The Society of Building Science Educators' Carbon Neutral Design Project:
The CND building case study protocols

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ABSTRACT: Inspired by Ed Mazria's 2010 Imperative and 2030 Challenge to both educators and the architectural profession, the SBSE Carbon-Neutral Design (CND) Project is an international educational resource development initiative on the topic of carbon neutral design. SBSE's goal is to capture, develop pedagogical approaches for, and disseminate the knowledge base that is emerging on producing buildings that require no fossil fuel energy and create no green house gas emissions. Phase I of the CND project has been funded by the American Institute of Architects and others, and has been underway since May, 2008. This paper will focus on the Phase I activity of building case studies and the specific CND project protocols that have been developed for this ongoing case study effort.
Keywords: Carbon Neutral, Energy, Case Study, Protocol, Society of Building Science Educators, SBSE

INTRODUCTION

Inspired by Ed Mazria's 2010 Imperative and 2030 Challenge to both educators and the architectural profession, the SBSE Carbon-Neutral Design (CND) Project is an international educational resource development initiative on the topic of carbon neutral design. SBSE's goal is to capture, develop pedagogical approaches for, and disseminate the knowledge base that is emerging on producing buildings that require no fossil fuel energy and create no green house gas emissions. The resulting educational materials will be disseminated through the AIA web site, through SBSE's international network, and through other academic and professional venues.

	Commercial/ Institutional Architecture	**Affordable Housing**
Architectural Design Studio Education	Building Case Studies/ Design Studio Case Studies	Building Case Studies/ Design Studio Case Studies
Professional Continuing Education	Building Case Studies/ Design Studio Case Studies	Building Case Studies/ Design Studio Case Studies

Figure 1: CND Project Phase I Themes

The themes that organize phase I of the CND project can be understood as a four-square matrix, with academic design studio focused education and professional continuing education sharing one axis, and commercial/ institutional architecture and low to zero-energy affordable housing sharing the other. A series of case studies of best practices in both carbon neutral building design and design pedagogy are the vehicles that allows us to simultaneously examine the commonalities of all four quadrants. This presentation will focus on the building case study aspect of the project.

THE CND BUILDING CASE STUDY EFFORT

This building case study effort itself is comprised of two distinct fronts- the development of an Excel based analytical tool- the "CND Case Study Protocol," and the development of a parallel template for graphic analysis of individual buildings. The two are woven together, though each can be pursued without undertaking the other. The intention is that the complete protocol will be adopted by educators as a design studio or seminar project template, and undertaken on buildings of particular local, regional or national interest, while practitioners wishing to better understand how their own projects compare with national models might simply undertake the Excel based analysis.

Professor Mike Utzinger is primarily responsible for the development of the "CND Case Study Protocol," while professor Wasley has been responsible for the development of the graphic analysis framework and for the initial case study work through his Fall 2008 Arch. 625-825 Architectural Design Studio.

In the Fall of 2008, 15 recently completed buildings were identified as approaching a carbon neutral design standard and teams of two students each in Professor Wasley's Arch. 625-825 Architectural Design Studio were assigned two or more of those projects. This mix included at least one affordable housing project and one or more commercial or institutional project per team.

The list of projects was selected by the CND Project team, working from the DOE High Performance Buildings Data Base, the AIA Cote Top 10 winners list, more general web-searches and calls made to known green design firms. A target of 30 kBtu/s.f.-year was set as a threshold for consideration, though in the final recruitment process this was honored in the breach.

The minimum information requirement for each case study has been a full set of architectural and mechanical systems drawings, selected specifications (primarily glazing specifications) and a year's utility data. Other resources have been provided by various architects and owners where available. Individual architects have also conducted phone/internet conference calls with the design studio to introduce the projects and talk through their technical issues.

This has been a compressed process. For this and other reasons, the goal of the project has been focused as much on the development of a framework that will be ongoing as it has been on the immediate 15 case studies, ten of which have been selected for continued in-depth development in the Spring of 2009, with six of those considered the core deliverable of the project.

THE CND PROTOCOL'S HYPOTHESIS

The underlying goal of this effort is to develop a detailed yet conceptually simple set of analytical tools that can be distributed to schools of architecture and to architectural practices, and that will lead over time to a deep data base of projects all sharing exceptionally high energy performance standards. These case studies are intended to sit between the introductory level of information typically available through the High Performance Buildings Data Base and the level of information flowing from a true energy simulation study or post-occupancy evaluation.

The Excel CND Protocol is not an energy simulation, but rather an inventory of many of the elements that would be inputs in such a model. The CND Protocol creates a description of the physical attributes of a building, cataloguing basic 'independent design variables' such as Glazing/sf. Floor Area, % Perimeter Zone Area, Installed Lighting Power, etc… It then calculates 'dependent variables' such as Energy Utilization Intensity (kBtu/sf-year) or Occupant Utilization Intensity (gross building floor area (GSF) per full-time occupant equivalent).

These variables do not in themselves describe the energy use of the building, though the gathered utility data does, for at least the period for which it was gathered. If we compare these case study buildings to cars, we are not describing how well the car is being driven. What we are doing even without the utility data is examining how aerodynamic the vehicle is and how large the engine is. With the utility data, to continue the metaphor, we are then reporting on the miles per gallon.

Our guiding hypothesis is that these exceptionally high performance buildings share certain physical attributes and constraints that maximize their ability to harness natural energy flows and limit their potential to waste fossil energy, regardless of how well or poorly they are operated. A typical attribute that we would hypothesize will prove to be common among carbon neutral buildings would be a high 'Skin Dominance Factor' (Total building enclosure area divided by gross building floor area- S.F./ S.F.). A typical constraint would be a consistently low lighting power density.

CND CASE STUDY PROTOCOL ORGANIZATION

To facilitate various levels of engagement with the tool, the CND Protocol is organized into three levels of detail. Level 1 considers only overall building descriptors and utility data to describe overall resource use. Level 2 requires more detailed inputs of window shading geometry and/or of sub-metered utility data, and produces an analysis of design related parameters. Level 3 will seek to describe proxies for estimating embodied energy, energy associated with water and the like.

A second concept that we are seeking to map through these three levels of difficulty are the three scopes of carbon accounting: On site combustion, off-site electricity generation, and indirect sources of carbon emissions such as transportation associated with the facility etc... We believe that this language is important for the architectural profession to become familiar with, though the details of how we or others will apply these concepts to this architectural analysis are yet to be resolved.

CND CASE STUDY PROTOCOL METRICS

LEVEL 1- PROJECT INFORMATION

Comparison of different buildings is achieved by normalizing independent and dependent variables to a unit building area. The complication comes in determining the appropriate area to measure. Three different building areas are described below. By measuring and reporting each of the areas, results reported in terms of one area, for example gross building area, can be normalized to different building area definitions. It is proposed that gross building floor area be the normalizing building parameter and that Conditioned and Occupied building floor areas also be reported. Case studies will be reported in Imperial and SI units.

- Climate descriptors- HDD, CDD, and Dew Point DD.
- Design and Construction Cost.
- Gross Building Floor Area (GSF)- SF [m^2] Total building floor area measured to outer surface of enclosure.
- Occupied Building Area (OSF)- SF [m^2] Occupied building floor area measured to inner surface of enclosure, includes all ventilated spaces, conditioned and unconditioned (ventilated garages would be included, unventilated storage would not).
- Conditioned Building Area (CSF)- SF [m^2] Conditioned building floor area measured to inner surface of conditioned enclosure (excludes garages, unconditioned storage, mechanical, unconditioned atria, etc.)
- Daylit Area _________
- Occupancy- FTE. The occupant full time equivalent includes staff, students, clients, and visitors.

LEVEL 1- BUILDING RESOURCE USE METRICS BASED ON GROSS FLOOR AREA

Energy Resources

- Energy Utilization Intensity (broken down by sources)- kBTU/SF/year [kWh/m^2/yr]
- Site Renewable Energy Generation- kBTU/SF/year [kWh/m^2/yr].
- Net imported energy intensity- kBTU/SF/year [kWh/m^2/yr].

Project Costs

- Unit Construction Cost- $/SF [$/m^2].
- Unit energy cost per year- $/SF [$/m^2].

Carbon Dioxide Emissions

- Carbon Dioxide Emissions- fossil fuels, biofuels, grid electricity, solar PV electricity- Tons C02. Total and Fossil Carbon Dioxide Emissions Intensity- Lb CO2/SF/year [kg CO2/ m^2/yr].

Water Usage

- Water Usage Intensity- Gal/SF/yr [l/m^2/yr]
- Site Recycled Water Percent- %
- Site Rainwater Harvest Percent- %

Resource Use Per Occupant

- Occupant utilization intensity- sf/FTE [$m^{2/}$FTE].
- Occupant energy intensity kBTU/SF/year [kWh/m^2/yr]
- Occupant imported energy intensity
- Occupant net carbon dioxide emissions intensity
- Occupant water use intensity- Gal/FTE/year [l/FTE/yr]

Daylighting

- percent daylit spaces.

LEVEL 2- BUILDING DESIGN METRICS

Enclosure metrics based on gross floor area

- Enclosure Area Per Unit Floor Area- SF/F [m $m^{2/}$ m m^2].
- Enclosure Thermal Transfer Rate- BTU/SF/Hr/°F [W/m^2/°C] The rate heat transfers across the building enclosure per gross building floor area.
- Building Thermal Capacitance- BTU/SF/°F [kJ/m^2/°C] The rate the building absorbs or releases heat per unit temperature per gross floor area.

Renewable Resource Metrics Based on Gross Floor Area

- Solar PV Density- W/SF [W/m^2] Installed PV peak power divided by gross building floor area.
- Solar Thermal Density- SF/SF [m^2/m^2] Solar thermal collector area per unit floor area.

Illumination Metrics Based on Gross Floor Area

- Lighting Power Density- W/SF [W/m^2]
- Building Glazing Areas per Gross Floor Area for Each Unique Orientation and Slope- SF/SF_{total} [m^2/m^2_{total}] SF/SF_{south} [m^2/m^2_{south}] Etc. The sum of the glazing ratios for each orientation and slope is the total building Enclosure Glazing Ratio.

Ventilation Metrics Based on Conditioned Floor Area

- Operable Window Area Per Conditioned Floor Area- %
- Outdoor Air Ventilation Rate- cfm/SF [l/s/m^2] Total provided outdoor air ventilation flow rate divided by gross building floor area.
- Installed Ventilation Capacity (supply and exhaust)- cfm/SF [l/s/m^2] Total installed fan ventilation rate divided by gross building floor area.

Heating and Cooling Metrics Based on Conditioned Floor Area

- Heating Capacity- BTU/SF & BTU/SF/°F-Day [W/m^2 & W/m^2/°C-Day] Peak heating delivery rate per unit floor area.
- Cooling Capacity- SF/Ton SF*°F-Day/Ton [m^2/kW & m^2*°C-Day/kW] Gross building floor area divided by peak cooling capacity. Product of gross floor area and cooling degree days divided by peak cooling capacity.

Fan and Pump Metrics Based on Conditioned Floor Area

- Fan Power Density (supply and exhaust)- W/SF [W/m^2] Total installed fan power per unit floor area
- % of Fan Power that is VFD or Variable Speed
- Fan Thermal Transfer Efficiency- Btu/hr-°F-W [kJ/hr-°C-W].

- Pump Power Density- W/SF [W/m^2] Total installed pump power per unit floor area
- % of Pump Power that is VFD- %
- Pump Thermal Transfer Efficiency- Btu/hr-°F-W [kJ/hr-°C-W].

NOTE: In addition to the quantifiable variables listed above, the case studies will include a more complete description of the HVAC system and lighting controls.

LEVEL 3 - INDEPENDENT DESIGN VARIABLES – TIME DEPENDENT

The time dependent design variables relate to the detailed performance of the glazing system. The glazing area, shading geometry, visible transmittance, solar heat gain coefficient for each orientation and slope are determined from the construction documents and specifications. The glazing system is then modelled each daylight hour of the year to determine the daily and seasonal variation of building irradiated fraction, visible transmittance and solar heat gain coefficient.

- Building Irradiated Fraction - f_i % Radiation weighted fraction of solar irradiated to total area of all building glazing surfaces irradiated by direct sunlight, calculated hourly for each month. f_i is a measure of the solar control effectiveness.
- Building Visible Light Admittance- Foot candles [lux] Average illumination admitted by all glazing surfaces per gross floor area. Visible admittance is calculated each hour for each month of the year
- Building Solar Heat Gain- Btu/hr/SF [W/m^2] Total solar heat gain thru glazing system per gross floor area. Averaged over each daylight hour for each month.

THE CND GRAPHIC ANALYSIS TEMPLATE

The Graphic Analysis of the CND case study buildings has evolved into an equally detailed description of the various environmental strategies and systems of the building as they relate to these core quantitative metrics. The intention here is to provide a graphically compelling description of these systems from a distinctly pedagogical perspective. We see them primarily as 'resources' for more focussed future use, either in a second phase of the CND project, or as downloadable materials for others to draw from in their own investigations, rather than fully formed narratives. The goal in this case is to be consistent in format, exhaustive rather than concise, and to describe each system and purposeful set of objectives individually. This, we hope, will allow others to be synthetic in their approach to the material.

The topics of analysis, which are coordinated with topics addressed by faculty curriculum materials in the portion of the CND Project chronicling Design Studio pedagogy, include the following:

Project Overview
Site
- Climate Analysis
- Site Analysis/ Site Design

Building Massing and Orientation
Providing Enclosure
- Aperture Distribution
- Thermal Enclosure
- Controlling Solar Gains

Providing Illumination
- Daylighting
- Electric Lighting

Providing Fresh Air
- Natural Ventilation
- Mechanical Ventilation

Providing Heat
- Passive Solar Strategies
- Mechanical systems

Providing Cooling
- Passive Strategies
- Mechanical Systems

Providing Renewable Energy
Minimizing Embodied Energy
Minimizing the Carbon Cost of Water

In addition, each graphic case study includes an abbreviated set of drawings, with critical dimensions included, and a set of high resolution photographs of the building. As future research unfolds, interviews with the architects and other design team members will be included.

A final intention of the graphic case study project has been to have students construct these graphics through the vehicle of a BIM model that they would construct from the working drawings provided by the architect. Our goal, only partially realized to date, is to use this model to extend the quantitative analysis of the projects by, for example, quantifying the materials in the building in order to estimate embodied energy content.

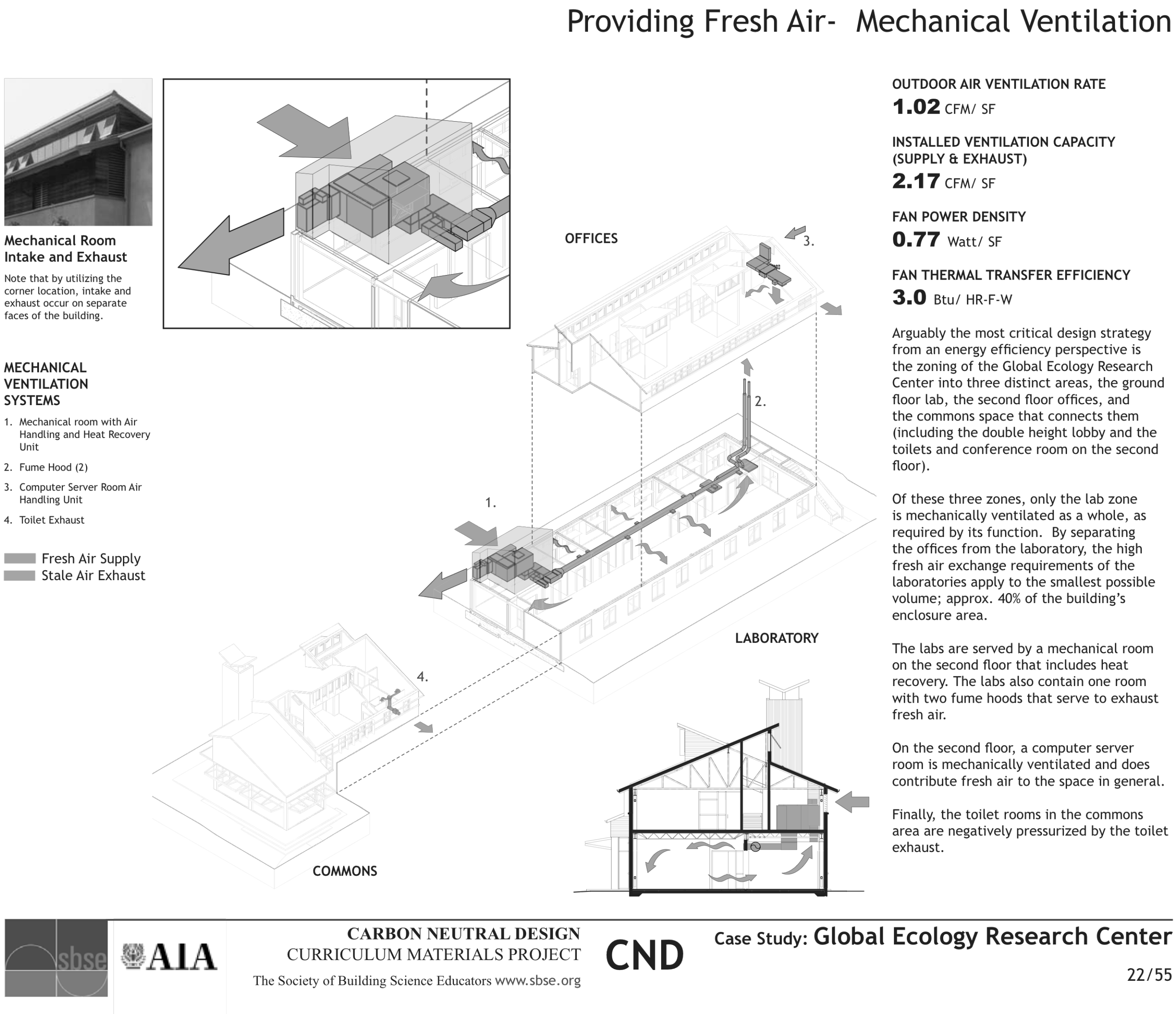

Figure 2: Sample graphic analysis. Center for Global Ecology, Scott Shell, EHDD Architects.

This strategy has proven very powerful, and we would argue that the act of creating an accurate model from plans is very instructive. It has, at the same time, proven to be a very steep learning curve.

CONCLUSIONS

The CND Project will be formally unveiled at the American Institute of Architects Conference in San Francisco, April 29, 2008. At that time, the first six case studies will be posted online and available for public use. It is our hope that these resources prove both useful and inspiring in their invitation to study additional buildings closely to better understand their shared intelligence.

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