The Quandary of Quantification: Verifying the Climate Impact of Sustainable Design

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How can we measure the impact of sustainable design in the rebuilding of New Orleans? How 'green' is the Tulane GREENbuild prototype house? What method could the Holy Cross community employ to verify progress toward carbon neutrality? How can the real impact of sustainable practices be quantified and verified? How can individual sustainable design initiatives integrate into international carbon trading systems? Is there a way to put a number to the good intentions?

An accurate and verifiable method to calculate the carbon emission savings of new construction is essential; this is the necessary basis for a Green House Gas (GHG) market. Although efforts are being made, there is no comprehensive national or international measurement strategy. Carbon offsets and voluntary reporting of greenhouse gas emissions and reductions are increasing, but currently consist of a wide range of sources using different calculation methods with varying results. GHG offset trading is an essential economic motivator for environmental action. A legitimate, international carbon trading market is evolving slowly, but it is needed now. To economically stimulate local sustainable design, we must be able to measure the impact of an individual home.

There are dual motivations to quantify sustainable design: first, a global need for GHG accounting for voluntary reporting and emission offsets trading and, second, individual project-specific accounting. The problem with both is the delicate balance between individual and statistical analysis. Statistical analysis uses accumulated data to create a common baseline that can be applied to each strategy. This type of measurement has conveniently broad application with less time and effort, but there are problems with accuracy, verifiability and specific relevance. Individual project analysis, including predictive modeling, quantifiable monitoring, and before/after assessment is more precise. It is also more time and energy intensive, and therefore more costly. It is complicated to make accurate comparisons between projects with different measurement strategies, or to apply generalized conclusions using the specific results.

Green House Gas offsets are based on reductions, so there must be a standard measurement and reporting standard. On a federal level, The Energy Information Administration of the US Department of Energy (DOE) created a process for the Voluntary Reporting of GHG. This is to encourage government agencies, corporations, and households to annually report their emissions, reductions, and sequestrations. Greenhouse gas emission levels are measured for a baseline period of one to four years previous to changes. This determines the standard annual emissions, and creates a base value to evaluate reductions. If this data is unavailable, as it is for new construction, the base value can be the historic emissions level or benchmark value, which are specified by the DOE through Energy Star.

In efforts to create an international standard, The Greenhouse Gas Protocol is a project partnership between the World Resources Institute and the World Business Council for Sustainable Development. They are in the process of creating a Project Quantification Standard to promote consistency of GHG quantification.

Energy Saving Certificates are the currency of the global carbon trading market. "There is the widely held view that energy efficiency measures are unreliable, unpredictable, and unenforceable. One solution for overcoming some of these problems is to institute strong energy efficiency measurement and verification methodologies along with a credible tracking system"(ii). These tags, otherwise known as Energy Saving

Certificates (ESC), are the individual, traceable property rights for specific GHG emission reduction and renewable energy generation. ESCs are generally known as Green Tags. These tags represent 1 mega-watt hour (MWh) of electricity generated renewably. Renewable energy can be measured directly through metering or monitoring of individual systems. Emission reductions are achieved though broad range of methods, and are more difficult to quantify consistently. White Tags, recommended by the Kendell Foundation, are a specific form of ESC. They may be a necessary medium for the GHG market. White Tags advocate a 'flexible' approach to calculating energy savings, based on international methods and supported by third party auditing. There is the deemed savings approach (which specifies a statistically determined average), predictive calculations, and energy monitoring. To analyze the resulting data, there must be a baseline in order to calculate energy savings. The ESC baselines reference European national industry standards- estimates of the predicted energy use for a particular home, system or appliance. In the United States, this can be accomplished through the DOE Energy Star guidelines and calculation methods.

Leadership in Energy and Environmental Design (LEED), which has become the national environmental design assessment standard, requires an energy efficiency improvement relative to a standard baseline. In the new construction standard, the energy performance of the building is compared to values in ASHRAE/IESNA Standard 90.1-2004. LEED generally advocates preliminary "energy and envelope systems analysis or design." LEED refers to the Energy Star for Homes standards. To become an Energy Star Qualified New Home, the construction must include energy saving features to become at least 15% more efficient than DOE standards, as specified in the 2004 International Residential Code (IRC). Energy Star homes must meet the DOE standards for effective insulation, high-performance windows, weatherproofing, efficient heating and cooling equipment, lighting and appliances. The Energy Star rating is supported by third-party verification and inspection.

Given the difficulty establishing a baseline for new construction, comparison to a set national average is a practical and effective method. This creates analysis contingent on a reduction goal rather than existing conditions. While these techniques are absolutely valid, this rating does not have a required or recommended method to assess the resulting savings after construction and installation.

This leaves a current conundrum for architects: how can we calculate the energy savings of new construction? There is no base value against which to compare, and the DOE has released no applicable benchmark values. The Greenhouse Gas Protocol has not released their standards. How can individual, differentiated projects be assessed and integrated into the evolving standards? Logically, a base value must be determined through regional energy use averages for comparable size and occupancy. This creates assumptions that are hard to verify, and compromises the integrity of the calculations. How should the positive effects of sustainable design be quantified? Rigorous estimates are essential in this process.

This investigation analyzed the Tulane GREENbuild project, a sustainable housing prototype. The GREENbuild house is a modular, eco-friendly housing prototype for Central City New Orleans. It was designed and built by Tulane architecture students to investigate and illustrate environmental strategies. The primary strategies are modular construction to reduce initial waste, energy efficiency measures, and solar strategies. To prevent material waste and to simplify construction, the design fully incorporates a 4'-0" x 8'-0" module in both the horizontal and vertical orientations. The 1200 square foot prototype is composed of three separately built modules: 1) a combination living/dining/kitchen space 2) a two bedroom module with a shared bath, and 3) a master bedroom suite. The framing and exterior finishes were completed at a warehouse, then the modules were installed on site. The living/kitchen/ dining module slips past the double bedroom module to share the bathroom. The master bedroom module is positioned to the rear to offer privacy and to enable its conversion into a separate rentable space. The multiple porches provide extensions of interior living space.

The home's form is derived from passive eco-friendly design strategies. In addition to maximizing daylighting and ventilation, the butterfly shape roof provides rainwater collection. The higher roof pitch at the Northern facade allows for clerestory windows that daylight the living/kitchen/dining and master bedroom modules. These are constructed with double insulated polygal, which has U-value comparable to insulated glass. The lower pitch on the Southern side helps to block the high, hot summer sun. Operable low-emissivity (low-e) windows are placed on at least two sides of each room to maximize cross-ventilation and reduce energy consumption. Ceiling fans in each space reduce air conditioning demand. High U-value soybean spray insulation throughout the building envelope further reduces the house's energy cost. Recycled and low-impact building products are used throughout, along with responsibly harvested lumber. Renewable cork and bamboo flooring and native landscaping further reduce the environmental impact.

Three primary quantifiable energy strategies were employed. The use of Energy Star additional appliances minimizes energy usage, thereby contributing to the carbon emission savings. Once the house is occupied, the specific energy savings can be verified, using the local average residential energy use as a base value. Heat pumps decentralize the heating and cooling load of the house, allowing zoned temperature control and eliminating the need for ductwork. This more efficient system reduces the total energy load. Solar panels, once installed, will power the refrigerator and provide emergency electricity.

Initial analysis used a statistics approach. Energy Star provides a starting point for carbon emission savings. The website provides interactive Excel spreadsheets for the majority of residential electricity uses. These Energy Star calculators provide user-friendly access to a vast amount of DOE statistical data on average energy use appliances, mechanical systems and light bulbs. Input can be changed to project specifications, and calculated for both annual and lifecycle savings. The savings calculators use specific assumptions about energy savings and the resulting carbon emission reductions. Energy Star uses the EPA 2006 electricity CO_2 emission factor (1.535 lbs CO_2/kWh) and various specified organization and industry data. These are available in a separate assumptions tab. Therefore the quantifiable impact of energy-saving lighting, heating, cooling, and appliances can be calculated efficiently.

Tulane Greenbuild Statistical Calculations	**Number of Units**	**Annual Savings per unit (kWh)**	**Total Annual Savings (kWh)**	**Lifecycle (years)**	**Lifecycle Savings per Unit (kWh)**	**Total Lifecycle Savings (kWh)**
Energy Star *						
Washing Machine	1	25.8	25.8	11	283.8	283.8
Dishwasher	1	136	136	11	1503	1503
Refrigerator**	1	110	110	10	1100	1100
Compact Florescent Bulbs 15-watt interior	16	50	800	9 (or 10,000 hrs)	450	7,200
Compact Florescent Bulbs 20-watt exterior	9	44.5	400	9 (or 10,000 hrs)	400	3,600
Ceiling fan with Light	5	151.25	756.3	10	1,513	7,563
Heat Pump- 9,000 btu Unit ***	3	445.3	1336	12	5,344	16,036
Heat Pump- 12,000 btu Unit ***	2	594	1188	12	7,128	14,254
Photovoltaic System******						
Solar Panels*****	2	3,757	7,524	25	93,925	187,850
Energy Star Total Annual Savings			**4,752.10**	**Energy Star Total Lifecycle Savings**		**51,494.80**
Total Annual Savings			**12,266.10**	**Total Lifecycle Savings**		**239,244.80**

* Energy Star Savings Calculators (default settings) http://www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing
** Assumed Frigidaire CRSE264J
*** Turbo Air indoor wall mounted split type units http://www.turboairinc.com/TA-Products/Split.html
**** Sharp Model NE-170UI Multi-purpose Module Panel 170 kW (+10% - 5%) model using 125mm poly-crystalline silicon solar cells with 13.10% module conversion efficiency. Reduced output 25% due to battery conversion.
***** Manufacturer Calculation for 3.0 kW-DC system (zip code: 70113): http://www.clean-power.com/sharp/ezcalculator.aspx

The principle design approaches- such as maximizing natural day lighting, ventilation, and outdoor living- cannot be quantified so easily. The engineered value of specific appliances and fixtures can be uniformly calculated; but the qualitative architectural strategies defied numeric translation. This is the central problem of this investigation- how to quantify the energy use impact of design.

Various energy modeling programs claim flexible, predictive modeling capacity. After assessing several programs, the Tulane GREENbuild house was modeled with EQuest (the QUick Energy Simulation Tool), which is produced by the Department of Energy. As of 2007, it is the required software for the California Energy Commission. But it required cumbersome amounts of data, had narrow options and resulted in inaccurate and non-verifiable results. Although it provided options for each input, the specific systems were not always available in the program. The zoned heating and cooling heat pumps in the GREENbuild house are not a standard system, and could not be accurately entered into the software. The specific use of electric heat pumps and natural gas stove was unavailable as well. Therefore the heating and cooling loads were not accurate, making the resulting data irrelevant. The results stated that 86% of energy would be involved with space heating. This is completely inaccurate for New Orleans, which has a hot, humid climate. Although the geographic data was entered, many programs do not have as accurate climatic information for the Southeast as other regions of the United States. Accurate climate data is essential for any energy calculations.

Energy modeling should be an integral design tool. During schematic design, it should affect the massing, orientation, and location of openings and overhangs. Energy modeling could directly and positively influence these design decisions. A practical predictive energy modeling software would be an invaluable asset to the sustainable design process. The Tulane GREENbuild has already been constructed; therefore the modeling software was not productive.

The most accurate method to calculate carbon emissions savings is actual field measurement, through monitoring or metering. A photovoltaic system will be installed on the house, which will be monitored. The electrical output of the panels can be recorded with per second accuracy, and downloaded into adjustable Excel spreadsheets. Once the house is occupied, this will verify the renewable energy produced by the system. With monitoring, however, there must still be a baseline for comparison. Entergy New Orleans, the local utility company, provided an average household electricity use from 2004. But this is not specific to varying number of rooms, occupancy, or square footage. Therefore any comparison to average local residential energy use is a broad estimate at best. Therefore the analysis could compare to the International Building Code residential standard, as in the Energy Star method. Therefore an overall percentage reduction can be determined. This encourages energy reduction goals for the construction and use of the home. Energy Star requires a 15% reduction, but with comprehensive and creative strategies, the energy use can be reduced much further.

The GREENbuild house will save 12,266 kWh of electricity annually. Using the standard referenced by Energy Star, the EPA 2006 electricity CO_2 emission factor of 1.535 lbs CO_2/kWh, this is an annual carbon emission reduction of 9.4 tons. The annual Energy Star appliance savings alone is 3.6 tons. Over the lifecycle of the house, the electricity savings of the house will be 239,245 kWh, which translates to 183.6 tons of carbon emission reductions. The lifecycle Energy Star savings are 39.5 tons. Once the house is occupied, metering will determine the energy use of the GREENbuild residence. This data can be compared to the baseline energy usage in ASHRAE/IESNA Standard 90.1-2004 Appendix G. This will determine the percentage of energy savings, which will reveal whether the house meets the baseline goal of an Energy Star Qualified New Home.

Sustainable design is essential. It is simply smart design. Yet sustainable design requires additional persuasion due to higher construction costs. There must be an accurate and verifiable way to predict and quantify the energy savings produced by sustainable design. Statistical analysis, predictive modeling, and metering can be used to determine these savings. Individual circumstances require for different applications of these methods.

Statistical analysis can reveal the energy savings and carbon reductions from the engineered systems. Predictive modeling, used as a design tool, can forecast the energy savings of a variety of architectural approaches. Metering or monitoring discloses the actual individual reductions of a project. These analyses can convincingly reveal the energy savings of sustainable design. This translates into carbon emission reductions and monetary savings for the client, in terms of defined lifecycle savings. As the GHG offset trading markets escalate in scale and value, this will provide additional lucrative benefit for sustainable designs. Can statistical and individual analysis be reconciled? Only if there is an accepted best practice method that allows translation from specific project data to global evaluation. All that is missing is an internationally accepted, precise and provable calculation method.

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