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INTEGRATING INDIVIDUAL BUILDING MODELS INTO CARBON PROJECTIONS FOR LARGE PORTFOLIOS

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ABSTRACT

This paper examines the creation of a new simulation tool designed to integrate the results of energy consumption models into the carbon projections for large portfolios of buildings. This is accomplished through the creation of the Individual Building Worksheet (IBW), which was designed to integrate with calculators and projections derived from the CACP Carbon Calculator. The IBW compliments a carbon calculator to determine how changes to individual buildings would impact the carbon footprint of a portfolio and creates a framework for the integration of detailed energy models into scenarios of future development for the portfolio.

INTRODUCTION

As humanity has passed into the 21st century the concern over the rising concentration of greenhouse gasses in the atmosphere has spurred many governments and institutions to action. (Switzer, 2004) While momentum at the international level has been slow to build, (Crowley, 2010; Guan, 2009) many smaller organizations have made policy changes in order to curb their GHG emissions. (Coffman, 2009) One tool used to enable this transition is a calculator can determines an organization's carbon footprint and make projections regarding future emissions.

A carbon footprint is a snapshot showing the amount of carbon dioxide that is produced by each sector of activity within an organization. In addition to determining the current level of carbon emissions, carbon footprints are also utilized as the baseline for simulations of future carbon emissions. Once a baseline for future emissions has been established scenarios detailing potential plans may be conceptualized and parameterized. The assumptions are then added to the calculator which may then be used to estimate the impact that scenario would have on future emissions.

A review of existing carbon footprint and emissions projection calculators shows that while many organizations rely on the information provided by these tools to form their carbon management strategies, many of the most commonly used calculators utilize simplistic mechanisms for making projections and few are capable of integrating with energy consumption models to provide a greater detail of information at the building level. In particular, the assumptions used to project emissions from large building portfolios are overly simplistic.

A common assumption is the use of a single annual rate of change for the consumption of each of the energy carriers based on the historical consumption of each utility. Often, this rate of change is applied to the organization-wide consumption of each utility from year-to-year to create a projection of future emissions with constant, invariable growth.

Applying a single rate of change to the energy consumption of an organization's built environment ignores the way that renovations, the primary drivers of carbon emission reductions within the built sector, are conducted by organizations managing large numbers of buildings. Rather than gradual improvements to all the buildings every year, varying degrees of renovations are typically applied to a small number each year, while the majority are left unchanged. To accurately project the emissions from an organization, the built sector must be modeled in a realistic fashion allowing changes to individual buildings to be considered.

To create more realistic and useful projections of future carbon emissions, a new tool was created that forms a link between reduced-order models of individual buildings to the carbon simulation of large portfolios of buildings. This new tool utilizes projections of the potential renovations to individual buildings, while also taking into account changes that affect the entire portfolio, such as a reduction in the carbon intensity of grid electricity. This allows scenarios to be created that represent the specific plans for renovations being considered by an organization which project their anticipated impact on future emissions.

The Individual Building Worksheet (IBW) is designed to work with carbon simulators derived from the Greenhouse Gas Protocol established by the World Business Council on Sustainable Development (WBCSD) and the World Resources Institute (WRI). The UPenn Carbon Calculator was used as an example as it is representative of the calculators used by many other organizations, based on the Clean Air-Cool Planet Carbon Calculator.

The IBW operates by extracting the organization-wide consumption of electricity, steam, chilled water, natural gas, and fuel oil from the existing calculator and apportioning it out to each individual building so that every unit of energy consumed is assigned to a specific building. The projection then determines the future emissions of each building based on assumptions regarding future renovations, to what extent, and what effect they will have on each individual building's energy consumption using reduced-order models.

The individual projections for each building can then be summed to create a projection of the overall energy consumption by the built sector. This is added back into the carbon calculator and replaces the mechanism that estimated year-to-year growth based on average annual rates of change. By allowing planners to make projections using the units of change that they actually control, the separation between the theoretical simulation and the actual renovation process is reduced allowing for better planning and a simpler means of determining whether the organization's carbon reduction goals can be met. This is a particularly powerful tool for near-term simulations as renovations to buildings are typically planned several years in advance, allowing a very accurate projection of the carbon emissions from the built sector to be formed for this time frame using the Individual Building Worksheet.

EXISTING CARBON CALCULATORS AND PROJECTIONS

Many universities and other organizations conduct annual carbon footprint analyses and simulations using the conventions and assumptions that were first established by the WBCSD and the WRI. These organizations adapted this basic framework for their setting by developing calculators modeled on the one developed by Clean Air-Cool Planet, which was established to tabulate the carbon footprint from academic institutions. (Zhaurova, 2008)

The Clean Air - Cool Planet Carbon Calculator was constructed in Excel, as are most of its derivatives, and creates a framework for an organization to enter the magnitude of consumption for each type of energy or material consumption each year. The methodology of the calculator is relatively simple. First it establishes each sector of activity that contributes to the carbon footprint. Secondly, it determines the magnitude of energy or materials that are consumed by those activities to create carbon emissions. (Sinha et al, 2010)

Next, it applies an emissions factor, which is established for each sector of carbon production and is linked to the units in which each sector's consumption is recorded and reported. Prior research has established the amount of carbon dioxide produced per unit for each activity. By multiplying the emissions factor by the magnitude of each energy or material consumed in a year, the carbon contribution from each sector of activity may be accurately determined. (Sinha et al, 2010)

The calculator also stores the consumption and emissions information for each sector from carbon footprints conducted in past years, allowing for analysis of the carbon footprint as it changes. This information is used to create the average, annual rate of change for each sector of consumption which is then used to project the emissions from each sector.

The projections made using this framework are useful for a broad consideration of how the carbon profile of an organization might evolve but two major failings prevent them from representing the ways the carbon emissions from the built environment are affected by mitigation efforts. The first failing is that the existing calculator relies on a single annual rate of change for each sector of carbon emissions, and that rate of change is kept constant for the duration of the projection. Clearly, few trends in the energy sector remain constant over 30 years. (Amjady, 2006)

The second failing was the way in which the original calculator treated the energy consumption of the built sector as an aggregate. While this is a valid and accurate means of determining the *current* carbon production from the built sector, applying an annual rate of change to the aggregated utility consumption does not accurately reflect the way in which renovations to a portfolio of buildings occur.

Rather than a gradual change affecting all properties simultaneously, changes to the built environment occur dramatically, but in isolated areas, as a portion of buildings undergo renovation each year. So, while the original projections created using the CACP Carbon Calculator indicate a slowly evolving campus, reality indicates a campus that largely remains static with pockets of isolated, but more dramatic, changes occurring in select buildings. This makes it difficult to create realistic projections using the method organizations have utilized to adapt the CACP Carbon Calculator.

The combination of these two factors creates a carbon simulation that does not accurately reflect the potential future emissions. Even if the projected carbon emissions were accurate, it would still be difficult to effectively use the tool to gauge to impact or effectiveness of alternate renovation scenarios, since it has no mechanism to consider the contribution of individual buildings. For these reasons it was decided that the methodology commonly used to adapt the Clean Air-Cool Planet Carbon Calculator to make projections should be analyzed and revised to incorporate greater detail regarding the future renovation of the built environment using reduced-order models.

INDIVIDUAL BUILDING WORKSHEET

The Individual Building Worksheet (IBW) was created to produce a more accurate carbon footprint and future emissions projection when using the Clean Air-Cool Planet Carbon Calculator framework. The IBW provides more accurate projections of future carbon emissions from the built sector using a method that more accurately reflects reality by considering how renovations to the built environment occur and incorporating the results of reduced-order models to determine their impact on energy consumption. The IBW draws on the portfolio-wide consumption of utilities, which is an input for the original calculator, and separates the aggregated consumption into the portions consumed by each building. This allows projections to be made regarding the performance of each individual building, based on scheduled or considered renovations, which can then be summed to create a projection of the portfolio's carbon emissions.

In order to create better projections of the future greenhouse gas emissions, it was necessary to consider the role of the individual buildings while retaining the existing framework of the CACP Carbon Calculator, since the majority of it operated as desired. To do this, the original carbon calculator was modified in order to accept the output of the IBW, which uses the projected future energy consumption of five types of consumable energy to predict carbon emissions contributed by the built environment.

The vast majority of the electricity and other utility consumption for most organizations occurs in the built environment and it is assumed that the entirety of the organization-wide metered consumption for each can be attributed to the sum of the consumption of the individual buildings. Thus if the consumption

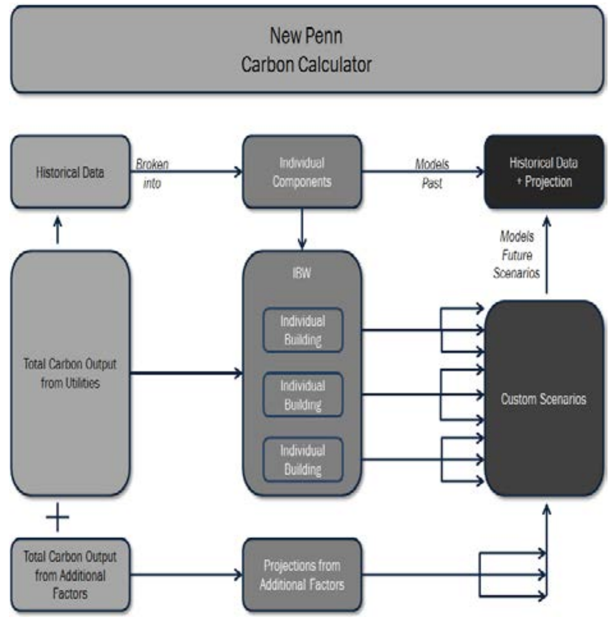

Figure 1- Interaction of Carbon Calculator and IBW

of utilities could be determined for each building, then the sum of those figures should come close to equaling the total metered amount for the whole built environment, less a small amount lost during transmission. While electrical consumption is traditionally metered for individual buildings, steam, chilled water and some other utilities might not be metered at the building level. In recent years, however, there has been increasing interest in metering each of these energy carriers.

The IBW exists as an Excel spreadsheet with separate worksheets detailing the past and projected utility consumption of each building and a single worksheet which serves to sum the consumption from each building for reintegration into the main calculator. This approach allows individual projections to be made for each building using the outputs of reduced-order models. Since the renovation of an organization's properties typically occurs as major upgrades to individual buildings, rather than gradual changes across the entire campus, this method of projecting future utility consumption from an organization's properties represents a more accurate means of estimating the potential for future carbon emissions reductions from a specific schedule of building efficiency renovations.

The IBW was designed to work in conjunction with pre-existing carbon calculators to ensure continuity between the historical footprints and the projections of future carbon emissions. Buildings typically use two or three energy carriers to supply their needs. Since most buildings are metered for electrical consumption, determining the portion of the

	Total Consumption	2009	2010	2011	2012	2013	2014	2015
Campus Total from Billing (The total utility use for the entire university, not submetered by building)	Electricity (kWh)	300,000,000	320,000,000	335,000,000				
	Steam (MLB)	1,160,000	1,100,000	1,200,000				
	Chilled Water (kWh)							
	Natural Gas (ccf)	200,000	230,000	160,000				
	Fuel Oil (gal)							
Sum of the Individual Buildings (Sum of the entries for each building listed below)	Total Consumption	2009	2010	2011	2012	2013	2014	2015
	Electricity (kWh)	235,000,000	250,000,000	255,000,000	240,000,000	230,000,000	225,000,000	222,000,000
	Steam (MLB)	0	0	650,000	650,000	655,000	660,000	640,000
	Chilled Water (kWh)	0	0	79,000,000	80,000,000	85,000,000	83,000,000	82,000,000
	Natural Gas (ccf)	0	0	0	0	0	0	0
	Fuel Oil (gal)	0	0	0	0	0	0	0
Difference (Amount from campus total not attributed to an individual building)	Total Consumption	2009	2010	2011	2012	2013	2014	2015
	Electricity (kWh)	65,000,000	70,000,000	1,000,000	0	0	0	0
	Steam (MLB)	1,160,000	1,100,000	550,000	0	0	0	0
	Chilled Water (kWh)	0	0	0	0	0	0	0
	Natural Gas (ccf)	200,000	230,000	160,000	0	0	0	0
	Fuel Oil (gal)	0	0	0	0	0	0	0
Difference (Projection) (Amount from campus total not attributed to an individual building)	Total Consumption	2009	2010	2011	2012	2013	2014	2015
	Electricity (kWh)	65,000,000	70,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
	Steam (MLB)	1,160,000	1,100,000	550,000	550,000	550,000	550,000	550,000
	Chilled Water (kWh)							
	Natural Gas (ccf)	200,000	230,000	160,000	160,000	160,000	160,000	160,000
	Fuel Oil (gal)	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Projected Footprint	Total Consumption	2009	2010	2011	2012	2013	2014	2015
	Electricity (kWh)	300,000,000	320,000,000	335,000,000	321,000,000	316,000,000	309,000,000	305,000,000
	Steam (MLB)	1,160,000	1,100,000	1,200,000	1,200,000	1,205,000	1,210,000	1,190,000
	Chilled Water (kWh)	0	0	0	0	0	0	0
	Natural Gas (ccf)	200,000	230,000	160,000	160,000	160,000	160,000	160,000
	Fuel Oil (gal)	50,000	50,000	50,000	50,000	50,000	50,000	50,000

Figure 2- Screenshot showing details of the Summation worksheet (demonstration values, does not reflect actual consumption)

aggregated electrical bill attributable to each specific building is typically simple. A growing minority of buildings are also being metered for their use of other energy carriers such as chilled water and steam consumption. Since buildings are the primary consumers of most utilities, if the metered consumption by individual buildings is subtracted from the total consumption of the organization. The remainder may then be divided proportionally amongst the remaining, unmetered buildings, according to estimates from energy consumption modeling software.

Once the metered data and estimates from the reduced-order energy models have been combined to create a snapshot of the annual energy consumption of each building, it is then possible to make a projection for each individual building regarding their consumption of utilities. These estimates can be based on specific planned or possible retrofits, the effects of which may be accurately modeled, or may represent general goals, such as bringing all portfolio buildings up to code. When a projection has been made for each building, they are combined to create an aggregated picture of the future energy consumption by the built environment.

It is assumed that the Individual Building Worksheet will be incomplete. In instances where good historical or modeled energy consumption data is not available, no estimate should be made regarding that building's energy consumption and the fields are left blank. Additionally, line losses cause some electricity, steam, and chilled water to be lost before reaching a building. Missing data and line losses means that the sum of the energy consumption of individual buildings will likely not quite equal the aggregated consumption. While the growth or decline of utility consumption attributed to each building is accounted for in the individual scenarios created for those buildings, the difference between the sum of the individual buildings and the aggregated utility consumption must be accounted for separately.

Since all the projections begin in the last year where historical aggregated utility data is available, the sum of the consumption attributed to the individual buildings for this prime year may be compared against the known total for the organization in this time frame and the difference determined. Just as individual buildings are projected from that base year, this difference is also 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 consumption the utilities is mathematically ensured.

Facility Name	ID #	Type	2011	2012	2013	2014
Building X	#	Electricity (kWh)	2010089	2025030	2025504	2006915
		Steam (MLB)	2970	2950	2954	2947
		Chilled Water (kWh)	40704	40704	40704	40704
		Natural Gas (ccf)	0	0	0	0
		Fuel Oil (gal)	0	0	0	0

Electricity		Month	2011	2012	2013	2014
Historical Data		July	196,002	164,008		
		August	153,873	214,092		
		September	178,395	146,120		
		October	210,874	171,705		
		November	176,384	149,716		
		December	137,298	174,663		
		January	157,905	206,018		
		February	150,253	135,492		
		March	177,431	139,571		
		April	141,053	138,035		
		May	170,928	187,347		
		June	159,693	198,263		
Historic + Scenarios		TOTAL	2010089	2025030	2025030	2006593
Scenarios (Select One)	0	BAU	0	0	2025029.63	2025029.63
	1	227: 2013/2014 Lightir	0	0	2025029.63	2006592.63
	0	E*75 in 2015	0	0	2025029.63	2025029.63
	0	E*90 in 2015	0	0	2025029.63	2025029.63
	0	ASHRAE in 2015	0	0	2025029.63	2025029.63
			0	0	2025029.63	2025029.63

Steam	Month	2011	2012	2013	2014
	July		0		
	August		100.510575		

Figure 3- Details of an example building in the IBW

Using the IBW several scenarios may be created for each building detailing the various ways in which they may be renovated or otherwise changed over the course of the projection. This allows the projection to follow the same decision making process for planning the future development of the portfolio. By linking the projection tool to the method by which decisions are made, a powerful tool is created that will provide assistance in forming a plan to achieve specific goals, rather than simply setting a goal and hoping that the changes being made at the organizational level will lead to its realization.

The IBW integrates with an existing carbon calculator by substituting its projection for the energy consumption of built environment for the typical means of projecting this consumption. The IBW outputs may be copied into the original calculator without causing any discontinuity. The carbon calculator now uses the projection provided by the IBW in the same fashion it used the values generated by the original projections based on annual growth. Each building's worksheet in the IBW 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 use of each. This change 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 for 30 years into the future to create a projection for each building. Before exporting the outputs of the IBW into the carbon calculator, each building should be set to simulate one of its predefined scenarios. Additionally, each utility type may be projected separately using custom scenarios.

CASE STUDY: THE IBW APPLIED TO A UNIVERSITY CAMPUS

For its initial application, the Individual Building Worksheet was used to create four example projections based on different potential scenarios of renovation for a portfolio of buildings. An urban university campus was chosen, due to the prior efforts there to create reduced-order models of each building on campus. Reduced-order models of energy consumption produce accurate estimates of annual heating, cooling, electrical, and other forms of energy consumption within buildings. They use normative equations based on the average energy consumption of other buildings of similar subtypes, which avoids many of the complex, physics-based equations used by higher order models, such as Energy Plus, saving computation time and requiring fewer input variables. This makes these models perfect when a large amount of modeled data is required. For disclosure reasons, the actual energy consumption values for the portfolio and its individual buildings have been increased by a set percentage so as not to publish protected information.

The outputs of the reduced order models were utilized in two respects. Firstly they were used to estimate the portion of the baseline consumption of each utility that could be attributed to individual buildings where metered data was unavailable. Secondly, they provided simulation results showing the effects of potential renovation options for individual buildings to be incorporated into the projections for emissions from the whole campus. This integrates the projections of the campus emissions with the precise modeled projections for the consumption of individual buildings allowing for more accurate and realistic carbon projections.

The first of these scenarios was the Business-As-Usual scenario. This assumes that none of the buildings will undergo any significant alterations over the next 30 years and that any renovations will restore the building to its current condition. In this scenario the energy consumption of all buildings remains constant from 2011. While the consumption from the existing buildings remains constant, campus growth and the addition of new buildings is expected to cause slowly rising emissions in this scenario.

The second scenario was based on a mandate whereby the university would dedicate itself to upgrading each building to Energy Star 75 efficiency

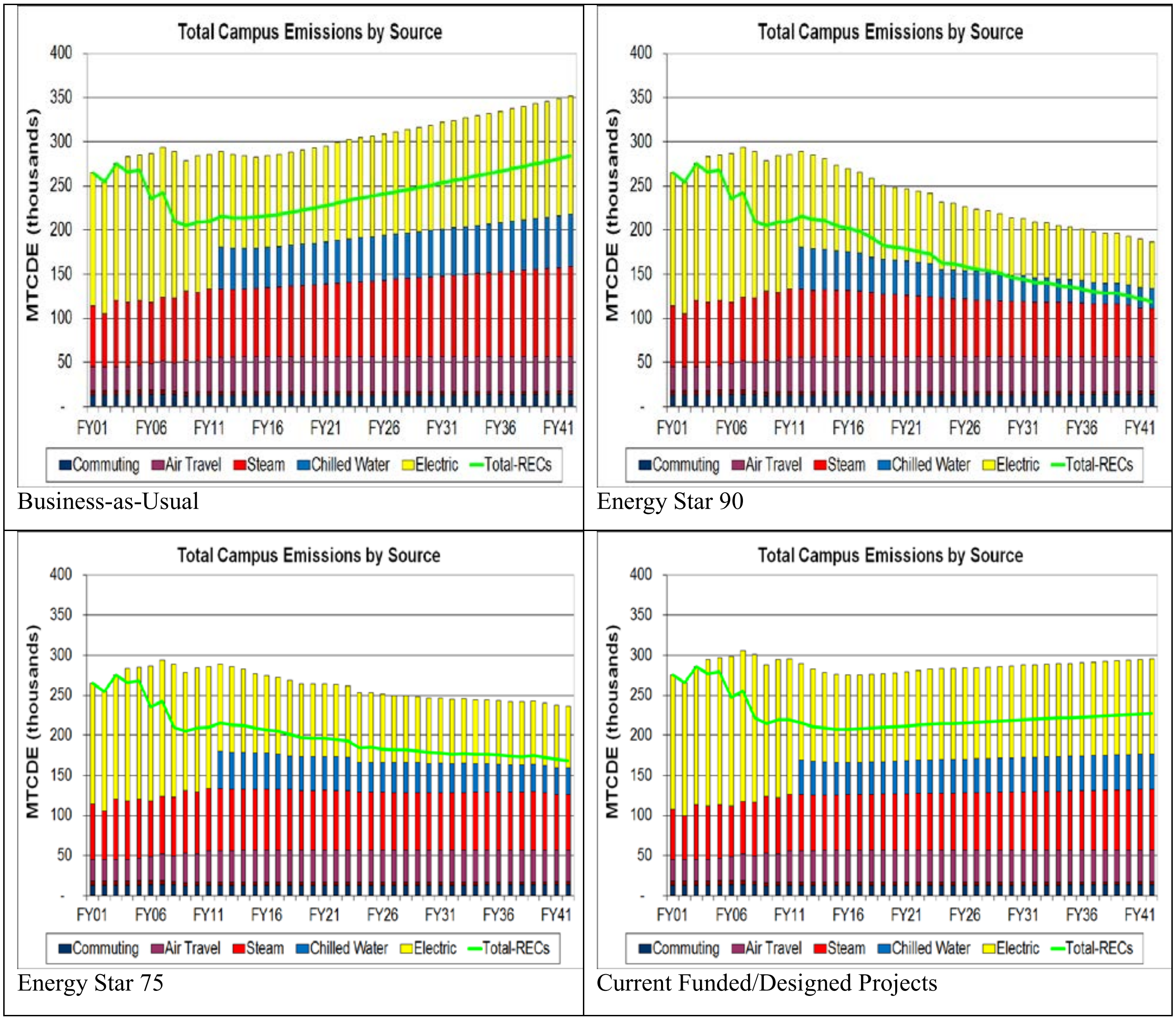

Figure 4- Side-by-side comparison of 4 Scenarios (n.b. values presented here are representative of example scenarios rather than reflective of actual university plans and consumption)

rating by 2042. Since this scenario spreads the efficiency upgrades over 30 years, and because the Energy Star targets are relative to the performance distribution of similar buildings, the Energy Star

Target was determined for each building using the 2012 Energy Star Target Finder and then decreased by 1% each year into the future that the building was scheduled to be renovated.

The year selected for the renovation of each building was randomly assigned to be spread equally from 2015 to 2042. Each building was assumed to have a constant level of consumption until the year of its renovation, at which point it would drop to its adjusted Energy Star 75 target through the end of the projection. Some building types cannot have Energy Star targets, such as Laboratories, and these buildings were given targets 20% lower than their historical usage levels, adjusted by 1% a year for each year into the future that the renovation is assumed to occur. In instances where a building was found to be outperforming their Energy Star 75 target, no change was made to the buildings consumption level and it remained at historical levels through the projection.

The third scenario was exactly the same as the previous except the Energy Star 75 targets are all replaced with Energy Star 90 targets, meaning the buildings perform more efficiently than 90% of other similar buildings. The improvements are assumed to occur on the same schedule as the Energy Star 75 scenario. For the building typologies that cannot have Energy Star targets generated for them, the more efficient targets are assumed to be 40% lower than the historical usage level, reduced 1% for each year into the future. Again, in those few instances where a building was found to be outperforming the Energy Star 90 target, the buildings consumption level remained constant through the projection.

The fourth and final scenario created in the Individual Building Worksheet was based on planned renovations. This scenario examines the projected change that will occur in the energy consumption of a building for each project which has been approved for funding and gone through a basic design analysis. Though a short list, this scenario represents the changes that are known that will definitely occur at the individual building level over the next few years. In the future it can be expanded to include additional projects as they are approved and designed. It perhaps is the most powerful of the projections because it directly shows the effects of actual projects and would, extended far enough into the future, be a mechanism for the creation of a plan of action to achieve specific carbon emissions goals with realistically achievable target dates.

One intriguing possibility for a future scenario would be one that attempted to equal the reductions seen in the Energy Star 90 scenario but which did so through a schedule of specific renovations to individual buildings, with the effect of each renovation being simulated by a reduced-order model. Such a scenario could be used to create a plan for meeting long-term carbon emissions reduction goals through concrete action rather than nebulous goals.

CONCLUSIONS

The IBW adds flexibility, accuracy, and increased validity to the projections that may be made using the CACP Carbon Calculator framework. 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 emissions reductions.

The Individual Building Worksheet represents a significant improvement on the existing CACP Carbon Calculator framework when it is applied to the projection of carbon emissions from an organization managing a large number of buildings. The original calculator, which was based on the Greenhouse Gas Protocol, was incapable of examining the energy consumption and resulting greenhouse gas emissions from individual buildings, instead relying on the organization-wide consumption of electricity, steam, and other utilities to calculate the contributions of the built sector to the overall carbon footprint. While this methodology is capable of providing an accurate estimate of the carbon emissions for the current or a previous year, it presents significant limitations in terms of projecting the carbon emissions for future years.

While a large number of organizations use the basic framework of the CACP Carbon Calculator, many have made significant alterations to the layout and aesthetic design in the formation of a carbon calculator or emissions projection tool. As such, the Individual Building Worksheet was designed so that it can be easily integrated into any calculator using the basic methodology of the CACP Carbon Calculator with only minor alterations. This is accomplished by creating an output that seamlessly integrates itself with the inputs required in the form of aggregated annual consumption of each energy carrier used in buildings for the entire organization.

The Individual Building Worksheet significantly enhances the original CACP Carbon Calculator framework by providing a higher level of detail to the current and future consumption of the built environment. The original framework only considers the aggregated usage organization-wide reported by the utility providers. While this provides a solid basis for the historical carbon emissions from the organization, it provides minimal information about the future path of those emissions or the magnitude of impact from specific intervention. Through a combination of metering and energy consumption models, it is possible to determine the approximate consumption of most buildings and make reasonable predictions regarding their future performance.

The greatest weakness of this approach proved to be the availability of metered data and the time required to generate simulation results of the baseline energy consumption or post-renovation energy consumption for each individual building. While it was necessary to utilize reduced order models due to time constraint, high order, physics based models would more accurately gauge the baseline consumption of unmetered buildings and would be able to more accurately predict the impact of renovations such as bringing a building up to code.

The negative effects of relying on the reduced order models is most clearly seen in the Energy Star scenarios where both the baseline and the target were generated through simulation for many buildings, leading to some uncertainty regarding the true impact of renovating a building up to that code. For instance, it is not certain that each building would be capable of being renovated to that standard given its initial condition. For smaller portfolios it may be possible to create higher order models of each building, but for larger portfolios an expansion of utility meters at the individual building level will provide a far better initial baseline, which will in turn improve and models that are created.

By only examining the organization-wide utility use it is impossible to simulate the renovation decision-making and construction process that actually occurs in the management of large building portfolios. While projections of the energy consumption from large portfolios are often made by assuming a gradual annual percentage change applied to the aggregated consumption of each utility, actual renovations are conducted on a building-by-building basis. By examining the individual buildings it is possible to more accurately model the ways carbon emissions from the built environment may evolve, but it also allows for a greater integration between the projected carbon footprint and the development of renovation schedules that will help an organization meet its emissions reductions commitments.

The four scenarios constructed for this report represent only a portion of what could be modeled using this tool. In particular, the Current Funded/Designed Projects scenario is proving to be a useful tool for estimating the effect of the planned and designed building renovation projects, providing accurate short-term projections based on the changes that are known that will occur in the next few years.

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REFERENCES

American College and University Presidents' Climate Commitment. Available Online At: http://www.presidentsclimatecommitment.org/

Amjady, N. and Hemmati, M. 2006. "Energy price forecasting - problems and proposals for such predictions." *Power and Energy Magazine, IEEE*. Vol. 4 (2). 20-29.

Coffman, M. 2009. "University leadership in island climate change mitigation." *International Journal of Sustainability in Higher Education*. Vol. 10 (3). 239-249.

Crowley, K. 2010. "Climate clever? Kyoto and Australia's decade of recalcitrance." in *Global Commons, Domestic Decisions: The Comparative Politics of Climate Change*. eds. Harrison, Kathryn and Sundstrom, Lisa McIntosh. MIT Press. Boston, MA.

Guan, D., Peters, Weber, and K. Hubacek. 2009. "Journey to world top emitter: An analysis of the driving forces of China's recent CO_2 emissions surge." *Geophysical Research Letters.* Vol. 36.

Park, C.S. and Augenbroe, G. (2003), Benchmarking of a Building Performance Assessment Toolkit, Proceedings of the ASCE (American Society of Civil Engineers) AEI (Architectural Engineering Institute) 2003, September 17~20, Austin, Texas.

Sinha, P; Schew, W; Sawant, A; Kolwaite, K; and Strode, S. 2010. "Greenhouse Gas Emissions from U.S. Institutions of Higher Education." *Journal of the Air & Waste Management Association*. Vol. 60 (5). 568-573.

Switzer, J. 2004. *Environmental Politics: Domestic and Global Dimensions*. Thomson-Wadsworth. Belmont, CA.

University of Pennsylvania Almanac. 2007. "President's Endorsement of Environmental Sustainability Strategy, Reduction of Greenhouse Gases." Vol. 53 (22).

University of Pennsylvania Carbon Footprint, 2007. Available Online At: http://www.aashe.org/resources/documents/PennGreenhouseGasReport.pdf.

University of Pennsylvania Carbon Reduction Action Plan. 2009. Available Online At: http://www.upenn.edu/sustainability/sites/default/files/pdf/PENN-2009-Climate_Action_Plan.pdf.

Wiedmann, T. and Minx, J. 2007. "A definition of 'carbon footprint'." *CC Pertsova, Ecological Economics Research Trends* Vol. 2. 55-65.

Zhaurova, L. 2008. *US Higher Education and Global Climate Change: An Exploration of Institutional Factors that Affect Greenhouse Gas Emissions*. ProQuest LLC. Ann Arbor, MI.