Daylight Model Construction and Analysis

A Pacific Energy Center Factsheet

Introduction

There was a time when working hours, office planning, and even the design, location and orientation of entire buildings were governed by access to natural light. Daylight connoted health and cleanliness, and good daylighting design was recognized as a measure of building quality and value. During the mid-to-late-twentieth century, with the development of new technologies such as fluorescent lighting, heat absorbing glass, and air conditioning, daylighting skills declined among many design professionals. Well daylit buildings became increasingly scarce, while overglazed and misoriented buildings became common practice.

Fortunately, many architects and engineers are revisiting daylighting design in new ways and integrating improved electric lighting and glazing technologies. Dimmable fluorescent fixtures, photocell-controlled lighting systems, and spectrally selective glazing are just a few of the technologies that can improve lighting quality, comfort, and energy performance in a building. Creating a well daylit space, however, requires more than the installation of technologies. Designers must effectively integrate technology and architecture. To make smarter decisions about the technology most appropriate for a space, designers must understand the daylight characteristics of that space. The physical daylight model is one of the most fundamental and useful tools for assessing and predicting daylight levels and qualities.

Energy Center Resources

The Pacific Energy Center (PEC) offers a collection of tools, exhibits, software, and consultants to assist in the design and evaluation of daylighting models. Because daylight is independent of scale, an architectural model is a very quick and inexpensive tool for exploring quantitative and qualitative daylighting issues. A daylighting model can also provide answers to questions such as:

- Does the distribution of daylight and relative illumination levels at different areas within the space meet my design intent?
- Are the luminance values of adjacent surfaces in the design acceptable for good visual comfort?
- How much daylight do I have three feet from the window or sixteen feet from the window?
- How will increasing the window head height and changing color or reflectance of walls, carpet, or office furniture affect lighting quality and illumination levels?
- Can I reduce the operating hours of electric lighting by installing skylights?

With this information, designers can better address comfort, design, and building performance issues.

Measuring Daylight Levels Using a Physical Model

One method of measuring and reporting a design's performance is in terms of daylight factors. A daylight factor is the amount of available light at a location inside the model expressed as a percent of available exterior daylight. Energy Center staff use the Skybox, photocells (light sensors), and a data acquisition system to measure daylight factors. Up to nine photocells are placed at strategic locations within the model to measure interior light levels, while a reference photocell placed on the model's roof measures available daylight. The value measured at each interior photocell is divided by the exterior reference value to determine daylight factors.

Daylight distribution and absolute illuminance are not solely dependent upon building properties such as geometry, glazing selection, and the finish of interior surfaces. Exterior conditions including ground reflectance and horizon obstructions such as buildings and vegetation also influence interior lighting characteristics. If the model does not include surrounding buildings and landscape elements, and the building site and model test site differ significantly, light level readings between the two spaces may not correspond.

To create consistent test conditions, the Energy Center conducts daylight analyses in the Skybox, which simulates overcast sky conditions, providing even lighting from all directions. To predict absolute illuminance levels, the staff relies on published weather data and daylight factors. However, because of the many factors that can affect illumination levels, the Skybox is best used for comparative evaluation of different design options rather than precise predictive measurements.

Building the Architectural (Physical) Model

To accurately predict daylight levels and daylighting characteristics, a model should be built with the following guidelines in mind:

- Models should be no larger than 4’ x 4’ in plan. The Skybox can accommodate larger models, but be sure to contact the Energy Center ahead of time if your model exceeds these dimensions.
- Use opaque materials to model opaque building elements such as walls. To determine whether the material is opaque, hold it up to the sun, and place your hand behind the material. If you can see the outline of your hand, add layers to the wall assembly or use different materials. Note that foam core and museum board are translucent. They can be used to achieve wall thickness but must be covered with an opaque material.
- To model a translucent material, use a similar translucent material (trace paper, vellum, translucent glass sample) in the model. For help determining the translucency of a material, contact the PEC staff.
- The model should be free of light leaks. Use opaque tape (black gaffer’s, electrical, or duct tape, for example) to cover seams or other sources of light leakage.

- Color, materials, and finish characteristics do matter, because they affect how light is reflected. However, testing models early in the design process, when it is unlikely you will have selected finish materials, makes it far easier to incorporate the findings as design revisions. When comparing schematic design options, it is more important that the options be consistently represented than that they precisely predict your final finish selections. If you don't know your finish materials, when building the model use an 80% reflective material for ceilings, 50% reflective for walls, and 20% reflective for floors.
- If you are testing a model later in the design process, you have the option to more closely represent finish materials. When selecting model materials, achieving accurate reflectance qualities is more important than correct color representation. Two colors can appear very different but have the same reflectance or gray-scale value. Simply comparing model-building materials to a manufacturer's color samples is reasonably accurate. Photographs of the model can be converted to grayscale and accurately represent the finished project. To achieve a higher level of accuracy, materials intended for use in the finished building can be evaluated using equipment from the Energy Center's Tool Lending Library to measure reflectance
- Glass affects daylighting performance. For glazed surfaces which vary significantly from single-pane clear glass, use glass samples or tinted acetate with similar color and light-transmittance qualities. For diffusing glazing, often found in skylights, use layers of tracing paper to match or approximate the actual visible transmittance. Alternatively, if one type of glass will be used throughout the space being modeled, the windows can be left blank and the interior readings reduced in proportion to the visible light transmittance of the glass to be specified in the building. However, this means that photographs of the interior of the model will not accurately reflect built conditions. If the glazing manufacturer's specifications are unavailable or you want to determine the visible light transmittance of a glazing sample or model building material, the Energy Center staff can measure those values.
- It is not necessary to build an intricate model. However, significant building geometries such as thick mullions, deep window frames, skylight wells, and light shelves should be accurately represented, since the precision of the analysis results is directly proportional to the accuracy of the model. If furniture plays a significant role in the composition of the interior, include rough mock-ups with the correct reflectances.
- The primary purpose of the model is to study the interior. Exterior elements only need to be included if they affect daylight transmittance. Whenever possible, include exterior objects that absorb or reflect light, such as walls of nearby buildings, nearby trees, and asphalt or concrete.

Model Construction Check List

Although each model is unique, the Energy Center staff recommends the following to avoid complications and minimize erroneous readings during the study:

- Build the model at a scale that results in an 18" x 18" to 24" x 24" overall dimension. Working with an oversized model is tedious and difficult, and working with a small model often makes photographing and constructing it difficult.
- Models should be constructed to allow for placement of a series of up to nine 1”-high, cylindrical photocells on the model’s interior floor surface. The scale of the model should be 3/8” or bigger. In addition, certain openings in the model should be provided to bring in the photocells (Figure 1a). Such openings could be existing windows; otherwise a piece of the façade material should be prepared to cover the openings to ensure correct daylight conditions. Ideally, one façade could be easily removed in order to move the photocells conveniently (Figure 1b). After the setup of the photocells is complete, the façade could be replaced (Figure 1c). All seams and gaps should be sealed with opaque tape.

(a) The opening in the left wall allows the photocell wires to pass through.

(b) The façade was removed so that the photocells could be easily moved.

(c) The façade was then placed back onto the model

- Provide a 1.5" x 1.5" opening through a wall for the cables connecting the photocells to the data acquisition system. This opening will need to be sealed while taking light measurements.
- Use a wide-angle lens to photograph the model interior. To accommodate the wide-angle lens, cut a 3 1/4" diameter opening, centered at eye level, and keep the remaining circle to plug the hole when not photographing. Two or three strategically placed photo ports are typically sufficient to capture the daylight conditions of most spaces.
- If exploring different options for glazing type or placement, skylight geometry, furniture color, etc., build the model in such a way that you can "plug in" or interchange options with minimal effort.
- Make sure the model will withstand tilts of up to 90 degrees for determining shading patterns at different times of year. For shading analysis information, see the Heliodon Studies Factsheet.
- Bring precise building orientation information for sun shading tests on the Heliodon. However, since the Skybox represents an overcast sky condition with evenly distributed skylight, orientation of a model for Skybox studies does not matter.
- Come prepared with questions and issues that need to be addressed. What do you want to know or what information do you want to have after the test?

Scheduling an Appointment

Contact the Pacific Energy Center, using the "Skybox Session Request Form," at least three days in advance to schedule a time to conduct the daylight analysis of the model. Once the data set is collected, the results will be downloaded into a Microsoft Excel spreadsheet to provide you with an electronic and/or hard copy of the results. You will need to bring a storage medium such as a writable CD or a USB drive

For further information on model construction, procedure, reflectance of modeling materials, contact our Architectural Programs Coordinator, Bill Burke, by email at wxb0@pge.com (that's a zero after the "b").