The Sun Emulator:
A Conceptually Clear Heliodon

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1. INTRODUCTION

Buildings use over one third of all the energy in the U.S., and most of that energy is for the heating, cooling, and lighting of those buildings. The solar response of a building's skin, which is mostly through its windows, will determine how much of the winter sun can be harvested to reduce the heating load, how much of the summer sun will be rejected to greatly reduce the cooling load, and how much quality daylight will be collected all year to minimize the need for electric lighting. If all windows in California were modified to become solar responsive, the energy crisis would go away. If all windows and building skins of California buildings had been designed to be solar responsive in the first place, even less power would be needed and instead of building more power plants California could shut down some of its controversial nuclear power plants.

Similarly, global warming could be significantly reduced with the world-wide use of solar responsive retrofits and design of new buildings. Global warming could well be the greatest threat to humankind in recorded history. Oceans are estimated to rise anywhere from to 2 to 30 feet. A two foot rise will result if the oceans only expand due to the heating of the water, while a 30 foot rise will result if much of the ice on Greenland and Antarctica melt. There is no comfort in the lack of a precise prediction. We should not gamble with spaceship earth, our only home. Although solar responsive buildings are not the only solution to the problem of global warming, they are a crucial part because of the immense amount of energy buildings consume.

Why were most windows not designed to be solar responsive in California or most of the rest of the world, and why is this still not considered a practical solution? I believe the answer lies primarily with the ignorance of the potential benefit of solar responsive design and the ignorance of how to design windows and building skins with such a goal in mind. Lack of knowledge is not just on the part of architects but also on the part of building owners (consumers), constructors, homebuilders, government officials, politicians, and just about everyone else because the decision making in the design of buildings is spread over most of society. At one time or another just about everyone has influence on how some building will be designed or built.

How then can this situation be reversed? From 27 years of teaching solar responsive design to architecture students and non-professionals, I am absolutely convinced that the use of physical models with a "**conceptually clear**" heliodon is by far the best method to demonstrate and teach the why and how-to of solar design. Within a few minutes of seeing models tested on such a heliodon, most people have an "ah-ha" experience about both the logic and potential benefits of solar responsive design. Working with physical models also creates an excitement that motivates students and non-students alike to explore the possibilities.

2. HELIODONS

Many different heliodons exist and almost all utilize one light to simulate the sun. Since the three variables of latitude, time of year, and time of day determine sun angles, a heliodon must be adjustable for all three factors. Only a few heliodons exist where the model is fixed and the light moves along three axes to adjust for all variables. In most heliodons, however, the model is rotated about one, two, or three axes instead of only moving the light (Fig. 1). The disadvantage of these types of heliodons is that they do not match our real world experience and therefore such heliodons are not "**conceptually clear**." They are neither very convincing to the uninitiated nor do they effectively teach the basic pattern of solar geometry as related to a building.

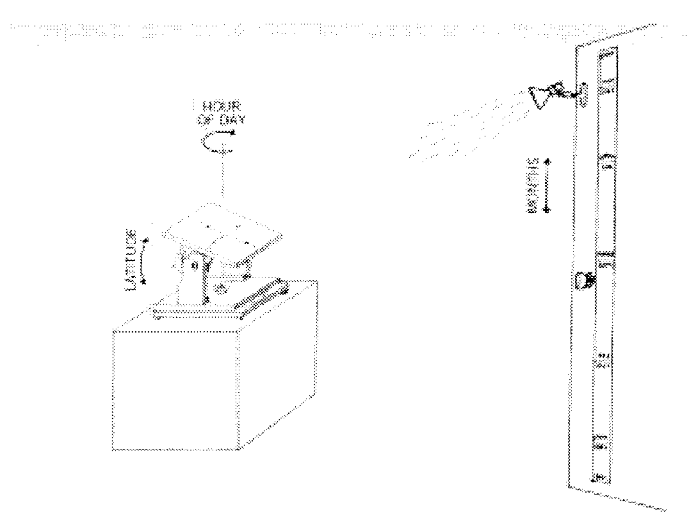

FIG. 1 This type of heliodon tilts the model for the latitude adjustment, rotates the model for the hourly adjustment, and moves the light vertically for the annual adjustment.

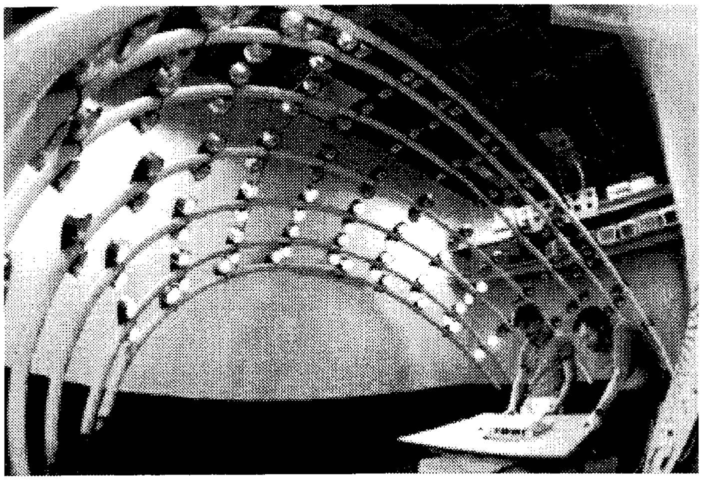

FIG. 2 This type of heliodon uses multiple lamps to simulate the daily and annual motion of the sun. For latitude adjustment the model table can be tilted a maximum of 10 degrees each way.

More than twenty years ago, the author built a heliodon with about 130 lights to simulate the sun every hour of the 21st day of all twelve months (Fig. 2). Thus, electrical switches control for the variables of time of day and year. The model table was still tilted for the latitude adjustment. Although "conceptual clarity" was greatly improved, there are a number of problems with tilting the model. With too much of a tilt, some of the conceptual clarity was lost, some lights moved below the horizon, and, of course, the model had to be carefully glued together and fastened to the table to keep it from sliding. Recognizing the weakness of a tilting table, the author developed over the last ten years a heliodon where the model of the building is placed and remains stationary on the table, while the light moves to simulate the sun's travels across the sky (Fig. 3). Although Copernicus would be upset, this situation fits perfectly with our daily real-world experience, and thus it allows us to form a mental model of the solar geometry that can be used for the design of buildings. While some heliodons accomplish this same goal with the use of only one light to simulate the sun, it turns out better to use seven lights to simulate the sun at different times of the year

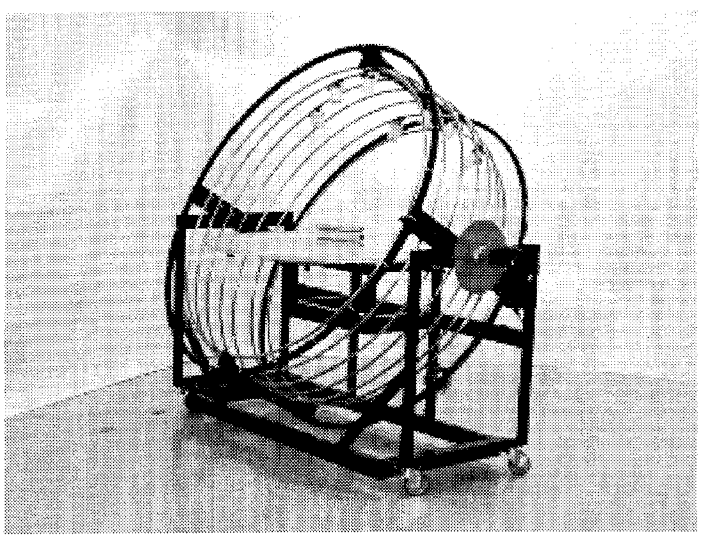

FIG. 3 The Sun Emulator simulates our real-world experience by keeping the building model stationary while the lights move to simulate all of the sun's apparent motion across the sky.

3. THE SUN EMULATOR

Because the Sun Emulator uses seven rings to simulate the 21st day of all twelve months, the heliodon is a 3-D model of the sun paths. At an instant, one can tell that the sun comes only from a part of the sky often called the solar window. It is also easy to see which part of the sky the sun shines from during the overheated period, which part of the sky in the underheated, and equally important which part of the sky the sun never shines from. It is also easy to show how these regions of the sky move up and down with changes in latitude. It is most important to understand that specific sun angles are not very meaningful and potentially misleading. For example, June 21 at 12 noon is not representative of the summer condition although frequently used in graphical approaches to solar design. Rather, it is very important to understand that the sun must be rejected whenever it comes from the summer **region** of the sky. The size of this region is a function of climate. Similarly, the sun angle of Dec. 21, 12 noon is not especially meaningful because we want to collect the sun when it is coming from the entire winter **region** of the sky.

By rotating the cradle, which holds the rings, it is easy to understand how to design a solar responsive building anywhere from the equator to the poles. It is instantly obvious that at the equator, north and south windows receive equal amounts of sun over a year (Fig. 4), while at the north and south poles, the north, south, east, and west windows all receive equal amounts of sunlight on any day. Thus the Sun Emulator is a powerful teaching tool even before its lights are turned on.

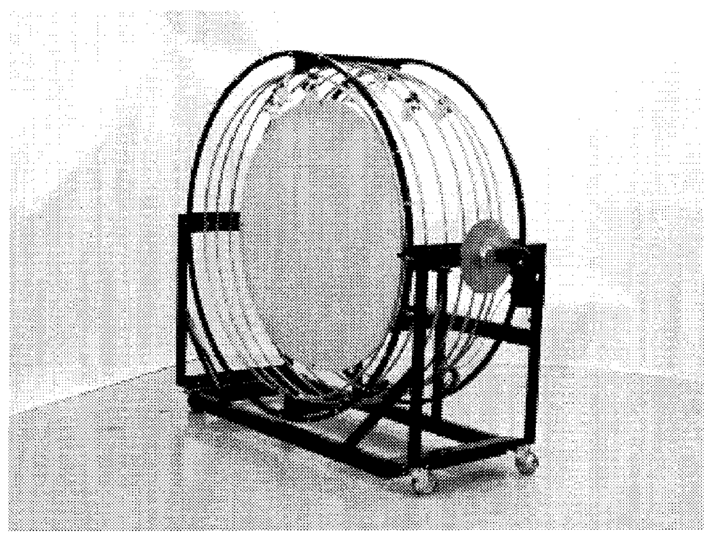

FIG. 4 The Sun Emulator in its storage mode. The cradle with the 7 hoops is set for 0 latitude, as it would be to simulate the solar geometry at the equator.

The Sun Emulator clearly shows not only the daily symmetry of the sun's travels across the sky but also the annual symmetry where the sunpath for Nov. 21 is the same as Jan. 21 and May 21 is the same as July 21, etc. It is for this reason that only 7 rings (sunpaths) are needed to simulate the 12 months. This heliodon also shows how for six months of the year the sun shines into north windows at all latitudes even if it is only for brief times and at very glancing angles. Many people erroneously believe that the sun never shines into north windows. For hot climates this fact is of great importance as the north shading sails of Will Bruder's Phoenix Central Library beautifully show. It is also easy to understand how the length of day is a function of not only time of year but also latitude, except of course, for the two days each year called the equinoxes. All this can be understood within minutes by any person, of any age, and any educational level.

Unlike graphical, verbal, or mathematical explanations, learning from a "conceptually clear" heliodon is exciting, easy, quick, and leaves a profound long lasting understanding because it does not depend on rote memory but a god's-eye-view of the relationships of a building with its constantly changing solar environment.

4. DIRECTIONS FOR USE

Printed directions for the use of the Sun Emulator are extremely brief and almost unnecessary because this heliodon simulates our everyday reality. First, the model to be tested is placed at the center of the round table, its south orientation aligned with that of the heliodon. Then the cradle holding the seven hoops is adjusted for the correct latitude by means of a single locking knob. Next, a twelve position rotary switch is used to choose the sunpath for the 21st day of any desired month. To simulate the daily motion, the appropriate hoop is rotated by hand from sunrise to sunset. Other hoops are then rotated to investigate solar access and shading patterns at other times of year. To see what happens through the year at a particular time of day, the lights of all the hoops are aligned and the rotating switch is turned to simulate the annual travel of the sun up and down the sky.

5. APPLICATIONS

Although the Sun Emulator was developed primarily for architecture students it is appropriate for a much wider audience, as will be discussed below. For architecture, landscape architecture, planning, and interior design students a heliodon has three separate applications: the initial learning of concepts and principles, the design process, and presentation. As was described above, the Sun Emulator is an excellent and exciting teaching tool. As a design tool, it can be used to actually assemble a design as, for example, when the length of an overhang is determined on the model by a trial and error method. Or the heliodon can be used as an analysis tool where a design developed away from the device is tested for its performance. In my own classes, I have students test models of designs that were previously created in studio. After the analysis establishes what works and what doesn't, the students redesign their projects to be more solar responsive. Next, fast and dirty study (not presentation) models are built and again tested on a heliodon to determine what weaknesses remain for further redesign. The most popular application among the students is for presentation purposes. They photograph their models to document their designs' solar responsiveness for juries and their portfolios.

Homebuilders are another major user group. Most homebuilders are in fact designers. They often decide which building design will be used, what its orientation will be, where it will be located on a lot, what trees will be left standing or where trees will be planted, etc. Each of these decisions would benefit greatly from the understanding of solar responsive design principles. Developers are even more in need of this knowledge because street orientation has major consequences, since it will usually determine orientation of the buildings which are almost always aligned with the street rather than the sun. One of the most successful developments in the second half of the twentieth century, Village Homes in Davis, California, was designed by means of physical models tested for solar responsiveness.

If homeowners and architectural clients are not interested in solar responsive design, then there is little incentive for building professionals to provide such designs. Thus it is imperative that all who finance or control the design of buildings should be knowledgeable about the potential benefits of working with the sun, and ironically, many of these benefits are free.

In effect almost everyone should understand the financial and environmental benefits of solar responsive design. Such a widely held understanding, I believe, is best accomplished by means of a "conceptually clear" heliodon. If the hands-on science museums for children had heliodons, children would understand early on and in a lasting manner the logic of designing with the sun. Schools too could use heliodons in their earth science or physics courses. If children routinely learned about these principles, we would have future generations that would demand the benefits of solar responsive design because they would know that they are real and achievable.

6. LIMITATIONS

The Sun Emulator is an excellent heliodon for teaching and designing where high precision is not vital which is the case for most building design. For example, the precise knowledge of the shading from a tree is meaningless since trees grow. Also weather is too variable to establish precise dates when sun or shade must be available.

Although the sun angles for the point at the center of the table are very precise, as one moves away in all three axes error accumulates. Thus small models are best and some larger models can be moved so that the part of the model being analyzed is placed over the center of the table.

The highest precision in model testing is possible with sundials mounted on models tested outdoors, the only place where parallel light rays are possible. Although such model testing is extremely precise, it is inconvenient, awkward, and conceptually unclear. It is awkward because you can't test models outdoors at night or when the sky is overcast, and it is frustrating and uncomfortable under partly cloudy, windy, hot and cold conditions. Testing models outdoors requires the model to be tilted to account for all three variables of sun angles: latitude, time of year, and time of day. As described earlier, this results in problems that are both practical and conceptual. Non-horizontal models must be well glued and prevented from sliding. They are also not easily analyzed since we find it hard to relate to buildings that are not horizontal. Consequently, I recommend outdoor analysis with sundials only after a design is ready for presentation purposes, or for fine tuning when high precision is required.

Although some other heliodons are more precise for larger models than the Sun emulator, its "conceptual clarity" ease of use, and other advantages more than compensate for its limits in precision.

7. ALTERNATIVE TOOLS

Computers with solar 3-D programs are an alternative for the analysis and presentation applications of heliodons. However, for the initial learning of the broad concepts and for developing a mental model of the solar geometry as related to buildings, heliodons with conceptual clarity are far superior.

Learning the complex geometry of the sun as related to a building on a computer sreen is like learning the street pattern of a complex medieval town by driving around it in a van that has only one window, the windshield. A much faster and deeper understanding of the town would occur by exploring it on foot. Not only is one free at all times to move in any direction, but also one is free at all times to look back or sideways. Because every view is in complete context of where one is, a mental pattern of the town will emerge faster, be more complete, and last longer than through a controlled drive-through. Thus, I believe, the initial learning of solar geometry will always be better with a heliodon like the Sun Emulator than with a computer program.

For the student still new to this knowledge, a heliodon would also be very useful in the analysis stage of design. It is not easy to know how a solar access analysis should be performed (i.e. what time of day or year should be investigated). A heliodon's intuitive clearness and immediate feedback helps in planning and performing a solar analysis.

Even at the presentation stage, a heliodon can be more advantageous than a computer. Although the presenter may not need the heliodon's clarity, the audience, which is often much less informed about solar geometry, would understand a solar responsive design more easily and believe more fully in the virtues of the design being presented.

8. CONCLUSION

It is hard to believe that a rather simple mechanical device could be a such a powerful teaching tool. It is also hard to believe that such a device could have a major impact on our energy future, the environment, and especially global warming. My 27 year teaching experience with heliodons makes me believe that "conceptually clear" heliodons are truly powerful teaching tools, that don't wear out and don't become obsolete. They also excite and motivate the users to explore the possibilities of solar responsive design.

More information about the Sun Emulator is available at: *www.cadc.auburn.edu/sun-emulator.*

9. REFERENCES

Lechner, Norbert, *Heating, Cooling, Lighting: Design Methods for Architects*, 2nd Ed., New York: John Wiley & Sons, 2001.