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MEMORANDUM

Date: March 9, 2006
From: Richard Keleher
Subject: **Parametric Daylighting/Energy Modeling Software**

The Problem

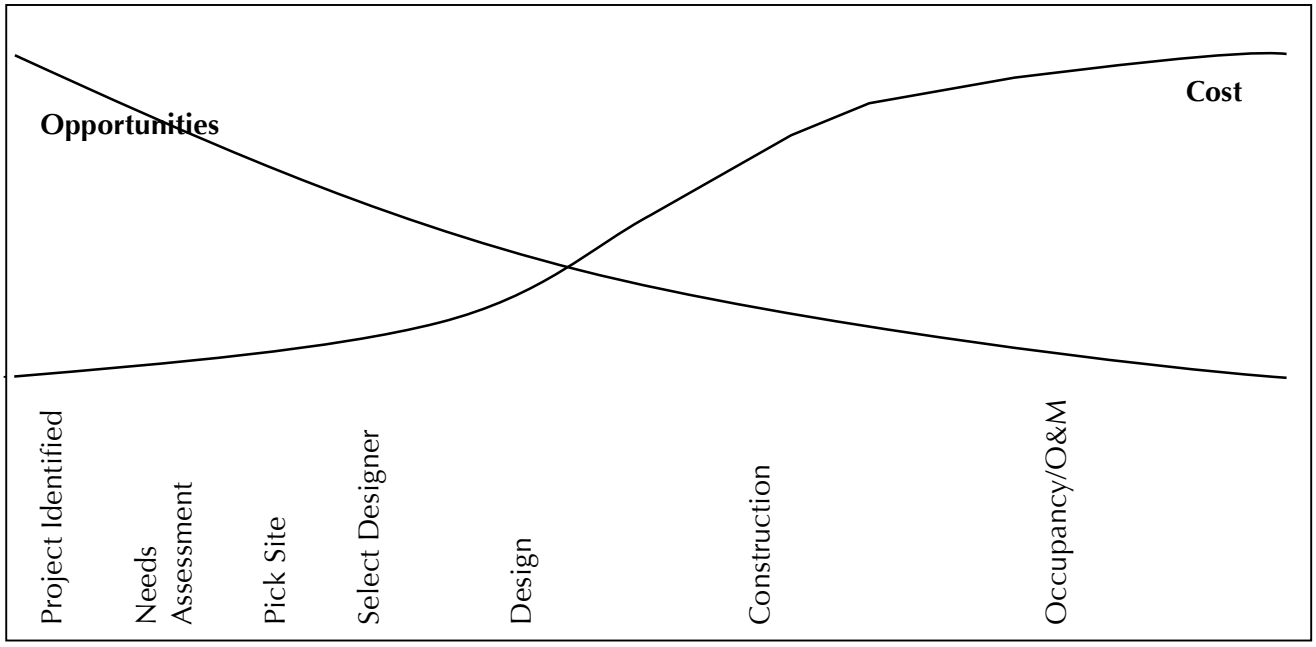
Due to the approaching end of the availability of fossil fuels and the environmental effects of greenhouse gases, we will have to fine-tune building envelopes so they do not use more energy than intended, and do not deteriorate prematurely. Yet we should not over-design, since it wastes embodied energy.

Contrary to common engineering practice, which is to reduce the glazed area to conserve energy,[1] architects often wish to increase the glazed area and include a view for psychological well-being[2]. We are only beginning to create the tools and gather the information necessary to apply the physics of light, heat, air, and moisture[3] and the biology of deterioration to our design of building enclosures in the way that structural design employs specific rational quantitative values to allow us to predict outcomes. Only when we are able to use similar specific values in building enclosure design will we be able to design novel enclosures that are also environmentally responsible.

The main initiatives that can be taken with regard to energy and the interior environment have to do with the management of daylight for energy reduction, moisture and heat gain/loss control through opaque portions of the enclosure, and, when appropriate, natural ventilation.

One of the needs, and the one which most clearly affects the schematic design more than most others, is the need for 3D parametric daylight and energy (heat) modeling software to enable designers to clearly understand the impact of detailed fenestration decisions (e.g. the design of overhangs, shading devices, light shelves) relative to the amount of light provided to interior spaces, so that increasing the availability of daylight for task lighting via light shelves and other fenestration options does not adversely affect the heat gain in the space. There appears to be no software program (and indeed no single tool of any kind) that will help a designer who is not a mechanical engineer to understand both the lighting and energy impact of fenestration decisions. While such programs exist, they are not benchmarked to US standards. Although foreign (UK) software vendors are moving in this direction, none of these programs are integrated with the BIM (building information model) software currently in increasing use in architects' offices. The current state-of-the-art requires modeling in multiple programs that are not particularly user-friendly.

The difficulty is to provide the design architect with useful information about these climatic factors early in the design process. This information regarding possible design solutions and the impact of alternatives must be readily accessible to the designer (who is also considering a multitude of other factors) so that a useful dialog can be initiated with mechanical and electrical engineers in an integrated design process. As a general rule, the opportunities for creatively addressing solutions occur very early in the design process (the later in the design process, the more expensive the implementation).



ENSAR / NATURAL LOGIC CHART / INTEGRATIVE DESIGN COLLABORATIVE

The Search for Possible Solutions

One must consider the relative merits of parametric digital modeling software versus physical the use of physical models that can be rotated on a device to simulate true sunlight conditions. Seattle's Daylighting Lab, the Pacific Energy Center in San Francisco, the Building Science Department at Auburn University, the Ball State CERES Lighting Lab, and many others use a device called a heliodon (picture is at left) to tilt an actual model to simulate various sun incidences. An overcast sky simulator should be used to create an artificial sky by using mirrors or diffusing light sources or both.

A professor at a School of Architecture and Design in Thailand[4] has built a heliodon with 270 lights and a 6m diameter "dome" to create an artificial sky. The artificial sky is particularly important because the sky is often is the primary source of light, and is said to be the best source of usable light, versus direct sunlight, which can be too bright and therefore cause glare.

Others would take the models out onto the roofs of their buildings, where an artificial sky is not required.

It has been noted that the drawbacks of the physical model approach are the time necessary to create the model, the necessity to have access to an artificial sky or the appropriate outdoor sky conditions, and access to a heliodon. Whether the true sky conditions can be replicated, whether models can be created that represent glass transmission, whether we can readily study alternative colors and configurations, are issues of concern. On the other hand, subtle qualities of lighting can be rendered more accurately with models and daylight.

Every design tool provides a way of fooling oneself, so it is wise to use multiple tools to give some degree of check and balance. Computer models of actual lighting effects (not artists' impressions) suffer the same difficulties of any photographic medium in that they tend to exaggerate contrast and may not render color as the eye would see it in reality. Computer models are easier to control, of course, and may give better absolute quantitative results than physical models. The physical model is, well, …real! The eye reacts to the environment in the model much as it would to the final building. However, it is possible to overlook subtle conditions that become problems at full scale. Physical modeling does give a quick, inexpensive way to compare the effects of alternative schemes.

Available Software Solutions

However, physical models have a major drawback for solving the posed problem; they cannot model the thermal impacts of the daylighting. Software can be more readily available to designers than physical models, since most architects have a computer on their desk. The software should be parametric and three-dimensional in order to evaluate multiple consequences of multiple possibilities in three dimensions. A survey of a range of possible programs to be used as tools for the designer, beginning with Power DOE, Energy-10, eQuest, and MIT Design Advisor, shows that none of them provide both a user-friendly interface and as well as meet the criteria for the software which require a parametric 3D model with numerical data available, an easily usable intuitive interface, a low cost/benefit ratio, a minimum amount of training, and be able to import/export to commonly-used CAD software (or, better-still, be able to be a part of it), be used by reputable users, be manufactured by a reliable manufacturer, work with appropriate standards, and have tech support available. While none of the programs investigated met all of these criteria, several were of interest (see comparison chart below).

Variables Accommodated

Comparison Chart

Criteria	**IES Virtual Environment**	**EcoTect***	**MIT Design Advisor**	**eQuest, SkyCalc, evaluator**	**Energy-10**	**Radiance**	**TAS**
Parametric 3D graphic model with numerical data	**Yes**	**Yes**	No	No	No	No	Yes
Easily usable; intuitive interface so many staff can easily use	**Yes**	**Yes**	No	No	No	**No**	**Yes**
Low cost/benefit ratio	Approx. $12,000 (trial $250)	Approx. $800	Free	Free	$250 ($1000 for 6-10 users)	**No:** $ to build overlying software	$3,500 plus $1,500 for CFD
Minimum training required	2 days $1500	? Setup tricky	?	?	?	**Requires experienced user**	**Very bad**

Criteria	**IES Virtual Environment**	**EcoTect***	**MIT Design Advisor**	**eQuest, SkyCalc, evaluator**	**Energy-10**	**Radiance**	**TAS**
Import and export to .dwg or .dxf	**Yes**	**Yes**	No	No	Probably		Yes; as a background
Used extensively by reputable users	ARUP was looking at it	2000+ students	800+	Probably many	Yes; NREL and LBNL		
Reliable/reputable manufacturer	?	?	**Yes** (LBNL)				?
Works with appropriate US standards?	No	Exports to EnergyPlus	Yes	Yes. DOE-2; primitive	Yes, but not ASHRAE 90.		
Affects relationship with engineers? Within office?	?	?	?	?			
Tech Support available?	Yes	**No**	No				
Variables Accommodated **(types of analyses done)**	**IES Virtual Environment**	**EcoTect***	**MIT Design Advisor**	**eQuest, SkyCalc, eVALUator**	**Energy-10**	**Radiance**	**TAS**
Visualization (3D)	**Yes**	**Yes**	No	No	No (but some say they can)	Yes	Yes
Shadows & Shading	**Yes**	**Yes**	No	No	No	Yes	Yes
Daylighting	**Yes, based on Radiance**	**Yes, based on Radiance**	**Yes, based on Radiance**	No	Yes; don't know how displayed	Yes	Export to Lightscape
Solar Analysis	**Yes**	**Yes**	No	Broad-brush	No	Yes	No
Lighting	**Yes**	**Yes**	No	No	No	Yes	Yes
Thermal	**Yes**	**Yes**	No	Broad-brush	Yes	No	Yes
Ventilation	**Yes**	**Yes**	No	No	No	No	Yes

Criteria	IES Virtual Environment	EcoTect*	MIT Design Advisor	eQuest, SkyCalc, evaluator	Energy-10	Radiance	TAS
Acoustic	**No**	**Yes**	No	No	No	No	
Carbon Emissions	**Yes**	**Yes**	No	No	No	No	Yes
Duct Sizing	**Yes**	No	No	No	No	No	Yes, w/ CFD
Pipe Sizing	**Yes**	No	No	No	No	No	
VE/Life Cycle Costing	**Yes**	**Yes**	No	**Yes**	No	No	
Ease of Use	Moderately difficult, on desktop	Moderately difficult, on desktop	Easy, on internet	Easy, on internet	Moderately difficult, on desktop	Very difficult; requires experienced user	Very difficult; requires experienced user
Website	www.iesve.com	www.squ1.com	http://designadvisor.mit.edu/design/		http://www.nrel.gov/buildings/energy10.html	http://radsite.lbl.gov/radiance/	http://ourworld.compuserve.com/homepages/edsl

THIS CHART WAS PREPARED IN 2004; IT HAS NOT BEEN UPDATED. SINCE THEN, ENERGY PLUS HAS REPLACED ENERGY 10 AS THE US ENERGY MODELING STANDARD AND DAYSIM HAS BEEN BROUGHT TO MY ATTENTION. DAYSIM DAYSIM IS A DAYLIGHTING ANALYSIS SOFTWARE THAT CALCULATES THE ANNUAL DAYLIGHT AVAILABILITY AS WELL AS THE LIGHTING ENERGY USE OF AUTOMATED LIGHTING CONTROLS. THE PROGRAM COMBINES THE BACKWARD RAYTRACING SOFTWARE RADIANCE WITH A DAYLIGHT COEFFICIENTS APPROACH. ANNUAL ILLUMINANCE PROFILES ARE COUPLED WITH USER OCCUPANCY DATA TO PREDICT THE ANNUAL USE OF ELECTRIC LIGHTING IN A BUILDING ZONE DEPENDING ON THE LIGHTING AND BLIND CONTROL STRATEGY.

*** DesignBuilder is a new program that has an interface that is similar to Ecotect, but does not use Radiance for daylight analysis; it was in beta test stage in 2004 when the chart was originally prepared.**

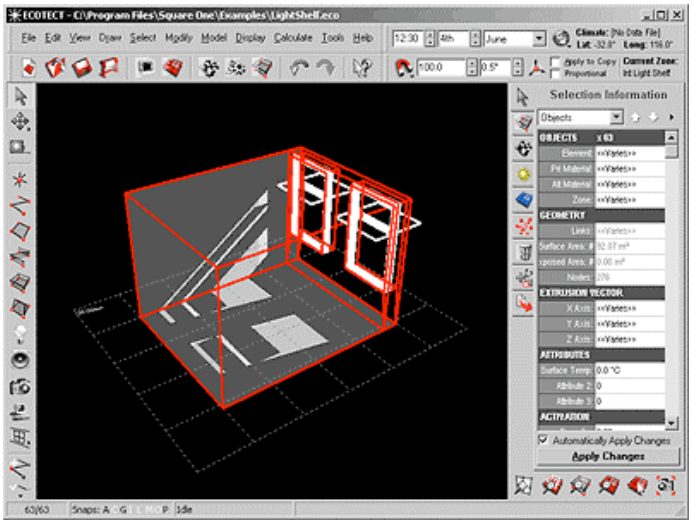
New Information from Building Design & Construction Online Magazine

Most recently, Green Building Studio www.greenbuildingstudio.com has developed a free Web-based service supported by targeted advertisements that enables Building Teams to integrate whole building energy analysis into the early stages of the design process. The program enables the design team to look at the energy impact of early design decisions and will soon compare alternatives without entering a new CAD model for each variation. Using 3D CAD software, designers construct their early building design model and then export a 3D file as a proprietary gbXML file which feeds an energy model that is automatically developed through the use of regional building standards and codes, and which enables the GBS system to make intelligent assumptions about items such as insulation and lighting levels. The resulting building description then goes through a DOE-2.2 hourly simulation using typical-year weather data for the building's location. The simulation generates estimates for annual energy consumption, costs,

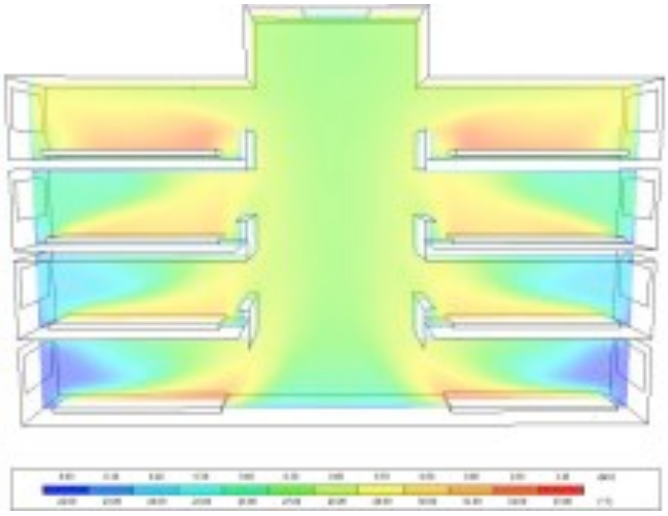
and a wide range of data on heating and cooling loads. However, this program will not model detailed design elements such as light shelves and overhangs.

The main drawback for Green Building Studio is that it cannot solve the posed problem; it cannot model the thermal impacts of the daylighting and does not show the impact of daylighting on the spaces affected in a direct, viewable way, since it exports to DOE 2. If it exported to Energy Plus, some of this capability would be available. But it would require too much computer capacity for Green Building Studio to do this in their online format.

Conclusions/Summary



The best of the programs reviewed are Ecotect, IES/VE and DesignBuilder. Ecotect (screen shot at left) has a superb user-interface[5] and even has educational components (it was developed as an education tool). It is very good at dynamic daylight modeling (climate-based, daylight autonomy, etc.)



IES/VE (screen shot at right) is a bit more difficult to use, and appears at first glance to be more robust from a mechanical engineering standpoint (it even has a computational fluid-dynamics module), but, like Ecotect, is usually not accepted by US engineers as being equivalent to the current US energy modeling software, such as Energy Plus. Also, its daylight modeling is reported to be just a rough daylight factor.

Recommendation

Given the need for tools that will enable designers to accurately predict the consequences of their design decisions early in the design process when it has the most impact and the convergence of recent developments[6], the time is ripe for the development of 3D parametric daylight and energy-modeling software that can be easily[7] used by designers to understand the precise affects of fenestration decisions on the aesthetic and functional use of daylight and its impacts on the energy usage of the structures involved. This software should be integrated with software to analyze moisture and heat gain/loss through opaque portions of the enclosure, and natural ventilation, so that one model can serve all types of analyses.

This software should run on BIM[8] platforms currently used by architects (e.g. Revit by AutoDesk and Microstation with Bentley Architecture by Bentley and others). In the near future, it may be necessary to model only typical portions of very large buildings due to file sizes and computing time and hygrothermal modeling may not be incorporated. Hopefully, even these limitations will be overcome in the not so distant future.

The Next Steps:

1. Obtain the opinion of Stephen Selkowitz, Head of the Building Technologies Department of the Environmental Energy Technologies Division at the Lawrence Berkeley National Laboratory for his review and comment.
2. Ask the chairs of the national network of Building Enclosure Councils (BECs) to review this proposal.
3. Approach the utilities for support and funding.
4. Approach NIB's International Alliance for Interoperability to ask for their support.

This report was started at The Stubbins Associates, with Ron Ostberg's initial inspiration and encouragement. It was completed with the assistance of commentary from David Altenhofen of Kling, Jeff Berg of Berg Howland Associates, and Marilyne Anderson of MIT.

Footnotes:

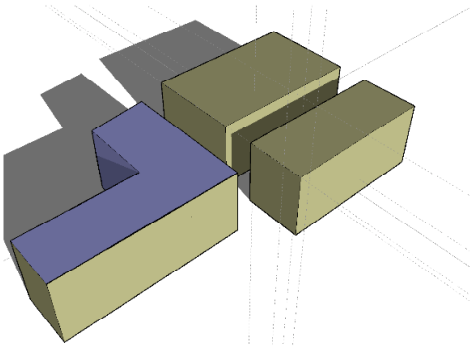
[1] For small-scale residential projects, the typical intent is to prevent heat loss in the winter by having less glazed area. For larger commercial projects, the intent is to save on heat gain in the summer.

[2] There is considerable data showing that occupants of buildings perform tasks better when well-controlled daylight and especially a view is present. The daylight must be well-controlled to avoid glare and excessive local heat gain. Go to Heschong-Mahone Group's website: www.h-m-g.com/downloads.htm to see studies.

[3] Straube and Burnett report the need for the development and use of practical hygrothermal analysis methods in, "Review of Modeling Methods for Building Enclosure Design," Dr. John Straube. University of Waterloo, and Dr. Eric Burnett, Pennsylvania State University. Hygrothermal analysis is the modeling of heat, air, and moisture and their interactions with materials in the building enclosure and is probably not in the immediate future for integrated parametric building modeling programs. They will probably remain stand-alone programs for the foreseeable future. In the meantime, the development of programs such as WUFI (www.ornl.gov/sci/btc/apps/moisture/) or the H.A.M. Toolbox (www.rousseaubuildingspecialist.com/) need to be made even more average architect user-friendly and more versatile.

[4] Acharawan Chutarat, an MIT doctoral graduate and a professor at King Mongkut's University of Technology Thonburi School of Architecture and Design in Thailand.

[5] The user–interface of even Ecotect and DesignBuilder could be improved if they were even more like Sketch-Up, a 3-D drawing program that has found great favor among architects for its ability to allow them to quickly "sketch-up" three-dimensional designs on the computer (screen shot of sun study for a specific time and geographical location done from scratch in one hour is below). See www.sketchup.com. Of course, to the extent that the 3D BIM programs are made to be usable in the conceptual design stage, like SketchUp, there may be a true convergence into one program.



SketchUp drawing

[6] The American Institute of Architects' initiative, "to achieve a minimum 50 percent reduction from the current level of consumption of fossil fuels used to construct and operate new and renovated buildings by the year 2010," and the movement of the CAD software industry toward 3D object-oriented (BIM) software.

[7] The ease of use is a critical aspect of this recommendation; if not elegant, intuitive, and accompanied by robust educational and help components, it will not be used by architects and designers.

[8] BIM with the noted enhancements, particularly relative to daylighting and energy modeling, should enable architects to achieve a long-sought goal, to stay engaged with their projects into the occupancy phase, to retrieve operational data to see if predicted performance agrees with reality. the feedback loop has long been recognized as one of the needed improvements to architectural practice and would enable the improvement of the tools (software). In fact, Stephen Selkowitz reports that on the New York Times building, the modeling software was used to actually run the control system hardware prior to occupancy, as a way of pre-testing. A similar process was used at the Genzyme Headquarters in Cambridge, MA during the dry-out period, to test the mechanical system's performance. So it is beginning...