PICTURING THE HIDDEN ENVIRONMENTAL BENEFITS OF PASSIVE BUILDING DESIGN DECISIONS

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ABSTRACT

Every design decision an architect makes carries with it a hidden environmental cost.

Architects are concerned about issues like sustainability, greenhouse gas production, and other environmental costs, but there is little they can do until there is an easy way to visualize exactly what these costs look like.

This paper describes a user-friendly microcomputer design tool that calculates the environmental costs of each architectural design decision, and then displays an easy-to-understand picture of how these costs change from one design to the next. This new version of SOLAR-5 shows how a well designed passive building produces less air pollution and greenhouse gasses, and thus how it contributes to a more sustainable environment. Seven different atmospheric pollutants are included in the database, measured in pounds of pollution per KwHr for electric power generated and per MMBTU of natural gas or heating oil burned. SOLAR-5 also displays the amount of energy a building uses and its cost of operation.

This new design tool can show that good passive buildings not only conserve energy, but also account for hidden environmental benefits. If we are to build a sustainable future for this planet, architects need easy-to-use design tools like this to help them visualize the many environmental consequences of their design decisions.

BENEFITS OF PASSIVE DESIGN

Every decision an architect makes has an impact on the environment. For example, changing the orientation of a window, or the color of the roof, or adding a suncontrol will change the amount of heating fuel the building uses and the amount of electricity it uses for lighting and air conditioning.

Buildings use about 35% of all the energy consumed in this country. Virtually every decision that architects, builders, and homeowners make about the design and operation of their buildings carries with it an energy cost, and all energy costs in turn have environmental costs.

The recent International Earth Summit in Rio demonstrated that it is the First World, not the Third World, that is responsible for the most serious threats to the global environment. Susan Maxman, then President of the American Institute of Architects and a delegate to the Rio conference, argued that architects must take a leadership role in solving these environmental issues. Since Rio, "sustainability" has become an increasingly popular topic, which shows why it is so important that architects are able to say whether each design decision they make will have a positive or negative impact. To take on this leadership role architects need easy-to-use design tools that show the environmental consequences of different building design and operating decisions.

To implement the Rio climate treaty, diplomats meeting in Berlin in 1995 reached an agreement that for the first time committed the United States to actually reducing emissions of carbon dioxide. As a result, when the "Kyoto Protocol" is formally signed in Japan in 1997, our government will have to face some hard choices, such as raising energy taxes, reducing fossil fuel subsidies, or increasing incentives for energy efficient new building designs and retrofit.[1]

The U.S Department of Energy estimates that by the year 2010, if we do not take serious action, buildings in this country will consume 38.5 quadrillion BTUs (quads) of energy annually. However, economically achievable conservation measures can reduce this total by 30% (saving 11.2 quads), while technologically feasible measures can reduce the total by an incredible 45% (saving 17.8 quads).[2] As a rough rule of thumb, 100,000 BTUs costs about one dollar, thus each quad costs ten billion dollars out of pocket. This means that implementing only the economically feasible conservation measures could save U.S. energy consumers $112,000,000,000 every year. This new design tool shows architects how much each of their clients will save of this total.

While the economics of building design decisions have direct and tangible impact on the people who use the spaces, the owners who pay the bills, and the utilities companies who sell the energy, they have no direct financial impact on the rest of us. On the other hand, the environmental consequences of building energy design decisions effect every living thing on the planet.

Thus, there are serious measurable costs to our shared environment for each square foot of building that is inefficiently heated, cooled, lighted, or even needlessly built in the first place.

GREENHOUSE GASSES

Utility companies generate electricity using a constantly changing mix of power sources, including natural gas, coal, nuclear, hydro, solar thermal, and wind. They use various criteria to shift this mix, one of which is the capacity of the local atmosphere to absorb and dissipate airborne pollutants.

Every kilowatt of energy does not have the same environmental impact. All utilities use a slightly different mix of oil, gas, and coal fired power plants. Each uses different fuel sources to supply base power compared to peaking capacity. Fortunately, for each of these different types of fuel we have found reasonably accurate estimates of the environmental pollutants they produce, as well as of the corresponding powerplant efficiencies and transmission line losses.

For example, fossil fuel use globally is annually dumping about 5 billion metric tons of carbon into the atmosphere.[3] Much of this pollution is produced by stationary sources like electricity generating powerplants and building heating systems. While the total picture is complex, there is general agreement about some of the basic categories of pollutants:

<u>Nitrogen Oxides (NOx)</u> are the primary cause of photo-chemical smog, plus they contribute to acid rain; about 59% is produced by stationary sources.

<u>Carbon Oxides (COx)</u> contribute primarily to greenhouse effects; stationary source fuel consumption contributes about 13% of the total.

<u>Sulphur Oxides (SOx)</u> are the primary cause of acid rain; over 80% is produced by heating and electricity generating sources.

<u>Particulate Matter (PM-10)</u> comes primarily from coal-fired boiler ash and flue scrubber wastes; particulates less than 10 microns in diameter causes visibility reduction, and both morbidity and mortality human health impacts.

<u>Reactive Organic Gasses (ROG)</u> include many different man-made compounds such as CFCs, which cause ozone depletion and other complex atmospheric gas effects.

SOLAR-5.4: Passive Solar Design Tool (Beta Test 960129) UCLA 01/29/96 12:34 PM

Project Title: EXHIBITION SOUTH

POLLUTION EMISSIONS: Default Values — Building Type: EXHIBITION S.

Scheme 4: 4'0" OVERHANGS.......... — Climate Data : Seoul based on Wash. TMY

Monthly Averages for all 8760 HOUR/YEAR.

ELECTRICITY: pounds/KwHr — Southern California Edison 1993 SCAQMD ELFIN Model

	NOx	SOx	PM-10	ROG	CO	C	CO2
JAN	1.11	.65	.048	.032	.191	161.75	593.08
FEB	1.95	1.15	.086	.056	.335	284.03	1041.45
MAR	2.51	1.48	.110	.072	.430	364.60	1336.90
APR	1.41	.83	.062	.040	.242	205.06	751.90
MAY	1.55	.92	.068	.044	.266	225.12	825.47
JUN	1.09	.65	.048	.031	.188	159.06	583.21
JUL	1.41	.83	.062	.040	.242	250.06	751.89
AUG	1.93	1.14	.084	.055	.331	280.68	1029.15
SEP	1.82	1.07	.080	.052	.312	264.28	969.03
OCT	1.68	.99	.074	.048	.289	244.70	897.25
NOV	1.87	1.11	.082	.053	.322	272.35	998.64
DEC	1.68	1.10	.081	.053	.320	270.64	992.36
HEATING FUEL: pounds/MMBTU — Average National data 1993 (not Calif. specific)							
Residential: 100.% Gas:	.07	.00	.015	.007	.017	.00	116.00
0.% Oil:	.07	.22	.019	.019	.030	.00	173.00
Commerical: 0.% Gas:	.10	.00	.003	.005	.019	.00	118.00
0.% Oil:	.14	.22	.019	.019	.038	.00	164.00

Do you want to make any changes("Y", "HELP", any option or ENTER)

Fig. 1 Pollution Emissions Table showing default values, although users may input their own local data.

DATA BASE

For this project we assembled a database of the monthly emissions of seven different atmospheric pollutants, measured in terms of pounds per KwHr, as well as comparable values for natural gas and fuel oil measured in pounds per MMBTU.

In this model users can load in their own local data, but we used the data Southern California Edison reports monthly to the South Coast Air Quality Management District giving the amount of electricity it has generated and the tons of pollution it has emitted (NOx, SOx, PM-10, ROG, CO, C, and CO2). For natural gas and fuel oil used by the building's on-site heating system, we used the national average data for 1993 (n.b.: at this printing the data for Heating Fuel is still incomplete in the areas of Carbon and SOx).[4] Heating fuels generate their pollutants at the site of the building, while electric power stations may be polluting another air-shed thousands of miles away. The default data used here, however, assumes that electricity is generated within the same air-shed where the building is located.

DEVELOPMENT PLATFORM:

As a development platform on which to implement this model, a new version of SOLAR-5 an existing building energy design tool has been created. It calculates how a building design will perform on any given hour or for an entire year. It displays the energy needed to heat and cool and light the building as designed, as well as the corresponding cost of that energy. This new version, known as SOLAR-5.4, now also displays the pounds of each of these seven air pollutants that the building generates.

The great advantage of this user-friendly design tool is that the architect can instantly go back and re-design the building and can immediately see if the air pollutant emissions, energy consumption, or operating costs, have been reduced.

SOLAR-5: A Brief History: The original SOLAR-5 microcomputer program was released in 1986 and is now in wide use and has received numerous research awards.[5]

Added to this latest version is a new graphic display technique that shows quantitatively how each successive design revision either increases or decreases the amount of pollution the building generates. Thus, this project addresses the twin problems of how to reduce a building's energy consumption and at the same time how to minimize environmental impact.

Making Initial Design Decisions: SOLAR-5 is unusual among computerized energy models because it was developed especially for use at the very beginning of the architectural design process, when the project is the most vaguely defined.

Decisions made during these critical early moments in the life of a building turn out to have the greatest impact on its eventual energy performance and the pollution it generates. SOLAR-5 uses many different techniques to deal with the "fuzzy" nature of the information available at this very early stage, and to acknowledge and enhance the architect's traditional design process. A unique feature of SOLAR-5 is its ability to display complex building performance information in various 3-dimensional graphic forms.

Because of the highly graphic (right-brain) nature of the output, architects not only grasp concepts faster and in greater detail, but they also come to understand intuitively the complex dynamics of how their building performs. SOLAR-5 has proven to be extremely successful at illustrating such concepts with greater clarity then is possible with traditional quantitative approaches. It lets designers define problems and explore results at whatever depth, at whatever pace, and following whatever path they choose.

With this knowledge, architects are in a better position to make informed judgements about the design and operation of their buildings.

Program Structure: SOLAR-5 is written to maximize the speed of computation. It takes only a few seconds for a building's energy and pollution performance to be computed and displayed for 12 months of the year using on NOAA monthly average weather data. For greater detail, the building's performance for each of the 8760 hours of a typical meteorological year (TMY) can be calculated in less than a minute.

It can handle everything from small single-zone residential buildings, to large commercial buildings of up to eight zones. It works equally well for new construction, retro-fit, building maintenance, or plant operation decisions for either commercial or residential building types. When it was evaluated using the BESTEST procedure it produced results well within the ranges of the larger energy models like DOE-2, TRANSYS, and BLAST.[6]

DESIGN EXAMPLE

Solar-5 was used recently during the schematic design phase of a large project involving an office tower, exhibition space, and meeting rooms. The dramatic exhibition and lobby wing posed the most challenging problems. The sequence of six schemes presented here demonstrate how various passive design decisions

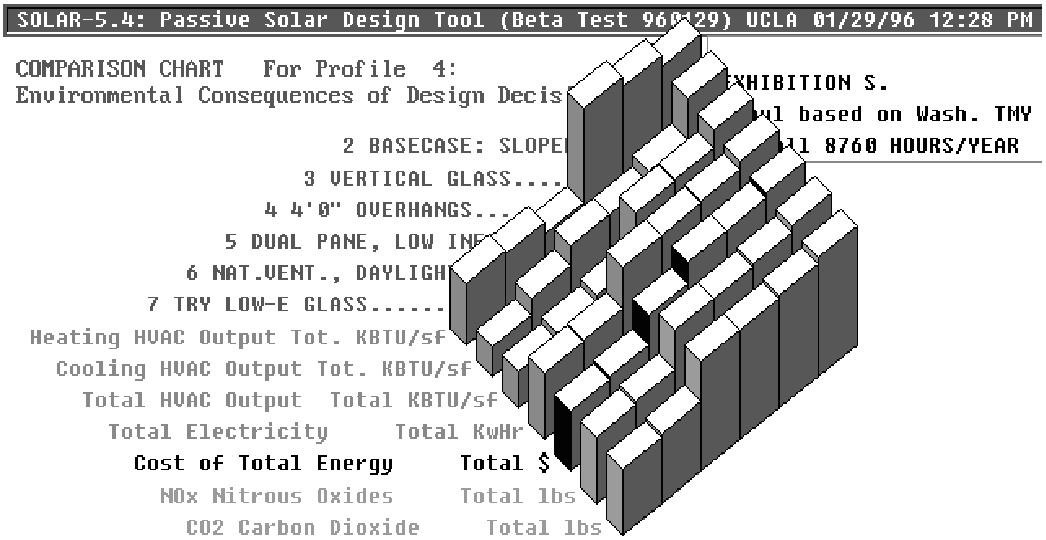

Fig. 2 This 3-D Comparison Bar Chart can be printed out for any combination of Design Schemes and Performance Attributes.

effect building performance, although not always in the magnitude or even in the direction usually expected:

<u>2. Basecase Design: Sloped Glass:</u> The main glazed facade faced 40 degrees east of south and sloped back at 35 degrees. The main floor covered 175' by 235' with three tiers of lobby/exhibition floors above.

<u>3. Vertical Glass:</u> The architect's first move was to change the huge sloped glass facade into a series of stair-steps with glass in the vertical sections.

<u>4. Add 4'0" Overhangs:</u> Next all these 6'0" high south-east facing windows were protected by adding a long overhang.

<u>5. Dual Glazing and Infiltration Control:</u> Conduction losses through the windows and infiltration were shown to be the next largest problems. This scheme switched to double pane glass. Infiltration can be brought down from 1.0 to 0.1 air changes per hour by adding things like airlock entries and weatherstripping.

<u>6. Economizer Cooling, Natural Ventilation and Daylight Controls:</u> In this climate there were many days when outdoor conditions were quite comfortable for these kinds of lobby/exhibition functions. Huge operable grills were integrated into the architectural design of the two end elevations, and a wall of french doors opening onto a patio was added at ground level. Night flushing was used to store "coolth" in the thermal mass of the building. It was assumed that automatic daylighting contols that could reduce lighting loads by 40%.

7.<u>Try Low-E Glass:</u> The final design in the sequence substituted high performance glass.

As an indication of the speed and power of SOLAR-5.4, it took less that two hours to create and evaluate these six designs.

3-D BAR CHARTS

The new 3-D Bar Charts created by SOLAR-5 give a clear picture of the complex interaction of how different design schemes performs according to different measures of building performance (see Fig. 2).

A few hints make it easier to read this display. The first scheme in the list is always used as the reference, or 100% value, as shown by the row of bars across the upper right, all the same height. The bars that make the greatest vertical drop show the design schemes that have the greatest benefits; in this example, Scheme 6 produces the greatest reduction in Carbon Dioxide emission, as shown in the set of bars across the lower right. Any of 40 different attributes can be plotted; the set shown here demonstrates that they all respond differently to each design revision, and thus no single attribute is sufficient to describe the relative performance of any set of design schemes.

COMPARISON TABLE For Profile 6:
Environmental Benefits of Passive Design

		Schemes/Combinations I.D. Numbers					
		2	3	4	5	6	7
Heating HVAC Output Tot.	KBTU/sf	-20.66	-22.98	-25.46	-4.19	-6.65	-7.42
Cooling HVAC Output Tot.	KBTU/sf	28.03	17.58	14.58	14.64	9.71	5.92
Total HVAC Output	Total KBTU/sf	48.69	40.56	40.04	18.84	16.36	13.34
Total Electricity	Total KwHr	1721826.00	1599449.00	1564396.00	1565347.00	967736.00	923421.00
Cost of Total Energy	Total $	187428.40	178392.50	179007.50	144066.80	95815.69	92472.55
NOx Nitrous Oxides	Total lbs	2844.96	2657.71	2601.27	2601.82	1609.30	1538.45
SOx Sulphur Oxides	Total lbs	1691.04	1580.26	1546.79	1548.41	957.40	915.53
PM-10 Particulates	Total lbs	126.04	117.87	115.44	115.06	71.24	68.15
ROG Reactive Organics	Total lbs	81.91	76.60	75.01	74.85	46.33	44.32
CO Carbon Monoxide	Total lbs	492.48	460.35	450.68	450.59	278.71	266.56
C Carbon	Total lbs	425965.80	397553.90	389014.60	389209.60	240781.40	229991.60
CO2 Carbon Dioxide	Total lbs	1531654.00	1432075.00	1402297.00	1399845.00	866306.50	828630.40

Fig. 3 A Table of Performance data can also be printed for the Design Schemes shown on the Bar Chart. This example fills two screens.

ENVIRONMENTAL IMPLICATIONS OF GOOD PASSIVE DESIGN DECISIONS

This new 3-D Bar chart helps reveal the hidden environmental benefits of designing good passive buildings. In this example, each design revision produced less pollution, by the final scheme eliminating an amazing 350 tons of Carbon Dioxide, the primary greenhouse gas (see Fig.3). In fact the emission of all seven air pollutants was cut almost in half.

It is surprising that all these design revisions, that usually create good passive buildings, produced significant savings in Cooling but only modest savings in Pollutants. Even more surprising is that all these design revisions, except one, actually increased Heating energy consumption. The greatest drop in Total Electricity consumption was produced by Scheme 6, the Daylighting Control Strategy, but the final height of the bars
show that a lot of Electricity consumption still remains in the building for lighting and equipment. The Heating seemed to end up quite high, implying that further optimizing of the south windows for passive direct gain might be possible.

The 3-D Bar Chart shows that some design changes can
Over the long term, the greatest benefit of this type of design tool is that it will demonstrate to people that there are real, tangible ways to quantify the environmental costs imposed on all of society by the decisions of an individual

make different variables go in opposite directions. For example, changing to Vertical Glazing reduced Cooling energy, but increased Heating, which left Total Energy consumption about the same.

Probably some of these design revisions would not be implemented. From the air pollution point of view, the

design revision that makes the greatest impact is installing automatic Daylight Controls. On the other hand installing Low-E glass does not have much impact on any of the measures shown in this 3-D Bar Chart.

Over $95,000 per year in Total Energy Costs was saved by this set of design revisions, which demonstrates that good passive design decisions can make good economic sense (see Fig. 3). In some locations there will soon be a market for avoided pollution, and so these hidden environmental benefits may also eventually have an economic value.

CONCLUSION: IMPACT ON OUR NATION'S ENERGY CONSUMPTION

architect or building owner. This may in turn eventually lead to a change in the decision making process in ways that might, for instance, require that environmental costs be quantified as a condition of receiving a building permit.

Alternatively it could, for example, serve as a simple tool for quantifying local-source emission mitigation off-sets, for example, if each new building offered to produce a comparable reduction in the emissions of another older building, in order not to increase total environmental impact within the air-basin.

It must be emphasized, however, that this project is only a beginning step. It demonstrates the feasibility of quantifying the environmental benefits of architect's design decisions. It addresses only a few of the many environmental impacts of a building's design, construction, operation, and eventual demolition. It is only the first small step, but we think it is an essential one.

ACKNOWLEDGEMENTS

The development of the software described in this paper was made possible by a grant from University of California Energy Institute.

The Co-Principal Investigator on this project is Arthur Winer, Director of the Environmental Science and Engineering Program at UCLA. For this first software development phase of the project, Guillemette Epailly developed the database, while Carlos F. Gomez wrote the new graphic display routines. Over the last twenty years dozens of Graduate Architecture Students at UCLA have contributed to the development of SOLAR-5; while there are too many names to mention here, the contribution of each is gratefully acknowledged.

ENDNOTES:

1.Flavin, Christopher, "Climate Policy Showdown in Berlin", World Watch Journal, July/August 1995

2. M. Levine, Paul Craig, F.Patterson, and K. Devereaux, "Executive Summary", Energy Policies to Address Climate Change, Proceedings of a Workshop, September 6-8, 1989, Published by the Universitywide Energy Research Group, University of California, Berkeley, CA, 1991

3. Flavin, ibid., also see Stephen Schneider, "The Changing Climate", Scientific American February, 1989

4. The best source for this type of data seems to be the CEQA Air Quality Handbook, but many other sources were consulted: Guillemette Epailly, Bibliography: SOLAR-5.4 Project, Department of Architecture and Urban Design, UCLA, 1995

5. SOLAR-5 is "shareware", which means that users are encouraged to make copies and share them with others. Over 300 copies were initially distributed by the Designers Software Exchange at MIT. It is also distributed by the National Energy Software Center, and hundreds more copies have been distributed by UCLA. It is now being used in about a third of the schools of architecture in North America, and by dozens of architectural firms. It seems safe to say that by now thousands of people have used it.

SOLAR-5 was selected by the Secretary of the U.S. Department of Energy as one of nine "National Energy Innovations for 1987". It was given a Commendation by the California Energy Commission. It also won a Research Citation in Progressive Architecture's National Design Awards Competition.

6. Lee, Shing-Kuo, Evaluation of SOLAR-5 Using the BESTEST Procedure, Department of Architecture and Urban Design, UCLA, 1995.