

# The Application of Daylighting Software for Case-study Design in Buildings

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*The application of different software, whether simple or complex, can each play a significant role in the design and decision-making on daylighting for a building. This paper, discusses the task to be accomplished, in real case studies, and how various lighting software programs are used to achieve the desired information. The message iterated throughout the paper is one that respects, and even suggests, the use of even the simplest software, that can guide and inform design decisions in daylighting. Daylighting can be complex since the position of the sun varies throughout the day and year as well as do the sky conditions for a particular location. Just because we now have the computing capacity to model every single minute of a day throughout a year, doesn't justify its task. Several projects; an architecture studio, a university office building, a school library and a gymnasium all present different tasks to be achieved. The daylighting problems, the objects and the software application and their outcomes are presented in this paper. Over a decade of projects has led to reflecting upon the importance of computing in daylighting, its staged approach and the result that it can achieve if properly applied.*

**Keywords:** *Daylighting Design, Daylighting Analysis, Radiosity, Ray-tracing*

## A GUIDE TO DAYLIGHTING

One of the objectives of International Energy Agency (IEA) Task 31 Daylighting Buildings in the 21st century was to construct a 'roadmap' towards guidance for better daylighting of buildings (Ruck, 2006). In doing so, three objective criteria; obtaining a desired illumination on the task, achieving overall lighting distribution and room definition and providing an optimised visual contrast and minimisation of glare, were established. Furthermore, several parameters to be considered for a space are its room characteristics in-

clusive of surface reflection and aperture (window) size, orientation, glass and shading type, as well as room geometry. Of course the ultimate consideration is the type of daylight (sky condition), its location and its availability.

There are specific programs (Daysim (Reinhart 2006, Yun and Kim 2013) or Perez's 16 different ISO sky types (CIE 2003, ISO 2004)) that provide for direct solar and sky light data to be produced for geometric computer models of buildings. Programs such as Lightscape®, 3d-StudioMax®, Desktop Radiance, Ra-

diance, whether radiosity or ray-tracing (Greenberg et. al. 1986, Ward 1994)) based on calculation principle, can take advantage of this sky lighting information. It is the program type and its application, which needs to consider the task, required to be solved. So often programs are applied without any objective or understanding of why the program is used in the first place. What is the task we want solved? What are we analysing and with what software are we doing it?

In hindsight, several basic steps are considered in the re-construction of the processes used in several real projects as related to producing good and successful daylighting design. These have encountered some of the simplest CAD programs, such as Google Sketch Up, through to very computationally complex programs such as Desktop Radiance and 3D-Studio Max.

**STEP 1: BUILDING GEOMETRY, APERTURES & SUNLIT CONFIGURATIONS**

Often there is no real option to external building geometry changes within a retrofitting project. About the only option is to consider where light has the possibility to enter the space, or not enter it. Sizes of window openings, glass type, their location and shading can all have an influence on the amount of lighting. However, this step, first and foremost, merely considers where and how light enters the space. An example in Figure 1 provides the sunlit configurations for extreme (Winter and Summer Solstice) periods for

this project. Note that the extreme conditions, the maximum and minimum solar penetrations are considered here for a clear day. Furthermore, for the specific case, an afternoon time is simulated due to the considered West facing orientation.

For the design studio presented here, the light distribution across the work plane would most likely be disruptive. Therefore strong direct solar bands of light are most likely not desired in this situation and occupants would much more desire a diffuse light. In reality, if blinds are provided they get drawn down by the occupants and remain down for a very long time before they are retracted again (Reinhart et.al. 2006). Yet, 'green building' codes in Australia encourage this feature of solar penetration and such results receive a higher (star) rating.

The study of sunlit configurations however is a very important first step in daylighting. What needs to be recognised is where and how far light penetrates into a space. This initial stage of analysis is important because it offers possibilities in the design that could be controlled if required. In the example of Figure 1, there is an extreme amount of seasonal light entering directly at the lower perimeter level, more daylight is desired in the central part of the floor plan. A means of achieving this task is through the introduction of a monitor or clerestory aperture on the façade. This positioning of light entry into a space can have a substantial impact to successful lighting in deeper plan areas, if properly controlled, and the light is diffused. Here the addition of a 'strip' of open-

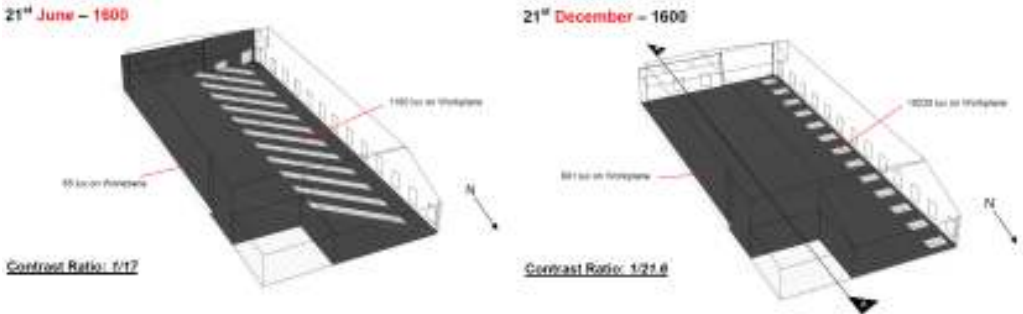
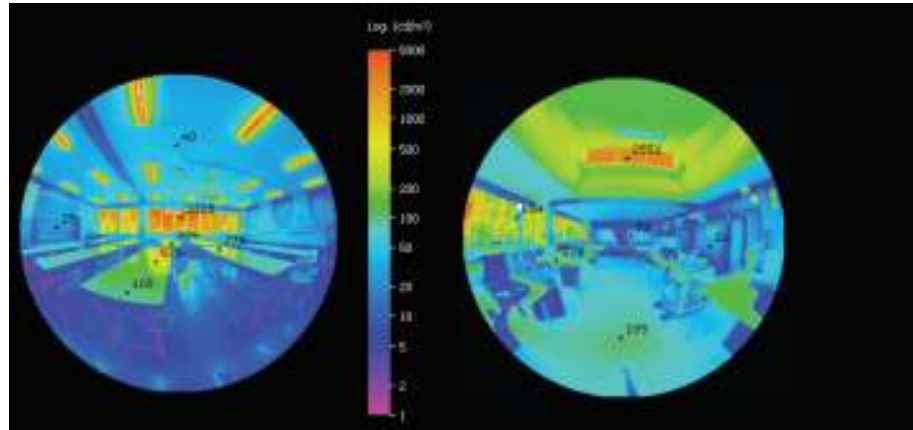


Figure 1  
Winter and Summer  
Solstice - daylight  
penetration  
extremes

Figure 2  
Before retrofit (left)  
with lights on and  
After (right)  
daylight only.



ings are positioned above the existing West facing windows (see Figure 6). It is most important to consider the glass opacity and transparency of solutions in this region of the façade to provide for a diffusion of daylight.

A real example of a successful design in relation to the concept of clerestory lighting is shown for a school classroom where before and after retrofitting results were measured. The measurement shown in Figure 2 utilises a CCD luminance camera, illustrating the surface  $\text{cd}/\text{m}^2$  results. Here the power of daylight is demonstrated, indicating better and more uniform results than an electric lit space. It should be noted that the daylight external conditions were practically identical for both cases.

Another example of utilising simple geometric computer simulation for studies of sunlit configurations throughout critical seasonal periods of a year is provided in Figure 3. In this particular case a library with an easterly facing façade is analysed. What is desired is the control of direct daylight into the space to avoid glare and contrast extremes. Here, again, seasonal extremes are selected for the analysis as well as time of day.

### **Step 2: Analysing Illuminance Levels:**

This next step is a significant jump from first. Now very generic interior surface reflectance's are applied

to floor, walls and ceiling (20, 50, 70%). It is critical to consider the type of sky that is being applied to the simulation. Intermediate lighting programs basically consider 3 types of sky conditions: overcast, clear or intermediate (partially overcast). For an analysis that generally requires compliance with standards, an overcast sky must be selected so that a daylight factor can be calculated. It is unfortunate how much importance is given to this single based metric (Ward 1994, Reinhart et. al 2006). It is highly conceivable that for many of our global locations an overcast sky is not a typical daylight condition.

Our standards often focus on the end result, meaning that the quantity of light received at a specific area or working plane is of greatest importance. Again, and unfortunately, this metric often does not provide us with the means and methods of how light achieves its result. In other words, comparing the light we use to see (illuminance) vs. the light we see by (luminance).

For the space in Figure 1, a partial cloudy sky, represented the average sky condition and that solar extremes June and December 21st would be explored. Of these cases the 9:00a.m., 12:00 and 16:00 times were studied and considered. (see Figure 4).

Too often, we design for the 'worst case scenario'. What needs to be asked, 'Is the overcast sky condition

Figure 3  
Cross-section of an  
East facing library  
with no vertical  
shading

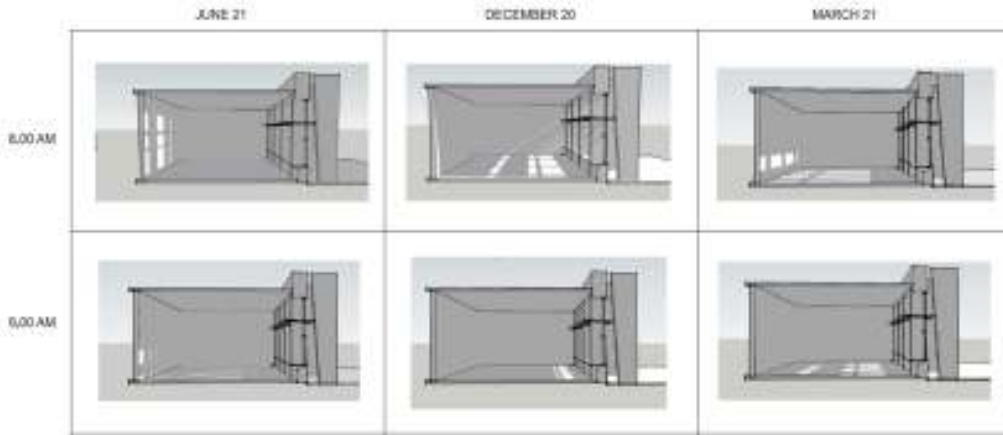
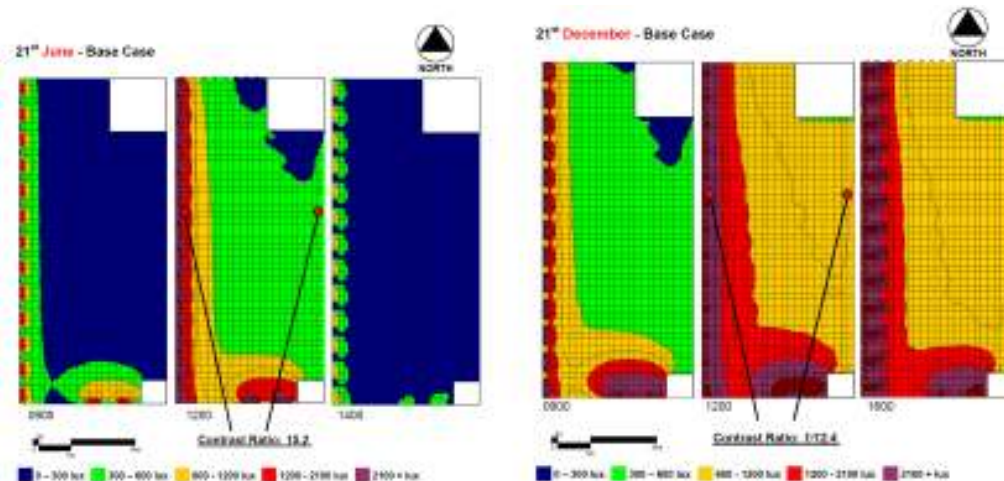


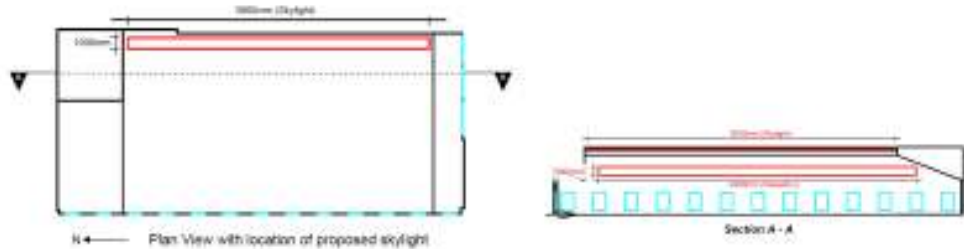
Figure 4  
Illuminance  
modelling for  
Winter and Summer  
(extreme) cases



really the worst case?’ Furthermore, it may be considered that diffuse sky light is more desired than direct light when considering the previous case in Figure 1. Another consideration might be to realise the particular type of sky that dominates climate and location for most of the year and to design for it. If we can

solve the daylight condition for the type of sky that is ‘typically’ present then perhaps it is most likely that we have allowed for the use of daylight for most of the year. Further to this concept is that lesser light conditions can be supplemented by electrical lighting.

Figure 5  
Additional window  
apertures  
considered for  
daylight retrofitting



### ***Design Alterations***

From a first glance, considering the illuminance levels on a work plane, it can be asked and answered as to whether an overall 'balanced' lighting distribution has been achieved. The next step is one of design experimentation and perhaps this develops with experience. It asks where daylight would be most beneficial in entering the space. In an effort to balance the daylight throughout the space, a skylight strip is added to the East side (opposite the west wall). The results for illuminance consider the wall reflectance on the east interior wall to be 60%. As mentioned earlier a 'clerestory' light for the West wall is considered to allow for greater light penetration into the central area of the floor plan, the client however rejected this and therefore it was not applied (see Figure 5).

The results of the apertures as compared to the base-case (Figure 4) are shown in Figure 6. These clearly indicate a significant amount of more light entering the space at extreme periods, especially for the December case. Note that the clerestory light on the West side would have benefited the central work plane.

### ***Refinements in the Design for Daylight***

For a particular design case, a gymnasium, a skylight was considered as the (only) option for bringing day light into the space (Figure 7). The refinements depended upon the size of the opening as well as the luminous (translucency and light transmission percentage) characteristics of the skylight. Furthermore,

the design of the adjacent sloped surfaces (adjacent to the skylight) and their highly diffused reflectivity was a major contributor to a uniform daylighting result on the work plane (in this case the gym floor). The skylight aperture required quite some design attention and variable parametric studies. Two particular sky conditions were investigated; an overcast sky (15,000 lux) and a uniform sky (25,000 lux). While both these sky conditions are probably a far cry from a clear day of 100,000 lux, they help assist in providing a 'worst case' and average scenario of daylight availability. In hindsight, simulations should have included a clear day as well, because the aperture was even more shaded (translucency reduced) in its instalment than what was calculated.

The intention is to diffuse the incoming light at the skylight right from the start. However, a diffuse reflective area over a much larger surface, (3-4 times) that of the actual opening, (the sloped sides adjacent the skylight) are the key answer to glare elimination and effective daylight distribution. It provides the perception of expansive, dominant and uniform strips of lighting for this space. The modelling of this design in Desktop Radiance®, which operates under the ray-tracing principle (Greenberg et. al 1986, Ward 1994). This program yields the 'brightness' (luminance) candelas/m<sup>2</sup> of the surfaces, which provides information on the amount of light emitted off each surface. The use of this metric is important in the study of contrast between surfaces and therefore the reduction of glare.

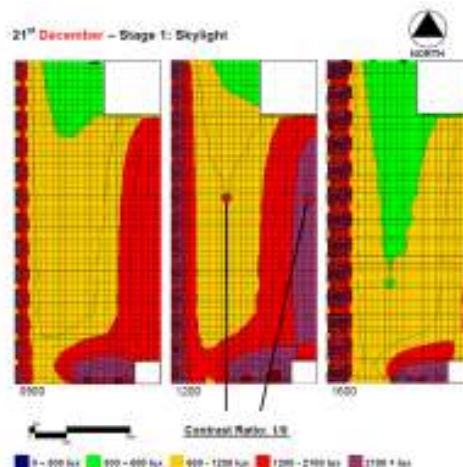
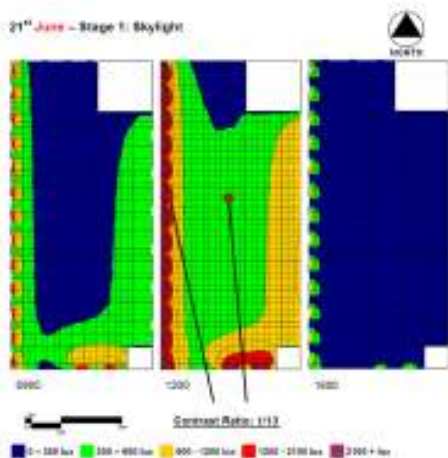


Figure 6  
Illuminance levels  
after alterations  
from the basecase  
in Figure 4.

Another case in daylighting refinement considered dividing the equatorial facing façade into two regions; an upper clerestory region and a lower vision region (Figure 8). Again, the initial modelling began with a basic sunlight configuration analysis using a simple geometric software that also had GIS location and solar position capabilities. Here studies were performed again for extreme seasonal periods; Winter and Summer solstice as well as an equinox period (March 21st) to observe the sunlit configurations.

The façade division's main purpose is to reflect the unshaded direct light back onto the ceiling plane and to provide daylight deep into the space. The lower shading device assists with the control of sunlight and eliminates a direct solar penetration. Studies using a ray-tracing tool program provided for the design optimisation of an 'inverted' Venetian blind (Greenup et. al. 2001) (see Figure 9). The results of the final design without and with the clerestory light guiding blinds is simulated in Lightscape a pro-

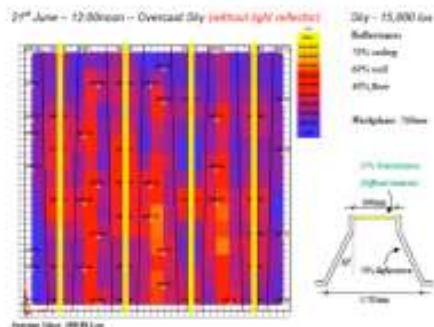


Figure 7  
Daylighting  
distribution from  
skylight strips in a  
gymnasium



Figure 8  
Cross-section of an office space indicating two regions in the façade.

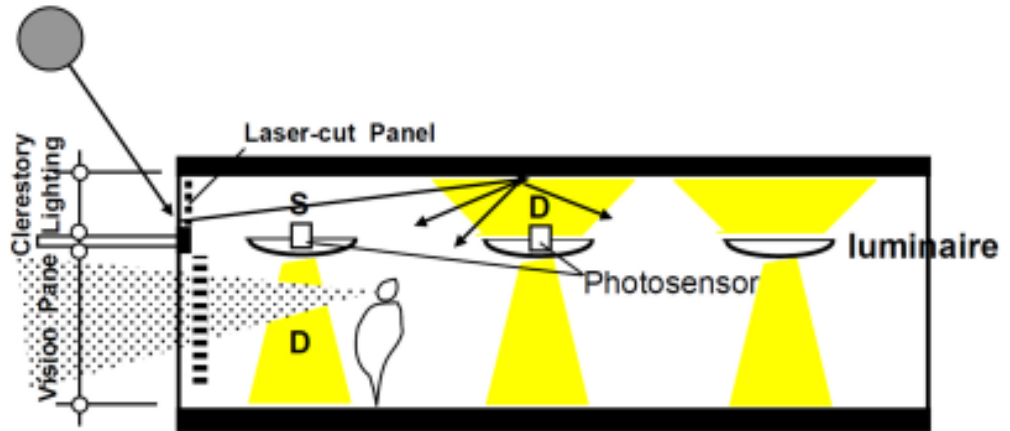
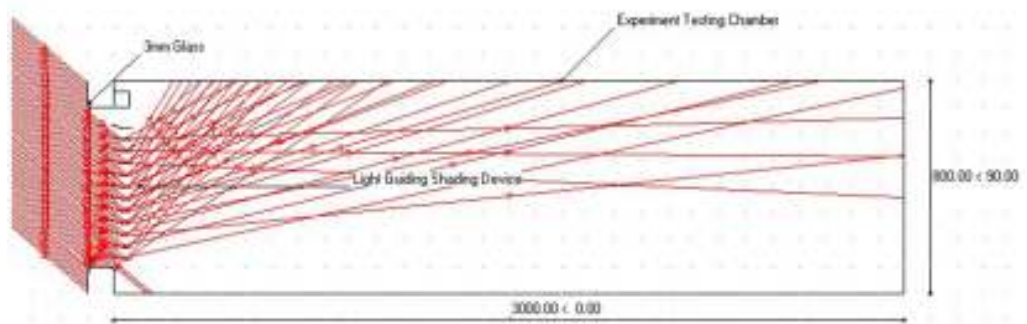


Figure 9  
An 'inverted' blind in the clerestory region for directing light onto the ceiling plane.



gram based upon the principles of radiosity (Maamari and Fontoynt 2002, Tsanggrassoulis and Bourdakis 2003) (see Figure 10).

### Selective Analysis

Probably one of the most important aspects of daylighting simulation is to be selective in computation. Knowing to apply boundary conditions, such as the simulation of extreme cases - Winter and Summer are

useful information in establishing the boundaries. Or in other cases, using the norm, a partially cloudy sky, to provide the definitive answer, is something that develops with experience. An iterative and parametric approach, in software, exists for the refinement to optimal daylighting design, where extreme sky conditions help to establish boundaries, alongside interior reflectance values, and window properties of



Figure 10  
Room without  
clerestory light  
guiding blind (left)  
and with guiding  
blind (right).

variable size, transparency, or translucency, in providing a compromised result.

In the example of a school library, a light-shelf is applied to reduce the direct sunlight 'hotspots', while it also directs light onto the ceiling plane (see Figure 11). The light-shelf serves as a shading device to the lower window region and is effective at eliminating a substantial portion of the 'hotspots' (see Figure 3). The initial geometry is constructed in Google SketchUp. This allowed for the preliminary study of sunlit configurations on the library work plane. For the refined lighting study the surface reflectance and curvature design of the lightshelf was studied using 3D-Studio Max. This program has the capability to utilise the Perez - 16 different sky types (CIE 2003, ISO 2004) which yield the effectiveness of the daylight distribution onto the ceiling plane for various day types, seasons, and time.

Additional illuminance studies on the work plane are performed, without and with a screen in the visual section under the lightshelf (Figure 12). For the particular case (sky condition and period) it is noticed that the central part of the floor plan maintains a significant illuminance level in either case, with or without the screen. This indicates that the particular lighting program applied has the capability to simulate several reflectances of light off various surfaces.

## CONCLUSION

There are numerous procedures and tools in researching, designing and simulating for a successful daylighting outcome. While recent approaches currently seem to suggest that high powered multiple hourly simulation of multiple sky types with ray-tracing are the most accurate, the requirement as to whether these tools are necessary at the beginning and intermediate stages of a design analysis is questioned. The novice to daylighting design requires a systematic method rather than diving blindly into simulation. This paper is written in hindsight, considering numerous projects of the past and revisiting their approach to daylight design, simulation, and refinement and in some cases, post measurement. In doing this exercise, a process is discovered that could be viewed as a method of daylight design and investigation for a project.

Foremost are the basic investigations of 'where the sun goes' throughout the year for the room considered. After this, and perhaps even before any daylight simulation analysis, design alternations and concepts for window location, size and transparency, shading types, light-shelves and light guides are considered.

The next step is to consider the type of sky condition and the seasonal periods (extreme and middle seasons). Together with this, is the metric being



sought from the simulation. If it is solely an 'end result', then illuminance is that parameter. However, if a more in depth understanding is sought on where the light is coming from, then luminance is the correct parameter. These two metrics, in particular lu-

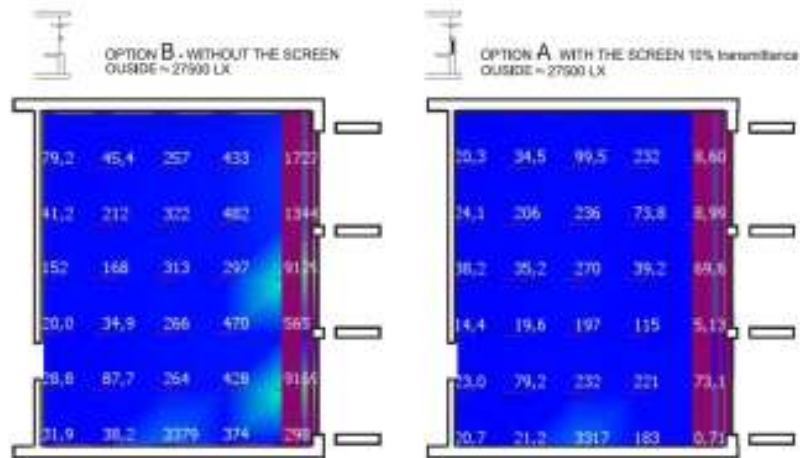
minance, need to consider the reflectance of the surfaces in the room.

In daylighting it is important to realise the criteria that controls the light. This begins on the exterior at the window opening size (aperture), its location,

Figure 11  
A light shelf for a library: SketchUp geometry (left), modelled with 3D-StudioMax (right)



Figure 12  
Illuminance result of light-shelf without (left) and with (right) screen: Dec. 21 - 10a.m.



translucency or transparency, shading or light guiding devices accompanying it. On the interior, it is the surface type; specular or diffuse, highly reflective or less reflective, horizontal or vertical, that determine how and where the light is distributed throughout the room.

It is also important to be selective with the time of day used for simulation, as with the first step (solar position and sunlit configuration) analysis to determine whether direct or diffuse sky lighting is incident upon the window apertures. Alongside the selection of sky condition; overcast, clear, or partially cloudy, is the importance in recognising what a typical average condition for the location might be. Instead of merely considering, what the standard requires (overcast sky), ask what the 'typical' sky condition for the location might be.

Finally, what might be most important is to consider the space function, and whether less daylighting supplemented by electrical lighting offers the best solution. It is better to be cautious and perhaps even a bit conservative with limits on daylight entering a space, since it often takes a long time before the blinds get pulled up again.

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