A DESIGN TOOL FOR MEETING THE 2030 CHALLENGE:
Measuring CO2, Passive Performance, and Site Use Intensity

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ABSTRACT

Ed Mazria, the AIA, the USGBC and others have jointly issued the 2030 Challenge, that asks architects to create buildings that are carbon-neutral by 2030. As a first step it asks that the fossil fuel consumption of all new buildings be reduced 50% between now and 2010. This target is readily achievable, but to do so Mazria says we need a little "performance feedback box" in our design tools and on our CAD drawings to show how close each design change gets us toward that goal.

This paper will illustrate one of the ways this kind of information can be generated and displayed. It will also discuss some of the unresolved issues with this approach.

A design tool that already calculates and displays this kind of data is HEED (Home Energy Efficient Design)[1]. The Site Energy Use Intensity (SUI) is calculated as the BTU equivalent of all the fuel and electricity used on site. The production of CO_2 is calculated for each kilowatt of electricity or therm of fossil fuel energy used in the building. Passive Performance is a measure unique to HEED that is displayed as the number of hours per year when the building uses neither heating nor cooling energy. HEED shows graphically how every design revision changes each of these three measures.

WHAT IS THE 2030 CHALLENGE?

The 2030 Challenge points out that buildings are responsible for about 48% of all the energy consumption and greenhouse gas (GHG) emissions in this country. "Immediate action in the Building Sector, and a concentrated global effort, are essential if we are to avoid hazardous climate change".[2]

The 2030 Challenge asks the building community to adopt the following targets: "That the fossil fuel reduction standard for all new buildings be Carbon-neutral by 2030 (using no fossil-fuel GHG-emitting energy to operate)", and also "That all new buildings, developments, and major renovations be designed to meet a fossil fuel, greenhouse gas emitting, and energy consumption performance standard of 50% of the regional average for that building type" by the year 2010.[2] A webcast explaining all this was recently seen by over a quarter million architects, designers, students, and other building sector members in 42 countries..

KINDS OF TOOLS DESIGNERS NEED

It must be possible for architects to instantly see how close each design revision gets the building's performance toward achieving the goal. This target is easiest to achieve at the very beginning of the design process when it is easiest to make major changes to building form, orientation, window location and sizing, glass type, building materials, and by incorporating passive heating, ventilation cooling, and daylighting strategies. If architects have to work without this immediate feedback, they might find themselves at the end of the Schematic Design Phase with a building that is a long way from

meeting the goal and that is very difficult to re-design in any significant way.

One example of an energy design tool that shows designers the building's performance at very step of the way is HEED (Home Energy Efficient Design).[1] When HEED is first launched it asks four questions about the project (building type, square footage, number of stories, and climate location). With this information it creates Scheme 1, a building that meets the California Energy Code. It then designs a second Scheme that is usually about 30% better (still not good enough). Next it suggests other strategies that designers can test using the remaining seven schemes. HEED makes it extremely simple for users to change any aspect of the building's design[3]. After each design change HEED shows how the building's performance compares with the 50% goal.

MEASURING SITE ENERGY USE INTENSITY

The way performance is measured in the 2030 Challenge is by Site Energy Use Intensity (SUI) which is the BTU equivalent of all the fossil fuel and electricity used on site.[4] HEED calculates the amount of fuel used for space heating, water heating, cooking, and clothes drying, all measured in Therms. One Therm is 100,000 BTUs. It calculates the electrical consumption for air conditioners, fans, lights (as reduced by daylighting), appliances, and if no fuel is available, for space heating, water heating,

Fig.1: Site Usage Intensity: Scheme 1 Meets the Energy Code and Scheme 9 uses about 58% less energy (blue is electricity, red is fuel). To see these percentages select the down arrow in the box in the top center of this graphic.

cooking, and clothes drying, all totaled into kWhr. This total electricity is then multiplied by 3.412 BTU/Watt. Both the fuel and electricity totals are added up, and then divided by the square footage of the building, to give the annual Site Use Intensity in kBTU/sf. All these results are shown on a screen titled BEPS (Building Energy Performance Standards). As each new design change is made HEED simulates the buildings performance for all 8760 hours per year and re-calculates this total Site Use Intensity.

In this example (Fig.1) the bars on the left represents Scheme 1 which is a building that meets the California Energy Code, while the final yearly total design in Scheme 9 uses 58% less energy. The kinds of design changes that were made in this example included:

- Long building axis running east-west
- Better window glazing and orientation
- Energy Star air conditioner and furnace
- Super insulation
- Awnings on S and W Windows in Summer
- Operable night insulation drapes
- High mass stone fireplace
- Energy Star appliances

.
Notice that all of these options use today's technology, and in fact there are many other combinations of fairly conventional design alternatives that could have produced the desired 50% reduction in eergy consumption.

MEASURING CO2 PRODUCTION

Buildings account for CO2 in two different ways: first from the on-site combustion of fossil fuels, and second in the off-site generation of electricity in coal burning power plants or natural gas or oil fired turbines. HEED assumes that even though most of the CO2 might be generated hundreds of miles away, it should still be charged to that building's total energy consumption.

CO2 from On-Site Fossil Fuel Combustion

Calculating the CO2 generated by on-site combustion is fairly straight forward. The BTU equivalent of each cubic foot of natural gas or gallon of fuel oil or propane is very stable. One Therm of gas is defined as 100,000 BTUs and is usually equivalent to 1 cubic foot. One Gallon of fuel oil ranges upward from 137,000 BTU/gal. This table (Fig.2) gives the pounds of pollution for NOx, SOx, PM-10 (particulates to 10
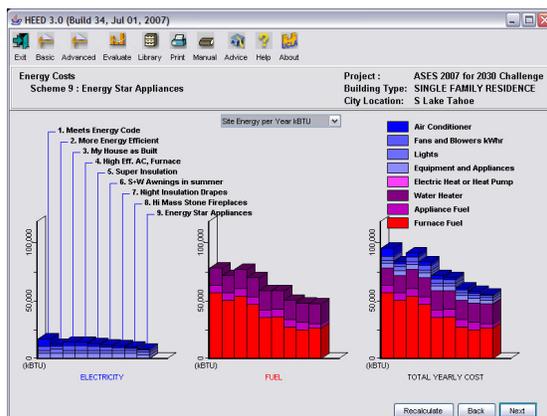
microns), ROG (reactive organic gasses), CO, and CO2. These data should be available from your local gas utility, or from EPA's E-Grid Program[5]. In this particular example the Residential building used 100% Gas, but other mixes of Gas and Oil would be possible.

Pounds/MMBTU
Average National data for 1993

	NOx	SOx	PM-10	ROG	CO	CO2
Residential:						
100% Gas:	0.066	.001	.015	.007	.017	116.00
0% Oil:	0.068	.218	.019	.019	.030	173.00
Commercial:						
0% Gas:	0.096	.001	.003	.005	.019	118.00
0% Oil:	0.136	.218	.019	.019	.038	164.00

Fig.2. This screen shows the initial values HEED uses to calculate the Pounds of Pollution per MMBTUs of fuel, for either natural gas or fuel oil, for either residential furnaces or commercial power plants, but users can change any of these values.

For each scheme HEED calculates (per the ACM) the total annual amount of fuel used for space heating, water heating, cooking, and clothes drying. If the fuel was natural gas, the total therms (at 100,000 BTU/therm) are converted into pounds of CO2 using the factor shown (Fig.2).

CO2 from Electricity Consumption On-Site

Calculating the CO2 equivalent of every kWhr generated is a bit more complicated because it is usually generated hundreds of miles away by a variety of generators.

Note that the pollution values all change monthly (Fig.3) because the amount of energy generated at each location is determined in part by the amount of air pollution that is allowed under the specific local climate conditions during that month. This means that during some months more or less power will be purchased from hydropower or nuclear power plants or renewable resources (wind, solar, geothermal, or

biomass). Your local utility may be able to provide this level of detail, however EPW's national E-Grid[5] data base usually will not have this data available for local utilities at this level of detail, therefore it may be necessary to use the same value for all 12 months. E-Grid provides data only for CO2, SO2, NOx, and HG.

Pounds of Pollution per mWh
Data from Southern California Edison 1993 SCAQMD ELFIN Model

	NOx	SOx	PM-10	ROG	CO	CO2
Jan:	1.110	0.650	0.048	0.032	0.191	593.08
Feb:	1.950	1.150	0.086	0.056	0.335	1,041.45
Mar:	2.510	1.480	0.110	0.072	0.430	1,336.90
Apr:	1.410	0.830	0.062	0.040	0.242	751.90
May:	1.550	0.920	0.068	0.044	0.266	825.47
Jun:	1.090	0.650	0.048	0.031	0.188	583.21
Jul:	1.410	0.830	0.062	0.040	0.242	751.89
Aug:	1.930	1.140	0.084	0.055	0.331	1,029.15
Sep:	1.820	1.070	0.080	0.052	0.312	969.03
Oct:	1.680	0.990	0.074	0.048	0.289	897.25
Nov:	1.870	1.110	0.082	0.053	0.322	998.64
Dec:	1.680	1.100	0.081	0.053	0.320	992.36

Fig.3: This Advanced Design screens shows the data HEED uses to calculate the Pounds of Pollution per mWhr, but users can change any of these values to match their local utility's performance.

For each scheme HEED calculates the total annual amount of electricity used for cooling, fans, lights, appliances, and if no fuel is provided also for space heating, water heating, cooking, and clothes drying. Once the total amount of electricity is calculated in kWhr it is converted into total pounds CO2 using the factors shown (Fig.3).

Total Building CO2 Production

Once the building's CO2 generated by fossil fuel combustion and from electricity generation is calculated for each scheme, they are added together and displayed in a summary Pollution Emissions Table (see second from bottom line on Fig 4.). This is the "performance feedback box" that Mazria asked for on the all our energy performance models and on all our CAD drawings.[6]

Toward Zero Energy Building

Attribute	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 7	Scheme 8	Scheme 9
Passive Hours (no heat or cool)...%	44.81	67.17	69.43	69.36	72.58	75.64	76.93	80.83	80.63
Total Floor Area .... sq.ft.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
Total Fuel consumed..... kBTU/sf	38.91	35.66	38.36	34.82	29.20	29.23	24.96	23.91	23.41
Total Electricity consumed kWhr/sf	2.46	1.77	2.03	2.00	1.88	1.65	1.57	1.41	1.20
Electricity Equivalent...in kBTU/sf	8.41	6.04	6.91	6.83	6.42	5.64	5.35	4.81	4.10
Site Energy Use Total......kBTU/sf	47.32	41.70	45.27	41.65	35.62	34.88	30.31	28.71	27.51
Site Energy Use. ....% of Scheme 1	100.00	88.12	95.68	88.02	75.28	73.71	64.05	60.68	58.13
CO2 Carbon Dioxide...........lbs/sf.	5.96	5.08	5.58	5.56	4.87	4.67	4.14	3.90	3.65
CO2.................% of Scheme 1	100.00	85.26	93.58	93.29	81.61	78.33	69.50	65.36	61.16

OK

Fig 4: HEED's "Toward Zero Energy Building" table shows on the bottom lines that the CO_2 generated by this building falls from 5.96 lbs/sf in Scheme 1, to 3.65 lbs/sf in Scheme 9, or 61% less (this design is not quite at the 2010 goal of 50% yet). This table is produced as one of the six Comparison Charts. The "Pollution Emission" chart also gives additional information on CO_2.

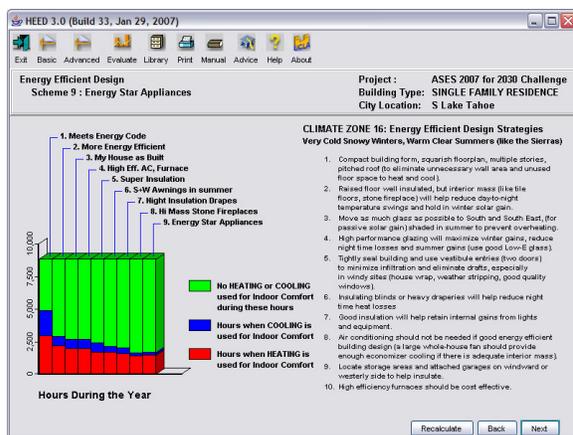MEASURING A BUILDING'S PASSIVE PERFORMANCE

Fig 5: The Energy Efficient Design Screen, unique to HEED, shows the Passive Performance of all schemes as the green bars, along with a list of the top ten Energy Efficient Design Strategies for this particular climate.

In HEED a building's Passive Performance is shown graphically as a bar chart of the number of hours per year when neither heating nor cooling is required (green bars), in other words when the building maintains comfort conditions completely passively. The remaining blue bars represent the number of hours when cooling is required, while the red bars represent the number of hours when heating is required. With each design change the height of the bars will change.
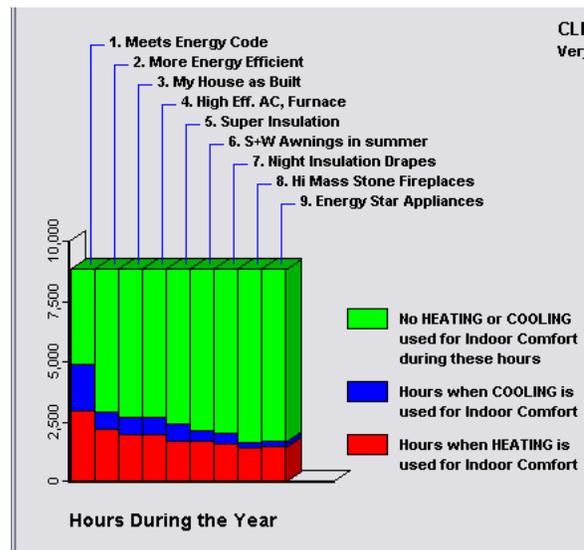

Fig.5a: In this detail from Fig.5, the Passive Performance, shown in green, represents the number of hours per year when the building uses neither heating nor cooling. Note that by Scheme 9 in this climate (Lake Tahoe) virtually all of the cooling hours (blue) have been eliminated and the heating hours (red) have been reduced by half.

Another feature of this same display (Fig.5b) is a list of design guidelines. This list is different for each of California's 16 climate zones. For climates outside California HEED uses the list that most closely matches that climate.

y Cold Snowy Winters, Warm Clear Summers (like the Sierras)

1. Compact building form, squarish floorplan, multiple stories, pitched roof (to eliminate unnecessary wall area and unused floor space to heat and cool).
2. Raised floor well insulated, but interior mass (like tile floors, stone fireplace) will help reduce day-to-night temperature swings and hold in winter solar gain.
3. Move as much glass as possible to South and South East, (for passive solar gain) shaded in summer to prevent overheating.
4. High performance glazing will maximize winter gains, reduce night time losses and summer gains (use good Low-E glass).
5. Tightly seal building and use vestibule entries (two doors) to minimize infiltration and eliminate drafts, especially in windy sites (house wrap, weather stripping, good quality windows).
6. Insulating blinds or heavy draperies will help reduce night time heat losses
7. Good insulation will help retain internal gains from lights and equipment.
8. Air conditioning should not be needed if good energy efficient building design (a large whole-house fan should provide enough economizer cooling if there is adequate interior mass).
9. Locate storage areas and attached garages on windward or westerly side to help insulate.
10. High efficiency furnaces should be cost effective.

Fig.5b: The Energy Efficient Design display also presents a list of the ten most effective building design strategies for houses built in this climate. This example is for Climate Zone 16 in Lake Tahoe.

ESTABLISHING TARGET ENERGY PERFORMANCE

The Key question in the 2030 Challenge to reduce consumption by 50%, is to define what is the basecase consumption: 50% of what?

Recently[7], Architecture 2030, The American Institute of Architects (AIA), American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), Illuminating Engineering Society of North America (IESNA), and the U.S. Green Building Council (USGBC), supported by representatives of the U.S. Department of Energy (DOE) ENERGY STAR Program established a common benchmark or starting point to measure the 50% energy reduction target.

The group agreed to define the baseline starting point for their common target goals as the regional (or National where regional data is not available) average energy consumption of

existing U.S. Commercial buildings as reported by the 2003 Commercial Building Energy Consumption Survey (CBECS). The CBECS data is a set of whole-building energy use measurements gathered by the U.S. Department of Energy's Energy Information Administration (EIA). The CBECS data can be used to determine a regional site energy use intensity (EUI) using kBtu/sqft-yr as the metric. For housing the baseline is the national averages for each housing type as defined by the 2003 Energy Administration Statistic.

Thus the current 2030 Challenge Targets are generated by a program created by Energy Star called Target Finder.[8] It asks the user to input a zipcode, a building type, floor area, number of occupants, operating hours, months of operation, and other data depending on building type. The Target Finder then prints out The Site Energy Use Intensity (kBtu/sqft/yr), and the Target CO_2 Emissions (1000 lbs/yr). Currently it calculates these values for 15 different building types, with more being added all the time. Unfortunately residential building types are not yet added to the Target Finder Calculator.

As an alternative, the California Energy Code defines how the initial basecase building shall be designed in a manual called the ACM (Alternative Calculation Method). It specifies how the basecase building shall be designed for each building type of any size in each type of climate, including information on maximum window areas and locations, glazing type, wall construction, etc. HEED uses these specifications to automatically create Scheme 1 the initial code compliant building. It does this based on the four pieces of data that the user provides on the Initial Design Screen: square footage, number of stories, building type, and climate location.

ASHRAE 90.1 uses a slightly different process to generate a basecase building[9]. There is general agreement that Title 24 is more stringent than ASHRAE 90.1, and so a factor is available that allows these two basecase buildings to be compared. LEED ™ for example gives Title 24 homes roughly 10% more LEED points that an ASHRAE 90.1 building with the same kBTU/sqft-yr calculated consumption, although this percentage is currently under review.[10]

ISSUES FOR FUTHER DISCUSSION

One issue that deserves further discussion is whether a national data base of energy benchmarks, like Target Finder, for each building type can be sufficiently accurate, or should each building in each climate determine its own basecase, like California's Alternative Calculation Method provides.

Certainly a National Database would be easier to use, however it needs to be much more sensitive to differences in climates and to different design approaches within a general building type (i.e. high mass vs. low mass buildings, schools that use single loaded corridors vs. double loaded, or single story vs., multi-story buildings, small homes vs. large homes each having one kitchen and laundry).

Custom Basecases are more accurate for each building, except that there is some disagreement about how to design the basecase building, especially when using ASHRAE 90-1. Recently "Addendum e" was approved for publication. It adds a new Informative Appendix G, Performance Rating Method, which is a generic method that can be referenced by any rating agency, although current discussion groups seem to indicate that there is certain amount of difference in interpreting the exact meaning and application of these additions.

Site vs. Source energy is a complex issue that clearly favors natural gas because its Source energy is not charged any efficiency penalty for long line transmission or for well-head pumping energy consumption. Source Electrical energy is charged a factor of three for the long-line transmission losses and for the inefficiencies of the initial generation. This means that a very efficient power plant located close to the consumer is assumed to provide the same Source energy as one that is much more inefficient and much further away. Currently the 2030 Challenge has resolved this issue by electing to use only Site energy.

ACKNOWLEDGEMENTS

ENDNOTES

[1] HEED is available at no cost from www.aud.ucla.edu/heed

[2] Both the 2030 Challenge and the 2010 Imperative are presented on www.2010imperative.org. This site references a number of articles that have been written and offers access to a webcast that was recently seen by over a quarter million architects, designers, students, and other building sector members in 42 countries..

[3] HEED tries to be the most user-friendly energy design tool available today. For example the designer can input each floorplan using a simple fill-in-the-squares technique (see Fig.6), and then can place windows by clicking and dragging them from the catalog line (see Fig.7). All kinds of construction options can be selected off a dozen different check lists (Fig.8. For more complex custom options there are another two dozen screens that allow detailed input of every building design variable.
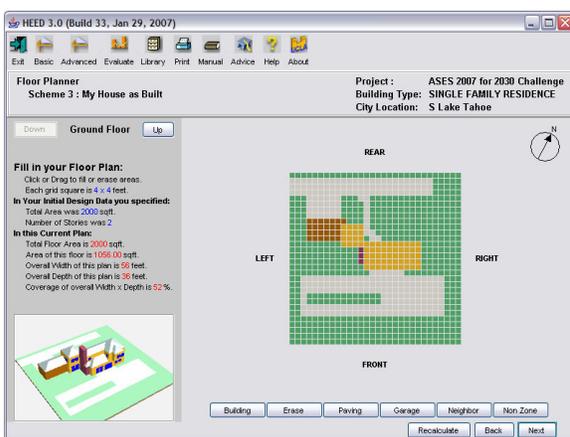
Fig.6: The Floor Planner screen lets the designer create any shape floor plan by filling in the squares. A 3-D image of the building appears in the lower left.
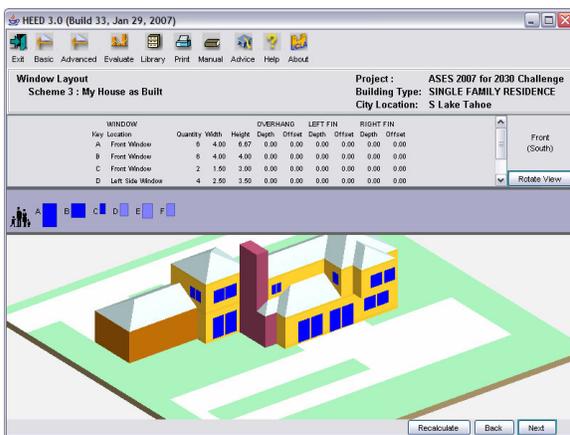

Fig.7: Windows can be clicked and dragged off the catalog line and placed on the elevation in their correct locations. The orientation, size and materials of windows is the major determinate of building energy performance, especially in envelope dominated buildings, so this screen helps the user see that that all windows have the correct dimensions and are on the correct façade.
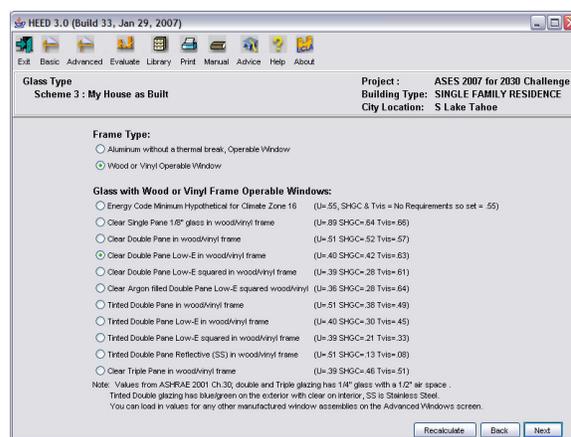

Fig.8: HEED has a dozen different checklists like this one for Glass Type (or Glazing) to define all aspects of building design.

[4] Site Energy is defined as all the energy that is used within the boundary of the building site. Source Energy, on the other hand, would include the additional energy consumed (lost) by long-line electrical transmission losses, and the losses due to generation inefficiencies.

[5] EPA's E-Grid program can be downloaded from www.epa.gov/airmarkets/egrid

[6] Note that this graphic display is a bit complex so watch the next release of HEED for a simpler version.

[7] Personal communication from Ed Mazria, April 26, 2007

[8] EPA's Target Finder Software is available at www.architecture2030.org/news/targets.html.

[9] ASHRAE 90.1 uses DOE-2 to calculate energy performance, which some claim is less accurate than the hourly heat balance methods at evaluating the effects of thermal mass in envelope dominated passive buildings. HEED and EnergyPlus use the Heat Balance method.

[10] LEED, Leadership in Energy Efficient Design ™, allows the most points credit in the Energy and Atmosphere category for building performance that is better than the basecase building. California's Title 24 buildings are allowed up to an extra 10% increase in points for the same kBTU/sf-yr (see Amendment # LEED 2.0-EAc1-133).