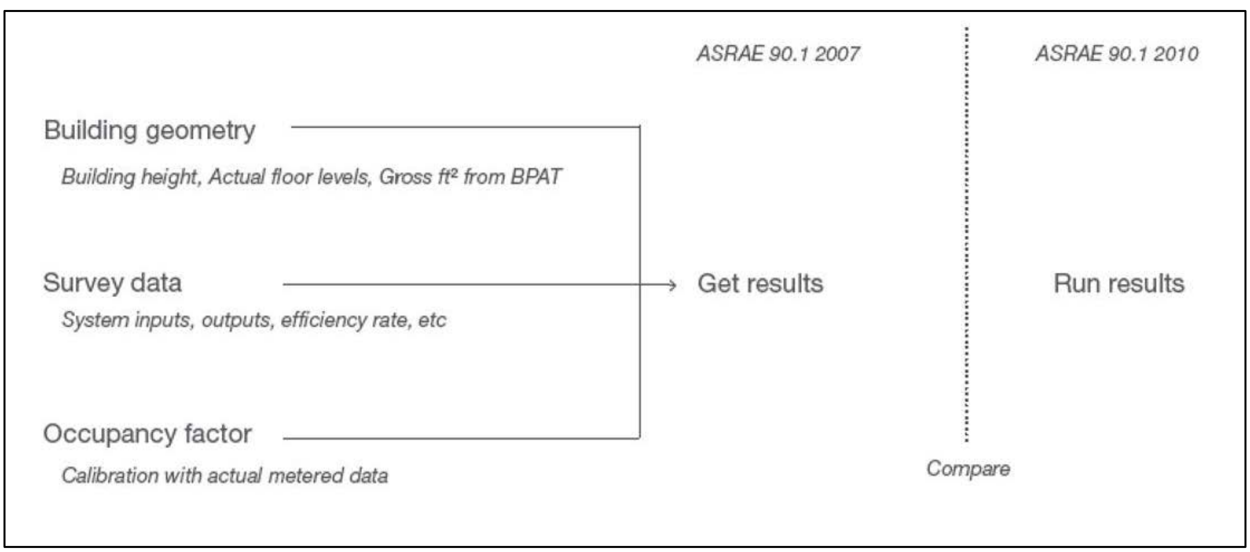


Figure 4- Flowchart of Process for Calculating Potential Energy Consumption

The project used computational energy simulation tool called EnergyPro for this project. Energy Pro uses thermal dynamic based DOE-2 engine, which requires all thermal boundary conditions for the tool to simulate. This is different than prescriptive code checklist tool like COMcheck. EnergyPro not only requires building geometry and material properties but also requires building system and schedules to calculate building energy demand and system require energy. Once whole campus building energy model was updated, project simulated whole buildings and acquired summary report for energy usages as shown in Appendix E.

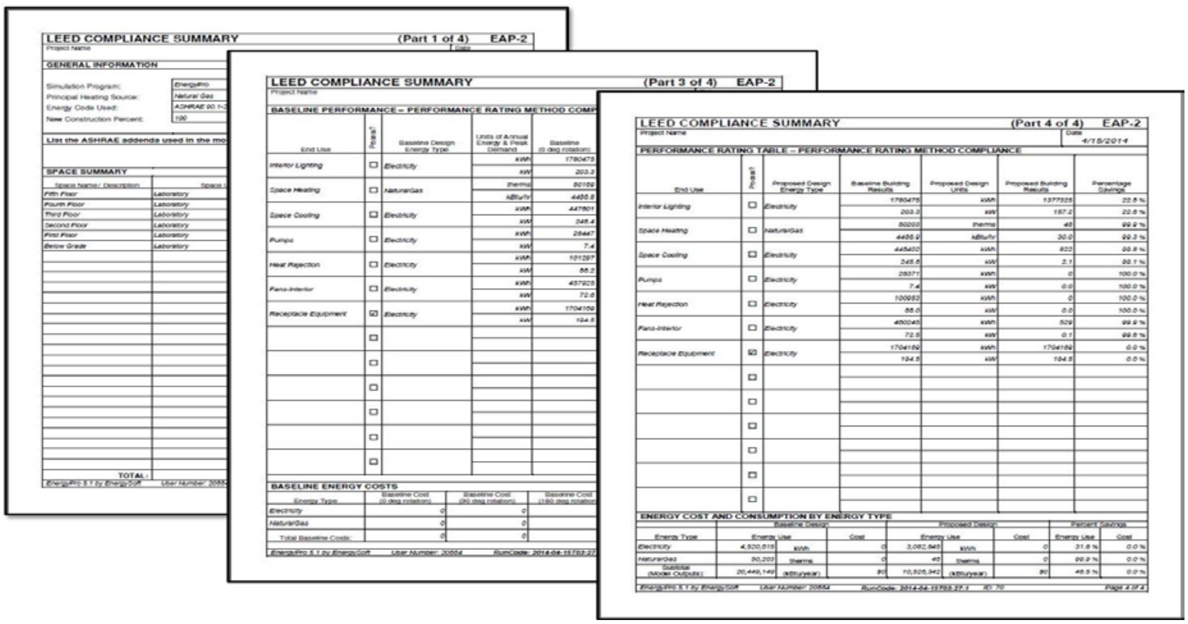


Figure 5- EnergyPro Report Comparing Results for ASHRAE 90.1: 2007 vs 2010

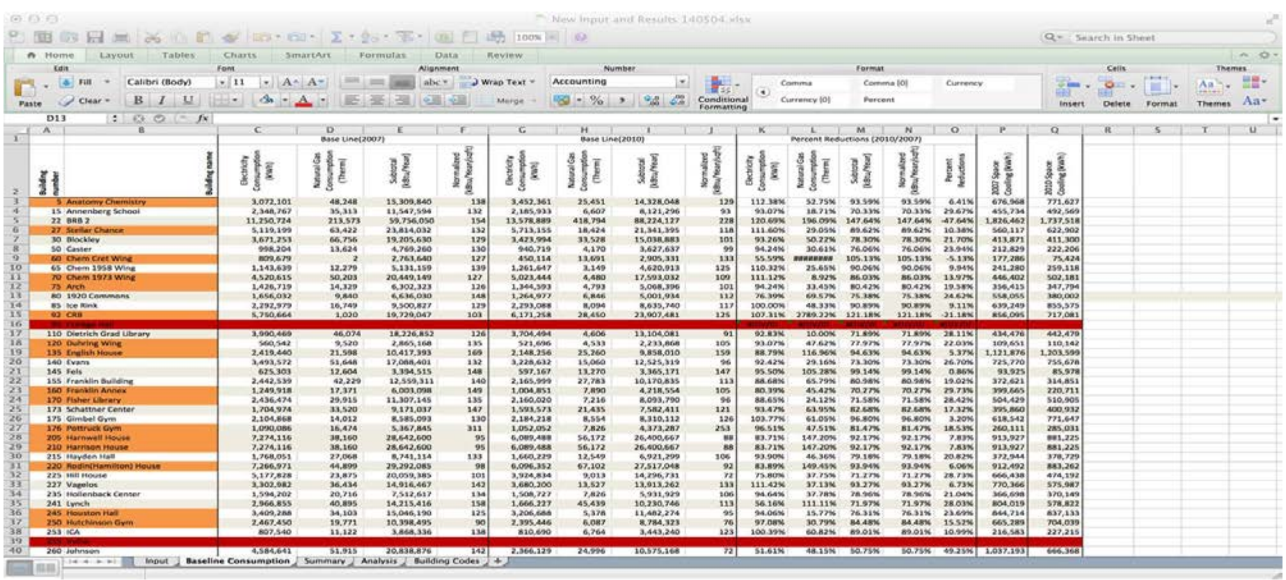


Figure 6- Comparison of EnergyPro results for 2007 and 2010 code

On average ASHRAE 90.1-2010 baselines will be 30% less energy intensive than ASHRAE 90.1-2007 baselines, however campus buildings show a range of variation of reduction from about 10% to up to 50%. Based on these results, different building types and building sizes were identified as a main factor for the variation. Figure 6 shows some of these buildings' potential reductions. The results from

EnergyPro for the whole set of campus buildings were then used to identify the 75 campus buildings that showed the greatest potential for improvement.

2.3- The Potential Savings of Individual Buildings

The potential savings for each building evaluated was determined by considering the total kbtu consumed as shown by the meters or building simulation and comparing this against the targets that were generated for its potential consumption if renovated, either to ASHRAE 90.1 2007 or ASHRAE 90.1 2013. Table 2 below shows a summary of these results for the top 30% of potential savings from buildings. Table 3 on the following page shows the same information only normalized by area impacted.

Table 2- Summary of potential energy savings for top 30% of buildings, kBtu

Top 30% of Buildings by kbtu Saved going to ASHRAE 90.1- 2010										
Building Information			Current Energy		Target Energy				Savings	
#	Building	Gross Square Feet (sqft)	Meters (kBtu)	BPAT	E Star 75 (kBtu)	E Star 90	ASH 07	ASH 10	Reduction (kBtu)	% Reduc. (%)
22	BRB2	421,531	274,298,661	188,594,601	31,058,944	23,270,641	113,564,999	141,427,753	132,870,909	48.44%
27	BRB1	225,627	121,275,496	105,756,803			59,110,872	41,913,964	79,361,532	65.44%
330	Stemmler	243,303	85,149,148	42,198,271	19,786,241	14,824,668	45,490,612	27,699,987	57,449,161	67.47%
617	Huntsman	356,683	96,089,143	90,637,666	29,313,209	21,962,665	47,212,289	39,902,984	56,186,159	58.47%
260	Johnson Pavilion	160,940	79,020,957	42,847,364	12,713,047	9,525,139	45,322,378	32,527,573	46,493,384	58.84%
630	Hill Pavilion	100,000	56,443,845	40,910,920	10,340,838	7,747,782	20,919,757	17,513,547	38,930,298	68.97%
92	CRB	204,366	86,618,818	74,132,765	16,950,335	12,699,889	44,551,851	47,781,892	38,836,926	44.84%
570	Towne	210,539	63,925,543	50,462,309	12,843,954	9,623,220	35,665,191	29,376,633	34,548,910	54.05%
225	Hill	220,370	55,541,443	40,910,920	9,042,245	6,249,706	30,124,091	23,049,221	32,492,222	58.50%
220	Rodin House	311,354	71,665,525	18,038,774	25,609,287	17,293,719	43,537,839	41,563,235	30,102,290	42.00%
210	Harrison House	309,982	70,517,063	17,866,571	25,320,293	17,102,895	42,911,817	40,446,597	30,070,466	42.64%
280	LRSM	95,150	46,616,223	12,996,902	7,361,621	5,515,630	20,110,733	18,490,934	28,125,290	60.33%
555	Stouffer Triangle	159,626	46,325,393	13,915,494	12,045,273	8,272,179	26,650,078	18,499,353	27,826,040	60.07%
295	Levy Dental	93,456	43,623,032	38,162,848	7,244,227	5,427,673	19,305,325	16,292,143	27,330,888	62.65%
500	Richards	104,344	52,016,658	37,958,487	8,124,867	6,087,486	32,464,260	25,018,420	26,998,239	51.90%
70	Chem 73	149,975	53,003,963	54,161,407	11,703,015	8,768,382	28,686,425	26,210,780	26,793,182	50.55%
600	Old Vet Quad	115,295	61,370,591	22,810,236	18,243,007	13,682,255	44,126,156	35,563,242	25,807,349	42.05%
520	Rosenthal	60,790	52,101,392	13,104,166	4,612,656	3,455,991	31,332,200	26,323,564	25,777,828	49.48%
241	Lynch	148,086	49,650,060	51,611,284	10,085,074	7,556,153	30,218,130	24,696,491	24,953,569	50.26%
595	Ryan	149,531	41,615,519	27,747,460	12,035,726	9,017,662	27,818,834	22,827,926	18,787,593	45.15%
205	Harnwell House	311,371	70,390,802	17,369,501	25,203,548	17,025,795	63,229,264	53,874,736	16,516,066	23.46%
65	Chem 58	42,250	22,249,887	5,197,598	2,917,855	2,186,178	6,991,404	6,602,855	15,647,032	70.32%
456	Skirkanich	61,182	24,136,538	18,546,811	4,041,238	3,027,862	12,852,232	9,799,706	14,336,832	59.40%
300	Levy tennis Pavillion	119,675	27,648,545	11,292,474	5,874,651	3,892,395	14,818,178	13,341,781	14,306,764	51.75%
335	John Morgan	207,991	38,301,566	54,073,051	17,012,097	12,746,164	24,279,806	24,215,217	14,086,349	36.78%
176	Pottruck	67,288	20,366,846	16,664,583	4,992,246	3,307,735	7,377,927	6,553,366	13,813,480	67.82%
227	Vagelos	115,570	43,981,224	39,303,335	8,189,487	6,135,901	32,790,862	30,461,159	13,520,065	30.74%
250	Hutchinson	134,811	25,626,423	10,705,139	15,477,270	10,254,846	14,850,008	13,500,173	12,126,249	47.32%
255	Irvine	115,668	13,933,046	55,943,994	2,576,648	1,895,501	2,843,878	2,115,880	11,817,165	84.81%
155	Franklin	100,718	27,229,899	28,464,400	7,385,362	5,533,418	18,504,238	15,721,404	11,508,495	42.26%
416	Walnut Street 3401	189,057	34,847,070	30,134,597	13,678,398	10,248,420	29,193,349	23,464,921	11,382,149	32.66%
80	Class of 1920	45,668	17,707,789	6,476,780			8,127,616	6,479,299	11,228,490	63.41%
450	Palestra	137,819	23,303,811	10,773,724	8,204,412	5,436,036	13,063,260	12,475,446	10,828,364	46.47%
175	Gimbell Gymnasium	66,104	18,587,010	16,385,597	4,419,602	2,928,316	8,462,105	7,946,545	10,640,465	57.25%
235	Hollenback Center	55,901	16,128,848	9,688,692	3,994,921	2,646,933	7,343,037	5,764,090	10,364,758	64.26%
293	Levine	50,474	19,470,379	12,071,942	3,237,716	2,425,831	9,880,098	9,347,338	10,123,042	51.99%
525	Charles Addams	44,335	14,737,723	5,295,118	3,197,852	2,395,962	8,062,973	7,345,648	7,392,076	50.16%
75	The Arch	32,567	10,879,329	4,929,826	2,312,699	1,732,769	3,942,913	3,520,062	7,359,268	67.64%
325	McNeil	134,213	24,893,821	22,674,650	9,434,063	7,068,389	22,192,527	17,654,029	7,239,792	29.08%
140	Evans	133,329	27,893,426	19,691,712	9,107,136	6,823,442	25,553,719	21,194,469	6,698,957	24.02%
550	Stiteler	45,966	12,685,565	5,968,073	2,330,649	1,746,218	6,977,854	6,053,445	6,632,121	52.28%
340	Meyerson	98,016	22,519,874	12,496,449	7,415,696	5,556,146	18,294,107	16,898,780	5,621,094	24.96%
95	College Hall	117,163	12,528,559		7,603,211	5,696,639	9,301,038	7,347,616	5,180,943	41.35%
190	Grad Towers B	211,325	37,275,660	15,413,410	17,111,834	11,659,935	38,683,914	32,418,756	4,856,904	13.03%
60	Chem Lab Cret Wing	22,645	7,812,450	2,911,665	1,398,720	1,047,978	3,508,116	3,275,143	4,537,307	58.08%
100	Colonial Penn Center	17,256	7,104,593	3,163,848	956,915	716,960	2,681,315	2,681,326	4,423,266	62.26%
560	Sweeten Alumni	11,674	6,090,744	2,532,939	1,095,010	793,356	1,730,487	1,734,948	4,355,796	71.52%
85	Class of 1923 Ice Rink	126,146	11,940,359	7,029,300	4,451,956	3,335,589	8,443,512	7,610,341	4,330,018	36.26%
285	Gittis Hall	38,818	8,337,918	3,339,752	2,358,790	1,767,303	5,196,186	4,569,779	3,768,139	45.19%
215	Hayden	65,630	13,781,756	5,536,696	4,576,141	3,428,634	12,233,264	10,452,821	3,328,934	24.15%

Table 3- Summary of potential energy savings for top 30% of buildings, kbtu/sqft

Top 30% of Buildings by kbtu/sqft Saved going to ASHRAE 90.1- 2010										
Building Information			Current Energy		Target Energy				Savings	
#	Building	Gross Square Feet	Meters	BPAT	E Star 75	E Star 90	ASH 07	ASH 10	Reduction	% Reduc.
		(sqft)	(kBtu)		(kBtu)				(kBtu)	(%)
22	BRB2	421,531	651	447	74	55	269	336	315	48.44%
27	BRB1	225,627	538	469			262	186	352	65.44%
330	Stemmler	243,303	350	173	81	61	187	114	236	67.47%
617	Huntsman	356,683	269	254	82	62	132	112	158	58.47%
260	Johnson Pavilion	160,940	491	266	79	59	282	202	289	58.84%
630	Hill Pavilion	100,000	564	409	103	77	209	175	389	68.97%
92	CRB	204,366	424	363	83	62	218	234	190	44.84%
570	Towne	210,539	304	240	61	46	169	140	164	54.05%
225	Hill	220,370	252	186	41	28	137	105	147	58.50%
220	Rodin House	311,354	230	58	82	56	140	133	97	42.00%
210	Harrison House	309,982	227	58	82	55	138	130	97	42.64%
280	LRSM	95,150	490	137	77	58	211	194	296	60.33%
555	Stouffer Triangle	159,626	290	87	75	52	167	116	174	60.07%
295	Levy Dental	93,456	467	408	78	58	207	174	292	62.65%
500	Richards	104,344	499	364	78	58	311	240	259	51.90%
70	Chem 73	149,975	353	361	78	58	191	175	179	50.55%
600	Old Vet Quad	115,295	532	198	158	119	383	308	224	42.05%
520	Rosenthal	60,790	857	216	76	57	515	433	424	49.48%
241	Lynch	148,086	335	349	68	51	204	167	169	50.26%
595	Ryan	149,531	278	186	80	60	186	153	126	45.15%
205	Harnwell House	311,371	226	56	81	55	203	173	53	23.46%
65	Chem 58	42,250	527	123	69	52	165	156	370	70.32%
456	Skirkanich	61,182	395	303	66	49	210	160	234	59.40%
300	Levy tennis Pavillion	119,675	231	94	49	33	124	111	120	51.75%
335	John Morgan	207,991	184	260	82	61	117	116	68	36.78%
176	Pottruck	67,288	303	248	74	49	110	97	205	67.82%
227	Vagelos	115,570	381	340	71	53	284	264	117	30.74%
250	Hutchinson	134,811	190	79	115	76	110	100	90	47.32%
255	Irvine	115,668	120	484	22	16	25	18	102	84.81%
155	Franklin	100,718	270	283	73	55	184	156	114	42.26%
416	Walnut Street 3401	189,057	184	159	72	54	154	124	60	32.66%
80	Class of 1920	45,668	388	142			178	142	246	63.41%
450	Palestra	137,819	169	78	60	39	95	91	79	46.47%
175	Gimbell Gymnasium	66,104	281	248	67	44	128	120	161	57.25%
235	Hollenback Center	55,901	289	173	71	47	131	103	185	64.26%
293	Levine	50,474	386	239	64	48	196	185	201	51.99%
525	Charles Addams	44,335	332	119	72	54	182	166	167	50.16%
75	The Arch	32,567	334	151	71	53	121	108	226	67.64%
325	McNeil	134,213	185	169	70	53	165	132	54	29.08%
140	Evans	133,329	209	148	68	51	192	159	50	24.02%
550	Stiteler	45,966	276	130	51	38	152	132	144	52.28%
340	Meyerson	98,016	230	127	76	57	187	172	57	24.96%
95	College Hall	117,163	107		65	49	79	63	44	41.35%
190	Grad Towers B	211,325	176	73	81	55	183	153	23	13.03%
60	Chem Lab Cret Wing	22,645	345	129	62	46	155	145	200	58.08%
100	Colonial Penn Center	17,256	412	183	55	42	155	155	256	62.26%
560	Sweeten Alumni	11,674	522	217	94	68	148	149	373	71.52%
85	Class of 1923 Ice Rink	126,146	95	56	35	26	67	60	34	36.26%
285	Gittis Hall	38,818	215	86	61	46	134	118	97	45.19%
215	Hayden	65,630	210	84	70	52	186	159	51	24.15%

These results allow us to clearly identify those buildings which are performing poorly when compared against their potential performance and choose to renovate those that will garner the greatest impact from renovation. As would be expected, the list is heavily populated by the larger buildings on campus, particularly those with significant area devoted to lab space or those buildings that house students. The range of savings in terms of % reduction varied greatly, from 13% to 69%, however these building typically showed a potential savings of 40-50%. This set of information forms the building blocks which allow the creation of scenarios based on a schedule of renovations to be carried out between now and 2042. This strategy and its results are discussed in detail in Section 3.

3.0- Carbon Dioxide Projections Based on Scenarios for the Built Environment

The primary goal of this work was to gauge the potential for the reduction of energy use from the built environment on the University of Pennsylvania central campus. While prior attempts to forecast this potential over the course of 30 year were limited to generalized assumptions about the changing nature of the campus or effectiveness of potential interventions on a broad scale, the new tools and techniques introduced by the T.C. Chan Center instead rely on specific details regarding the impact of definable actions. Rather than broad goals that suggest emissions could be reduced via a concerted effort, the focus on individual buildings allows a plan of action to be created that consists of definable actions with quantifiable results, combined to form a larger scenario. This technique, which ties specific actions to results, creates a scenario which relies less on assumptions, gives greater validity to the results, and provides a specific plan of action to achieve the anticipated reductions.

In forming the Climate Action Plan 2.0 one of the primary tasks was to revisit the original carbon reduction goals that were set in 2009 and to determine that those goals were appropriate, still accurate, and, if not, to replace them with new carbon reduction goals using more accurate assumptions and information. To accomplish these tasks scenarios were created that used the information regarding the potential reduction in individual buildings, as described in Section 2, to form a schedule of specific renovations that would renovate a set percentage of the worst performing buildings to a modern code standard. Four separate scenarios were described and their impact investigated. The four scenarios were based on the four possible combinations of renovating the worst 20% and 30% of the buildings and renovating them to current or next-gen ASHRAE 90.1 building code between the years 2016 and 2042.

The reductions anticipated by each of these scenarios were then compared against several baselines to gauge their efficacy and the resources that would be involved in pursuing those schedules of renovation. These baselines included a scenario that only considers the impact of the Century Bond projects and one which assumes that no significant improvements will be made to the built environment over the course of the projection. As a final point of comparison, all of the scenarios and baselines were compared against the levels of energy consumption and carbon dioxide production in 2007, against which the Climate Action Plan 1.0 goals had been set, and 2014. The assumptions used for each scenario and their parameterization were kept constant as much as possible, with the only significant difference between them the level and number of renovations that were scheduled across the period of time of the projection. Once all the scenarios had been analyzed they were compared against each other and a selection made to represent the goals for the Climate Action Plan 2.0, based on cost, feasibility, and impact.

3.1- The Calculators and Tools Used to Generate Data

3.1.1- EnergyPro

EnergyPro is a tool widely used by industry, which was developed to quickly determine the ASHRAE code requirement for buildings that do not conform to the simpler prescriptive format of the code. It uses relatively simple inputs and many assumptions to check for compliance with the ASHRAE 90.1 code and to determine the energy that a given building should consume if it were built to code. This allows users to make reasonable estimates of the benefits of bringing a building to one level of code versus another and to determine if any additional costs associated with a higher standard would be economical. For the purposes of this study EnergyPro was used to determine the energy consumption of the largest 100 buildings if they were renovated to improve their performance. Targets were generated according to ASHRAE 90.1-2007 and ASHRAE 90.1-2010. Following the format of the code, EnergyPro uses some simplifying or restrictive assumptions to model specialized building types such as labs, for example excluding the plug loads of lab equipment beyond a baseline minimum. To develop realistic performance targets for the buildings at Penn, post-simulation adjustments were made to the results generated by EnergyPro.

3.1.2- The Individual Building Worksheet

Individual Building Worksheets were developed in 2011 to track and project the consumption of energy by individual facilities in the built environment of the University of Pennsylvania Campus. They work in conjunction with the UPenn Carbon Calculator by determining what portion of the overall campus consumption of steam, electricity, and chilled water can be attributed to each individual facility. Any remainder of the total campus consumption that cannot be attributed to a specific building is tracked as a separate category. Once the current campus consumption has been attributed to individual facilities, projections may be made for each facility to determine how its energy consumption may change over time.

These projections run for 30 year spans and may reflect the effects of renovations, behavioral changes, or the installation of new equipment. The effects of these changes are applied to a specific year and their impact on steam, electricity, or chilled water consumption may be calculated through engineering formulas or estimated based on the impact of similar projects in other buildings. The remainder from the campus total that was not attributable to a specific building is also projected into the future, typically with an assumed growth rate equal to the historic average annual rate of change observed for the campus total consumption. This summation of projections forms the new overall projection for the consumption of energy by the built environment in the UPenn Carbon Calculator. Further details on the operation of this tool may be found in Appendix C.

3.1.3- The UPenn Carbon Calculator

The UPenn Carbon Calculator is based on the framework developed by Clean Air – Cool Planet for the reporting of greenhouse gas emissions on college campuses. The methodology identifies three scopes from which emissions can arise due to campus activities. Scope 1 considers sources which are used on the campus and which produce their emissions onsite. Scope 2 considers those sources of emissions which are used on campus but which produce emissions remotely. Finally Scope 3 sources of emissions are those activities that take place off campus.

Within each of the three scopes specific sources of emissions are identified and the level of activity in each source is recorded in consistent units over a set period of time, typically a year. The calculator determines the emissions from each source within the three scopes by multiplying the magnitude of each activity by a specific emissions factor that determines the megatons of carbon dioxide equivalent (MTCDE) each unit of activity produces. The contributions from every source within each scope are finally then summed to produce the carbon footprint for that campus in that year. This simple method relies on relatively few, easily determined inputs that allows a carbon footprint to be easily calculated for most campuses.

The UPenn Carbon Calculator was designed to not only calculate the carbon footprint in any given year, but to also serve as a repository for all past carbon footprint data as well as a medium for projecting the University's carbon footprint into the future. As mentioned in the previous subsection, the Individual Building Worksheet has taken over the projection of the Scope 2 sources of emissions, steam, chilled water, and electricity, which are utilized almost exclusively for the built environment. While the UPenn Carbon Calculator is still used to track all historical consumption of these three, the values for future consumption are based on the most recent historical year and then projected and resumed for the individual buildings before being reintroduced into the UPenn Carbon Calculator.

Other sources of carbon are still projected by the original calculator, however. These projections are typically based on a simple average annual percent growth based on historical data. Since these sources represent only about 15% of the carbon produced by the campus and are also areas which are less subject to influence by FRES, these sources have not been the focus of investigation and the simpler projection technique has been considered adequate. The calculator also tracks and projects the purchase of renewable energy credits (RECs), which serve to directly offset the emissions produced through campus activities. Since the University purchases RECs through wind electricity credits, these decrease the UPenn carbon footprint using the same emissions factor used for electricity.

One final, but very important, projection made by the calculator is not for the consumption of an energy carrier or tracking a particular activity, but rather considers the changing nature of the emissions factor associated with each of these energy carriers and activities. Electricity and chilled water are both directly influenced by the sources of the electricity that is being supplied to the grid while steam may be co-generated by the Veolia plant using several different fuel sources. The historical trend has been for these sources to become less carbon intensive over time, which has led to a significant decline in the emissions produced from these sources, particularly in steam. As federal and state standards improve, it is expected that these emissions factors will continue to improve, leading to a general trend of decarbonization and a decrease in the annual carbon footprint from the university.

3.1.4- The UPenn Carbon Financial Calculator

While the Individual Building Worksheets were designed to provide inputs for the UPenn Carbon Calculator, the UPenn Financial Calculator accepts the outputs of the UPenn Carbon Calculator and generates additional analyses regarding the financial costs or savings from enacting each scenario. While the other tools focus on what is possible, this tool attempts to determine what course of action would be most fiscally responsible while still achieving the goals the University has set for carbon dioxide reductions. This is accomplished through a net present value calculation that accounts for the change in electrical and steam consumption, carbon dioxide released, and the additional capital costs in a scenario compared against that seen in the business-as-usual baseline.

The first step in using this tool is to establish the baseline conditions. The baseline, and every scenario, relies on a small handful of inputs, most of which may be drawn from the outputs of the UPenn Carbon Calculator. These include: 1) a projection of electrical and steam consumption for every year of the scenario; 2) a projection of the carbon dioxide emissions resulting from each scenario, including from sources other than electricity and steam; 3) the projected rate paid per unit of consumption paid for electricity and steam; 4) the value of carbon over time in $/MTCDE; and 5) the assumed discount rate.

The final input that is required is the additional capital costs of a scenario for each year of the projection. There are two means of inputting this information that will achieve equivalent results. The first is to enter the full capital costs in each year for both the baseline (business-as-usual) scenario as well for the scenario of action being investigated and allowing the calculator to determine the incremental cost between the two. Alternately, if the incremental cost is already known, or if it is not possible to determine the baseline costs but the incremental costs can be estimated, then the incremental cost maybe input directly into the scenario of action while leaving the costs of the baseline scenario as zero. A detailed description on the operation of the UPenn Financial Carbon Calculator may be found in Appendix D.

3.2- Crafting Scenarios for Comparison

The tools described above were used to create projections of carbon dioxide emissions for several scenarios and baselines. A business as usual scenario was created to serve as a baseline for comparison against which other scenarios might be compared. This scenario assumed that no significant changes would occur in the built environments and that the only changes would be a small rate of growth due to the expansion of the university and fluctuations due to changing emissions factors in the electricity and steam supplies. However this scenario must be complimented by a second baseline, one that maintains the basic assumptions of the business as usual scenario but also considers the effects of the Century Bond projects, many of which will be completed in the next three years. This scenario represent the anticipated effects of those projects which have already been funded and approved in the effort to reduce energy consumption and can serve as the baseline for all other scenarios as well as a gauge of the cost associated with the reduction of emissions through the renovation of university buildings.

Since this study had already identified the built environment as the primary target for intervention to reduce emissions, many of the basic assumptions used to create the business as usual scenario were kept constant for all of the other scenarios. A full list of these assumptions may be found in Appendix F but most factors were held constant if they had no impact on changes to the built environment. These included the campus growth rate, the assumed emissions factors, and the costs associated with energy. The only variables that were changed were in the relative consumption of electricity and steam. The differences were calculated by considering the impacts of future renovations to specific buildings, either based on engineering calculations performed for the Century Bond projects or through models which calculated the potential consumption of those buildings if they were brought to ASHRAE code. Each scenario then subtracted this impact from the projected business as usual scenario in the year when the renovation is scheduled to occur and for all subsequent years. The following section describes each scenario and the impact that the scheduled renovations would have economically, on energy consumption, and in terms of the associated carbon dioxide emissions.

3.2.1- Business as Usual

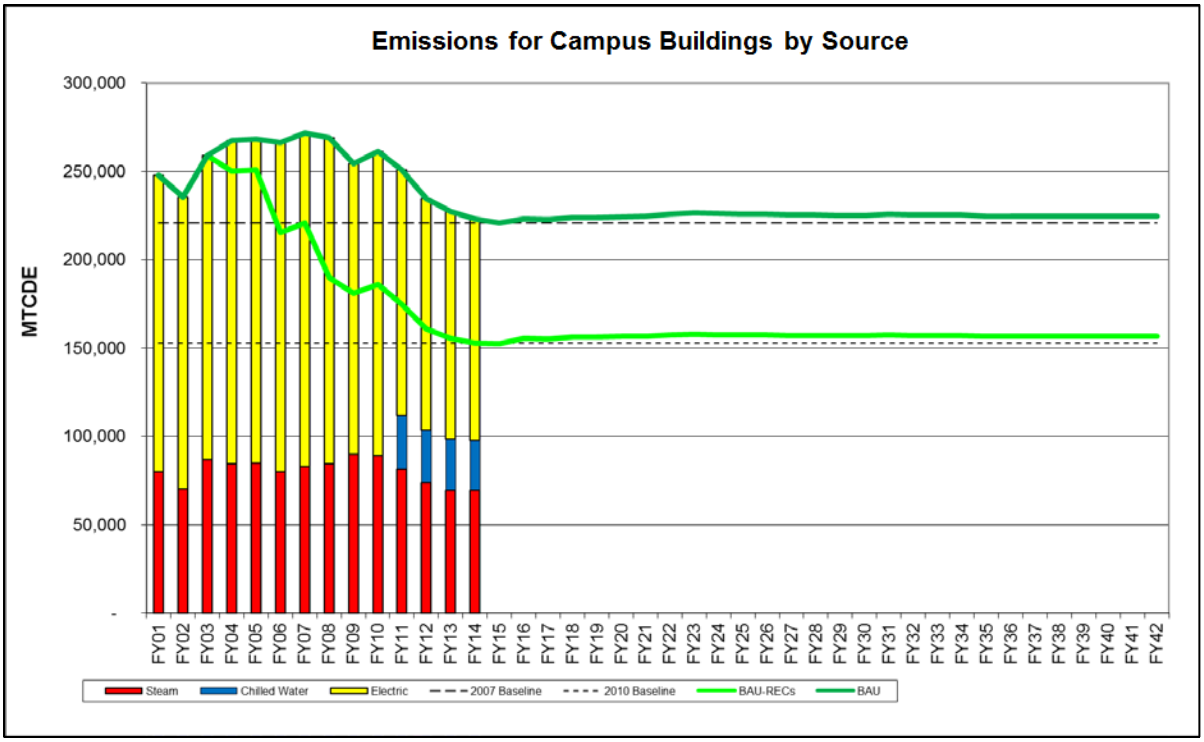


Figure 7- Projected Carbon Footprint, BAU

Table 4- Summary of Result of BAU Projection

	by/in Year	Scenario, Annual	% Change vs 2014	Cum. Change vs BAU
Carbon Produced	2019	156,485	+4%	n/a
(MTCDE)	2042	156,860	+5%	n/a
Energy Consumed	2019	2,595	+3%	n/a
(mil kBtu)	2042	2,705	+8%	n/a

Figure 7 displays the effects of the Business as Usual Scenario compared against the 2007 and 2014 baselines. As the only assumed change in consumption in this scenario comes from a 0.85% growth rate due to the expansion of the campus coupled with a moderate decarbonization of the electrical grid over time, there is only a moderate increase in consumption over the course of the projection. Also shown on this graph are the 2007 Baseline and the Business as Usual Scenario without RECs considered. These two lines are useful for comparison in this instance but will largely not be considered when examining other scenarios.

Evident in this graph is the rather significant reduction in carbon between the 2007 and 2014 baselines. This is primarily due to improvements in the emissions factors from the electrical grid and the Veolia steam plant during that period of time. Also shown are the effect of the RECs, which account for nearly a third of the emissions produced by the built environment. Accounting for reductions in carbon intensity of the energy carriers, the moderate campus growth rate still leads to at best a leveling off of annual carbon emissions and illustrates the need for further intervention. While a greening of the electrical and steam supplies drove a significant reduction over the past seven years, nothing indicates that this improvement will be experienced again in the near future. Instead all action must be driven by actual energy reductions in the built environment.

3.2.2- Century Bond

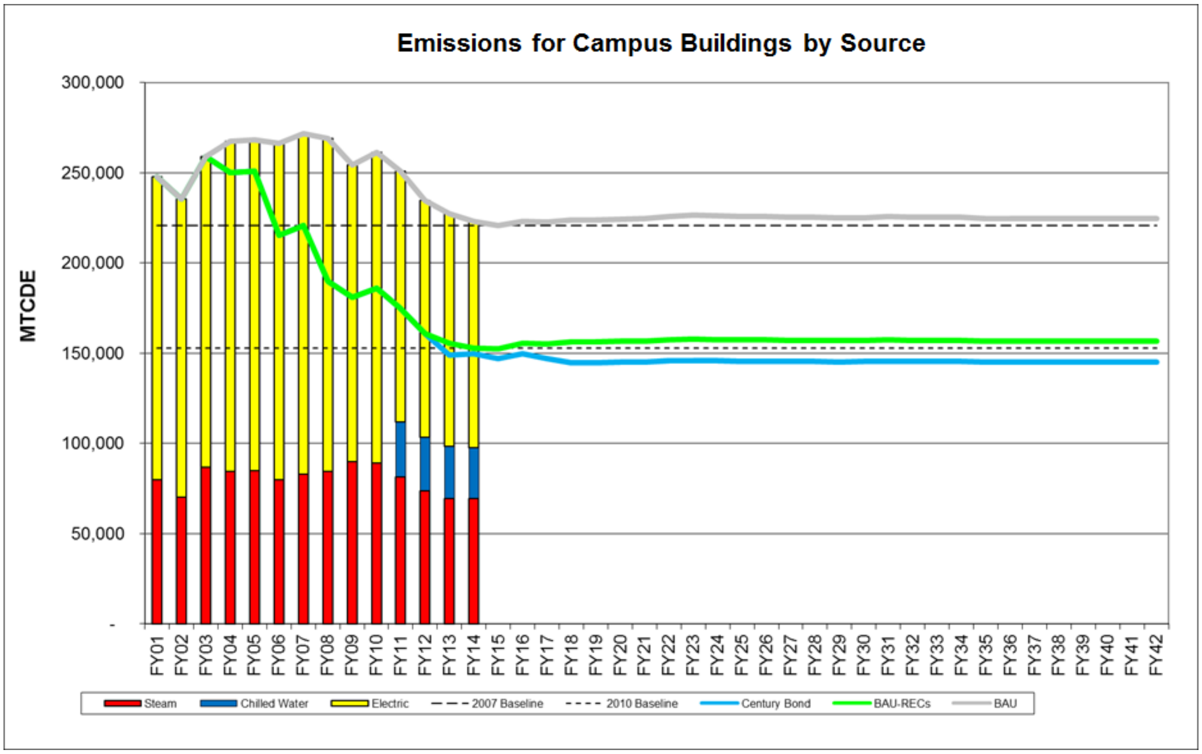


Figure 8- Projected Carbon Footprint, Century Bond

Table 5- Summary of Result of Century Bond Projection

	by/in Year	Scenario, Annual	% Change vs 2014	Cum. Change vs BAU
Carbon Produced	2019	144,816	-3%	-42,248
(MTCDE)	2042	145,150	-3%	-312,222
Energy Consumed	2019	2,477	-3%	-411
(mil kBtu)	2042	2,582	-3%	-3,179

While the Business as Usual Scenario describes the effects if nothing is done to improve the built environment over the course of the projection, the Century Bond Scenario includes those renovations which have been designed, funded, and scheduled in the near future through the Century Bond fund. While dozens of smaller lighting projects were approved and have been implemented across the campus, the focus of this scenario was on the 9 larger HVAC renovations that were approved. These renovations are ongoing through 2017, when the last should be completed. This scenario is identical to the Business as Usual Scenario in all years except 2015-2017, each of which sees the completion of a portion of the Century Bond projects. While the time span and scope of these projects are limited, they produce an appreciable impact in a relatively short period of time. This causes a net reduction in carbon dioxide emissions by 2019 of -3%, a reduction which is maintained over the course of the projection. While these effects are limited to a few years, they show both the potential and the cost of reduction for University carbon emissions from the built environment. All the ASHRAE 90.1 Scenarios build off this one by recommending a series of renovations to be scheduled after the first round of Century Bond projects is completed.

3.2.3- ASHRAE 90.1-2007, 20% and 30% of Buildings

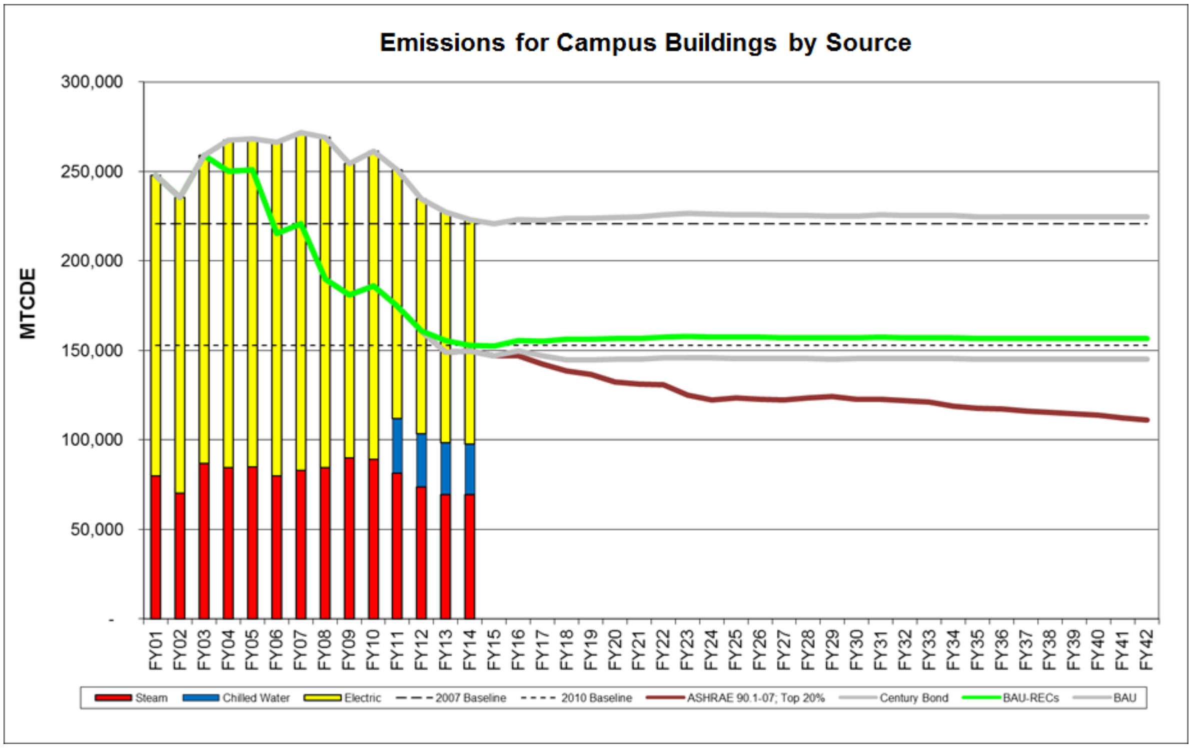


Figure 9- Projected Carbon Footprint, ASHRAE 90.1-2007, 20%

Table 6- Summary of Result of ASHRAE 90.1-2007, 20% Projection

	by/in Year	Scenario, Annual	% Change vs 2014	Cum. Change vs BAU
Carbon Produced	2019	136,443	-9%	-64,056
(MTCDE)	2042	110,973	-26%	-895,246
Energy Consumed	2019	2,303	-8%	-879
(mil kBtu)	2042	1,854	-26%	-15,518

The first scenario that assumes action will be taken each year until 2042 picks up where the Century Bond projects leave off by creating a schedule that attempts to evenly divide the square footage from the 20% of the buildings that would improve the most through a renovation to ASHRAE 90.1-2007 code, not considering those that are not controlled by the University or were already being renovated via a Century Bond project. The 20% of the buildings that would show the greatest improvement includes 35 buildings with approximately 5.5 million gross square feet of floor area. On average 212,000 gsf/year would need to be renovated, typically consisting of 1 to 2 buildings each year. This effort leads to a significant improvement in both the consumption of energy and the production of carbon, a -9% reduction in carbon and a -8% reduction in energy by 2019 and a -26% reduction in both by 2042, compared to the 2014 levels. The list of the top 20% of buildings can be found in Appendix A.

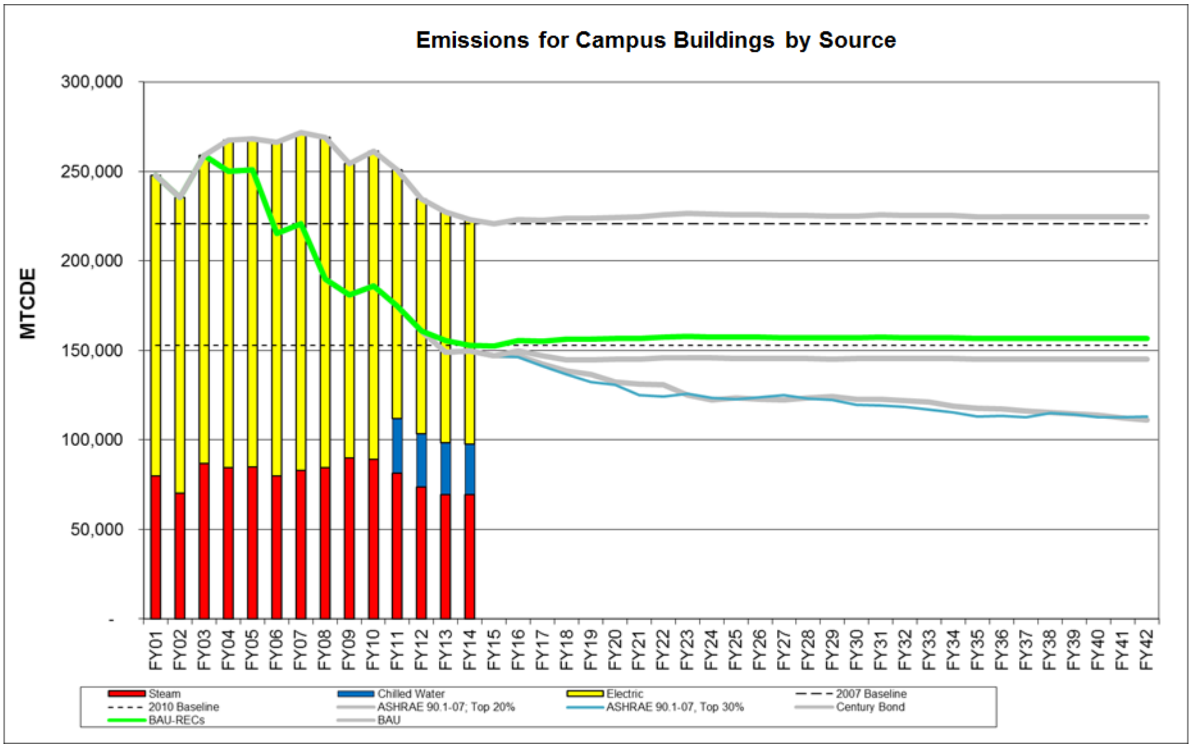


Figure 10- Projected Carbon Footprint, ASHRAE 90.1-2007, 30%

Table 7- Summary of Result of ASHRAE 90.1-2007, 30% Projection

	by/in Year	**Scenario, Annual**	**% Change vs 2014**	**Cum. Change vs BAU**
Carbon Produced	2019	132,383	-12%	-72,002
(MTCDE)	2042	113,171	-24%	-942,396
Energy Consumed	2019	2,254	-10%	-1,007
(mil kBtu)	2042	1,826	-27%	-16,924

This scenario is the same as the previous but it assumes that the next 10% of the eligible buildings will be renovated based on the level of improvement that could be expected from a renovation to ASHRAE 90.1-2007 code. This represents 50 buildings and 6.5 million gsf of built environment. Approximately 251,000 gsf would need to be renovated each year which would typically be represented by 2 buildings each year. This full list may be found in Appendix A. An annual net reduction of -12% in carbon and -10% in energy was projected by 2019 and an annual net reduction of -24% in carbon and -27% in energy was projected by 2042. It is interesting to note that adding an additional 10% of the buildings only improves the carbon reduction by ~2%, indicating that the majority of the ‘low hanging fruit’ can be found in the first pool of 20% of the buildings.

3.2.4- ASHRAE 90.1-2010, 20% and 30%of Buildings

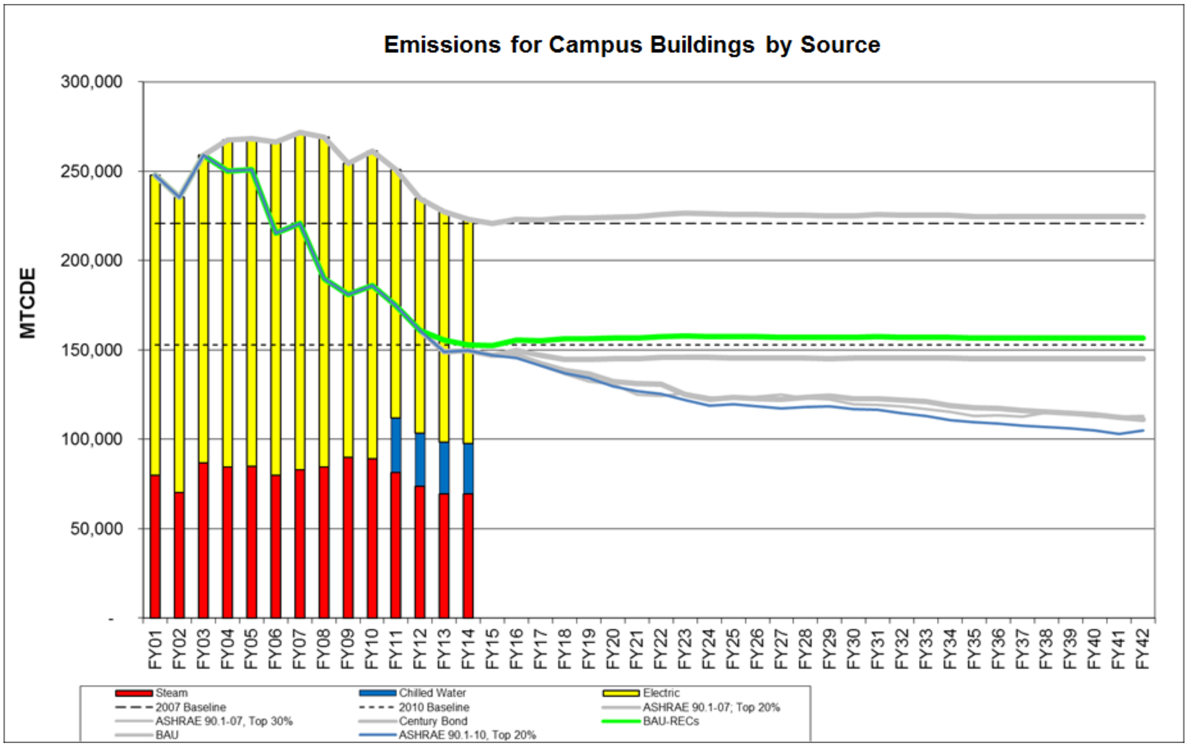


Figure 11- Projected Carbon Footprint, ASHRAE 90.1-2010, 20%

Table 8- Summary of Result of ASHRAE 90.1-2010, 20% Projection

	by/in Year	Scenario, Annual	% Change vs 2014	Cum. Change vs BAU
Carbon Produced	2019	134,385	-10%	-70,456
(MTCDE)	2042	104,836	-30%	-1,045,575
Energy Consumed	2019	2,284	-9%	-933
(mil kBtu)	2042	1,803	-28%	-16,707

These two scenarios mirror the two from the previous section in terms of the buildings that would be impacted each year (the 20% and 30% lists), however instead of renovating these buildings to the ASHRAE 90.1-2007 code it was assumed that they would be brought to ASHRAE 90.1-2010 code. This resulted in reductions that were a moderate improvement over the scenarios that renovated the buildings to the 2007 ASHRAE code. An annual net reduction of -10% in carbon and -9% in energy was projected by 2019 and an annual net reduction of -30% in carbon and -28% in energy was projected by 2042. This is a 2-3% improvement over the reductions seen when applying the lesser code to the renovations of the same set of buildings.

As would be expected, the greatest reductions could be seen in the scenario which projected the renovation of the top 30% of the eligible buildings to ASHRAE 90.1-2010 code. An annual net reduction of -13% in carbon and -11% in energy was projected by 2019 and an annual net reduction of -32% in carbon and -31% in energy was projected by 2042. This is a 2-3% improvement over the reductions seen when applying the lesser code to the renovations of the same set of buildings. Just like all of the previous incremental steps in terms of the number of buildings being renovated and the extent to which they will be improved, a 2-3% improvement in the reductions can be seen over the previous scenario, compared to the 2014 levels of emissions and consumption.

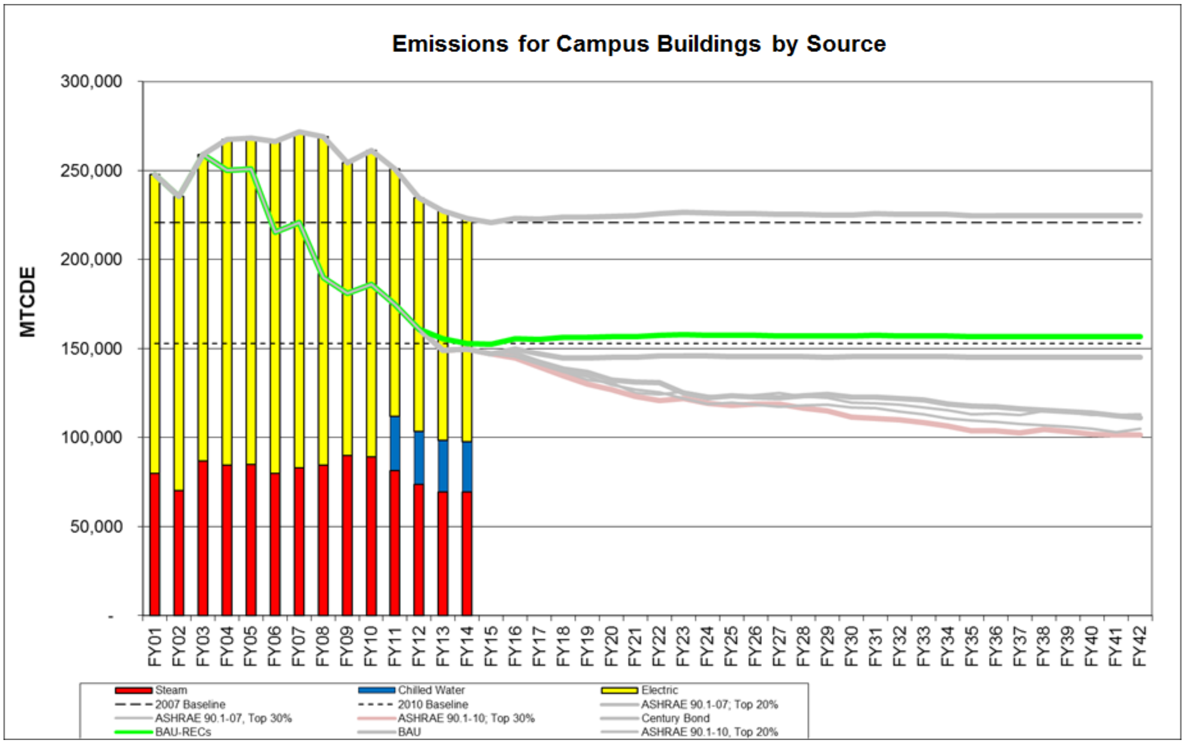


Figure 12- Projected Carbon Footprint, ASHRAE 90.1-2010, 30%

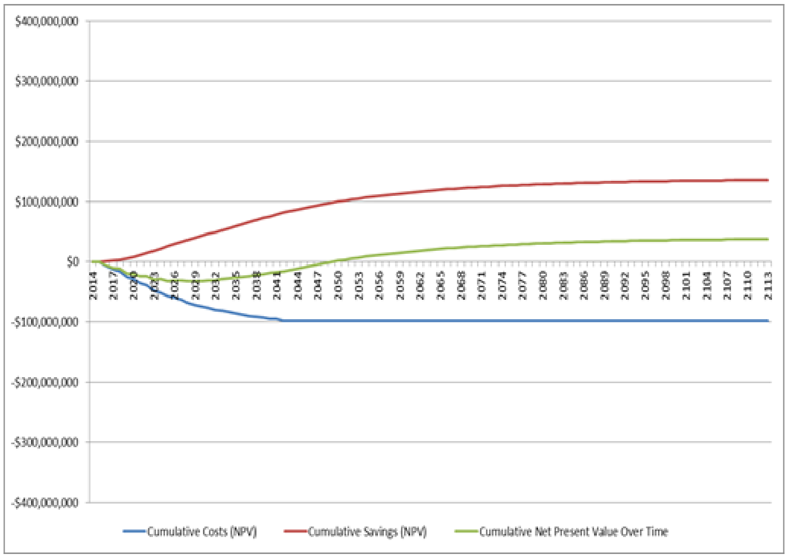
Table 9- Summary of Result of ASHRAE 90.1-2010, 30% Projection

	by/in Year	Scenario, Annual	% Change vs 2014	Cum. Change vs BAU
Carbon Produced	2019	130,031	-13%	-79,520
(MTCDE)	2042	101,522	-32%	-1,123,437
Energy Consumed	2019	2,230	-11%	-1,077
(mil kBtu)	2042	1,729	-31%	-18,400

3.3- Financial Analysis of the Scenarios

While the above scenarios describe the potential for energy consumption and carbon dioxide emissions reductions they do not consider all of the factors which would be included in a decision to pursue a course of action or not. While it would be optimal in some regards to simply choose the scenario which would garner the greatest reductions, these benefits must be weighed against the costs of achieving that reduction. To provide this additional factor for consideration a financial analysis of each scenario was carried out that considered the net present value of the costs of the renovations and the value of the energy that was saved compared to the Business as Usual scenario.

This analysis was conducted using the UPenn Financial Carbon Calculator and operated by determining the savings accrued through energy consumption reductions as compared to the baseline and the incremental costs of conducting any renovations for each year, then applying a compounded discount rate for each year into the future to determine the net present value of the costs vs. savings for that year. The net present value of the costs and savings are summed for each year of the projection to generate the net present value of the entire scenario. Since the savings from the energy reductions will continue for many years beyond the end of the renovations program, these savings were considered over a 100 year time span, although due to a discount rate of 4.86%, the net present value of these annual savings quickly drops to $0 by 2080, approximately four decades after the last renovation would have been completed.



Examined over a 100 year span
Assumes: 4.86% Discount Rate
$112.67/sqft Renovation Costs
30% of this cost is incremental over Business as Usual

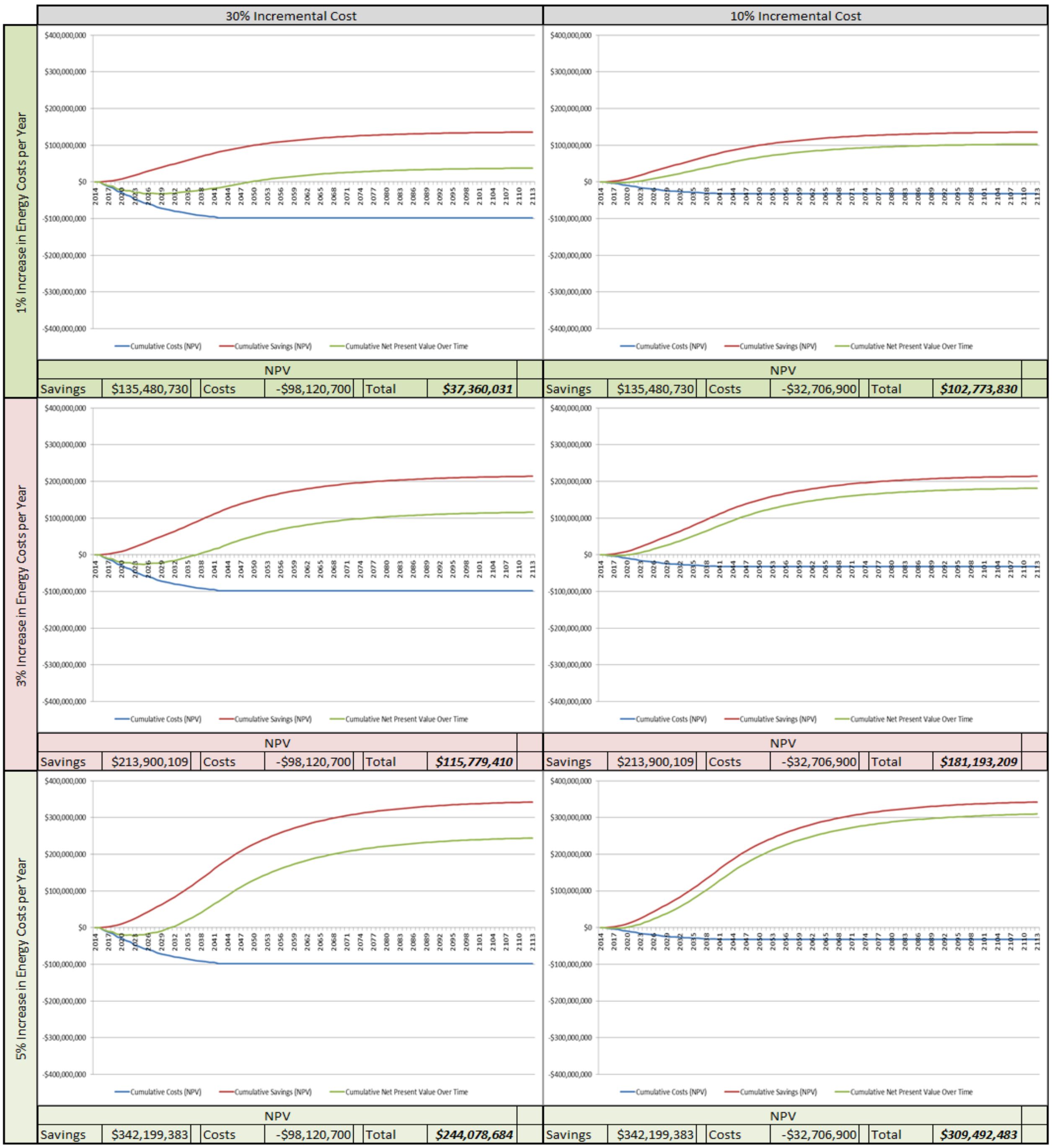
NPV of Costs = - $98.1mil
NPV of Savings = $135.5mil
NPV of Scenario = $37.4mil

Figure 13- Initial Net Present Value Projection for ASHRAE 90.1-2010, 20%

The results of the financial analysis showed that the scenario for renovating 20% of the building stock with the greatest potential for improvement to ASHRAE 90.1-2010 code. This result makes common sense as the primary factor that would increase or decrease the relative costs between these four scenarios is the square footage being renovated, since only a small incremental cost was associated with renovation to 2010 vs. 2007 code. This then naturally favors the scenarios for renovating 20% vs. 30%of the existing building stock. The remaining question was, did the incremental cost of achieving 2010 code over 2007 code outweigh the energy reduction benefit?

The results showed that this was not the case and so the scenario with the greatest financial outlook and the second greatest energy reduction is the 20% of buildings to ASHRAE 90.1-2010 code. Assuming that only 30% of the full cost of the renovations is incremental over that which would be spent in the Business as Usual Scenario and that the cost of energy increases at the slow rate of only 1% per year, then this scenario has a net present value of nearly $37.4 million dollars. However this result is quite variable based on the assumptions that are used and this figure represents the most conservative of the values.

This study determined that the result of this financial analysis is highly dependent on two assumptions which have not yet been accurately parameterized. The first of these assumptions is the rate of annual increase for the cost of energy. Energy prices have frequently been volatile, stagnating for periods and then experiencing rapid growth. Recent shale gas exploration has kept this growth in cost to a minimum but it is not expected to continue. Unfortunately, the changing cost of energy is difficult to predict 10 years into the future, let alone several decades, so while a growth rate of 1% was assumed for the initial analysis, rates of 3% and 5% were also considered. The second assumption driving these results regards the costs of the renovations. While the original analysis assumed that 30% of the full cost of the renovation would be incremental above any charges that could be expected in the Business as Usual scenario, there is the potential for substantial overlap so that substantially less of the costs may be incremental above Business as Usual. To reflect this, in addition to the 30% incremental costs used in the first analysis, incremental costs 10% were also considered.



Energy cost increase	Incremental cost	NPV Savings	NPV Costs	NPV Total
1%	30%	$135,480,730	-$98,120,700	***$37,360,031***
1%	10%	$135,480,730	-$32,706,900	***$102,773,830***
3%	30%	$213,900,109	-$98,120,700	***$115,779,410***
3%	10%	$213,900,109	-$32,706,900	***$181,193,209***
5%	30%	$342,199,383	-$98,120,700	***$244,078,684***
5%	10%	$342,199,383	-$32,706,900	***$309,492,483***

Figure 14- Combinations of variables showing significant sensitivity to cost of energy and level of incremental cost

Every combination of these two variables was analyzed to create a matrix of the financial outlook of the optimal scenario showing the variability achievable through a normal range for these two variables. Every combination of the two shows significant improvement in the net present value over the original analysis with most breaking even by 2040, showing a substantial positive net present value by the end of the projection. These range from the $37.4 million NPV seen with a 1% annual growth rate for energy costs and a 30% incremental cost to a NPV of +$300 million. Further study is required to determine with greater certainty the value that is appropriate for these variables and given the wide range of results possible until that time these figures are best used for comparison between scenarios which share those assumptions. Table 10, below, provides a summary of the anticipated net present values under each combination of rate of energy cost growth and % of Costs Incremental above BAU.

Table 10- Summary of NPV considering variable Incremental Costs and Change in Energy Costs

NPV of 20% to ASHRAE-2010		% of Costs Incremental Above BAU	
		30%	10%
% Annual Increase in Energy Rates	1%	$37,360,031	$102,773,830
	3%	$115,779,410	$181,193,209
	5%	$244,078,684	$309,492,483

4.0- Using the Developed Scenarios to Develop Climate Action Plan 2.0

Much of the impetus for the current slate of research conducted by the T.C. Chan Center on behalf of Facilities and Real Estate Services has centered on the University of Pennsylvania's commitment made in 2007 to achieve a carbon neutral campus by 2042. In 2009 the Climate Action Plan 1.0 was enacted and milestones were determined to serve as goals for the reduction of carbon emissions from the campus. Five years have passed and during that time a great deal has changed in the energy climate, the actions the University is taking to curb its emissions, and in the techniques used to create the projections for potential carbon reductions that those goals are based upon. The fifth year of the Climate Action Plan 1.0 represented a perfect opportunity to both gauge how the University was doing in regards to the original goals set in 2009 but also to decide if those goals represented a realistic potential outcome for the University's continued efforts. Using the newest techniques and tools, several scenarios and a new baseline were created to account for the many changes that have occurred since CAP 1.0 and to set new carbon goals for the future.

The goal set using this year's data has several advantages in terms of the methods used to generate projections. The transition to focusing on individual buildings, aggregating them together to achieve values for the whole university rather than focusing on the campus level consumption, greatly improves the accuracy and reduces the number of assumptions and generalizations that had to be used in the projection. Instead, the focus on individual buildings lends itself to the creation of an action plan by creating a scenario with a schedule of specific renovations to be carried out in certain years. Whereas before the scenario would consist of general ideas and assumed reductions in carbon associate with those activities, this method ties specific results to the building blocks that's make up the scenario. This gives the user a much better understanding of the costs and effects of the interventions being introduced and allows them to craft a detailed scenario that meets the specific needs and requirements of the University, shifting to a style of holistic planning rather than piecemeal. One area where this is particularly useful is in determining the financial impact of pursuing these goals. By associating reductions with specific actions, far better estimates of cost can be generated and metrics developed to determine the relative worth of each project.

4.1- The Scenario Chosen as the Basis for CAP 2.0

Based on the amount of level of carbon emission and energy consumption reductions and the relative costs of the different scenarios modeled it was decided to base the Climate Action Plan 2.0 on the scenario where, in addition to the Century Bond projects that have already been funded and designed, the top 20% of buildings in terms of potential savings will be renovated to next generation ASHRAE 90.1 code. The potential benefits were calculated using the ASHRAE 90.1-2010 code as this was the most recent for which modeling software was available (the 2013 code is designed to be 5-10% better than the 2010).

This plan considers the 9 buildings that will be receiving HVAC renovations through the Century Bond funding, approximately 1 million square feet, and 36 additional buildings which will receive the renovations bringing them to next generation ASHRAE code, approximately 5.5 million square feet. After the current slate of Century Bond projects is completed in 2017, approximately 215,000 square feet of the 36 buildings will need to be renovated each year. In addition to this renovation the Century Bond and ASHRAE 90.1 buildings will also be recommissioned every five years. Any other buildings that were not slated for renovation were instead scheduled to receive recommissioning every 10 years in order to avoid a decline in performance over time. This schedule of recommissioning will require approximately 19 buildings to be recommissioned each year, which is an increase from the current rate of 12 per year at an incremental cost of approximately $700,000.

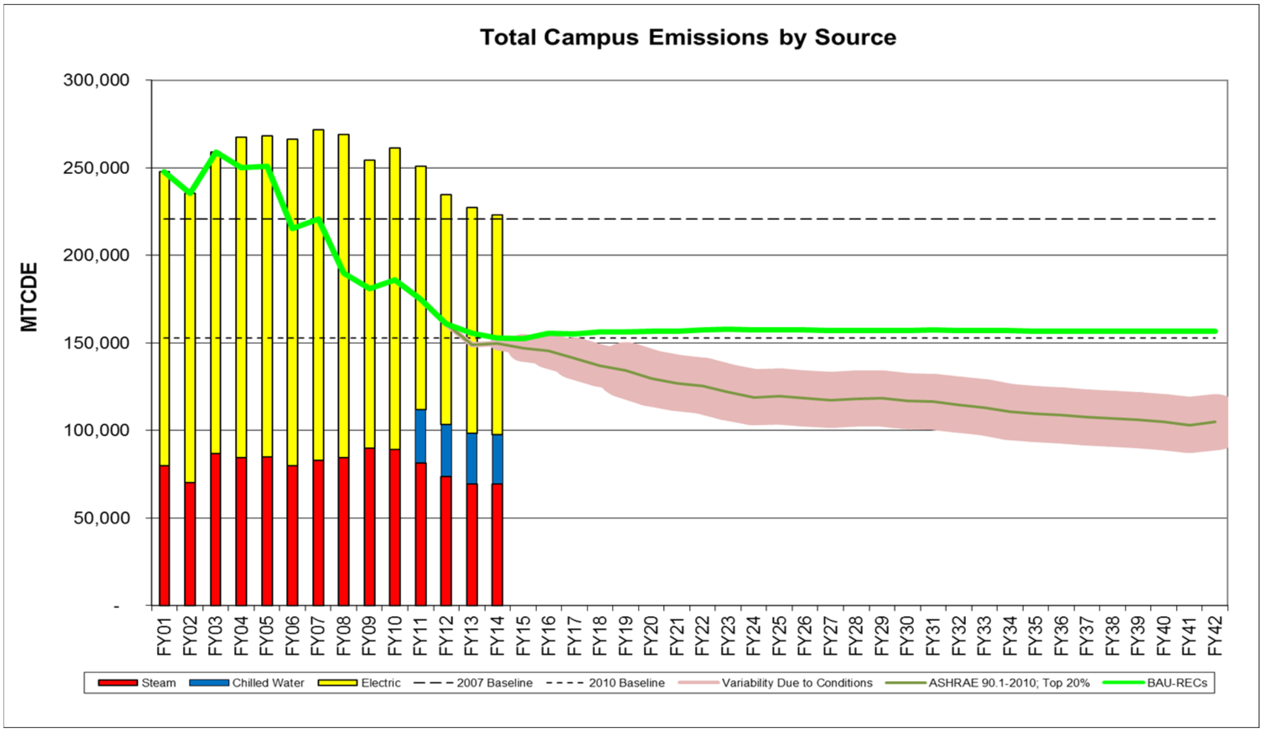


Figure 15- Projected Carbon Footprint, ASHRAE 90.1-2010, 20% with Uncertainty Due to Variable Conditions

Table 11- Buildings scheduled to be renovated under Century Bond and a list of buildings suggested for renovation afterwards to meet the 2019 goals for carbon reduction

Renovation List				
Year of Work	Building	Type	SqFt	Sqft/yr
2014	Chem 73	CB	149,975	149,975
2015	Leidy	CB	66,636	
2015	LRSM	CB	95,150	
2015	Richards	CB	104,344	658,964
2015	Ryan	CB	149,531	
2015	Stemmler	CB	243,303	
2016	Evans	CB	133,329	
2016	Meyerson	CB	98,016	
2016	Rosenthal	CB	60,790	395,568
2016	Chem 58	ASHRAE	42,250	
2016	Skirkanich	ASHRAE	61,183	
2017	BRB 1	ASHRAE	225,627	225,627
2018	CRB	ASHRAE	204,366	204,366
2019	Huntsman	ASHRAE	356,683	356,683

This plan results in a projected reduction of 10% in carbon emissions and energy consumption by 2019 and a 20% reduction in carbon and a 27% reduction in energy consumption in the built environment by 2042, excluding the impact of purchased RECs. The previous studies into variability due to weather indicates that deviations from the expected norms of as much as ±5% can be expected under extreme weather conditions. Figure 15 shows this projection with the assumed margin of error shown. In order to enact this plan it would be necessary to begin the planning and preparations for the next 5 years immediately so that work on the renovation beyond the Century Bond projects could begin in 2016. Above, in Table 11, is a list of the Century Bond projects and the buildings that are recommended to be renovated to ASHRAE code by 2019 in order to achieve the 10% reduction in carbon production and energy consumption promised by the scenario projection.

Figures 16, 17, and 18 show the effects of this scenario as compared to the 2007 baseline. These graphs compare the actual historical data for consumption and carbon production through 2014 against the goals determined by CAP 1.0. When the historical data ends the graph compares the projections determined by the recommended scenario against the Business as Usual baseline. This data illustrates several interesting points. Firstly the CAP 1.0 goals for reductions in carbon emissions have so far been met; however the lack of improvement in energy consumption indicates that these improvements were mostly due to the reduction in emissions factors in the production of steam and electricity rather than due to any particular action on the part of the University. This highlights the difficulty of achieving significant reductions from the built environment unless a concerted effort and significant resources are devoted to the issue. This level of impact can be seen in recent years as the result of improvements through the Century Bond lighting projects which have been enacted in recent years and which are ongoing. As a result, the energy consumption reduction goals of CAP 1.0 were not met.

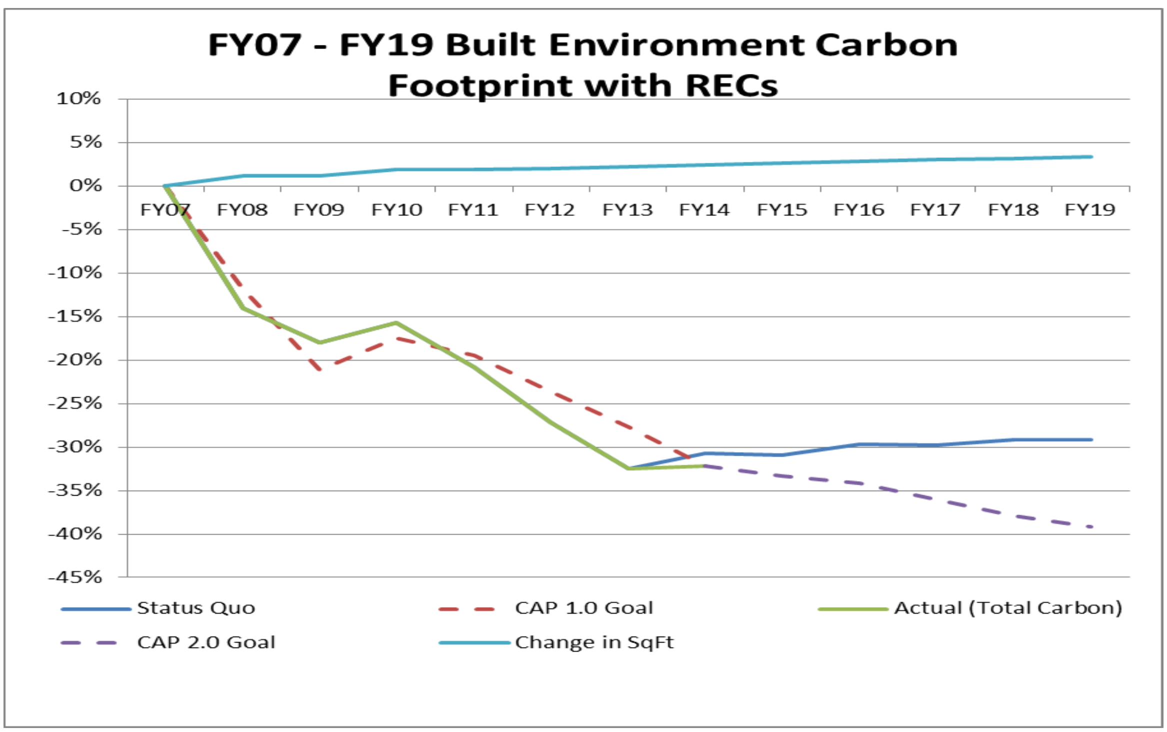


Figure 16- Actual Carbon vs Carbon Goals in Action Plans 1.0 and 2.0, including RECs

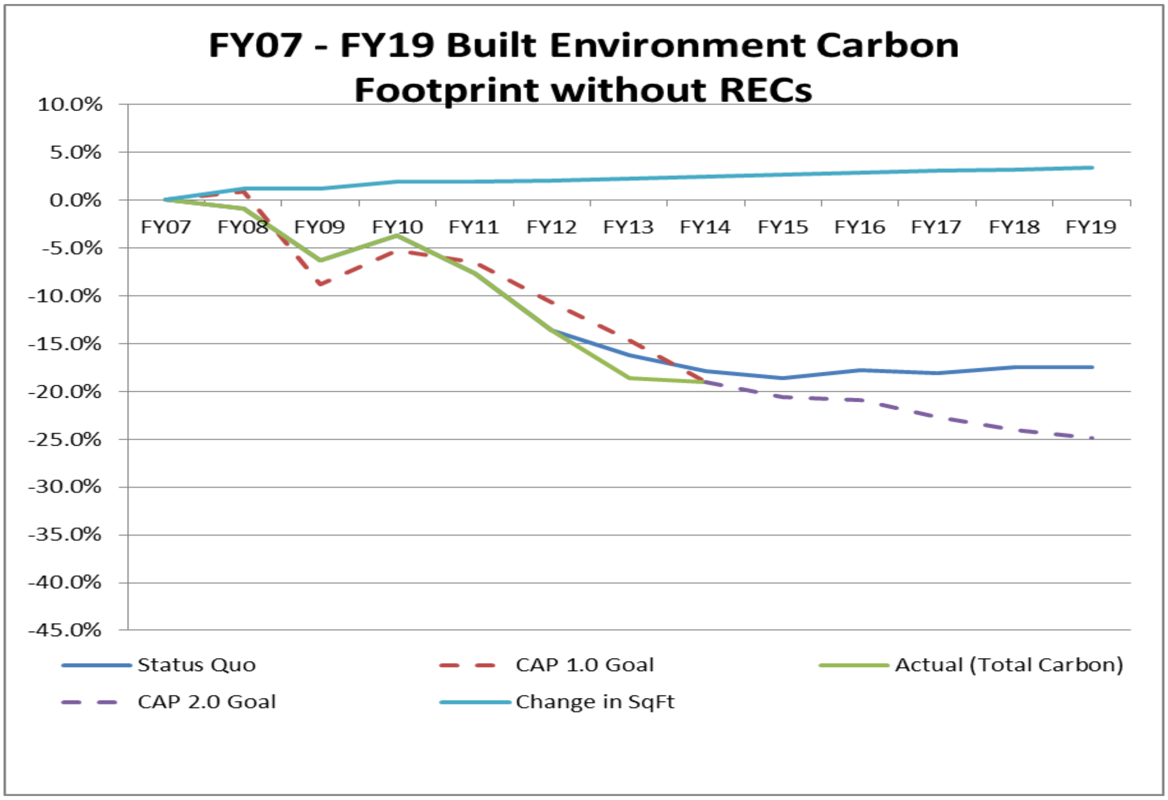


Figure 17- Actual Carbon vs Carbon Goals in Action Plans 1.0 and 2.0, not including RECs

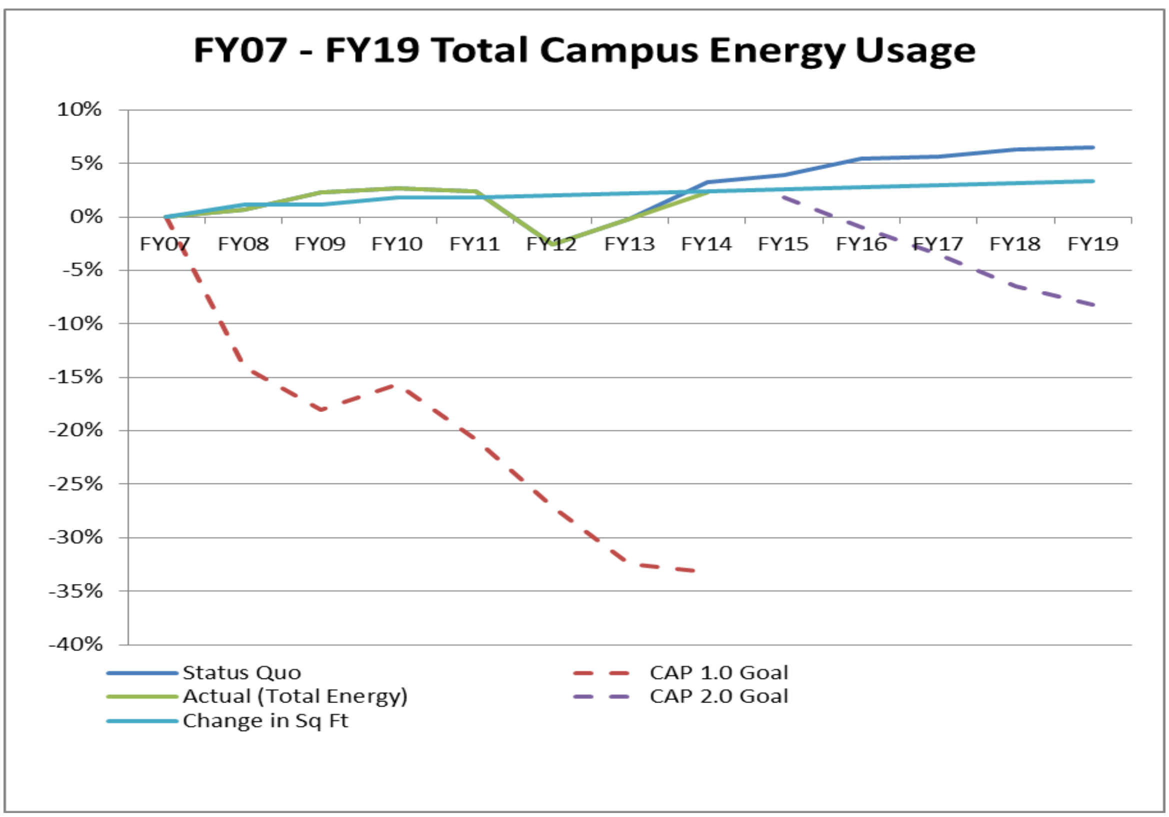


Figure 18- Actual Energy Consumed vs Energy Goals in Action Plans 1.0 and 2.0

4.2- The Limitations of the Scenario as a Basis for CAP 2.0

The level of effort involved in CAP 2.0 scenario represents a sustained commitment of resources that must be devoted to the renovation and maintenance of buildings. It is an ambitious plan that represents the greatest reasonable expenditure that can be justified to reduce carbon emissions and energy consumption with current energy prices and forecasts. If the market price of energy rises more rapidly or carbon costs are internalized in energy prices, the scenario could change dramatically. In other words, Carbon Action Plan 2.0 is a fundamentally conservative plan. The projections created for this scenario illustrate the limitations of achieving energy and carbon reductions through building renovation. To achieve carbon neutrality for the campus, these efforts would need to be accompanied by additional efficiency improvements, carbon reductions, or by increasing the number of RECs purchased.

The focus of this report has been the effect of renovation and efficiency improvements on the built environment, but this must be accompanied by other methods for reducing carbon emissions and energy consumption, particularly behavioral change efforts designed to reduce energy consumption. It is anticipated that the revisions of the utility cost allocation among the schools and centers to reflect real utility usage offers real opportunities for change. The ways in which these costs and reported and passed down to the real consumers has the potential to dramatically alter the behavior of the schools and centers in their approach to building projects and even to shift the culture of energy usage among the University population. In addition, there are other sources of emissions besides the built environment. While many of these other sectors that produce smaller amounts of emissions, commuting and air travel account for the nearly 15% of emissions and they require quite different kinds of strategies.

Fundamental limitations arise by the general difficulty in making any projection into the far future. Such projections necessarily rely on multiple assumptions. These assumptions, especially those involving annual rates of growth, can have a dramatic impact through very slight changes when compounded over a 30 year time span. Assumptions that were made that could easily change include: the emissions rates for supplied steam and electricity; the price of energy over time; and the rate of growth for the university. It is recognized that a change in any of these factors could have a dramatic impact on the magnitude of reductions or the costs of a project. Therefore, the CAP 2.0 scenario was formulated conservatively, to minimize risk.

A final limitation of the current set of scenarios and their projections is their reliance on simulation to establish baselines and future performance targets. The targets used in the CAP 2.0 scenario show generally what is possible when building are brought to next gen code levels, but they cannot identify the specific improvements required to achieve those goals. As the installation of steam and chilled water meters on the major consumer buildings are completed this year, they will not only provide firm data on current consumption, but also material for more accurate projections and simulations. This will be further facilitated by the installation of a new, state-of-the-art Supervisory Control and Data Acquisition (SCADA) system, which will make much deeper analysis of building performance possible.

5.0- Future Research

Through the work performed for this study, several areas were highlighted that would benefit from additional research or that become possible with the newly installed meters and SCADA system. These include sections of the current year of research that would be refined or recalculated with better data and others involve the development of new tools and techniques which can be used to provide better information regarding the built environment. These areas include: refined analytical techniques to determine the performance baseline for current campus and individual building energy consumption; improved projection techniques to estimate the potential energy consumption of individual buildings; integration of existing calculators and tools into a single unit that can easily or automatically accept inputs from the University collected metered data, and extension of the carbon footprint to additional University properties.

The most direct extension of the work done this year would be the more refined analysis of the metered data collected for steam, electricity, and chilled water at the building level. This rich source of data is just becoming available in significant amounts. It will be useful for a number of different aspects including the improvement of the inverse modelling techniques, the identification of buildings as targets for renovation, and the identification of buildings with performance issues compared to comparable buildings or considering their own past behaviors. With the recent purchase of new SCADA software for the collection and management of this information, this is an area that will need exploration and development so that the University can fully utilize the software's capabilities and expand upon them effectively.

The normalization of energy consumption at the building level to generate a validated baseline performance model is a critical tool for determining the impact of changes on the energy consumption of a building. Normalization techniques examine the historical consumption of energy and determine the relationship between these values and a set of independent variables which will influence consumption. Outdoor temperatures are the most intuitively linked to variations in building energy usage, but consumption can be affected by many other factors, from daylight hours to occupancy patterns and even school or building culture.

In order to improve these normalization techniques there are a number of approaches. One would be to refine and add to the analysis by considering additional variables until all of the important factors that influence energy consumption can be identified and included in the analysis the predictive power of the baseline generated. A second approach is to reduce the increments of time being examined to provide greater detail. Currently all of the independent and dependent variables are aggregated across each calendar month before being used in the regression analysis. Experience suggests that significant improvement in accuracy could be garnered if finer time scales were considered. This would be particularly useful in the university setting as variables such as occupancy rates vary greatly, both from month to month as well as within a given month. By reducing the time increments to daily aggregations, many of these variables will be much more closely tied to their actual impact on the level of consumption, rather than having this effect diluted through aggregation at the monthly level. Now that sufficient metered data is available for consumption, it should be quite feasible to generate values at the daily level for both consumption and the independent variables influencing this figure.

Another area needing development is the development of an integrated tool which would incorporate all of the functions of the existing set of tools used in these analyses, to serve as a repository of historical data and projections of future consumption, and to use as a platform for future analysis that could draw on the collected data. Such a program should be designed to work with the new SCATA system so that it can easily or automatically accept input regarding the metered consumption.

A final area of work that is outlined in the CAP 2.0 proposals by the sub-committee on the Built Environment is the extension of the University's carbon footprint to its additional properties such as the Hospital of the University of Pennsylvania, the New Bolton Center, the Morris Arboretum, and even client buildings in the University's real estate portfolio.

Appendix A- Summary of Top 100 Energy Consumers and ASHRAE 90.1 Targets

Table 12- Complete List of Annual Consumption for Top 100 Consumers, Actual vs. ASHRAE 90.1 Targets

			kWh			kBtu			kBtu/sqft		
		Sqft	Actual	ASHRAE 07	ASHRAE 10	Actual	ASHRAE 07	ASHRAE 10	Actual	ASHRAE 07	ASHRAE 10
103	Cyclotron	11,907	3,739,533			12,759,286			1,071.6		
520	Rosenthal	60,790	15,270,045	9,182,943	7,714,995	52,101,392	31,332,200	26,323,564	857.1	515.4	433.0
22	BRB2	421,531	80,392,339	33,283,997	41,450,103	274,298,661	113,564,999	141,427,753	650.7	269.4	335.5
630	Hill Pavilion	100,000	16,542,745	6,131,230	5,132,927	56,443,845	20,919,757	17,513,547	564.4	209.2	175.1
27	BRB1	225,627	35,543,815	17,324,406	12,284,280	121,275,496	59,110,872	41,913,964	537.5	262.0	185.8
600	Old Vet Quad	115,295	17,986,691	12,932,636	10,422,990	61,370,591	44,126,156	35,563,242	532.3	382.7	308.5
65	Chem 58	42,250	6,521,069	2,049,063	1,935,186	22,249,887	6,991,404	6,602,855	526.6	165.5	156.3
560	Sweeten Alumni	11,674	1,785,095	507,177	508,484	6,090,744	1,730,487	1,734,948	521.7	148.2	148.6
500	Richards	104,344	15,245,211	9,514,730	7,332,479	52,016,658	32,464,260	25,018,420	498.5	311.1	239.8
260	Johnson Pavilion	160,940	23,159,718	13,283,229	9,533,286	79,020,957	45,322,378	32,527,573	491.0	281.6	202.1
280	LRSM	95,150	13,662,434	5,894,119	5,419,383	46,616,223	20,110,733	18,490,934	489.9	211.4	194.3
295	Levy Dental	93,456	12,785,179	5,658,067	4,774,954	43,623,032	19,305,325	16,292,143	466.8	206.6	174.3
92	CRB	204,366	25,386,524	13,057,401	14,004,072	86,618,818	44,551,851	47,781,892	423.8	218.0	233.8
100	Colonial Penn Center	17,256	2,082,237	785,849	785,852	7,104,593	2,681,315	2,681,326	411.7	155.4	155.4
456	Skirkanich	61,182	7,074,015	3,766,774	2,872,129	24,136,538	12,852,232	9,799,706	394.5	210.1	160.2
80	Class of 1920	45,668	5,189,856	2,382,068	1,898,974	17,707,789	8,127,616	6,479,299	387.8	178.0	141.9
293	Levine	50,474	5,706,442	2,895,691	2,739,548	19,470,379	9,880,098	9,347,338	385.8	195.7	185.2
227	Vagelos	115,570	12,890,159	9,610,452	8,927,655	43,981,224	32,790,862	30,461,159	380.6	283.7	263.6
70	Chem 73	149,975	15,534,573	8,407,510	7,681,940	53,003,963	28,686,425	26,210,780	353.4	191.3	174.8
125	Edison Building	8,039	830,491	630,489	630,994	2,833,635	2,151,229	2,152,951	352.5	267.6	267.8
330	Stemmler	243,303	24,955,788	13,332,536	8,118,402	85,149,148	45,490,612	27,699,987	350.0	187.0	113.8
60	Chem Lab Cret Wing	22,645	2,289,698	1,028,170	959,889	7,812,450	3,508,116	3,275,143	345.0	154.9	144.6
241	Lynch	148,086	14,551,600	8,856,427	7,238,127	49,650,060	30,218,130	24,696,491	335.3	204.1	166.8
75	The Arch	32,567	3,188,549	1,155,602	1,031,671	10,879,329	3,942,913	3,520,062	334.1	121.1	108.1
525	Charles Addams	44,335	4,319,380	2,363,122	2,152,886	14,737,723	8,062,973	7,345,648	332.4	181.9	165.7
570	Towne	210,539	18,735,505	10,452,870	8,609,799	63,925,543	35,665,191	29,376,633	303.6	169.4	139.5
176	Pottruck	67,288	5,969,181	2,162,347	1,920,682	20,366,846	7,377,927	6,553,366	302.7	109.6	97.4
120	Duhring Wing	21,227	1,827,328	1,205,621	1,021,569	6,234,843	4,113,580	3,485,594	293.7	193.8	164.2
555	Stouffer Triangle	159,626	13,577,196	7,810,691	5,421,850	46,325,393	26,650,078	18,499,353	290.2	167.0	115.9
235	Hollenback Center	55,901	4,727,095	2,152,121	1,689,358	16,128,848	7,343,037	5,764,090	288.5	131.4	103.1
50	Caster	24,636	2,071,185	1,558,039	1,493,338	7,066,882	5,316,029	5,095,269	286.9	215.8	206.8
175	Gimbell Gymnasium	66,104	5,447,541	2,480,101	2,328,999	18,587,010	8,462,105	7,946,545	281.2	128.0	120.2
595	Ryan	149,531	12,196,811	8,153,234	6,690,482	41,615,519	27,818,834	22,827,926	278.3	186.0	152.7
550	Stiteler	45,966	3,717,927	2,045,092	1,774,163	12,685,565	6,977,854	6,053,445	276.0	151.8	131.7
155	Franklin	100,718	7,980,627	5,423,282	4,607,680	27,229,899	18,504,238	15,721,404	270.4	183.7	156.1
617	Huntsman	356,683	28,162,117	13,837,131	11,694,896	96,089,143	47,212,289	39,902,984	269.4	132.4	111.9
225	Hill	220,370	16,278,266	8,828,866	6,755,340	55,541,443	30,124,091	23,049,221	252.0	136.7	104.6
9855	Locust Walk 3615	13,489	975,633	562,375	557,893	3,328,860	1,918,823	1,903,532	246.8	142.3	141.1
300	Levy tennis Pavillion	119,675	8,103,325	4,060,596	3,627,888	27,648,545	13,854,753	12,378,355	231.0	115.8	103.4
220	Rodin House	311,354	21,003,964	12,760,211	12,181,487	71,665,525	43,537,839	41,563,235	230.2	139.8	133.5
340	Meyerson	98,016	6,600,198	5,361,696	4,952,749	22,519,874	18,294,107	16,898,780	229.8	186.6	172.4
415	Jaffe	13,069	875,763	838,175	767,504	2,988,102	2,859,855	2,618,724	228.6	218.8	200.4
210	Harrison House	309,982	20,667,369	12,576,734	11,854,220	70,517,063	42,911,817	40,446,597	227.5	138.4	130.5
205	Harnwell House	311,371	20,630,364	18,531,437	15,789,782	70,390,802	63,229,264	53,874,736	226.1	203.1	173.0
284	Lauder Fisher	24,779	1,607,860	1,163,154	1,046,777	5,486,020	3,968,681	3,571,605	221.4	160.2	144.1
285	Gittis Hall	38,818	2,443,704	1,522,915	1,339,326	8,337,918	5,196,186	4,569,779	214.8	133.9	117.7
590	Vance	103,047	6,445,566	6,017,614	5,884,242	21,992,272	20,532,098	20,077,033	213.4	199.3	194.8
215	Hayden	65,630	4,039,202	3,585,365	3,063,547	13,781,756	12,233,264	10,452,821	210.0	186.4	159.3
140	Evans	133,329	8,175,096	7,489,367	6,211,744	27,893,426	25,553,719	21,194,469	209.2	191.7	159.0
250	Hutchinson	134,811	7,510,675	4,352,288	3,956,675	25,626,423	14,850,008	13,500,173	190.1	110.2	100.1
130	GSE	48,175	2,651,464	2,233,246	1,951,862	9,046,797	7,619,835	6,659,754	187.8	158.2	138.2
325	McNeil	134,213	7,295,962	6,504,258	5,174,100	24,893,821	22,192,527	17,654,029	185.5	165.4	131.5
416	Walnut Street 3401	189,057	10,213,092	8,556,081	6,877,175	34,847,070	29,193,349	23,464,921	184.3	154.4	124.1
335	John Morgan	207,991	11,225,547	7,116,004	7,097,074	38,301,566	24,279,806	24,215,217	184.1	116.7	116.4
615	Dunning Coaches	15,429	830,997	2,115,298	1,635,622	2,835,361	7,217,395	5,580,744	183.8	467.8	361.7
180	Goddard Labs	43,985	2,334,627	3,085,337	3,048,310	7,965,747	10,527,171	10,400,835	181.1	239.3	236.5
190	Grad Towers B	211,325	10,924,871	11,337,607	9,501,394	37,275,660	38,683,914	32,418,756	176.4	183.1	153.4
450	Palestra	137,819	6,829,956	3,828,623	3,656,344	23,303,811	13,063,260	12,475,446	169.1	94.8	90.5
245	Houston	99,882	4,880,400	6,296,960	5,237,215	16,651,926	21,485,229	17,869,376	166.7	215.1	178.9
396	Locust Walk 3611	6,244	300,938	265,803	268,629	1,026,800	906,920	916,561	164.4	145.2	146.8
345	Moore	49,661	2,379,065	3,221,172	3,246,032	8,117,370	10,990,637	11,075,460	163.5	221.3	223.0
253	ICA	28,029	1,333,873	1,602,952	1,499,621	4,551,173	5,469,273	5,116,706	162.4	195.1	182.6
460	Carriage House	8,050	381,789	346,878	339,145	1,302,663	1,183,548	1,157,163	161.8	147.0	143.8
286	Tanenbaum	116,864	5,198,576	6,216,621	5,282,840	17,737,540	21,211,110	18,025,049	151.8	181.5	154.2
45	APPC	54,896	2,365,389			8,070,708			147.0		
510	DRL	228,821	9,751,985	10,761,668	8,891,291	33,273,774	36,718,811	30,337,085	145.4	160.5	132.6
160	Franklin Annex	40,234	1,700,089	3,662,530	2,781,572	5,800,705	12,496,554	9,490,725	144.2	310.6	235.9

			kWh			kBtu			kBtu/sqft		
		Sqft	Actual	ASHRAE 07	ASHRAE 10	Actual	ASHRAE 07	ASHRAE 10	Actual	ASHRAE 07	ASHRAE 10
605	Weightman	86,298	3,577,956	4,603,322	3,921,637	12,207,985	15,706,534	13,380,625	141.5	182.0	155.1
170	Fisher and Duhring	118,286	4,832,316	5,176,174	4,062,258	16,487,863	17,661,107	13,860,426	139.4	149.3	117.2
135	English House	68,212	2,768,190	6,115,600	6,115,091	9,445,065	20,866,428	20,864,691	138.5	305.9	305.9
110	Dietrich Grad Lib	145,001	5,646,646	6,655,881	5,170,403	19,266,355	22,709,867	17,641,416	132.9	156.6	121.7
310	Cohen	88,434	3,404,569	3,603,084	2,764,664	11,616,388	12,293,724	9,433,033	131.4	139.0	106.7
585	Van Pelt Res	73,602	2,818,973	5,098,229	3,329,329	9,618,336	17,395,156	11,359,671	130.7	236.3	154.3
90	Class of 1925	39,766	1,507,920	1,550,294	1,167,767	5,145,025	5,289,604	3,984,419	129.4	133.0	100.2
115	DuBoise House	88,401	3,347,981	3,830,171	2,698,195	11,423,311	13,068,542	9,206,241	129.2	147.8	104.1
173	Schattner	76,602	2,775,090	3,906,110	3,450,628	9,468,608	13,327,647	11,773,542	123.6	174.0	153.7
30	Blockley	173,168	6,259,578	8,011,977	6,785,562	21,357,681	27,336,866	23,152,338	123.3	157.9	133.7
385	Fagin	192,740	6,943,846			23,692,402			122.9		
255	Irvine	115,668	4,083,542	833,493	620,129	13,933,046	2,843,878	2,115,880	120.5	24.6	18.3
610	Steinberg Conference	157,951	5,397,110	8,586,829	5,942,068	18,414,939	29,298,259	20,274,338	116.6	185.5	128.4
365	Music	29,364	965,946	1,380,890	1,140,366	3,295,808	4,711,596	3,890,930	112.2	160.5	132.5
145	Fels	22,896	747,595	1,295,865	1,271,371	2,550,794	4,421,493	4,337,919	111.4	193.1	189.5
620	Williams	130,945	4,200,285	5,539,334	4,243,815	14,331,372	18,900,208	14,479,897	109.4	144.3	110.6
95	College Hall	117,163	3,671,911	2,725,978	2,153,463	12,528,559	9,301,038	7,347,616	106.9	79.4	62.7
535	Steinberg Dietrich	198,468	6,152,954	9,540,557	8,437,058	20,993,879	32,552,380	28,787,241	105.8	164.0	145.0
580	Van Pelt Lib	223,201	6,448,092	8,486,159	6,840,298	22,000,890	28,954,774	23,339,096	98.6	129.7	104.6
5	Anatomy Chemistry	125,648	3,500,551	7,440,561	5,197,253	11,943,879	25,387,194	17,733,026	95.1	202.1	141.1
85	Class of 1923 Ice Rink	126,146	3,499,519	2,474,652	2,230,463	11,940,359	8,443,512	7,610,341	94.7	66.9	60.3
395	Locust Walk 3609	6,258	166,902	283,905	285,049	569,470	968,683	972,586	91.0	154.8	155.4
15	Annenberg School	92,900	2,403,137	4,864,148	3,933,570	8,199,503	16,596,473	13,421,340	88.3	178.6	144.5
380	Grad Towers A	279,313	6,993,998	8,310,475	7,712,111	23,863,522	28,355,341	26,313,722	85.4	101.5	94.2
575	Museum	267,965	6,695,956	10,364,582	8,788,482	22,846,601	35,363,954	29,986,301	85.3	132.0	111.9
475	Psychology	59,248	1,389,682	2,996,317	2,444,639	4,741,595	10,223,432	8,341,109	80.0	172.6	140.8
290	Leidy Labs	66,636	1,507,866	3,934,782	2,840,837	5,144,837	13,425,476	9,692,936	77.2	201.5	145.5
10	Annenberg Center	157,631	2,606,935	4,529,053	3,742,071	8,894,861	15,453,130	12,767,945	56.4	98.0	81.0
270	Kings Court	64,166	1,015,031	2,662,761	2,521,096	3,463,286	9,085,340	8,601,980	54.0	141.6	134.1
305	Silverman	130,397	1,905,741	3,769,413	3,271,872	6,502,389	12,861,238	11,163,627	49.9	98.6	85.6
490	Quadrangle	520,877	5,791,543	21,706,217	17,532,335	19,760,745	74,061,612	59,820,326	37.9	142.2	114.8
320	Mayer	72,049	742,168	3,560,552	3,072,516	2,532,277	12,148,603	10,483,423	35.1	168.6	145.5
650	36th Street S 133	56,959	584,889	2,216,093	1,709,206	1,995,641	7,561,309	5,831,811	35.0	132.7	102.4

The above list represents the baseline and targets for annual consumption of the top 100 energy consuming building on the main University of Pennsylvania campus. While the University of Pennsylvania utilizes more than 200 facilities in the Philadelphia area, and many hundreds more worldwide, this list was selected from those buildings which are located on the main campus and which are operated and controlled by Facilities and Real Estate Services. This list comprised 180 buildings, however as the plans only considered renovations to the top 20% and 30% of energy consumers and since many of the smaller buildings were not metered for, or not connected to, steam and chilled water, it was not necessary to examine the entire list. Sufficient data was available for the top 100 and so this was selected as the number to analyze.

The actual consumption is based primarily on metered data; however estimates from simulations were used in some cases where insufficient data was available from the meters. The ASHRAE targets were al generated using the EnergyPro simulation tool. Selections for the top 20% and 30% of the buildings for renovations were made by determine which facilities showed the greatest potential for improvement between the Actual and ASHRAE Target values.

Appendix B- Linear Regression to Create Baselines for Consumption

This appendix will serve to discuss the means that was used to calculate the accuracy of the baselines compared to the actual consumption at the campus level. Actual consumption was drawn from the meters which measure and report consumption at the campus level. This information was aggregated at a monthly level and separated into electricity, steam, and chilled water. Two types of baselines were then generated. Several were based on linear regression using one or multiple variables to determine a correlation with consumption based on a linear relationship with each variable. A final baseline was created where the consumption for each month of the baseline was equal to the average of the consumption for that month from the historical data.

Table 13- Example of Average Absolute Monthly Deviation to Gauge Accuracy of Baselines

% Difference Baseline, All vs Actual Consumption							
	2007	2008	2009	2010	2011	2012	2013
Jan	-5.28%	-0.96%	-4.94%	6.20%	-0.90%	2.04%	5.05%
Feb	-1.13%	0.80%	4.96%	2.27%	-18.53%	4.43%	13.51%
Mar	-5.25%	-3.47%	1.49%	-3.84%	2.16%	3.51%	6.55%
Apr	-3.20%	3.70%	2.41%	-0.84%	-4.35%	-1.01%	3.95%
May	-0.20%	8.26%	-1.40%	-5.46%	-1.40%	2.11%	-0.86%
Jun	0.75%	-12.25%	3.13%	-2.34%	-0.60%	6.77%	7.34%
Jul	-2.40%	4.71%	10.03%	5.16%	-4.42%	-10.26%	
Aug	-4.93%	5.06%	-2.62%	-1.76%	-0.12%	5.24%	
Sep	-3.26%	-0.19%	-2.97%	-6.04%	-0.33%	15.44%	
Oct	-14.01%	3.12%	-0.20%	34.30%	-0.31%	-10.52%	
Nov	-0.32%	-1.19%	1.56%	2.48%	-5.23%	3.18%	
Dec	4.18%	4.30%	-4.74%	-6.86%	0.76%	3.57%	

Absolute Value % Difference Baseline, All vs Actual Consumption							
	2007	2008	2009	2010	2011	2012	2013
Jan	5.28%	0.96%	4.94%	6.20%	0.90%	2.04%	5.05%
Feb	1.13%	0.80%	4.96%	2.27%	18.53%	4.43%	13.51%
Mar	5.25%	3.47%	1.49%	3.84%	2.16%	3.51%	6.55%
Apr	3.20%	3.70%	2.41%	0.84%	4.35%	1.01%	3.95%
May	0.20%	8.26%	1.40%	5.46%	1.40%	2.11%	0.86%
Jun	0.75%	12.25%	3.13%	2.34%	0.60%	6.77%	7.34%
Jul	2.40%	4.71%	10.03%	5.16%	4.42%	10.26%	
Aug	4.93%	5.06%	2.62%	1.76%	0.12%	5.24%	
Sep	3.26%	0.19%	2.97%	6.04%	0.33%	15.44%	
Oct	14.01%	3.12%	0.20%	34.30%	0.31%	10.52%	
Nov	0.32%	1.19%	1.56%	2.48%	5.23%	3.18%	
Dec	4.18%	4.30%	4.74%	6.86%	0.76%	3.57%	

To determine which of these methods was most accurate it was necessary to compare them to the historical data on a month by month basis to see how much of a deviation each baseline showed in any given month from the actual historical data. While the baseline generated from the average could not respond to any specific circumstances in a given month, it had the advantage of including every factor that typically would affect the consumption in a month while those generated via regression could only consider those factors which were included in the calculation and which factored in several assumptions. A measure was created to gauge the overall accuracy of each baseline by looking at the deviation from the actual consumption for each month, taking the absolute value of that deviation, and averaging this across all the months. An example of this can be seen in Table 13. Figure 19, below, shows these monthly deviations displayed by year, showing the spread and the average in each year, comparing the baselines generated from the average values as well as regression considering CDD, HDD, sun hours, and occupancy.

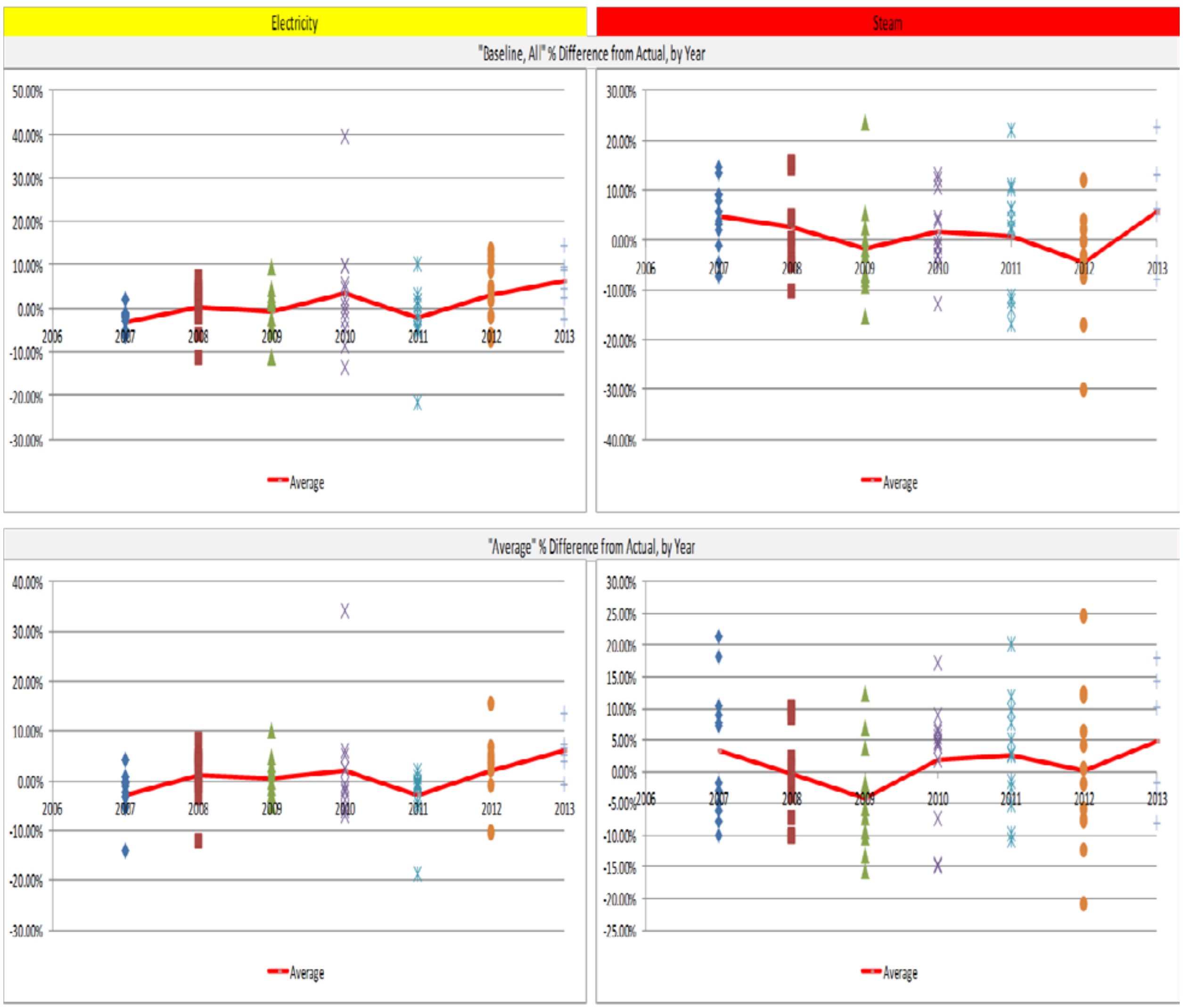


Figure 19- Monthly Deviations for Electricity and Steam, Regression with All Variables vs. Average by Month

Appendix C- Individual Building Worksheet Manual

The Individual Building Worksheet (IBW) was created to collect the historical utility consumption from the buildings included in the University of Pennsylvania carbon footprint and to make detailed projections regarding the future consumption of each building under a variety of different scenarios. In previous projections of the University of Pennsylvania's carbon footprint, the contributions from the university properties were treated as an aggregated whole, with the effects of future policies being estimated through a single reduction factor applied across all properties. This means of estimating the effect of emissions reductions due to a program of building efficiency upgrades provides little insight into how these goals are actually to be achieved, simply providing an expected reduction in each given year. By only looking at the aggregated whole it is difficult to form a plan to achieve the desired reductions through specific retrofits to university buildings.

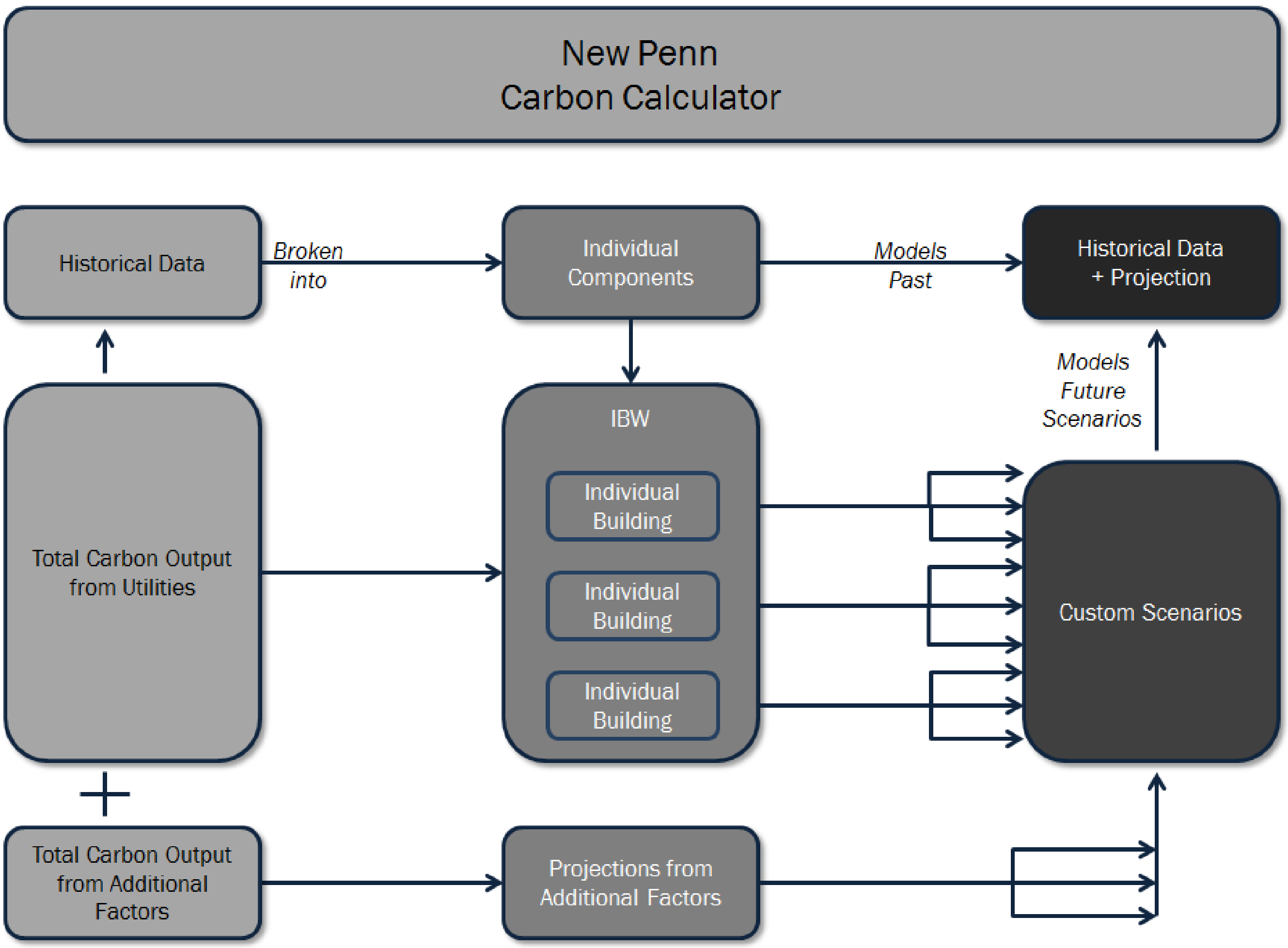


Figure 20- Interaction of Carbon Calculator and Individual Building Worksheet

The IBW exists as an Excel spreadsheet with a worksheet detailing the past and projected future utility consumption for each building and a single worksheet which serves to sum the consumption from each building. This approach allows individual projections to be made for each building, separately from the others, as was done in the Century Bond Scenario described in Section 4.3. Since renovation of campus properties occurs through major upgrades building by building rather than by gradual changes across the entire campus, this method of projecting future utility consumption from university properties represents a far more accurate means of estimating the potential for future carbon emissions reductions through a specific schedule of building efficiency renovations.

The IBW was designed to work in conjunction with the pre-existing Penn Carbon Calculator to ensure continuity between the historical data and the transition to projections. Campus buildings primarily use two or three energy carriers to supply their needs. Steam provided from Veolia supplies most of the heat to campus buildings, while a chilled water loop supplies cooling to many of the buildings. Electricity is consumed by plug loads, compression chilling for those not supplied by the chilled water loop, and a variety of other building systems' needs. Since nearly every building is metered for electrical consumption, determining the portion of the university electrical bill attributable to each specific building is simple. A large minority of the buildings on campus are also metered for their chilled water and steam consumption. These meters are relatively new but have been able to supply a reliable year of data for many of the buildings. Since buildings are the sole consumers of steam and chilled water on campus, this known level of consumption may be subtracted from the university total consumption of steam and chilled water and the remainder can be divided up amongst the remaining, un-metered buildings. The division of the remainder is weighted proportionally according to estimates from BPAT+ models which were previously created of each university building. A few buildings also consume natural gas and fuel oil, and these figures are supplied from historical utility bills.

Once the metered data and estimates from the BPAT+ models have been combined to create a snapshot of the annual energy consumption of each building on campus, it is possible to make a projection for each individual building regarding their consumption of electricity, steam, chilled water, natural gas, and fuel oil out to the year 2042. These estimates can be based on specific planned or possible retrofits, the effects of which may be accurately modeled. When a projection scenario has been made for each building regarding the planned upgrades that it will undergo, those projections are combined to create a combined picture of the utility consumption of the university's built environment. The projections all begin in the last year where campus level energy consumption data is available.

In the IBW each building's worksheet is capable of storing up to six possible scenarios for each type of energy carrier that might be consumed. Each scenario begins with the last year of estimated or metered data, generally the most recent year, and makes an assumption for each subsequent year regarding whether or not the building will change its consumption of each energy carrier. This change, if there is one, typically refers to the consumption from the previous year and either alters it by a percent or by an absolute value, depending on the event being simulated. These assumptions are made for each year out to 2042 to create a projection of the expected energy consumption for each building. The user selects a scenario by entering a 1 in the space to the left of where the desired projection begins. This automatically causes the worksheet to select that scenario as the projected utility consumption for that building. Each utility type may be controlled separately with a custom scenario.

	A	B	C	D	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1														
2		Facility Name	ID #	Type	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
3		Anatomy Chemistry	5	Electricity (kWh)	1823305.41	2059711.4	2071479.68	2025363.63	2025363.63	2025363.63	1179125	1179125	1179125	1179125
4				Steam (MLB)	0	0	2947.009508	2947.009508	2947.009508	2947.009508	1716	1716	1716	1716
5				Chilled Water (kWh)	0	0	40704	40704	40704	40704	27190	27190	27190	27190
6				Natural Gas (ccf)	0	0	0	0	0	0	0	0	0	0
7				Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0
8														
9		Spaces												
10		GSF		125655										
11		# PCs		358										
12		Operating hrs/ wk		56										
13		# Main Shift Workers		738.5										
14														
15		Electricity		Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
16		Historical Data		July	195,658	162,870	196,366	154,008						
17				August	166,911	141,148	153,042	204,092						
18				September	162,484	153,334	178,841	166,120						
19				October	184,340	212,452	210,620	170,705						
20				November	146,570	127,824	106,743	150,716						
21				December	129,119	183,238	147,755	176,663						
22				January	187,962	201,858	187,254	204,018						
23				February	151,701	140,958	171,857	144,492						
24				March	140,494	200,469	177,471	149,571						
25				April	71,800	181,647	160,953	129,369						
26				May	121,848	165,233	200,928	197,347						
27				June	164,419	188,683	179,650	178,263						
28		Historic + Scenarios		TOTAL	1823305	2059711	2071480	2025364	2025364	2025364	1179125	1179125	1179125	1179125
29		Scenarios (Select One)	0	BAU	0	0	0	0	2025363.63	2025363.63	2025363.63	1179125	1179125	1179125
30			0	227: 2013/2014 Lightin	0	0	0	0	2025363.63	2006926	2025363.63	1179125	1179125	1179125
31			0	E*75 in 2015	0	0	0	0	2025363.63	2025363.63	1572167	1179125	1179125	1179125
32			1	E*90 in 2015	0	0	0	0	2025363.63	2025363.63	1179125	1179125	1179125	1179125
33			0		0	0	0	0	2025363.63	2025363.63	2025363.63	1179125	1179125	1179125
34			0		0	0	0	0	2025363.63	2025363.63	2025363.63	1179125	1179125	1179125
35														
36														

Summation | Sample A | AnatomyChemistry_5 | AnnenbergCenter_10 | AnnenbergSchl_15 | BRB1-StellarChance_21 | BiomedicalResearchBuilding2_22

Figure 21- Screenshot showing details of a building sheet in the IBW

It is assumed that the Individual Building Worksheet will be incomplete; many buildings are not metered and good estimates of their current usage difficult to make. In an instance where good historical or modeled energy consumption data is not available, no estimate is made regarding the buildings energy consumption. Additionally, line losses cause some electricity, steam, and chilled water to be lost before reaching a building. This means that the sum of the energy consumption of individual campus buildings, due to missing data, will not always equal the total aggregated university consumption as reported through billing. While the growth or decline of the portions of utility consumption attributed to each building can be accounted for in the scenarios created for those buildings, the difference between the sum of the individual buildings and the campus level aggregated utility consumption must be accounted for. Because all the projections begin in the last year where campus level historical utility data is available, their sum may be compared against the known total for the university and the difference determined. Just as each individual building may then be projected out from that base year, the amount of the difference may also be projected, with growth or decline attributed to it in each year of a projection based on the assumptions of the scenario. By adding the yearly projected difference to the yearly projected sum of the buildings energy consumption, a seamless projection continuing the historical campus level consumption of electricity, steam, chilled water, natural gas, and fuel oil is not only possible, but mathematically ensured.

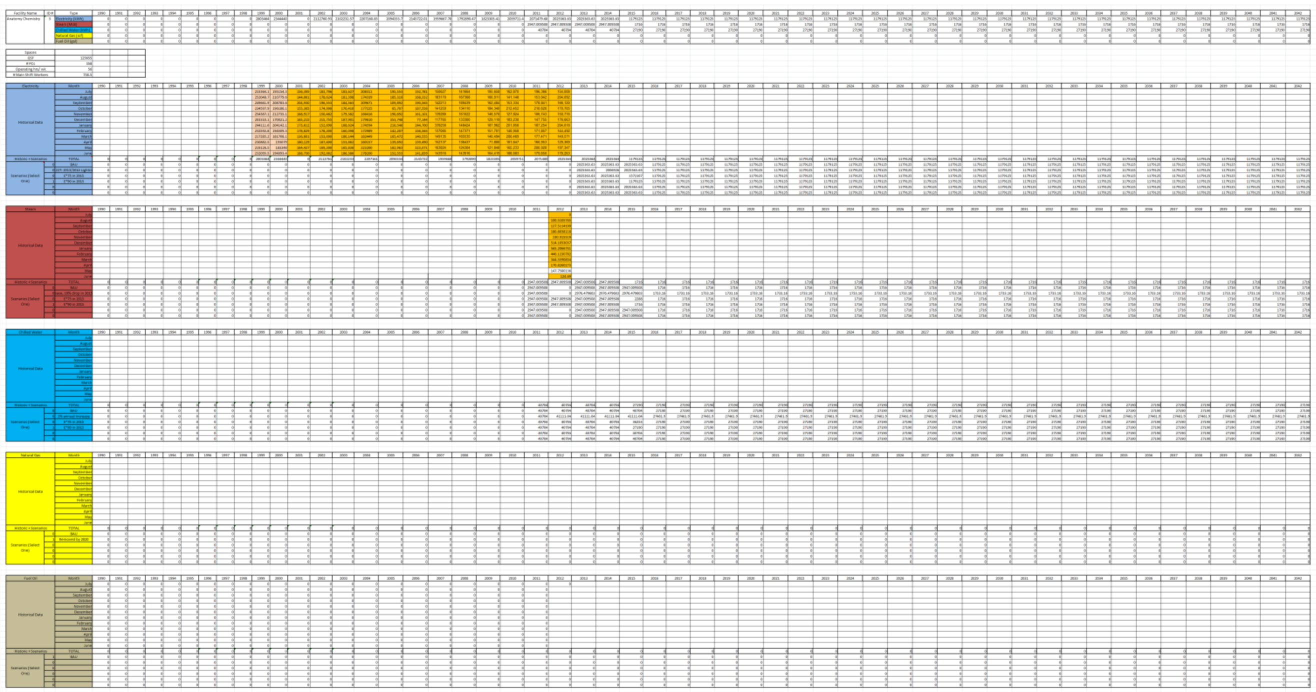


Figure 22- Screenshot showing fully expanded view of a building sheet in the IBW

9												
10	Campus Total from Billing	Total Consumption	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
11		Electricity (kWh)	334,695,863	333,439,214	318,979,612	326,146,533	327,352,479					
12	(The total utility use for	Steam (MLB)	1,068,585	1,086,843	1,159,152	1,147,592	1,137,900					
13	the entire university, not	Chilled Water (kWh)										
14	submetered by building)	Natural Gas (ccf)	207,520	229,855	216,848	233,288	164,451					
15		Fuel Oil (gal)										
16												
17	Sum of the Individual	Total Consumption	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
18	Buildings	Electricity (kWh)	243,745,278	240,481,134	246,062,083	239,400,203	243,866,321	240,327,739	240,327,739	240,327,739	230,202,175	224,277,645
19		Steam (MLB)	0	0	0	0	716,006	716,005	716,005	716,005	705,372	696,070
20	(Sum of the entries for	Chilled Water (kWh)	0	0	0	0	82,451,255	86,961,203	86,961,203	86,961,203	86,895,830	86,610,593
21	each building listed	Natural Gas (ccf)	0	0	0	0	0	0	0	0	0	0
22	below)	Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0
23												
24	Difference	Total Consumption	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
25		Electricity (kWh)	90,950,586	92,958,080	72,917,529	86,746,331	1,034,903	0	0	0	0	0
26	(Amount from campus total	Steam (MLB)	1,068,585	1,086,843	1,159,152	1,147,592	421,894	0	0	0	0	0
27	not attributed to an	Chilled Water (kWh)	0	0	0	0	0	0	0	0	0	0
28	individual building)	Natural Gas (ccf)	207,520	229,855	216,848	233,288	164,451	0	0	0	0	0
29		Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0
30												
31	Difference	Total Consumption	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
32	(Projection)	Electricity (kWh)	90,950,586	92,958,080	72,917,529	86,746,331	1,034,903	1,034,903	1,034,903	1,034,903	1,034,903	1,034,903
33		Steam (MLB)	1,068,585	1,086,843	1,159,152	1,147,592	421,894	421,894	421,894	421,894	421,894	421,894
34	(Amount from campus total	Chilled Water (kWh)										
35	not attributed to an	Natural Gas (ccf)	207,520	229,855	216,848	233,288	164,451	164,451	164,451	164,451	164,451	164,451
36	individual building)	Fuel Oil (gal)	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996
37												
38		Total Consumption	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
39		Electricity (kWh)	334,695,863	333,439,214	318,979,612	326,146,533	327,352,479	328,323,845	328,323,845	328,323,845	318,132,908	311,923,141
40		Steam (MLB)	1,068,585	1,086,843	1,159,152	1,147,592	1,137,900	1,137,899	1,137,899	1,137,899	1,127,265	1,117,963
41	Projected Footprint	Chilled Water (kWh)	0	0	0	0	0	0	0	0	0	0
42		Natural Gas (ccf)	207,520	229,855	216,848	233,288	164,451	164,451	164,451	164,451	164,451	164,451
43		Fuel Oil (gal)	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996	52,996
44												

Summation / Sample A / AnatomyChemistry_5 / AnnenbergCenter_10 / AnnenbergSchl_15 / BRB1-StellarChance_21 / BiomedicalResearchBuilding2_22

Figure 23- Screenshot showing details of the Summation Sheet in the IBW

The IBW integrates with the Carbon Calculator by replacing a single worksheet in the original calculator with three sheets in the new version. The three new sheets replace the original Raw Usage worksheet, which was the original entry point for the campus wide utility consumption data in their original units. The three new sheets are labeled the Historical Usage, Projected Usage, and Historical + Projected Usage. The Historical Usage worksheet is essentially the same as the original Raw Usage worksheet, containing all of the known, historical, campus wide utility consumption data. The primary difference is that there are no longer any projections made on this page beyond the known data.

The Projected Usage worksheet replicates the format and layout of the Historical Usage worksheet, except it has an additional section where two tables from the Summation worksheet of the IBW are to be copied and pasted. The copied data is then automatically converted into the same format as is found in the Carbon Calculator. The yearly utility consumption on the Historical Usage and the Projected Usage worksheets should be exactly the same for each year where historical data is found. The Historical + Projected Usage worksheet once again has the same format and layout as the original Raw Usage worksheet. Its annual consumption values are generated by looking first for data in the correlating cell in the Historical Usage worksheet. Only if there is no historical data available will the worksheet then look for a value in the correlating cell in the Projected Usage worksheet.

Projected Usage

	Chilled Water Use	Steam Use	Electric Use	Non-Steam Natural Gas Use	Fuel Oil 2 Use
	Ton-days	MLB	kWh	Ccf	Gallons
FY90	-	-	-	-	-
FY91	-	-	-	-	-
FY92	-	-	-	-	-
FY93	-	-	-	-	-
FY94	-	-	-	-	-
FY95	-	-	-	-	-
FY96	-	-	-	-	-
FY97	-	-	-	-	-
FY98	-	-	-	-	-
FY99	-	-	187,776,560	-	-
FY00	-	-	187,403,956	-	-
FY01	-	1,031,483	285,914,252	-	-
FY02	-	903,745	282,305,516	-	-
FY03	-	1,118,313	293,510,958	132,848	37,352
FY04	-	1,087,908	312,022,063	255,629	29,925
FY05	-	1,094,320	312,669,637	254,085	45,131
FY06	-	1,029,990	327,877,907	217,005	52,996
FY07	-	1,068,585	334,695,863	207,520	52,996
FY08	-	1,086,843	333,439,214	229,855	52,996
FY09	-	1,159,152	318,979,612	216,848	52,996
FY10	-	1,147,592	326,146,533	233,288	52,996
FY11	82,451,255	1,137,900	244,901,224	164,451	52,996
FY12	86,961,203	1,137,899	241,362,642	164,451	52,996
FY13	87,248,175	1,141,654	242,159,139	164,451	53,171
FY14	87,536,094	1,145,422	242,958,264	164,451	53,346
FY15	87,759,590	1,138,568	233,634,462	164,451	53,522
FY16	87,763,960	1,133,023	228,480,926	164,451	53,699
FY17	85,509,937	1,124,569	224,823,613	164,451	53,876
FY18	79,215,077	1,103,489	218,167,810	164,451	54,054
FY19	79,093,271	1,067,514	203,184,193	164,451	54,232
FY20	78,045,197	1,059,066	199,705,895	164,451	54,411
FY21	77,042,831	1,054,149	197,437,190	164,451	54,591
FY22	75,601,661	1,039,157	193,820,650	164,451	54,771
FY23	74,154,908	1,027,517	189,921,822	164,451	54,952
FY24	64,535,414	997,679	182,422,680	164,451	55,133
FY25	64,329,485	995,199	181,253,865	164,451	55,315
FY26	63,918,994	985,598	175,112,454	164,451	55,498
FY27	63,782,198	965,682	170,385,017	164,451	55,681
FY28	63,445,248	959,755	169,012,822	164,451	55,865
FY29	63,279,723	951,171	162,923,842	164,451	56,049
FY30	57,204,109	945,757	159,383,506	164,451	56,234
FY31	57,240,665	942,385	156,410,072	164,451	56,419
FY32	55,433,772	925,875	151,394,001	164,451	56,606
FY33	55,179,762	926,753	151,032,624	164,451	56,792
FY34	52,383,889	922,739	147,191,782	164,451	56,980

Sum of the Individual Buildings (Sum of the entries for each building listed below)	Total Consumption	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	Electricity (kWh)	0	0	0	0	0	0	0	0	0	187,776,560	187,403,956	156,146,224
	Steam (MLB)	0	0	0	0	0	0	0	0	0	0	0	0
	Chilled Water (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
	Natural Gas (ccf)	0	0	0	0	0	0	0	0	0	0	0	0
	Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0	0	0

Difference (Amount from campus total not attributed to an individual building)	Total Consumption	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	Electricity (kWh)	0	0	0	0	0	0	0	0	0	0	0	129,768,028
	Steam (MLB)	0	0	0	0	0	0	0	0	0	0	0	1,031,483
	Chilled Water (kWh)												
	Natural Gas (ccf)	0	0	0	0	0	0	0	0	0	0	0	0
	Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0	0	0

Campus and Intensity Growth	Total Consumption	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	Electricity (kWh)												
	Steam (MLB)												
	Chilled Water (kWh)												
	Natural Gas (ccf)												
	Fuel Oil (gal)												

Sum Of Projected Utility Consumption	Total Consumption	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	Electricity (kWh)	0	0	0	0	0	0	0	0	0	187,776,560	187,403,956	285,914,252
	Steam (MLB)	0	0	0	0	0	0	0	0	0	0	0	1,031,483
	Chilled Water (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
	Natural Gas (ccf)	0	0	0	0	0	0	0	0	0	0	0	0
	Fuel Oil (gal)	0	0	0	0	0	0	0	0	0	0	0	0

Intro | AlexSummary | Summary | Historical+Projected Usage | Historical Usage | Projected Utility Usage | Emissions | Historic Raw Usage | Fleet | Agricultu

Figure 24- Screenshot showing Projected Usage sheet in Carbon Calculator

The Carbon Calculator now looks to the Historical + Projected Usage worksheet as though it were the original Raw Usage worksheet, and uses the information found there throughout the remainder of the calculations concerning the future emissions from the University's consumption of electricity, steam, chilled water, natural gas, and fuel oil. This seamlessly integrates the projected utility consumption from the Individual Building Worksheet into the original Carbon Calculator. By doing this the output from Individual Building Worksheet replaces the simple formula based growth or reduction patterns based on a consistent change from year to year to the aggregated campus utility consumption that were the only mechanism for scenario creation with just the original model. This tool adds flexibility, accuracy, and increased validity to the projections that may be made using the Carbon Calculator. This will allow the creation of scenarios that are based on specific actions, allowing precise estimates of the net environmental and financial impact of each possible course of action. This will allow for a smarter use of resources and increase the likelihood of setting and meeting realistic goals for future emissions reductions.

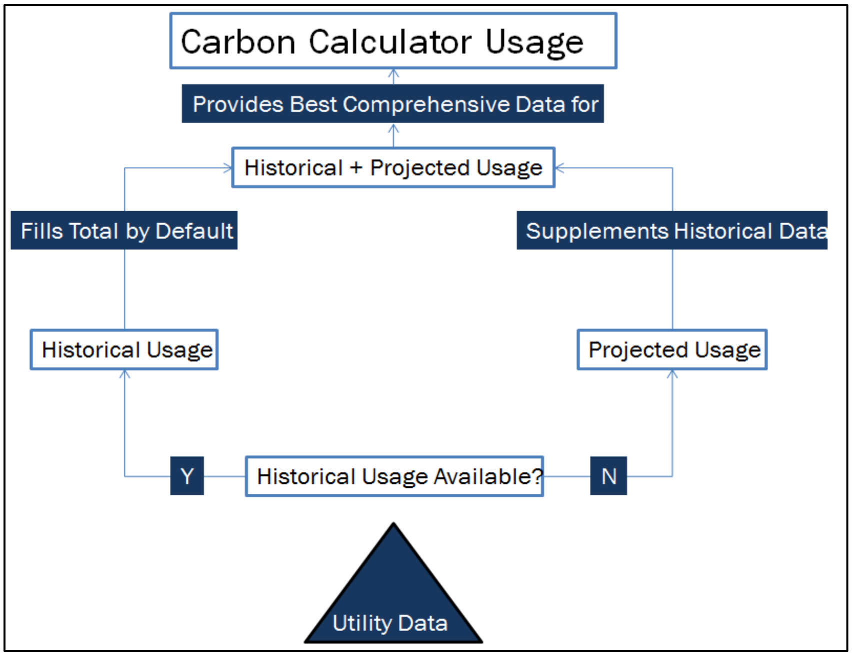


Figure 25- Decision tree to determine whether historical or projected data will be called by the Carbon Calculator

Appendix D- The UPenn Carbon Financial Calculator Manual

The Penn Financial Calculator was developed to provide an economic analysis of the scenarios that were being projected using the energy and carbon focused tool already in use. While the previous tools could be used to estimate the potential for a given scenario to reduce energy consumption and carbon dioxide production, this information lacked the financial component that would inform the decision makers about the economic feasibility and relative value of each scenario. This allows planners to choose a plan for achieving their carbon reduction targets while minimizing the expenses associated with such a shift. Further details on the operation of the Penn Carbon Financial Calculator can be found in Appendix A.

The primary output of the Penn Financial Calculator is the Net Present Value of each scenario being considered, including the net present value of a baseline scenario against which the others are compared. In each scenario the anticipated costs and energy consumption reductions associated with a set of planned building renovations or operational changes are determined. For each of the scenarios considered, the costs were calculated as the anticipated costs of any renovations in addition to the cost of adding new square footage through the construction of new buildings. The savings were calculated by determining the value of the avoided consumption of electricity and steam and the avoided emission of carbon dioxide. Each of these factors is valued at the rate paid by the University for utilities and carbon RECs. The costs and savings from reduced energy consumption are summed for each year of the 30 year projection and the result discounted to convert the nominal cost that would be paid at that date into its equivalent value in present day dollars. The discounted sum of costs and savings for each year of the projection are combined to calculate the net present value of the scenario. This can be represented by the following:

$$NPVscen = \sum_{n=1}^{30}(Elec\$_n * [ElecBase_n - ElecScen_n] + Steam\$_n * [SteamBase_n - SteamScen_n] + Carbon\$_n * [CarbonBase_n - CarbonScen_n] - [ScenarioCost_n - BaselineCost_n]) * (1 - DiscRate_n)^{(n-1)}$$

Elec$, Steam$, and Carbon$: The rate the university pays for electricity, steam, and carbon RECs for a specific year. Expressed using current dollars in $/kWh, $/MLB, and $/MTCDE, respectively.

ElecBase, SteamBase, CarbonBase: The total amount of electrical consumption, steam consumption and carbon production for a specific year in the baseline. Expressed in kWh, MLB, and MTCDE, respectively.

ElecScen, SteamScen, CarbonScen: The total amount of electrical consumption, steam consumption and carbon production for a specific year in the scenario being compared to the baseline. Expressed in kWh, MLB, and MTCDE, respectively.

ScenarioCost, Baseline Cost: The sum of the costs for renovations, standard building maintenance, and new construction for a specific year for the scenario being evaluated and the baseline, respectively. Expressed in current dollars.

DiscRate: The discount rate used to reduce the present value of future costs and savings based on anticipated rates of return and inflation. This is an index that is calculated at the national level for a specific currency, in this case U.S. dollars. While the discount rate can be individually set for each year, this variable typically is kept constant over the course of the projection and from scenario to scenario.

n: This variable refers to the year of the projection. The above equation is repeated for each integer of n from 1 to 30, with each variable using the data drawn from the nth year of the projection.

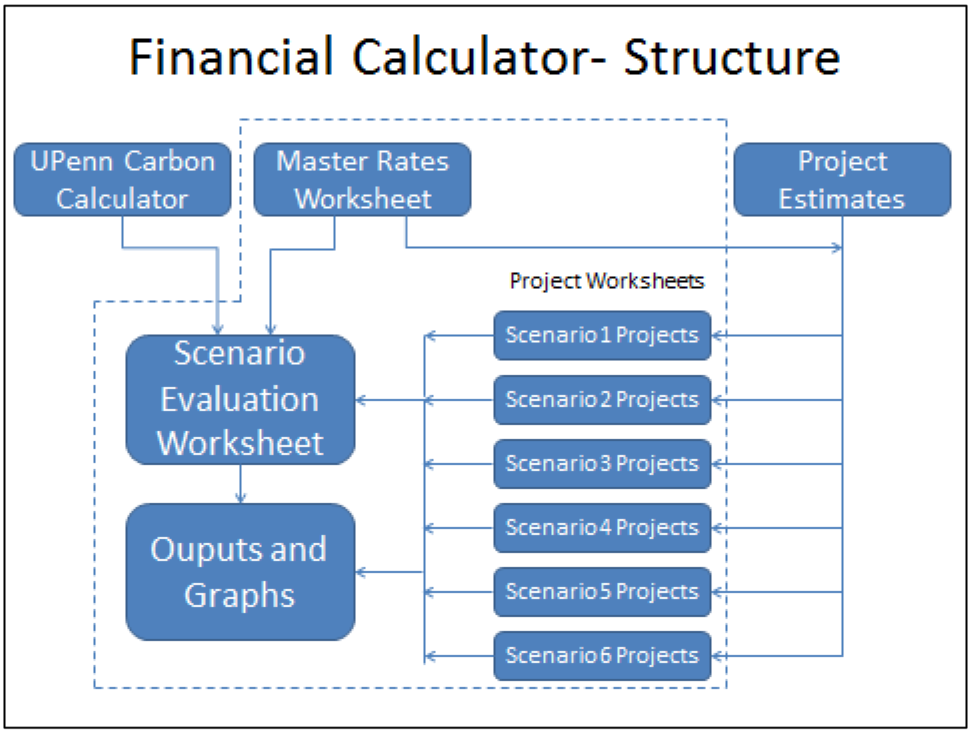


Figure 26- Flowchart of information for Financial Calculator

The calculator was constructed to work with the existing Penn Carbon Calculator by making it simple to copy and paste the results of the Carbon Calculator into the Penn Carbon Financial Calculator to easily determine the difference in energy consumption and carbon emissions of any scenario modeled. In addition to the energy and carbon information provided by the Penn Carbon Calculator, the Penn Carbon Financial Calculator also requires estimates of the costs of each scenario. The simplest of these to determine is the baseline scenario, which can be drawn from the historical costs associated with the maintenance and renovation of the campus buildings, but for the other scenarios the incremental cost of the additional efforts must be determined and added to the baseline costs.

When designing the Penn Carbon Financial Calculator a conscious decision was made to focus on three specific factors to compare the carbon and energy differences between the scenarios and the baseline. In addition to considering the overall carbon avoided and the associated value, the calculator also considers the value of the electricity and steam consumption which is avoided between the scenario and the baseline. However, steam and electricity do not account for all of the carbon producing sectors that contribute to the overall footprint and which may vary from one scenario to the next.

Differences in these other carbon producing sectors (such as natural gas consumption, commuting faculty members, air travel, etc.) could all potentially contribute to incremental differences in the economic costs associated with each scenario, such as through the avoided consumption of natural gas or through fewer air miles travelled, but the incremental difference between them is not considered in the economic evaluation of the scenario. There are several reasons that the focus of the economic analysis is on steam, electricity, and carbon. This first is that more than 85% of the emissions from the campus originate from the built environment, where electrical and steam consumption account for the vast majority of the carbon produced. Because of this, both the cost and the carbon associated with each scenario are primarily dependent on the use of electricity and steam by buildings.

In addition to accounting for the majority of the carbon production on campus, steam and electrical consumption by buildings also represents the primary area that can be easily affected by Facilities and Real Estate Services. The next largest contributors of carbon dioxide are air travel and commuting, which FRES has no ability to affect. While natural gas, solid waste, fuel oil, and fleet operations all contribute to the carbon footprint and to the expenses of a scenario, these additions are negligible comparatively. Since steam and electrical consumption represent the majority of the carbon production and expense associated with each scenario, and because they represent the areas where FRES can most easily bring about a change, these two types of consumption were used to represent the savings from a scenario due to reduced consumption. All other factors are kept constant between the scenarios or have relatively minor effects which are then captured in the incremental difference between the overall carbon production of the scenario compared to the baseline.

For some scenarios, determining the incremental cost is a simple task, especially for those which are based on specific planned renovations the costs of which can be estimated by the contractor. But as the scenarios reach further, in both extent and into the future, the incremental costs become more difficult to estimate. Scenarios which involve changes to a large portion of the buildings are the most difficult to estimate for two reasons. Firstly the amount of modeling and calculation that needs to be done to determine the costs and effects of renovation to any large building is extensive, and generating this level of information for a large number of buildings can be extremely time consuming and expensive.

Secondly, since there is a finite rate at which buildings can be renovated for expense and logistical reasons, any scenario which is based on making changes to a large number of buildings must create a schedule for those changes which extends through the full timeline of the projection. As the date of renovation is pushed further back, it becomes proportionally more difficult to estimate the costs and effects of the project. While providing extremely detailed information will reduce uncertainty, the returns for doing so diminish as the costs rise. Therefore, these scenarios are best used to provide guides for what levels of reduction are possible at the campus levels given long term goals and efforts but provide less accuracy at the building level, while more specific scenarios provide more accurate short term results but become burdensome to generate over a longer time scale.

This section describes the practical use and application of the Penn Carbon Financial Calculator, focusing on entering information into the calculator from external sources and identifying the relevant outputs.

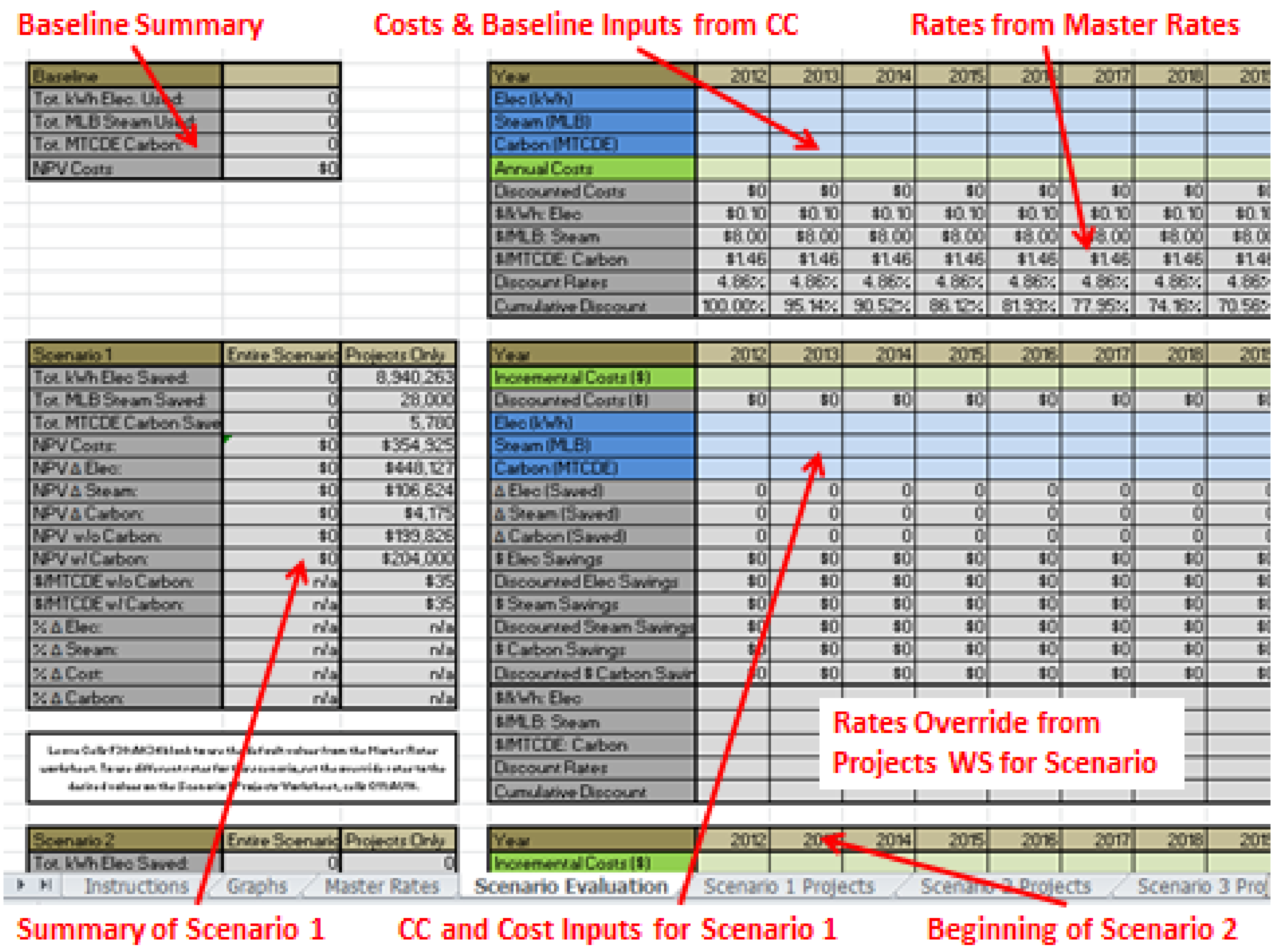


Figure 27- Layout of Penn Carbon Financial Calculator, Scenario Evaluation Tab

Figure 27, above, shows the Scenario Evaluation tab. This tab serves as the primary repository of information regarding campus level consumption of energy and emissions of carbon dioxide for each scenario and performs the calculations that compare each scenario to the baseline to determine the net present value of each. The scenarios are stacked vertically, with each scenario having a small table on the left which aggregates the effects from the entire projection and a larger table which contains the analysis for each year comparing the energy consumption, cost, and carbon production of each scenario to the baseline. Each scenario is also linked to an individual tab describing any individual projects that will be a part of the scenario. This allows the effects of the specific projects being considered to be separated out from the broader effects that might influence campus level emissions that are not captured as specific projects, such as switching utilities to a provider with a lower carbon emissions factor per unit of energy produced.

The blue colored cells indicate information that can be copied directly from the Penn Carbon Calculator outputs, while the green cells indicate the annual costs of the scenarios, which must be calculated separately by the user. The gray cells indicate information that is calculated from user entered information or are variables linked to master rates which are universal across all scenarios. Some of these master rates may be overridden for individual scenarios to mimic specific financial or energy situations, such as the value of energy and carbon and the discount rate used to evaluate the present value of future costs and savings.

While the differences between the energy consumption and carbon production of the scenarios will be largely determined by university actions, the financial impact of these actions is subject to a variety of factors that are not controlled by the university and which are assigned estimated rates. Changing these rates then illustrates the uncertainty in any given scenario due to external financial influences. The financial evaluation of each scenario is highly sensitive to shifts in the cost of energy and the discount rate, as even a low rate of change of a few percent become significant when applied across a time span of 30 years.

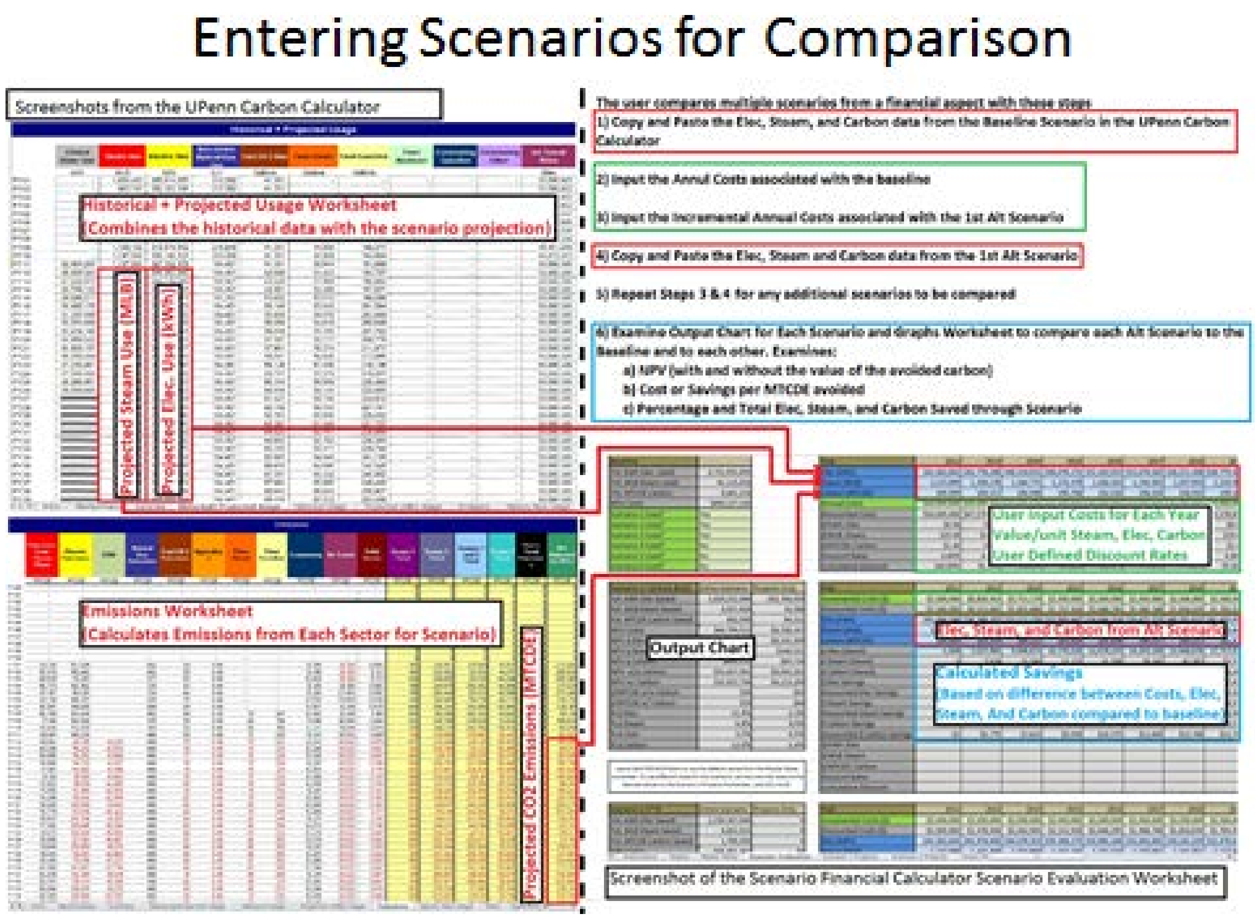


Figure 28- Entering Scenario Data into Penn Carbon Financial Calculator

Figure 28 illustrates the process for transferring information from the Penn Carbon Calculator into the Penn Carbon Financial Calculator. The diagram shows the locations of the three sets of information that must be copied and where they must be pasted into the Scenario Evaluation tab of the Penn Financial Calculator. The diagram shows data being entered for the baseline scenario from the Penn Carbon Calculator, but the process is the same for the additional scenarios. The user selects which scenarios they wish to compare using the section in the Baseline Summary. While the Penn Carbon Financial Calculator was constructed to compare six scenarios, additional scenarios may be added by copying and pasting one of the existing scenario blocks of cells to the space below the last included one.

Care should be taken by the user to ensure that that only the values of the cells are copied, rather than the formulas or format.

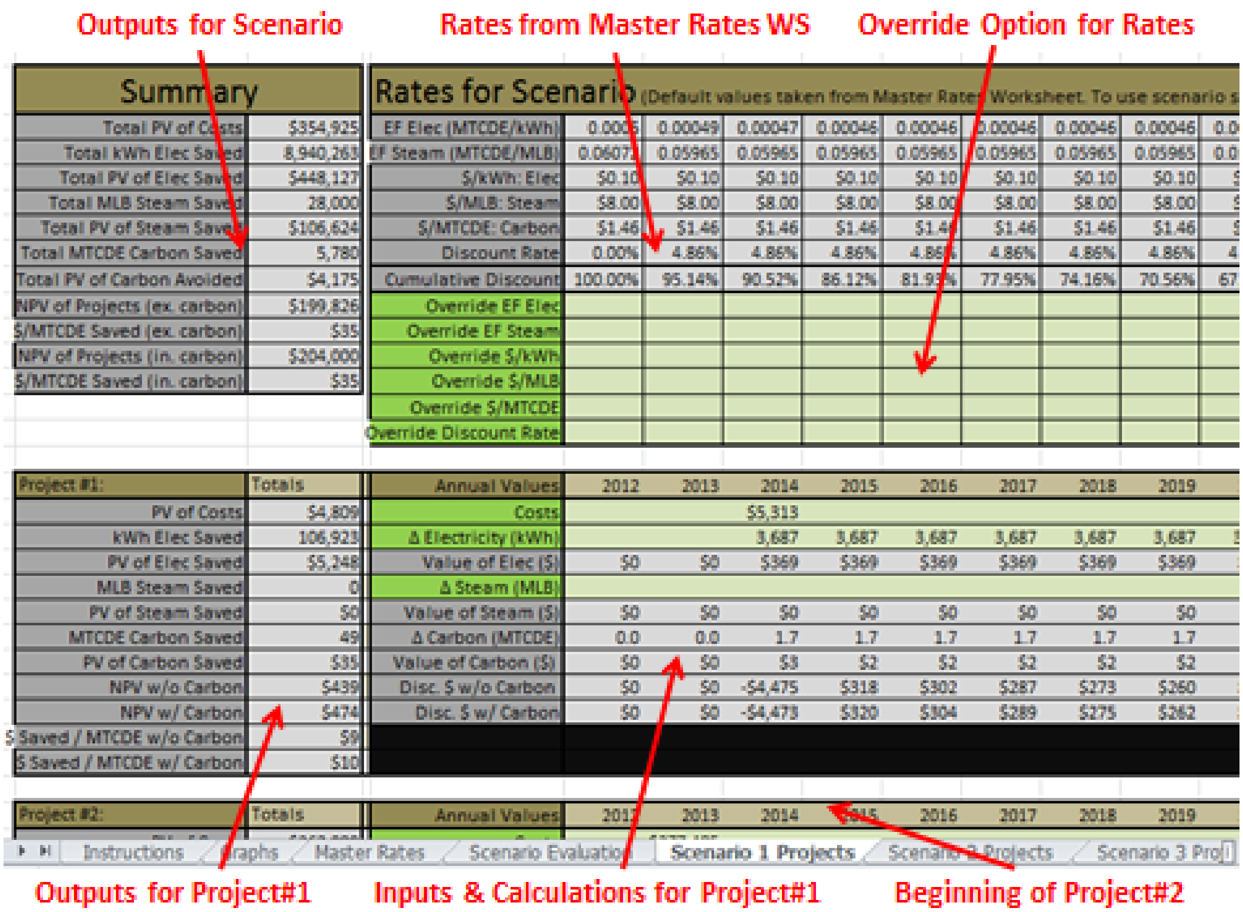


Figure 29- Layout of Penn Carbon Financial Calculator, Scenario Projects Tabs

Figures 29 and 30 display two of the tabs associated with a specific scenario which was designed to aggregate any available information regarding specific projects. While the Scenario Evaluation tab provides an overview that is useful for comparing one scenario to another, these scenario specific tabs provide much greater detail regarding the effects and financial impact of the individual projects making up a scenario as well as to compare the effects of the individual projects versus the effects that impact the entire scenario. This granularity of detail allows a user to identify elements of a scenario which either do not lead to a significant carbon emissions reduction, that do not break even over the course of the projection, or which achieve lesser results per dollar spent on the intervention. This section of the tool thus serves as a repository for the project specific information, but also as a comparative tool that can be used to refine a scenario by eliminating those elements with the worst performance.

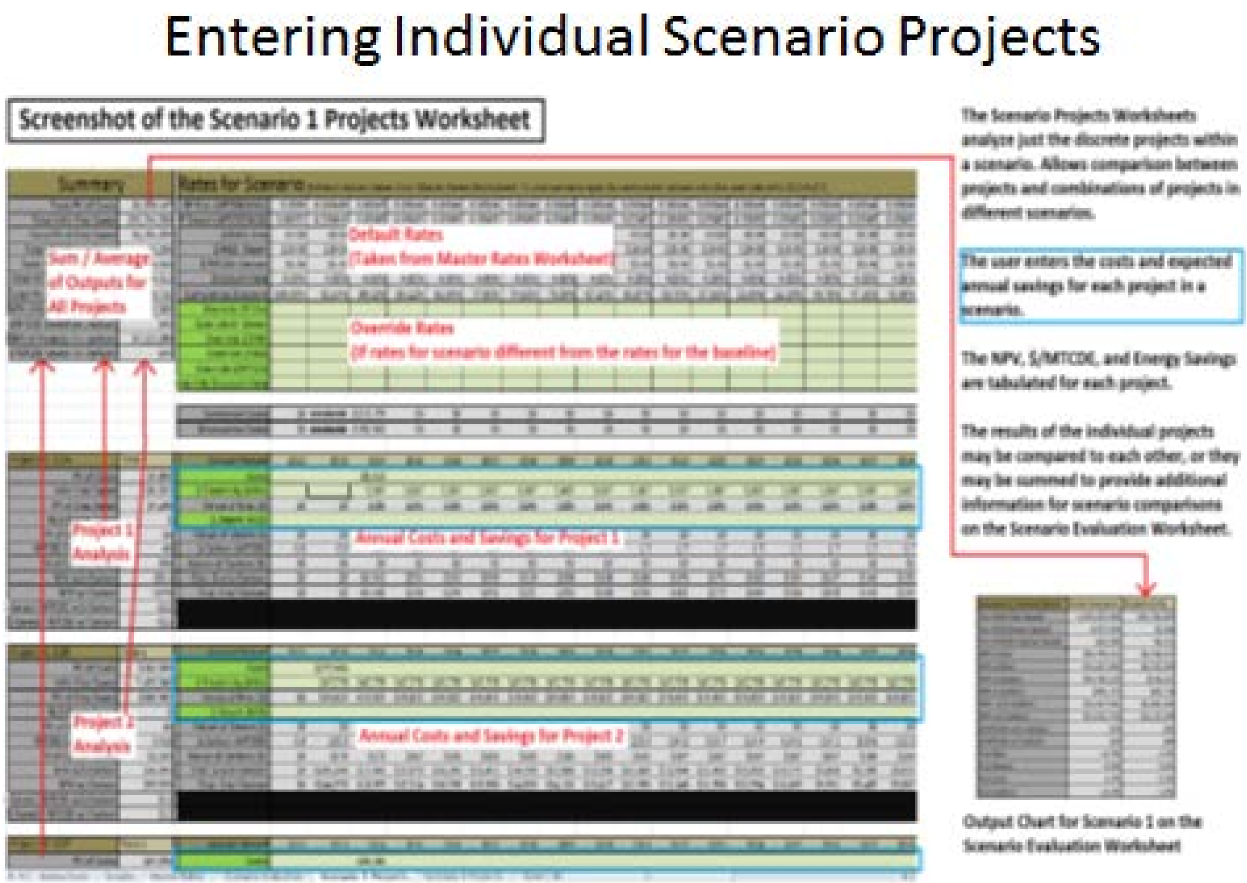


Figure 30- Entering Project Data for a Specific Scenario into Penn Carbon Financial Calculator

As with the Scenario Evaluation tab, each scenario tab has an expandable structure that allows the user to add additional sections to include an infinite number of individual projects. The projects are stacked vertically and the last one listed should be kept blank as a template. To add space for additional projects this template can be copied and pasted at the end of the projects list and its effects will be automatically added to the totals in the Summary chart in the upper left hand corner. The Summary chart on each of the Scenario Projects tabs is linked to the section for the corresponding scenario on the Scenario Evaluation tab, supplying the combined effects of the individual projects for comparison to the effects of the entire scenario. This is a useful comparison because it highlights the extent to which the University can actually reduce their emissions versus the effect of broader changes outside of University control.

Appendix E- EnergyPro Manual

EnergyPro is a tool that is used to calculate the anticipated energy consumption of a building if it were brought up to a specific level of ASHRAE 90.1 code. This tool was utilized to generate targets for the potential consumption of campus buildings which were later used to determine the level of saving that could be realized through a systematic long term effort toward energy efficient renovations focused on the poorest performing buildings. Below are several screenshots showing the operation of this tool.

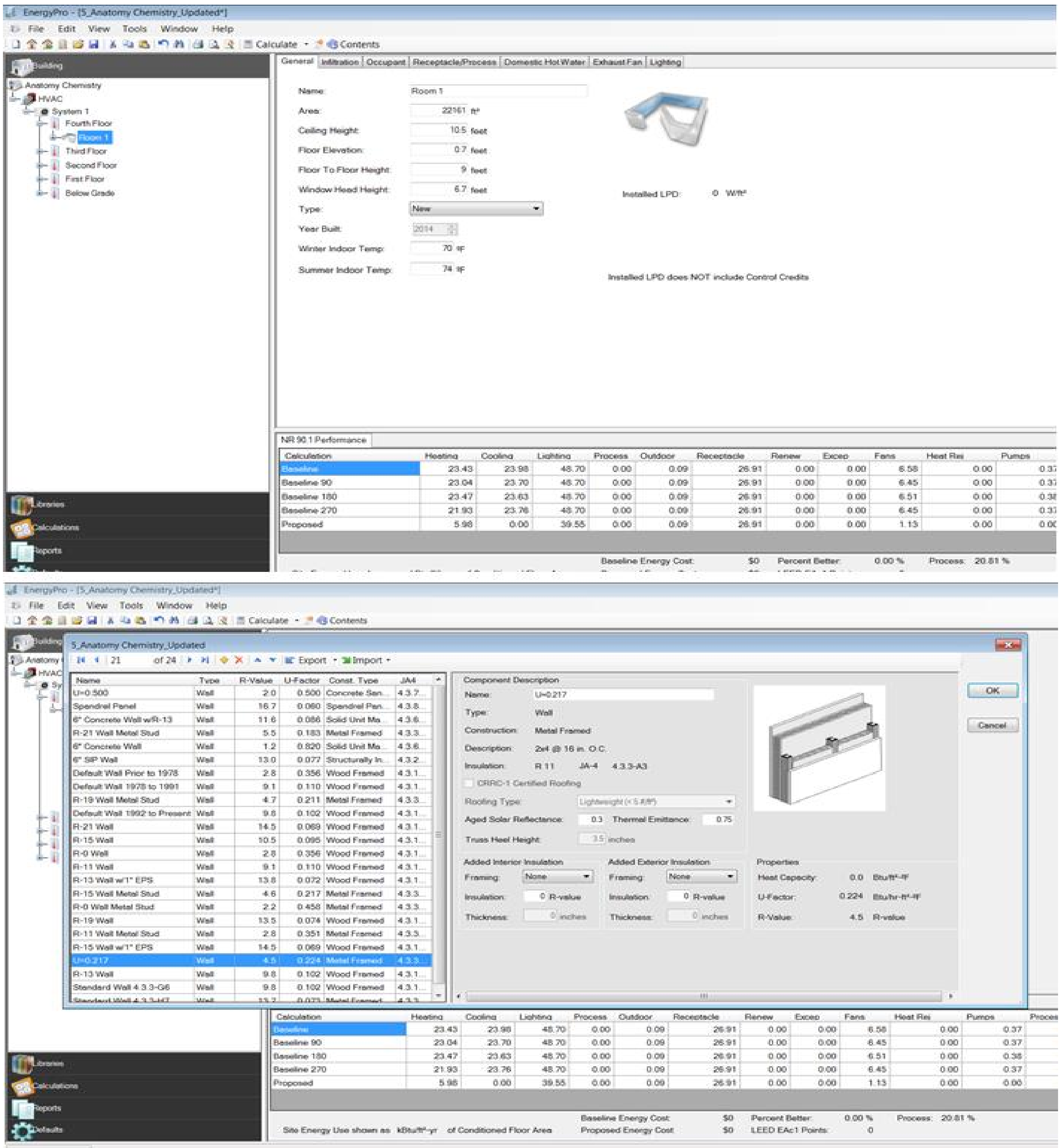


Figure 31- Screenshots of EnergyPro Operation

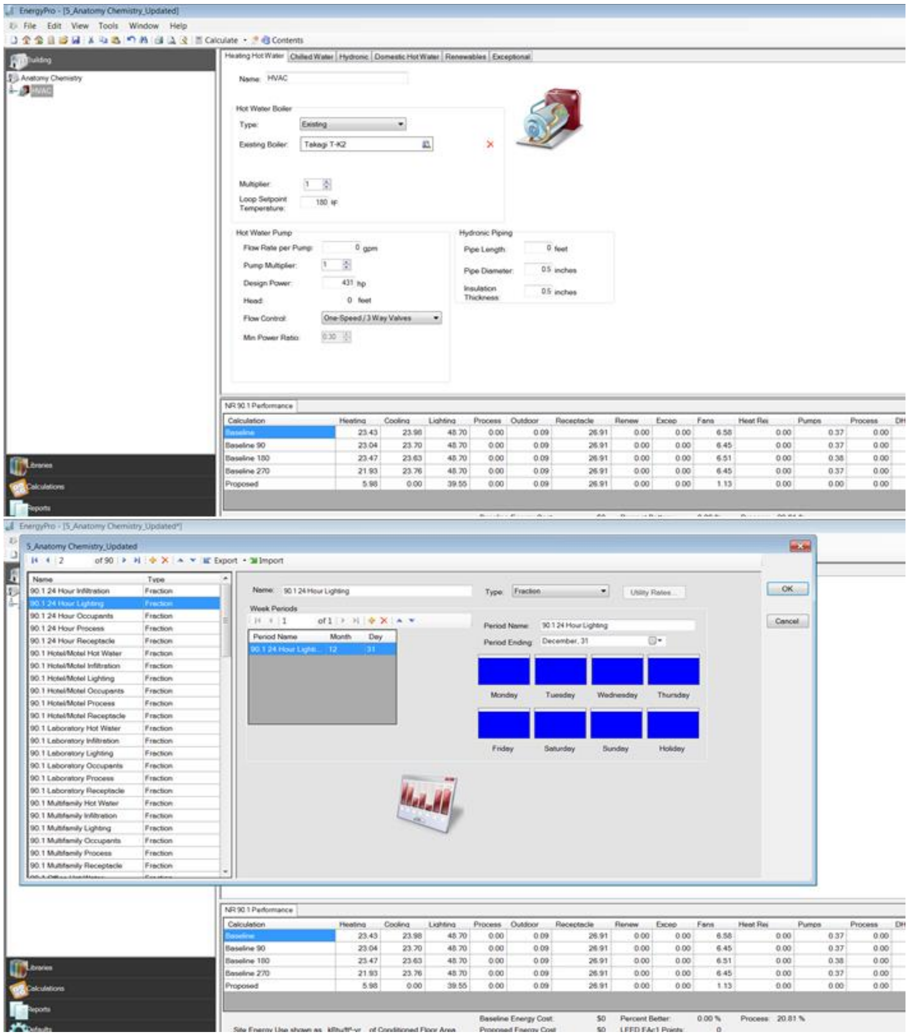


Figure 32- Screenshots of EnergyPro Operation

Appendix F- List of Assumptions

Future Emissions Factors- The emissions factors were derived from actual consumption for all past years. Future emissions factors for electricity were drawn from EIA and PJM projections and decrease slightly over time and an inconstant rate. Future emissions for steam were not estimable and so were kept constant at the 2014 historical levels.

ASHRAE 90.1-2007 Targets- The ASHRAE 90.1-2007 Targets were developed using the Energy Pro tool which estimates the energy consumption of buildings if they were operating at ASHRAE 90.1-2007 code. This tool provided estimates of the heating, cooling and electrical demand for lighting for the building. The heating and cooling demand were converted to determine the MLB and kWh of steam and chilled water that would be demanded from the building. As Energy Pro does not factor in plug loads, these values were estimated and then added to the targets output by the program. Additionally the portion associated with cooling was adjusted by a factor of 3 to account for the difference between cooling work provided vs the energy represented by the electrical consumption as each unit of electrical energy moves several units of heat energy due to the COP of the cooling system.

ASHRAE 90.1-2010 Targets- Energy Pro was also used to generate targets for building performance under the 2010 version of the ASHRAE 90.1 code. These targets used the same inputs and were adjusted in the same fashion as the 2007 targets.

Schedule of Renovations- Two schedules were created to represent different rates at which the University could pursue renovation and maintenance of campus buildings. The first assumed that 1-2 buildings, representing ~215,000 sqft of campus space, would be renovated each year. The second assumed that 2-3 buildings, representing ~300,000 sqft of campus space would be renovated each year. The order in which the buildings are scheduled to be renovated remains the same, regardless of the rate at which the buildings are renovated. The order is determined by prioritizing the buildings showing the greatest overall reduction in energy use due to the renovation. Minor adjustments were made to the final schedule by shifting the renovation dates of some buildings by a year into the future or into the past to ensure that approximately the same square footage was scheduled in each year.
Campus Growth Rate – Energy Growth

Discount Rate- A discount rate of 4.86% was used to calculate the present value of all future costs and savings. This figure was taken from existing UPenn financial analyses.

Rising Energy Prices- Based on conversations with FRES, we are assuming that energy prices will have a real increase of 1% each year for each year of the projection. This rate was applied to both electricity and steam. The financial calculations proved to be sensitive to this rate and 3% and 5% were examined.

Cost of ASHRAE 90.1-2007- \$90.76/sqft. The cost of this level of renovation was derived from the existing estimate of the costs for the Century Bon Projects. The lower range of the estimates was taken for the HVAC and Lighting renovation options described for each building and converted into a combine cost per square foot. The average cost per square foot to complete these HVAC and lighting renovations was then calculated and set as the cost per square foot to upgrade to current code. That rate was then multiplied by the square footage of the buildings being renovated in any given year and discounted to equal its present value cost.

This is another variable that the outcomes are sensitive to, as it determines the incremental cost of the renovation. Future efforts should attempt to prorate this cost based on the extent of the energy consumption improvement expected for each building, which can be used as an indicator of the extent of the work that would need to be completed.

Cost of ASHRAE 90.1-2010- $112.56/sqft. The cost of this level of renovation was determined by examining the upper range of renovation options suggested in the Century Bond Projects. An average difference in cost of about 20% was observed compared to the lower range of options and so the rate for renovations to the next generation of code was calculated as 120% of the rate used for renovations to current code. As with the cost of current code, these rates were multiplied by the square footage scheduled for renovation in each year and then discounted to their present value cost.

Cost of Maintenance- $100,000 per building recommissioned beyond 12 each year which is the current rate. The cost of maintaining the buildings under the Baseline is assumed to be applied at the slower schedule, once every 10 years for most buildings and once every 5 for buildings that are to be renovated, but it is assumed that this causes no energy consumption reduction for each building; rather it allows the building to maintain its performance levels.

Campus Growth- It is assumed that the campus will add new square footage at a growth rate of 1%. Under the Baseline and Century Bond scenarios, this equates to a rise in energy consumption of 1%.