THE DAYLIGHTING DESIGN PROCESS – TOOLS FOR PREDICTING
DAYLIGHT AND TECHNIQUES FOR MAKING SOUND DECISIONS
ABOUT DAYLIGHT DURING DESIGN

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ABSTRACT

Today’s technology offers architects and engineers a wide range of tools to assist with
daylighting analysis during the design phase of a project. However, the ultimate success of a
daylit building still rests in a careful balance of art and science.

Massive amounts of data can be generated by today’s sophisticated computer models, but what
does it all mean? How can we transform all of this data into sound design decisions for our
architectural projects? Reliance on over-simplified quantifications such as daylight factors or
glare probability indices will never result in well-daylit buildings and certainly never produce
beautiful architecture. Therefore it is critical to use all of the available technology wisely.

This session will explore some of the daylighting tools and techniques commonly employed
during the design process using the David L. Lawrence Convention Center located in Pittsburgh,
PA as a case study.

DAYLIT ARCHITECTURE vs. BUILDINGS WITH WINDOWS

Before reviewing tools available for predicting daylight, it’s worth trying to define “daylit
architecture.”

Daylight itself is good for people since it sets our biological rhythms, gives us a connection to
the weather and time, and keeps us physically and mentally healthy. Daylight is a high-quality,
high-color-rendering light source that’s always changing: daily, seasonally, and with the weather.
With more and more time being spent indoors, inside architectural environments, people are
being deprived of the natural light that is responsible for sustaining life. Architects through the
ages have designed architecture to effectively introduce sunshine and daylight into building
interiors, to not only provide task lighting (before the advent of electric lighting) but also to
sustain human life and allow it to flourish.

Key Words: Daylighting, tools, techniques, process, architecture, schematic design, design
development, construction documents, sun-path diagram, aperture, glazing-to-floor-area,
computer models, redirected light, sundial, heliodon, illuminance level, daylight factor, Daylight
Autonomy, Useful Daylight Illuminance, Daylight Saturation, LEED.

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Good interior lighting can simplistically be defined as lighting that enables people to perform visual tasks and to be comfortable while performing them. Daylighting design is inseparable from electric lighting design and must consider issues such as:

- Brightness balance
- Distribution of light in space and time (time of day and season)
- Appropriateness of illumination levels
- Energy saving techniques

THE ARCHITECTURAL DESIGN PROCESS

Although the architectural design process is usually a non-linear exercise in creating forms and spaces, the architectural profession itself has developed a well-recognized building design procedure that usually consists of several phases: Schematic Design, Design Development, Construction Documents, and Construction Administration.

For interior spaces in which sunlight (illuminance from direct sun) and daylight (illuminance from the sky dome) are an integral part of the luminous environment, special care must be taken early in the design process to ensure proper orientation, massing, space planning, and sizing and shaping of apertures, since these early decisions will have the biggest effects on the overall building performance.

Schematic Design

After establishing the program for a project, the focus in the architectural design process shifts from defining the problems to solving those problems. During schematic design, the emphasis is on the overall concept or “big idea”. Here, minor details are set aside in order to concentrate on creating a coherent solution that forms the project as a whole. It’s during this phase that daylighting techniques must be explored since they will affect the very form of the building.

Most architects start with a concept or grand vision of the form. In the case of the David L. Lawrence Convention Center (DLLCC), the program, the city site, its proximity to the river, and the existing structures all influenced the basic shape and design aesthetic.

2 Rafael Viñoly Architects.
Conceiving the grand exhibition hall as a daylit space, the architect had to understand the site and climate: Where is the sun and how often does it shine? Scale models were constructed and used for studying the building massing and for presentations to the client. Renderings were also produced for presentations to the client. These renderings are very powerful in conveying the spirit of the concept but should be accurate in representing the actual solar conditions of the space. Many ‘tricks’ can be played with hand-drawn or computer-generated renderings in order to create a special luminous quality. However if the designer and renderer are not properly communicating, the resultant design could be a great disappointment, not to mention a possibly unusable space. For example, even though south is to the left in image 2, the renderer chose a light source coming from the north. The shadows cast by objects in the space are darker than those cast by the building. The actual space will never look like this rendering.

IMAGE 2: Early presentation rendering.³

Using simple tools such as sun-path diagrams early in schematic design can enable the designer to determine an accurate relative position of the sun in the sky at any time during the day and year, along with the impact of elements surrounding the building site.

IMAGE 3: A sun-path diagram with an acrylic dome reflects site obstructions.⁴

³ Rafael Viñoly Architects.
⁴ Perusion Solar Path Finder. Solar site analysis.
Once the basic building form is established, these tools can be applied to determine sun penetration at various times of day and year through simple two-dimensional section studies. On the DLLCC project, image 5 showed us early on that clear glazing on the south curving glass wall would result in too much direct sun in the exhibit hall. The architect still wanted the roof structure to ‘float’ and so a small strip of clear glass was used at the top of the curve with diffusing fabric membrane below.

Determining the amount of aperture in the very beginning of schematic design is most often based on a designer’s experience or on rules of thumb. Simple ratios of glazing-to-floor-areas are cited as early as the writings by Vitruvius in his *De architectura*.

Shortly after two-dimensional sections are studied, a physical or computer model is typically used by the design team to further study the effects of sunlight patterns in the architecture as well as initial quantifications of daylight. Computer models are fast becoming useful tools early in

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5 Pilkington/Libby Owens Ford Sun Angle Calculator.
6 DLLCC.
the design process. Programs like SketchUp or Ecotect can provide quick and accurate thumbnail renderings relatively easily.

IMAGE 6: A SketchUp model of another project shows shadow patterns based on real sun positions.7

IMAGE 7: Ecotect allows the user the ability to move the sun around a model quickly and study the shadow patterns. It also graphically indicates the solar path diagram in three dimensions making it very easy to understand the sun’s movement and position for a given latitude.8

The shortcomings of these computer tools are that they do not render bounced or redirected light as quickly as they provide shadow patterns. Since the calculations take considerable time, these computer programs still remain less pliable than physical models this early in the design phase. Many times it is more intuitive and quicker for the designer to construct a physical study model to test the results of sunlighting effects on the built form.

Since the architect for the DLLCC had constructed a detailed physical model of the exhibition hall, the team used it to study sun patterns as well as measure relative light levels. With a basic sundial (and the sun or a directional light source), simple sunlighting tests were performed by adjusting the sundial for the correct latitude and properly orienting it on the model.

7 Google SketchUp. 3D Modeling. 2007.
Design Development

During the design development phase the concept is developed into a final design. In previous phases, the project was viewed as a whole. During Design Development, it becomes important to focus attention on each aspect and detail of the project. When dealing with the daylighting aspect, further information can be gathered about the design through more detailed physical or computer model analysis, as noted before. Sunlighting animations of the DLLCC were made using a physical model on a heliodon (tilt-table) with a digital video recorder, primarily for presentations to the client. When a scale model uses materials that represent the light reflectance of the actual finishes and the relative apertures are accurate, measurements can also be taken within the model with a light meter or a series of light sensors and the resultant measurements, if normalized to actual conditions and multiplied by designed glass transmissions, will be close to those of the actual space. Overcast conditions are often more easily quantified as “daylight factors” – a percentage representing light at a particular point inside relative to the light outside.

Image 9: A portion of the DLLCC exhibit hall model on a heliodon table with a digital video camera. The table is designed to lock in latitude and time of year. Only the top platform is rotated to simulate time of day.9

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9 Model testing at Lam Partners, Cambridge, MA for the DLLCC, Pittsburgh, PA.
The original daylighting tests for the DLLCC were done almost ten years ago. Today there are a host of computer programs that can be used to produce the same data as the physical model with more accurate results; DaySim, Radiance, AGI, SPOT, and Window, to name a few. It is still sometimes quicker, however, to produce animations with a physical model and video recorder since a computer model requires time-consuming calculations for thousands of times throughout the year. Also, when creating computer models, special care must be taken to include relevant information both inside and outside of the model. A physical piece of chip board or foamcore naturally has two sides. That’s not the case in a computer model. Unless a surface is ‘mapped’, that surface does not exist in the virtual world and will result in bogus quantitative analysis. The computer model shown in Image 11 looks like a foam-core model in the way the adjacent planes are created. These planes, i.e. the courtyard on the far side of the building, are just as important as the lightshelf in bouncing daylight into the space and therefore must be included in the computer model.

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10 Model testing at Lam Partners, Cambridge, MA for the DLLCC, Pittsburgh, PA.
11 Lightscape model for classroom daylighting study, Lam Partners.
Aside from basic illuminance levels and daylight factors, computer programs are also embracing other metrics such as Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), and Daylight Saturation. Metrics such as ‘Daylight Autonomy’, which represents the percentage of work hours in which daylight is sufficient to perform a given task, are particularly useful since they incorporate a large amount of data for each point in a space for an entire year. These kinds of tools and metrics allow a designer to make better-informed decisions earlier in the design process.

**Construction Documents**

At this stage of the architectural design process, the effort shifts from design to communicating the design and providing the information necessary for construction, typically through drawings and specifications. Usually daylighting systems are refined, details developed and documented, and a full energy analysis is performed with more accuracy. It is typically not until construction

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documents or late in design development that active shading devices and electric lighting controls are detailed for augmenting the daylight and sunlight for programmatic and energy-saving purposes.

One of the more creative components in the DLLCC came in the form of a shading system for the exhibition space, and particularly the strip skylights. Due to the varied activities taking place in the hall, multiple visual scenes were required regardless of sky conditions. And, although the architectural systems could not make a sunny day out of a cloudy day, it could make a cloudy day out of a sunny day by diffusing direct sunlight through a series of translucent shades. In addition, blackout shades were part of the roller shades so the sun could be continuously ‘dimmed’ in the space based on programmatic needs. Image 13 shows how the active shading system integrated into strip skylights at DLLCC works.

![Diagram of overlapping shading system](image13.jpg)

**IMAGE 13:** Diagram of overlapping shading system.  

The final piece of the overall visual environment is how well the electric lighting is integrated into the daylighting system. Using fluorescent lighting as the primary electric source in such a large volume as the DLLCC seemed pretty unorthodox. The original design concept of using fluorescent lighting came as a reaction to the building architecture. Using T5 high output fluorescent lighting was an innovative approach to achieve a balanced lighting environment.

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13 Mecho-Shade development drawing for DLLCC. Pittsburgh, PA. Design by Lam Partners.
fluorescent lamps allowed a lot of light to be packed into a small package. The paired fabric ducts spaced at 60’ on center served as large-scale luminaires in which to integrate the custom lighting hardware and to ‘marry’ to the basic lines of the building. The mounting detail that supported the light fixture also supported the fabric ductwork in a way that kept the basic shape of the fabric tube even under a no-airflow condition. This was an important feature since the tubes flanking the light fixtures were intended to baffle and redistribute the light from the very bright fluorescent lamps. The concept was tested in several full-scale mock-ups; another important tool for the designer when models and simulations are simply not adequate.

Obviously a key part of the energy savings was the ability to control, or completely turn off the electric lights under adequate daylight conditions. Traditional lighting of large-scale exhibition halls is frequently accomplished with high intensity discharge sources such as metal halide. These sources are not easily dimmed or switched. The fluorescent sources used at the DLLCC are controlled automatically with photocells.

![Image 14: The electric lighting was integrated between paired ducts and controlled with photocells based on daylight availability. The indirect distribution blends seamlessly with the fading daylight in the space.](image)

**Construction Administration**

Although Construction Administration is not considered one of the ‘design’ phases, it is the final piece of the process and extremely important in the overall success of the project. The design team is responsible for clarifying design intent by answering questions and visiting the site for observations during construction. It is during the Contract Administration phase that daylighting systems, electric lighting systems, and control systems are all commissioned. This commissioning is critical for insuring that the systems are operating as intended and that the energy saving potential is fully realized.

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14 DLLCC. Lighting design by Lam Partners.
CONCLUSION

Daylighting has been an integral part of the built environment throughout architectural history, and structures that are thousands of years old are still revered for their daylighting qualities. It’s only within the last seventy years or so that daylighting has been supplanted by electric lighting as the primary source of interior daytime illumination. In most cases, daylight is thought of as an amenity, instead of as the primary source of interior illumination. This doesn’t make much sense for a space that is used primarily during the day when electrical demand is the highest.

Designing a daylit facility and forecasting the benefits takes an experienced design team. Programs such as LEED are excellent incentives for promoting green design. Unfortunately, some qualitative aspects of the architecture have to be quantified in order to achieve LEED points. For example achieving the ‘Views’ point in LEED simply means you have a view to the outside, it doesn’t matter if it’s a wide panorama of a mountainside or a porthole view into an alleyway. Quantifying the performance of daylight and sunlight is a very difficult task and quite different from simply measuring footcandles, kilowatt-hours, or BTUs. It is important to use all of the available tools that technology has to offer, but these tools must be understood and properly implemented in order to create the best possible interior visual environment. Fine meals are not rated on calories per dollar; lighting should not be evaluated by daylight factors or lumens per watt alone. Just as the introduction of electric lighting itself did not improve the visual quality of interior architecture, sophisticated analytical tools will not necessarily create a better daylighting design.

The David L. Lawrence Convention Center was designed ten years ago. The sophisticated computer programs and design tools we have today were not readily available and/or less user-friendly at that time. However, if this project were being designed today with our better tools, would it have influenced the overall design? Perhaps not. We may have had better or more accurate results of energy usage or daylight availability, or been more efficient in the design process, but it probably would not have severely altered the overall parti. The main reason is the fact that the design started with a solid premise: a daylit hall that inspires the human spirit. Aperture sizes, glazing characteristics, etc could have been fine-tuned, and perhaps resulted in better energy savings, but the basic approach would have been the same. Good daylight design comes from good design, as well as intuition, knowledge, talent, and a comprehensive design process. The tools constantly improve, enabling early decision-making, but the tools will never produce architecture or great daylight design. The beauty of the final object is a result of the craftsmen who use the tools and recognize the best tools to be used at the best time.

The true success of tomorrow’s daylit buildings will be measured in beautiful architecture that saves our natural resources, yields economic benefits, and creates comfortable, exhilarating places to be.
Bibliography


