Object in Light: From Power to Purpose

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Abstract

As we rush headlong into the 21st century, replete with its very real man-made challenges of energy dependence, we cannot lose sight of the fact that architectural sustainable design is the proverbial solar compass by which we must plot our course.

According to the U.S. Energy Information Administration (EIA), the Building Sector consumes nearly half (49%) of all energy produced in the United States.[1] Seventy-seven percent (77%) of all the electricity produced in the U.S. is used just to operate buildings. [2]

Furthermore, in a 2002 report entitled "National Lighting Inventory and Energy Consumption Estimate", we read: "The commercial sector is the largest energy user overall, having large quantities of energy used by all three light sources [incandescent, fluorescent, and high intensity discharge]. Fluorescent and incandescent are the two largest commercial lighting energy users, accounting for 56% and 32% of its annual 391 TWh/year of electricity use. In the residential sector, energy use is primarily driven by incandescent technologies, where 90% of the energy is consumed by this light source." [3] Given these known parameters, as architects, engineers and educators, the challenge before us is finding the right balance of controlling building lighting through intelligent design so that we can control total energy usage.

To that end, The "Object in Light" is an engineered daylighting analysis device developed by three college professors to teach the principles of sunlight restriction, collection and distribution within an architectural space. Through the use of computer modeling and simultaneous physical modeling, pedagogy was developed to achieve the twin goals of daylighting and energy conservation. This paper will describe how this sustainable design project was created to address these challenges using knowledge from different fields of architecture and engineering in order to raise awareness of the appropriate technologies available to solve for these problems.

Introduction

How does one engineer a system to capture the abundant energy of the sun in an effective and efficient way and make it usable? Any sustainable design engineering solution should not foreshadow the foremost hierarchal fact that buildings are designed for people and should be designed for their comfort, not just to meet energy objectives. Sustainable design then, has the dual task of capturing the abundant energy of the sun for luminosity and heating while at the same time controlling the pernicious effects of unwanted and costly heat load. Solar radiation is one of the most important natural contributors to heat gain in buildings. [4] In that the sun changes its position relative to location, time of day and time of year it is crucial that buildings adjust their apertures in such a way as to harness the power of the sun economically. Detailed engineered solutions to guard against heat retention and plan for heat rejection are advancing apace and will be addressed in a future paper but for this educational sequence, only the basic concepts will be referenced.

Sun Movement

In terms of teaching the logical implications of the movement of the sun in an architectural class setting, two-dimensional drawings and animations routinely come up short in cementing student understanding of this crucial sustainable design variable of solar tracking. Knowing that kinesthetic learning is most efficacious in driving this concept home (especially where unintuitive published sun charts data are concerned), Prof. Norbert Lechner, Architectural Technology Professor Emeritus from Auburn University has engineered a portable piece of equipment called a Heliodon to make the movement of the sun in relation to a specific building in a specific location abundantly clear to the learner. [5] In the span of two short years, this single piece of engineering technology has brought significant pedagogical advancement for solar responsive design throughout the five years of sequenced studios. We have also displayed and demonstrated the heliodon at conferences and industry "green building" venues. (Figure 1) Our program strives to integrate architectural engineering technology courses with design studio work.

Figure 1: Author demonstrating heliodon at GlassBuild America Convention Educational Seminar (www.glassbuildamerica.com)

Parenthetically, two-dimensional sun data charts are conceptually difficult to visualize and although the information may be accurate, effective application becomes a challenge for the architectural student.   Students can use the heliodon to duplicate and verify unintuitive sun chart data. (Figure 2) Interestingly, this reverse verification of sun motion chart data solidifies student understanding.

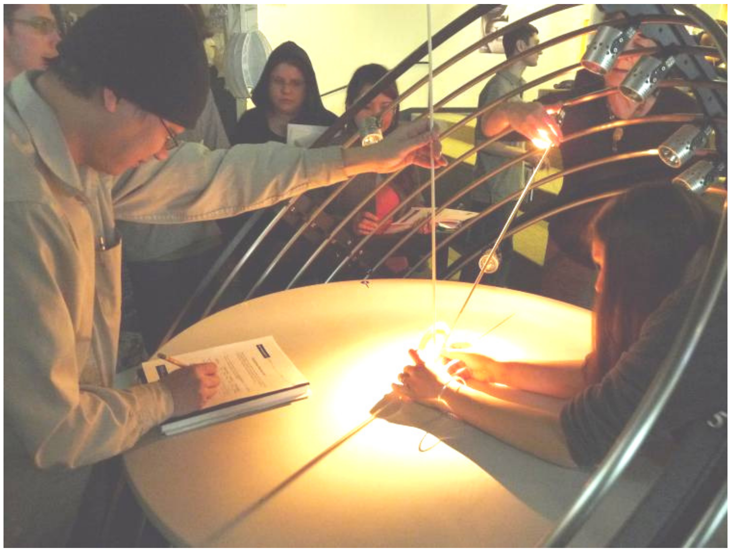

Figure 2: Students being instructed on the heliodon with exercises of duplicating published sun chart data

The sequence leading to engineering devices for daylighting requires first to develop an understanding of shading devices to block unwanted direct sun. Pedagogically this is taught by way of an exercise where the students construct quick shading devices on models using simple materials (folders, scissors and tape) with the Heliodon providing immediate feedback on their efforts. The Heliodon allows a student to observe each attempt to block direct sunlight with the final outcome that each and every student realizes that compass orientation of the window is critical in the final design solution. (Figure 3)

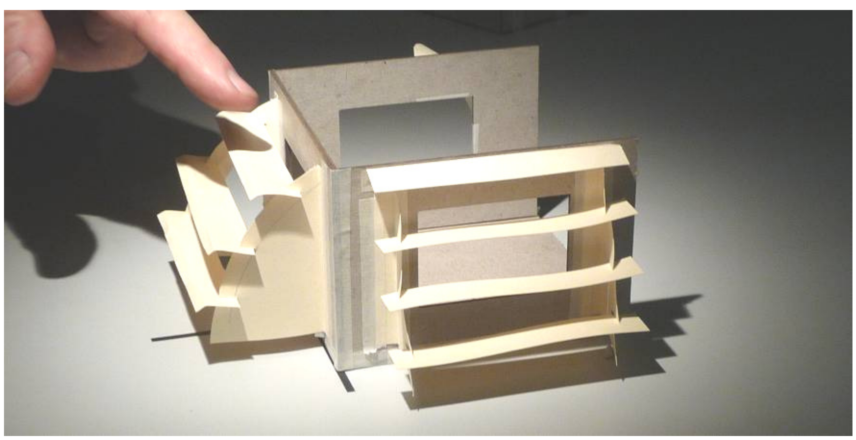

Figure 3: Student experimentation with solar shading devices

In addition to compass orientation, the class is broken up into teams and each is given a different city to design a device for. This exercise foregrounds the importance of geographical location. The next exercise is for the students to construct orthographic drawings in plan and section of the shading devices. This requires the culmination of data reflecting latitude, sun path, location, time of day and time of the year overlaid on scaled drawings of the shading device design. Further instruction is given how to record the data effectively. (Figure 4)

Figure 4: Students producing 2d drawings combining shading device data derived from 3d modeling.

Seventy-seven percent (77%) of all the electricity produced in the U.S. used to operate buildings. The single highest use of energy within the building sector is lighting. Engineering professionals at the Illuminating Engineering Society (IES) have established appropriate light levels for spaces occupied by humans engaged in different tasks. For instance for reading the amount of light needed as measured by a light meter is approx. 50 footcandles. If we take a light meter and walk outside on a clear day in an open area, we will record approx 8000 footcandles. That is approximately 160 times more than we need! How do we take this renewable source of free energy and make it useful to us. (Figure 5) How do we deal with an overabundant 200x concentrated source? A gallon of paint is altogether useless in its collective state sitting in the can. It is only of value when evenly distributed on the walls of a space. This is analogous to full sunlight penetration into an office space. Like a gallon of paint, only when it is evenly distributed can it be of effective use. Additionally, research has found daylight to be an important factor influencing human behavior, health and productivity. [6]

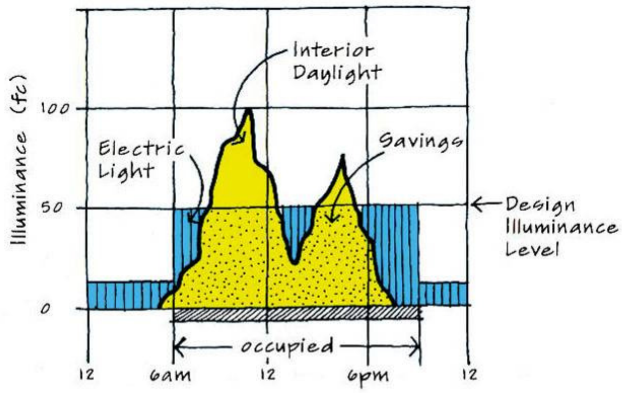

Figure 5: Daylight infusion graph illustrating potential for energy savings [7]

Distributing the energy lighting source of the sun evenly throughout a space is challenging. These challenges form the basis of our investigative pedagogy in how to understand, analyze, evaluate and utilize modern lighting needs. Combining the experience and teaching expertise of three Architecture Technology professors to develop an "Object in Light" in order to kinesthetically demonstrate foundational daylighting principles to the students was a rewarding experience. Each detail was laboriously discussed, revised and reworked. This modeling device, as shown in Figure 6, and the series of sequential steps in the exercise was choreographed to amplify technological awareness.

Figure 6: Professors Bronne Dytoc and Gary Parker planning a simulation exercise with the "Object in Light" testing device on a tilt table.

To teach the concept of daylighting, a single rough base unit was constructed for all students to use as a benchmark. The overall size of the unit was arrived at as a synthesis of portability, the size of tilting table and the ability to take multiple readings with a hand held light meter. Because of the particular size of our model, it became unusable on our heliodon (which has a limited effective model size of approx. 6" x 6" x 4" based on the beam spread of the rotating "sun" lamps). This was not considered a negative, but a positive next step which allowed to introduction of an alternate sun/shading study strategy. This new approach is capable of accommodating any size model using the actual ultimate source of light power – the sun. Proper alignment is achieved by the use of a tilting table and a sun dial chart. A model, ("Object in Light" in our case) is secured to the base of the tilting table. Next step is to place a sundial chart specific to the latitude in question on top of the model. By moving the model around, one can effectively duplicate the angle of the solar rays striking the model at a specific solar time. All of this presupposes that the head of the central peg is aligned (Figure 7) so that the tip of the peg intersects the current time. Note that since the sun is always moving, the table will have to be periodically adjusted to follow the sun path.

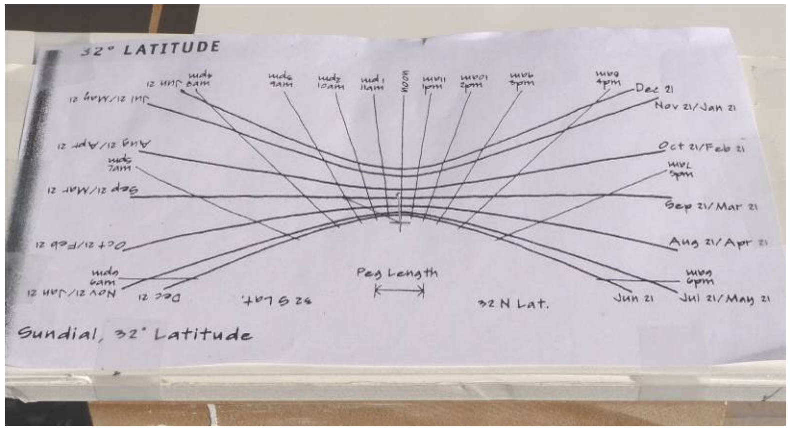

Figure 7: 32 degree latitude Sundial chart set for 9AM on March 21/Sept. 21 Equinox

The students then designed and constructed an insertable solar shading/daylighting device into the south end of the model as shown in Figure 8. The north end was left open, with the assumption of being totally glazed allowing maximum indirect North light to enter the space. [It important to note that direct sunlight does in fact enter north facing glazing, one of the many counterintuitive discoveries revealed by simulations on the heliodon. Sun penetration occurs in the summer months past the equinox in the northern hemisphere.] Measurements with a light meter (in footcandles) were taken at different locations within the space which in turn were converted to daylight factors. The daylight factor is a ratio of exterior to interior illuminance under an overcast, unobstructed sky and remains constant regardless of changes in absolute sky luminance. [8]

Students were to perform the following tasks:

- Document the daylight footcandle levels for benchmark conditions (without solar shading/daylighting device)
- Document the daylight footcandle levels with solar shading/daylighting device insert
- Graph the results and convert to daylight factor
- Photograph exterior view of solar shading/daylighting device at designated solar times
- Photograph interior view of solar shading/daylighting device at designated solar times

Figure 8: Solar shading/daylighting device design study by Kevin Chong and Katherine Gella

The second phase of this exercise was to introduce computer modeling into the study of the "Object in Light." We teamed with an outside engineer who specialized in a new computer modeling product called Autodesk® Ecotect® Analysis. Autodesk® Ecotect® Analysis sustainable design analysis software is a comprehensive concept-to-detail sustainable building design tool. Ecotect Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. [9] The program is very comprehensive and complex. The daylighting simulation portion of the program is small, but at the time appeared to be the industry leader and the only feasible option considering software was supplied free to students. After going through a series of educational workshops, we gleaned the necessary kernels of computer leveraged tasks to introduce to the students.

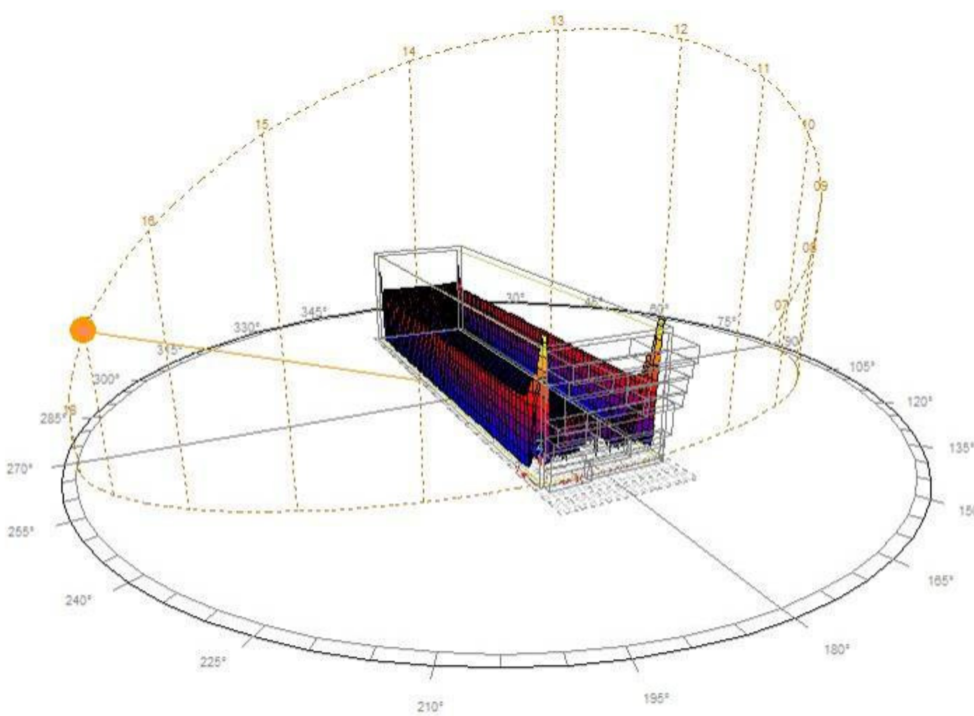

Figure 9: Ecotect Modeling of sunpath with shading device inserted into simulated “Object in Light” daylighting model

Years of experience in the classroom has shown that introduction too quickly into “problem solving” computer programs have reduced value when foundational architectural principles are not fully understood. Obscure results are not easily identifiable among the flash and whiz-bang of tantalizing graphics and animated repetitive sequences. After being engaged with my colleagues in several training sessions, I liken the program to be the equivalent of purchasing a Ferrari to drive to the pool and tennis facility in your subdivision, when a simple golf cart would do. Nonetheless there was a value in introducing the students to the breadth of possibilities. Simple operations were selectively determined to employ in our exercise. A word of caution here, one has to be wary of whether the student's output is truly reliable because buried down deep in the multiple layers of the program commands are obscure checkboxes that can negatively skew the results.

Students were to perform the following tasks:

- Duplicate a digital model of the “Object in Light” with their solar shading/daylighting device insert (Figure 9)
- Run the daylight simulation sequence to achieve footcandle levels across the floor plane
- Graph the results and convert to daylight factor
- Prepare a presentation poster (Figure 10)

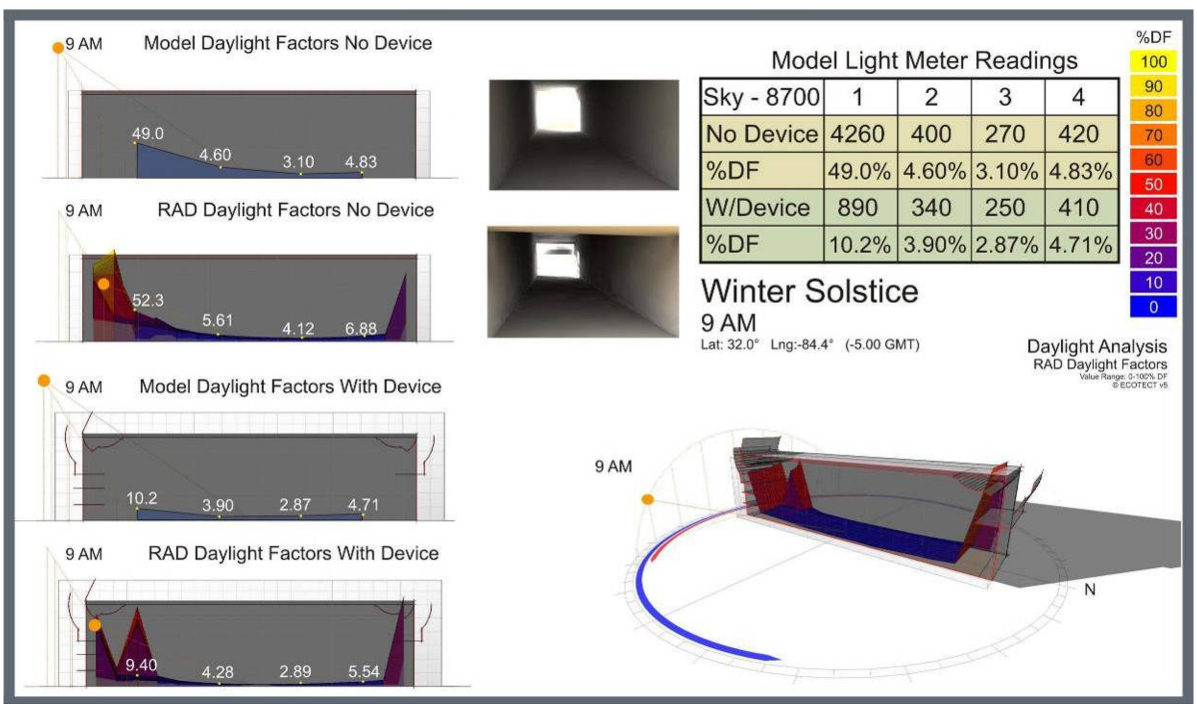

Figure 10: Portion of final project presentation poster by William Tessier & Antonio Hinson

Conclusion

The effective understanding and application of daylighting strategies in the building sector will have a significant impact in the reduction of energy usage. Important to note is that any successful daylighting program must incorporate an automatic lighting control system. With the cost of energy climbing ever higher, the use of automated daylight controls can save 30-50% of electrical lighting energy in the building. [10] As the natural luminescence of the day increases, the lighting fixtures in that defined space will automatically dim to maintain only the required foot-candle levels. All areas that receive at least half of their illumination from sunlight for several hours a day should have automatic daylighting controls. Natural light strategies, although more complicated to design for, carefully incorporated into any "Object in Light" will have profound positive impacts. Moreover, people naturally want and feel a psychological need for the proper amount of natural light. Increasingly, more sophisticated tools are becoming available to maximize the utility of this resource but only through a foundational knowledge of basic architectural principles as demonstrated through this class exercise can these futuristic tools be effectively used.

In closing, savor the perspicacious words of Louis I. Kahn (1901-1974), world-renowned American architect and professor of architecture at the School of Design at the University of Pennsylvania: *We were born of light. The seasons are felt through light. We only know the world as it is evoked by light. To me natural light is the only light, because it has mood, it provides a ground of common agreement for man, and it puts us in touch with the eternal. Natural Light is the only light that makes architecture architecture.* [11]

Bibliography

[1] Architecture 2030 *Problem: The Building Sector, Why?* http://architecture2030.org/the_problem/buildings_problem_why

[2] Architecture 2030 Problem*: The Building Sector, Climate Change* http://architecture2030.org/the_problem/problem_climate_change

[3] Navigant Consulting, Inc., “National Lighting Inventory and Energy Consumption Estimate” U.S. *Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Program,* September 2002, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lmc_vol1_final.pdf

[4] Olgyay, Aladar and Olgyay, Victor. *Solar Control and Shading Devices*, Princeton University Press, Princeton, NJ, 1976, p. 56

[5] Lechner, Norbert, *Heating, Cooling, Lighting: Sustainable Design Methods for Architects,* Hoboken, N.J., John Wiley & Sons, 3rd Edition, 2009, page 145

[6] Stein, Reynolds, Grondzik and Kwok, Mechanical *and Electrical Equipment for Buildings.* John Wiley & Sons Inc., Tenth Edition, 2006, p. 580

[7] Brown, G.Z. and Dekay, Mark. *Sun, Wind & Light: Architectural Design Strategies*, Wiley & Sons Inc., 2nd Edition, October 24, 2000, p. 280

[8] Moore, Fuller. *Concepts and Practice of Architectural Daylighting,* Wiley & Sons Inc. 1984, p. 22

[9] Autodesk® Ecotect® Analysis http://usa.autodesk.com/adsk/servlet/pc/index?id=12602821&siteID=123112

[10] Brown, G.Z. and Dekay, Mark. *Sun, Wind & Light: Architectural Design Strategies*, Wiley & Sons Inc., 2nd Edition, October 24, 2000, p. 279

[11] Ronner, Heinz, *Louis I. Kahn: Complete Work 1935-1974* Birkhäuser Basel, 1989 page 344

Biography

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