Carbon Footprinting:
A classroom exercise

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ABSTRACT: This document outlines a carbon footprinting methodology that can be conducted by graduate or undergraduate students as a classroom exercise. A class of graduate students at Arizona State University in the College of Design and School of Sustainability used a methodology to determine the carbon footprint of three campus buildings. This methodology included an energy consumption analysis of the existing building, the creation of an as-built energy model, and the study of carbon footprint improvement scenarios with the ultimate goal of achieving carbon neutrality. Each improvement scenario was analyzed to determine its effect on the annual electric consumption, annual gas consumption, and overall carbon footprint.

Keywords: carbon footprinting, carbon neutrality, classroom methodology

INTRODUCTION

A method for determining the carbon footprint of a building has become important and timely. Carbon policies exist on an international level and are beginning to gain traction on a national level. Initiatives such as “The 2010 Imperative” and “The Architecture 2030 Challenge” [1] are pressuring a deadline for achieving carbon neutrality. Arizona State University has recently signed on to The American College and University Presidents Climate Commitment [2], a pledge committing the university to carbon reduction and eventual carbon neutrality. In light of this, ASU’s College of Design and newly established Global institute of Sustainability formulated a graduate level class where students in the fields of architecture, building design, urban planning, and sustainability applied a methodology to determine and improve a building’s carbon footprint.

In the spring semester of 2008, this class was run as a prototype with the hopes of creating a carbon footprinting course that would be available to the undergraduate students in the College of Design and the School of Sustainability. In addition to the obvious educational benefits of this process, over two-hundred buildings on four ASU campuses require determining their current energy performance and carbon emissions. This effort to evaluate the performance of individual campus buildings is part of a greater ASU initiative that focuses on carbon neutrality, zero waste, and active engagement. A related component of this initiative is a campus-wide energy dashboard project, the Campus Metabolism project [3], which will allow students to monitor an individual building’s resource consumption. This project was launched in 2008 for the Global Institute of Sustainability, currently has thirteen buildings, and will be expanded up to fifty buildings by the end of 2009 (Fig. 2). This project gives students the opportunity to view the impact of their daily behaviours as the dashboard is measuring several campus dormitories. The utilization of this project in accordance with the carbon footprinting course will give students a more meaningful understanding of energy consumption and carbon emissions.

Figure 1: Rendering of the Global Institute of Sustainability showing the recent renovations.

EXERCISE SYNOPSIS

Teams of students conducted a carbon footprint analysis of three buildings (Table 1) on the campus of ASU: the College of Design South (CDS), the College of Design North (CDN), and the recently renovated Global Institute of Sustainability (GIOS) (Fig. 1). The methodology for

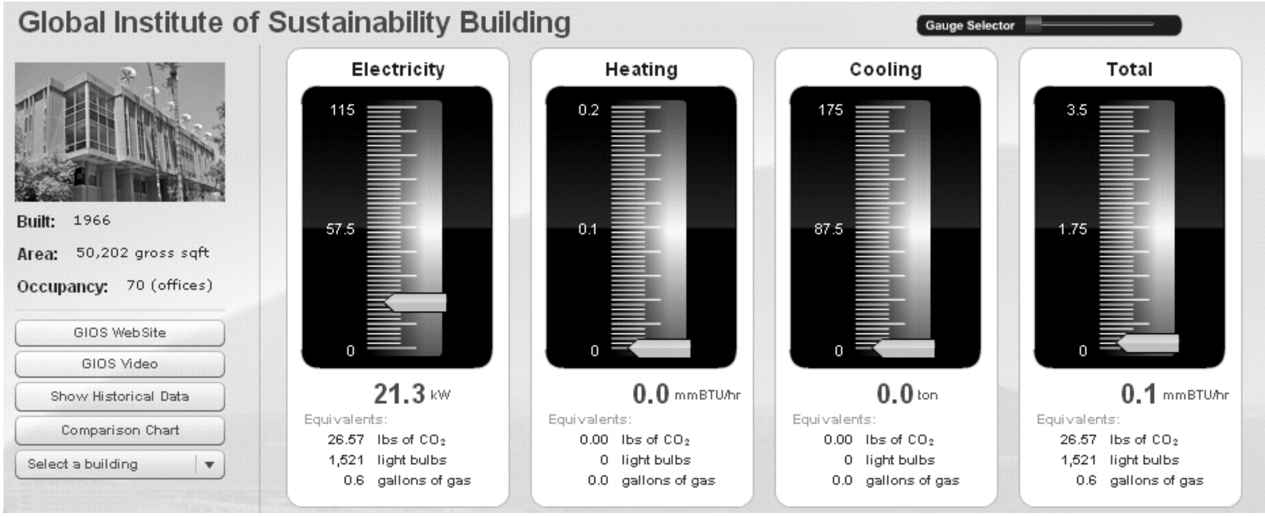

Figure 2: Screenshot of Campus Metabolism, ASU's newly launched energy dashboard.

this analysis was divided into three phases: 1) a study of energy consumption factors, 2) creation and calibration of an as-built energy model, and 3) an exploration of scenarios to improve the buildings' carbon footprint and ultimately achieve carbon neutrality. It should be noted that this methodology will only determine the operating carbon use intensity (CUI). However, the carbon footprint determined and reflected in the data for this class also includes materials carbon, using a set materials CUI of 1.943 lbs/ft^2/yr that was determined for ASU buildings in a separate study [4]. Demolition carbon was not included in this analysis.

Table 1: General building information.

Building	Area (ft^2)	Year Built	Number of Floors
College of Design South (CDS)	63,621	1970	3 + basement
College of Design North (CDN)	104,901	1989	3 + basement
Global Institute of Sustainability (GIOS)	48,806	1966 (renovated 2007)	4 + basement

EXISTING ENERGY CONSUMPTION FACTORS

An accurate as-built building energy model requires a study of how and when the building is using energy. To determine the existing electrical energy consumption for each building, students studied the existing energy consumption factors by conducting detailed surveys of the buildings to determine existing lighting and plug loads. The buildings were analyzed by the thermal zones specified in the energy model. An inventory of lighting fixtures, computers, electronics etc. was created and their respective wattage and schedule was noted. Watt meters were utilized on some electronics to determine the exact energy consumption. Electronics that had varying energy consumption such as computers and printers were considered. Lighting and plug/equipment schedules and power densities in W/ft^2 were determined for each zone (Table 2). At the time this survey was conducted, the GIOS building was not fully occupied due to the recent renovation and plug loads were estimated to reflect energy consumption for the fully occupied building.

Table 2: Building average of combined lighting and plug/equipment power densities.

Building	Average Power Density (W/ft^2)
CDS	2.10
CDN	2.23
GIOS	1.92

ENERGY MODEL AND CALIBRATION

Determining an operating carbon footprint requires the annual amount of electric and gas consumption. A simple method to find this information would be to consult the utility records. However, this is not always possible as was the case for the three buildings under analysis for this class. Due to the fact that the buildings are connected to a central plant, determining the energy consumption for individual buildings is difficult. Therefore, an as-built building energy model using eQUEST was created to determine the annual energy use (Fig. 3).

Using the power density and scheduling data from the building survey, a model was created to closely mimic the existing buildings' energy use. Additionally, the specifics of ASU's central plant and its impact on the buildings' energy use were programmed into the models. To ensure accurate results, the models were calibrated to

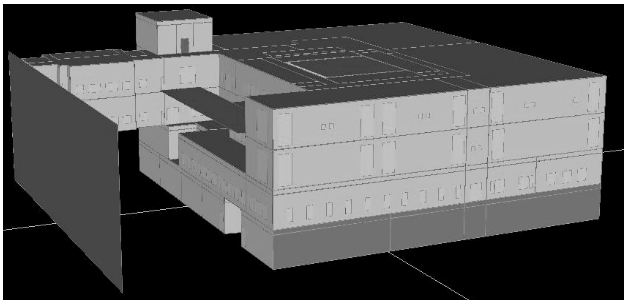

Figure 3: eQUEST building energy model of the College of Design North (CDN.)

the existing buildings. Fortunately, in early 2008, electric sub-meters were installed on buildings campus-wide to address the previously mentioned Campus Metabolism energy dashboard project. Because this class took place in the spring of 2008, only a few weeks of data were available. A weather file was created for the time period of data that was available and the electric energy consumption was calibrated accordingly. The major discrepancies between the models and the actual building data were the overnight loads. A few changes to scheduling and power densities resulted in a close electrical energy consumption calibration for CDS (Fig. 4) and CDN (Figure 5). Due to the fact that GIOS was not operating at full occupancy, students were not able to calibrate that particular energy model. Also, the simulated gas consumption was not able to be calibrated due to a lack of data. For future exercises, it would be optimal to calibrate the models to an entire year of data to be sure to determine an accurate operating carbon footprint.

If utility data is available, creating a building energy model is not necessary. However, having the as-built model allows for a more accurate analysis of scenarios for the carbon footprint reduction.

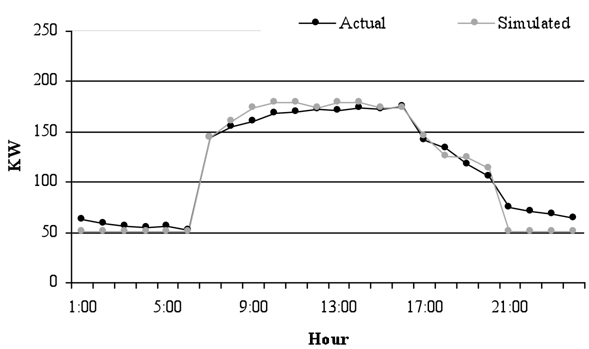

Figure 4: CDS energy model calibration of April 22, 2008.

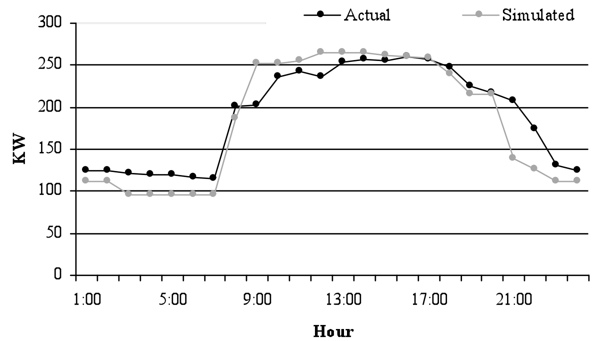

Figure 5: CDN energy model calibration of April 22, 2008.

EXISTING BUILDING ENERGY ANALYSIS AND CARBON FOOTPRINT

The calibrated building energy model allowed the existing buildings' energy use to be studied to get a better idea of where the energy is being used. It was determined that all three buildings are internal load dominated buildings, with over half the electrical energy devoted to lighting and plug/equipment loads (Table 3). Located in a hot-arid climate, Tempe experiences extremely hot summers with more than 100 days above 100°F. Although this is an extreme climatic condition, the winters are temperate and the feasibility for utilizing solar radiation is very high. This analysis comes into play when determining how to improve the buildings' performance.

Table 3: Percentage breakdown of annual electrical energy use.

	CDS	CDN	GIOS
Lighting	33%	41%	27%
Miscellaneous Equipment	24%	27%	37%
Space Cooling	23%	17%	20%
Ventilation Fans	15%	10%	11%
Pumps and Aux.	5%	5%	5%

The annual energy consumption data that is determined by the building energy model can be used to find the energy use intensity (EUI) and operating carbon use intensity (CUI.) These two figures can help to gauge how well the building is performing. The DOE/EIA Commercial Building Energy Consumption Survey (CBECS) database is utilized by The 2010 Imperative and The Architecture 2030 Challenge as a metric for analyzing building performance. The average commercial building in the U.S. has an EUI of 25.8 kWh/ft^2/yr (88 kBtu/ft^2/yr) compared to an EUI of 12.9 kWh/ft^2/yr (44 kBtu/ft^2/yr) for the average commercial building in the European Union. The Architecture 2030 Challenge targets buildings on average to half their EUI's now (12.9 kWh/ft2/yr (44 kBtu/ft2/yr)) and strive to achieve carbon neutrality by 2030. The three campus buildings under analysis have an EUI ranging from 14.04 kWh/ft^2/yr (47.9 kBtu/ft^2/yr) for CDN to 22.32 kWh/ft^2/yr (76.2 kBtu/ft^2/yr) for CDS (refer to Table 4).

Table 4: Comparison of the calculated as-built EUI, CUI, and building carbon footprint.

	CDS	CDN	GIOS
Annual Electric Consumption (MWh)	852.37	1302.29	635.48
Annual Natural Gas Consumption (MBtu)	1860.30	587.86	897.00
EUI (kWh/ft^2/yr)	22.32	14.04	18.57
CUI (lbs-CO_2/ft^2/yr)	26.79	22.07	24.80
Operational Carbon (tons/yr)	778.16	1056.76	557.84
Materials Carbon (tons/yr)	60.85	102.01	47.42
Total Carbon (tons/yr)	839.01	1158.76	605.25

As the EUI is a useful building performance metric, the CUI is becoming a more relevant as it places the emphases on CO_2 emissions, the most dominant gas contributing to global warming. Measuring performance with the CUI shifts the focus from reducing energy to reducing carbon emissions. The CUI is determined by using a conversion factor to convert kWh to lbs-CO_2. Based on the Energy Information Administration, a conversion factor of 1.57 lbs-CO_2/kWh for electricity and 0.40 lbs-CO_2/kWh for natural gas was used for this exercise. This conversion will only determine the operating CUI; a more accurate CUI will incorporate materials, maintenance, and demolition. The operating CUI found in this analysis ranged from 22.07 lbs-CO_2/ft^2/yr for CDN to 26.79 lbs-CO_2/ft^2/yr for CDS. To calculate a more accurate CUI, a materials CUI of 1.943, determined from a separate study of ASU campus buildings [1], was added to the operating CUI (refer to Table 4).

The final step in the energy and carbon analysis was the calculation of the buildings' annual carbon footprint. The same carbon conversion factors used to determine the CUI were used for this calculation. The annual carbon footprint for the existing buildings' (including operating and materials carbon) for CDS, CDN, and GIOS were found to be 839 tons/yr, 1159 tons/yr. and 605 tons/yr respectively (see Table 4). The analysis of the buildings' energy consumption and carbon footprint brings to light several strategies for improvement. Understanding effective ways to reduce the carbon footprint is the next step in working towards carbon neutrality.

CARBON FOOTPRINT REDUCTION SCENARIOS

The final part of this exercise was the application of different scenarios for the reduction of the carbon footprint, working towards the ultimate goal of carbon neutrality. Each group of students chose scenarios ranging from energy conservation, energy efficient technology and renewables. Tables 5-7 summarize the improvements from the following scenarios chosen for each building:

- **External shading system installation.** (GIOS only) To reduce the solar heat gain, 2ft overhangs and 2ft fins are added to all windows.
- **Envelope insulation improvements.** (CDS & CDN only) In CDS, 3in of rigid insulation is added to the exterior walls (the existing building lacks any exterior insulation.) This scenario in CDN involves adding blown insulation into steel framed wall cavities and retrofitting the roof to include tapered roof insulation upgrading wall and roof insulation to approximately R-30.
- **Glazing upgrade.** The glazing in CDS is upgraded from single pane to a high efficiency double low-E glass. The 1980s era double-pane windows in CDN are also upgraded to double low-E glass. Although the GIOS building was recently renovated, it is still equipped with the original glass that was installed in 1966. Due to the high percentage of fenestration, the glazing in the GIOS building is upgraded to a triple low-E glass.
- **Lighting load reduction.** In CDS and GIOS, lighting loads are reduced by building users eliminating unnecessary lighting loads during the day and overnight. Although this may seem to be easily executed, it can only be accomplished by occupant participation. CDN reduces its lighting loads through the installation of occupancy sensors in all classrooms, studios, and offices. Additionally, circulation spaces were simulated at 50% lighting levels during low occupancy schedules.
- **Lighting fixture upgrade.** Although the majority of the lighting fixtures are fluorescents, a few rooms in CDS are still using the energy intensive incandescent lighting fixtures. A scenario was simulated upgrading the incandescent fixtures to fluorescent. Additionally, lighting fixtures in all three buildings are upgraded to LED technology (assuming the future availability of LED lighting fixtures,) reducing the lighting load by approximately 45%.
- **Plug/equipment load reduction.** The small amounts of power (ghost loads) consumed by unused office equipment that is plugged in or in

sleep/standby mode are eliminated. Computers will no longer remain in sleep mode overnight but will be powered down at the end of the day. This scenario also relies on the behaviour of the building users. In CDS, several wasteful equipment loads such as the abundance of mini-fridges in offices (as opposed to sharing the communal refrigerator) and were observed during the initial building survey. These loads were also eliminated.

- **Fan static pressure improvement.** The static pressure in the HVAC fans was decreased from 3.0 WG to 1.5 WG.
- **Central plant upgrade.** ASU's central plant is upgraded to a more efficient natural gas powered CHP plant.
- **Rooftop PV system installation.** (CDS & GIOS only) A PV feasibility study for CDS and GIOS was completed to determine how much solar energy could potentially be produced on the roof area. Unfortunately, the rooftop of CDN has too many obstructions to host a PV system. It was determined that CDS could host a 510 panel 86kW system (Fig. 4) and GIOS could host a 318 panel, 56kW system. Both systems use 14% efficient mono-Si panels. This is a realistic scenario as of June 2008 ASU contracted the installation of 2 megawatts of solar modules on about 135,000 ft^2 of campus rooftop space. The first campus installation was completed in December 2008.

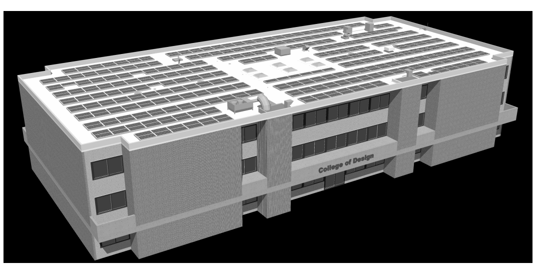

Figure 4: Rendering from the CDS PV rooftop feasibility study.

Table 5: Percent improvement from the baseline ***electric*** *consumption from the improvement scenarios.*

Scenario	CDS	CDN	GIOS
External shading system			2%
Envelope insulation	3%	1%	
Glazing upgrade	2%	0%	1%
Lighting load reduction	5%	13%	1%
Lighting upgrade- fluorescent	3%		
Lighting upgrade- LED	14%	18%	15%
Plug/equipment load reduction	5%	5%	11%
Fan static pressure improvement	7%	1%	7%
Central plant upgrade	12%	11%	16%
Rooftop PV system	15%		14%
Combined Scenarios	50%	48%	63%

Table 6: Percent improvement from the baseline ***gas*** *consumption from the improvement scenarios. The reason for the negative improvement of the combined scenarios is the switch from electric to natural gas in the proposed CHP plant.*

Scenario	CDS	CDN	GIOS
External shading system			1%
Envelope insulation	12%	15%	
Glazing upgrade	10%	4%	4%
Lighting load reduction	-2%	-6%	0%
Lighting upgrade- fluorescent	0%		
Lighting upgrade- LED	2%	-16%	-3%
Plug/equipment load reduction	-1%	-1%	-2%
Fan static pressure improvement	-3%	0%	-3%
Central plant upgrade	-130%	-741%	-286%
Rooftop PV system	0%		0%
Combined Scenarios	-112%	-747%	-247%

Table 7: Percent improvement from the baseline ***annual carbon footprint*** *from the improvement scenarios.*

Scenario	CDS	CDN	GIOS
External shading system			1%
Envelope insulation	4%	1%	
Glazing upgrade	3%	0%	1%
Lighting load reduction	4%	11%	1%
Lighting upgrade- fluorescent	3%		
Lighting upgrade- LED	14%	16%	12%
Plug/equipment load reduction	4%	4%	9%
Fan static pressure improvement	6%	1%	6%
Central plant upgrade	-9%	-12%	-11%
Rooftop PV system	13%		12%
Combined Scenarios	38%	21%	26%

The most effective scenarios are: upgraded lighting, upgraded central plant and installation of a PV system. Due to the fact that these buildings are internal load dominated, it is not surprising that the building envelope improvements did not significantly increase performance. Tables 8-10 compare the energy consumption, EUI, CUI, and annual tons of carbon for the existing and improved buildings. Although there is not a large change in the EUI, the CUI is significantly smaller. This is due to the switch from an electric to natural gas in the proposed CHP plant and in the case of CDS and GIOS, the instalment of the PV system. Even though the carbon footprint of each building was significantly reduced, it is still a far reach for carbon neutrality. This study suggests the need for rapid expansion of renewables and technological advancements in lighting and equipment efficiency to move towards carbon neutrality.

Table 8: Comparison of the existing and improved CDS.

	CDS Existing	CDS Improved
EUI ($kWh/ft^2/yr$)	22.32	25.30
CUI ($lbs\text{-}CO_2/ft^2/yr$)	26.79	16.69
Operating Carbon (tons/yr)	778.16	568.34
Materials Carbon (tons/yr)	60.85	60.85
Solar Carbon Reduction (tons/yr)	0.00	106.59
Total Carbon (tons/yr)	839.01	522.60

Table 9: Comparison of the existing and improved CDN.

	CDN Existing	CDN Improved
EUI ($kWh/ft^2/yr$)	14.04	20.28
CUI ($lbs\text{-}CO_2/ft^2/yr$)	22.07	17.53
Operating Carbon (tons/yr)	1056.76	818.54
Materials Carbon (tons/yr)	102.01	102.01
Total Carbon (tons/yr)	1158.76	920.55

Table 10: Comparison of the existing and improved GIOS.

	GIOS Existing	GIOS Improved
EUI ($kWh/ft^2/yr$)	18.57	25.49
CUI ($lbs\text{-}CO_2/ft^2/yr$)	24.80	17.12
Operating Carbon (tons/yr)	557.84	442.16
Materials Carbon (tons/yr)	47.42	47.42
Solar Carbon Reduction (tons/yr)	0.00	71.88
Total Carbon (tons/yr)	605.25	417.70

CONCLUSION

This exercise outlines an effective methodology for determining a building's carbon footprint that can be utilized in a classroom setting. It is of growing importance to understand how to measure and reduce carbon emissions. This class along with the Campus Metabolism energy dashboard and the ASU's expansion of solar energy are active strategies that belong to a larger initiative that ASU is undertaking in correspondence to its commitment to carbon reduction and eventual carbon neutrality. We also believe that classes like this can help the design community to better understand the complexities of carbon neutrality and how buildings can successfully achieve this objective.

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