design brief

UNDERSTANDING DAYLIGHT METRICS

Summary

The dynamic nature of sunlight poses many challenges when defining the quantity and quality of daylighting that effectively illuminates an interior space. Static and dynamic daylighting metrics have been developed to inform and guide designers. Sustainable building rating systems such as the United States Green Building Council Leadership in Energy and Environmental Design (LEED®) and the Collaborative for High Performance Schools (CHPS) also require some level of quantifying daylighting designs.

For lighting designers and energy consultants, it is important to understand the various daylight terms, calculation methods, and metrics that are used in the rating systems and by the daylighting community. Each has its place for use when analyzing different aspects of a design. Metrics such as Daylight Factor and Single Point in Time are widely used to give a general sense of the daylight quantity in a given space. Less familiar metrics, which include Daylight Saturation Percentage and various Daylight Autonomy hybrids, tend to be more robust, though more calculation intensive. All hold merit for lighting designers to understand and consider.

This Design Brief describes commonly used terms, various methodologies, and daylight metrics. It provides an opportunity for the advanced reader to understand the facets involved in balancing the quantity and quality of daylight entering into a given space. In particular, metrics are compared and a classroom daylighting example is examined. Also, calculation tools that enable designers to effectively evaluate the impact of their daylighting and electric lighting designs are briefly described.

Daylighting provides energy and productivity benefits. The benefits may be fully realized if the design is well balanced in quantity and quality. Daylight metrics help to inform and guide daylighting design.

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Introduction

Various scientific studies[1] and anecdotal evidence show a positive correlation between the presence of daylight in an occupied space and human health, comfort, and productivity. In addition, daylighting a space provides significant energy savings when the electric lighting system is dimmed or turned off. Because these benefits are in harmony with environmentally conscious design, daylighting design is a key aspect of building rating systems such as LEED® and CHPS. Therefore, it is important for lighting designers and energy consultants to understand the methodology used to define the quantity and quality of daylighting entering into a space.

Fundamentally, most rating systems use measurements, metrics, and criteria to benchmark designs (see Rating Systems Defined sidebar). Measurements are individual bits of information such as the illuminance at a point on the workplane, or wall, ceiling, and floor reflectance characteristics of a given space. Individual measurements are assembled using a calculation method to create a meaningful metric, which is used to define criteria for specific applications. Designers who meet or exceed the criteria for a given space are more confident that the amount and quality of daylight will be acceptable. Both the LEED and CHPS rating systems include criteria based on specific metrics that designers must meet to qualify for credits. The intent of the criteria is to help designers avoid undesirable outcomes such as too much glare or solar gain in a space. Such shortcomings can decrease comfort, interfere with productivity, and, potentially, increase energy use.

Typically, metrics address the quantity of daylight saturation sufficient to turn off electric lights. Metrics also address many facets of quality such as glare and uniformity that shape the luminous environment. The list of daylight metrics is growing. Some metrics are static, such as Daylight Factor, while others are dynamic, such as Daylight Saturation Percentage. Some provide direction for one design aspect such as average workplane illuminance, though do not account for other aspects. While no one metric that exists today perfectly encompasses the quantity, quality, energy, and other aspects of a daylighting design, **dynamic daylight metrics** seem to encompass more complete benchmarks than **static metrics** (see Daylighting Basics sidebar). Metrics that use dynamic calculation methods, such as Daylight Autonomy, are able to better incorporate project design

parameters (e.g., illuminance criterion and occupancy schedules), climate, and the variability of daylight.

Successful Daylighting Design

Successful daylighting design starts with clearly defined goals. Design teams should first establish project goals that affect the quality of daylight in a space, setting parameters for direct solar control and uniformity of distribution. Secondly, quantitative goals such as illuminance and energy targets, and cost considerations should be understood. Usability and functionality goals and architectural integration are equally important to establish, through a more subjective lens. Metrics or rating programs should be used as a design guide only if the goals of the project are in line with the daylighting credit/point intent.

Quality

Direct Solar Control

Although direct sunlight is necessary for passive solar strategies, photovoltaic applications, and solar hot water systems, it is critical to control direct sun intended for interior daylighting purposes. Without proper control that meets the project design goals, glare from direct sun is likely to disrupt occupants during certain times of the day and year. As a result, building residents will use shading devices to control unwanted glare or other extreme measures, which undermine the design team's original goals for daylight illuminance, uniformity, functionality, energy use, and architectural integration. Direct sun tests (see sidebar on page 6) are used by many designers as a means of avoiding direct sun issues. The **For More Information** section lists publications that address direct solar control strategies.

Uniformity

If direct sun control is properly implemented based on space orientation, occupancy schedule, and other factors, the next measure of success is the quality of daylight distribution. A uniform distribution is desired for many space types because it distributes consistent daylight throughout a room and avoids the discomfort that can result from high brightness ratios. Uniformity also implies a less shadowed environment, which is more suitable for task work.

Quantity

Illuminance Targets

Proper control of direct sunlight and the uniform distribution of daylight render a space usable and comfortable. The quantity of distributed daylight determines the extent that electric lights can be dimmed. The goal is to meet workplane illuminance requirements for the majority of the year. Target illuminance are typically those recommended by the Illuminating Engineering Society of North America (IESNA) for a given space type.

One method of designing appropriate illuminance levels is to divide the lighting resource(s) for task requirements (specific work areas with small objects) and ambient requirements (general areas for way finding or with large objects). Designers may decide to provide the entire task plus ambient goals, or just the ambient goal. In most applications, the task/ambient approach is recommended because it allows for varied light levels and provides more synergy with total building energy concerns than using the ambient only approach.

Energy Targets

California's Energy Efficiency Standards for Residential and Nonresidential Buildings, also known as Title 24, provide lighting power densities (LPD) for various applications. For example, Title 24

Lighting power density is the maximum allowable lighting density permitted by local or national codes. It is expressed in watts per square foot for a given space type.

Left image is an (Old National Bank, Indiana) example of daylighting design that allows for daylight illuminance to be projected deep into the office space with the aid of a daylight redirection device (interior optical louvers) located at the upper portion of the daylight glazing. Interior blinds are used to control glare for individual work areas next to the glazing. The right image is an (Fossil Ridge High School, Colorado) example of balanced ambient daylight illuminance for a majority of the workplane. Task lighting is available for supplementing light levels in the individual work areas.

Source: Architectural Energy Corporation

2005 requires a LPD of 1.2 watts per square foot for schools. For Title 24 2008, the LPD is 1.0 watt per square foot. By utilizing daylighting strategies integrated with energy-efficient electric lighting systems, energy targets such as LPD can be successfully met. In California, LPDs of 0.8 watts per square foot have been achieved in classrooms. CHPS advocates the use of teacher, student, and audio/visual task-specific lighting schemes to reduce an unnecessary wash of electric light across a classroom. ASHRAE 90.1[2] also provides lighting energy targets for various building applications.

Cost

Daylighting systems should be evaluated in terms of life-cycle cost, which looks at both first cost and operation and maintenance (O&M) expenses. The first cost of the daylighting solution should be in line with the overall scope and construction budget of the project. O&M costs should be reduced or at least balanced due to the hard cost savings from reduced electric lighting use and associated reduction in cooling loads, and from soft cost savings due to gains in productivity.

One test to detect the presence of direct sunlight is to examine workplane illuminance at critical times of the year such as morning, noon, and afternoon on the summer solstice and equinox, which are times required for the CHPS (California version) direct sun test. If the illuminance exceeds a direct sun threshold on the workplane, direct sunlight is assumed present and control measures need to be reevaluated.

It is difficult to provide full cutoff for winter conditions, and the winter sun can be beneficial as a passive heat gain in cold climates. Winter may be a critical time to evaluate based on project goals and space task requirements.

Direct sun tests can be completed through a variety of methods including sun path diagrams and cutoff angles, physical modeling, or computer simulation of the space.

Subjective Goals

Usability and Functionality

Usability and functionality are more variable and dependent on the building owner's requirements from project to project than the previous goals. The general intent for usability and functionality is to allow for user adjustment and override, and ensure adequate daylight to all occupants of the daylit space. Usability and functionality goals also may relate to credits within the green building rating systems such as the LEED Indoor Environmental Quality credit that requires providing a view to the outdoors and controls to reduce electric lighting use.

Architectural Integration

The most subjective goal, and the most difficult to account for in any daylighting metric, is architectural integration. A broad definition of the goal without specific criteria is for the daylighting design to fully integrate with the architectural expression of the building inside and outside. It means full integration with various systems including the building envelope, mechanical, structural, heating, ventilation, and air conditioning, electrical, lighting, and interiors.

Daylight Metrics

Daylight metrics have been developed with the purpose of setting a scale for designers to use when comparing aspects of daylighting design. Criteria are paired with the metrics in rating programs to help distinguish well-lit, comfortable environments throughout the day and year from those where daylight is minimal or a hindrance. Each metric differs and has a variety of strengths. Two sustainable building rating systems predominately use daylight metrics—the LEED New Construction (NC) rating system has widespread use in California and across the U.S., and the CHPS Best Practices, both the California (CA) and New York (NY) versions, are widely used by school districts. School districts in other states also are adopting CHPS into their building programs. Definitions are given on Page 2 in the Rating Systems Defined sidebar to define a hierarchy.

The calculation methods and encompassing metrics defined in this Design Brief include those associated with the LEED and CHPS rating

systems, as well as several dynamic daylight metrics. All establish the "workplane" as the datum for analysis, which is typically 2.5 feet above the finished floor. Calculation methods such as Annual Light Exposure and Luminance Ratios are omitted because they typically analyze different planes. This is not to say these methods do not have a place in future metrics.

Basic Calculation Methods

The following calculation method descriptions are the most commonly used in the daylighting community. The methods may be used as stand-alone metrics; most are often combined or manipulated for use in rating programs to address certain design goals.

Maximum to Minimum Illuminance Ratios

Similar to a direct sun test, maximum to minimum illuminance ratios provide a method that can help detect glare and unbalanced illuminance on the workplane by establishing an acceptable threshold, which is variable by specific application. A workplane calculation must be performed to find the point illuminance at the desired time of year or the averages based on an annual calculation. The method then requires a computer-aided or manual search for the workplane extremes so the maximum to minimum illuminance ratio can be calculated. While detecting imbalance in a space, the ratio does not account for the gradient of the workplane distribution or extremes in frequency or location. Therefore, it is often combined with other metrics for design comparison.

Maximum to minimum illuminance ratio is the highest horizontal illuminance point divided by the lowest horizontal illuminance point or area.

Single Point in Time (SPT)

This method requires a workplane illuminance calculation for one time of the year. The time can be selected to represent an average daylight condition such as sunny equinox at noon or an extreme scenario such as cloudy winter solstice. The SPT method accounts for variability in designs such as orientation and shading mechanisms. However, care should be taken to select a point in time that is representative of the building's occupancy schedule and energy loads, and relevancy to the design goals for the space.

Daylight Factor (DF)

Daylight Factor is defined as the ratio of the internal illuminance at a workplane point in a building to the unshaded, external horizontal illuminance under a CIE[3] overcast sky. DF is well defined and simple to calculate. However, it does not account for orientation, shading and glare control, or changes in sky conditions. DF can give a general report of the average daylight conditions in a space, but cases of exceedingly high illuminance cannot be addressed. In other words, DF is most useful for locations with overcast skies; direct sunlight or sunny skies are not well represented.

Daylight Autonomy

Daylight Autonomy (DA) at a specified workplane location is defined as the percentage of year when a minimum illuminance requirement is met by daylight alone. The exact method for sky and time simulation over a typical year is not defined, but the fact that it requires an annual simulation classifies this calculation method as dynamic. The minimum illuminance is typically the IESNA recommendation for a given task type. The use of the DA metric dates back to a Swiss standard, circa 1989.[4] Variations of the original DA have been developed and Continuous DA methods such as incremental summing and continuous summing may more closely predict daylight performance.

Incremental Summing

Defined in 2002 by Reinhart,[5] incremental summing refers most closely to the original DA method. The difference is that times of year are only included in the sum when the space is occupied. In other words, the denominator of fractional count is the total number of occupied hours addressed. The numerator of each fractional count is a one or zero depending on whether the minimum daylight illuminance is met. The 2002 application of incremental summing by Reinhart marks a trend toward a more robust set of calculation methods, which are referenced in this Design Brief as dynamic daylight metrics. The concept refers to allowing flexibility in addressing the multitude of design variables in any given space.

Continuous Summing

Proposed by Rogers in 2006,[6] continuous summing is the term used for a method that gives partial count to times when the daylight illuminance at a given point lies below the task/ambient lighting criterion. Continuous summing also addresses only occupied times of the year. This summing method shows no difference from the incremental summing method for a well-lit or over-daylit design. However, this method becomes useful for showing the potential energy savings if the electric lights have dimming or multi-level switching capabilities. Accounting for partial daylight saturation is important because of the human health, comfort, and productivity benefits.

Maximum Daylight Autonomy

To be used in conjunction with the continuous summing method, Rogers also defined Maximum Daylight Autonomy (MaxDA).[6] MaxDA is an incremental summing method that uses a maximum illuminance bound instead of a minimum. Times of the occupied schedule are counted if the given point has an exceedingly high illuminance, which is used as an indicator of glare or unwanted heat gains. The threshold typically is ten times the illuminance criterion,[7] though this value is not grounded in a specific glare or heat gain study.

A specific example is given later in this Design Brief illustrating the various static and dynamic metrics. Comparisons of the metrics are presented using a simulation software tool that modeled a north-facing classroom space.

Program Applications

The use and transformation of the calculation methods as LEED and CHPS metrics are described for each compliance path along with criteria for achieving each credit/point.

LEED NC Metrics

The U.S. Green Building Council developed a green building rating system for newly constructed commercial buildings, known as LEED NC. The rating system offers three compliance paths – Glazing Factor,

SPT, or Measurement – for documentation of Indoor Environmental Quality Category, Credit 8.1 Daylight & Views. The three paths are shown in the Metric Path and Criteria Definitions – LEED NC Version 2.2 reference box.

Glazing Factor

The LEED NC version of Daylight Factor uses a simple spreadsheet tool to relate glazing transmittance, areas, height, geometry, and space area to the daylight saturation. The metric's calculation method is similar to Daylight Factor because it is a ratio bounding the daylight saturation at a "worst-case" condition (only diffuse sky contribution). Differing from Daylight Factor, Glazing Factor is not calculated using a workplane illuminance point grid or exterior horizontal illuminance. As a result, it does not account for specific space properties or changes in sky luminance. The Glazing Factor criterion requires a two-percent threshold for 75 percent of the spaces to be met for the daylighting design to receive credit.

Single Point in Time (SPT)

Based on a simulated model, this path requires the design to meet a minimum threshold of 25 foot-candles (fc) for 75 percent of the space(s) on a sunny, equinox day at noon. A workplane point calculation is required using an approximate two-foot spacing. The credit states the need for direct solar control and gives a table of options such as blinds and overhangs. This aspect of the metric does not require a calculation method for proof, but it is assumed for equal design comparison.

Measurement

The final compliance path for the LEED NC daylighting credit is to take physical measurements on a ten-foot grid at workplane height, which is a SPT (without a defined point in time) or DF method. The threshold for receiving credit is 25fc or 2 percent, respectively, per measured point.

CHPS CA

CHPS is a nation-wide rating system of comprehensive benchmarks that focus on environmentally efficient and healthy K-12 schools. The CHPS organization publishes a Best Practices Manual that has been adopted by numerous California school districts. Other states such as New York have adopted the CHPS building rating system with slight modifications.

The CHPS Environmental Quality credit 1.1 for daylighting offers up to four points that are incrementally achieved based on the calculation results. As with LEED, a choice of three compliance paths is offered for daylight credit documentation—SPT, DF, or DSP. Each of the metrics includes a direct sun calculation at specific times and a translucent glazing check for glare prevention, as well as a photocontrol requirement as a prerequisite. A variety of simulation tools can be used to document the credit.

Single Point in Time (SPT)

Similar to the LEED SPT, the CHPS version requires a minimum of 25fc on the workplane on a sunny, equinox day at noon. The same workplane spacing requirements apply for the grid point calculation. In addition to the actual SPT calculation, the CHPS SPT metric requires

daylight uniformity that does not exceed an 8:1 maximum to minimum illumination ratio at the same point in time. This metric uses a combination of calculation methods to account for both lower and upper illuminance bounds at the select time.

Daylight Factor (DF)

The DF metric is named for the calculation method and has no variation in its approach. The goal is to achieve an average of two-percent Daylight Factor across the workplane using a four-foot grid. CHPS requires that the space be located no more than 20 miles from the coast (i.e., in an overcast climate) for this compliance path to apply. This requirement minimizes the metrics failure to account for exceedingly high illuminance as it would be in a typically sunny climate.

Daylight Saturation Percentage (DSP)

DSP uses a combination of Daylight Autonomy calculation methods. CHPS is the first sustainable building rating system to use Daylight Autonomy as a method in one of the compliance paths. The DSP metric is defined as:

$$DSP = DSP_{40} - 2 \cdot DSP_{400}$$

The first term on the right represents continuous DA at 40fc and the second represents incremental DA at 400fc, which is equivalent to 10 times the illuminance criterion, also represented as MaxDA. The calculation is to take place over a typical school occupancy schedule between 8:00 AM and 3:00 PM, Monday through Friday, from August 15 through June 15 for each point on a 4-foot by 4-foot workplane grid. The DSP for each point is averaged over the space and area weighted for an entire school for criteria comparison. Criteria for each CHPS compliance path is shown in the Metric Path and Criteria Definitions – CHPS CA reference box.

CHPS NY

CHPS for New York school districts offers one compliance path for its five-point daylight credit. The metric is called Daylight Autonomy Ratio (DAR) and is the basic continuous DA calculation. To achieve the

Metric Path and Criteria Definitions – CHPS CA

EQ1.1.1	Single Point in Time Approach Option	
	1 Point	25% of classrooms are daylit
	2 Points	50% of classrooms are daylit
	3 Points	75% of classrooms are daylit
	4 Points	100% of classrooms are daylit
EQ1.1.2	Daylight Saturation Percentage (DSP) Approach Option	
	1 Point	30% average DSP for all classroom space
	2 Points	45% average DSP for all classroom space
	3 Points	60% average DSP for all classroom space
	4 Points	75% average DSP for all classroom space
EQ1.1.3	Daylight Factor Approach Option This approach is applicable only to California climate zone 3 and to any location in California climate zone 1.	
	1 Point	25% of classrooms are daylit
	2 Points	50% of classrooms are daylit
	3 Points	75% of classrooms are daylit
	4 Points	100% of classrooms are daylit

To qualify as a daylit classroom:

EQ1.1.R1 Given the geometry of the classroom and with consideration of site obstructions, fixed exterior shading, interior light shelves, and/or fixed blinds or louvers located between glazing, no direct sun can strike the teaching surfaces or a work plane located 4 ft inside the exterior walls at 9:00 AM, noon and 3:00 PM on the summer solstice and the equinox.

EQ1.1.R2 Skylights shall meet the requirements of no sun penetration, as described above, unless they have diffusing glazing.

EQ1.1.R3 Photocontrols shall automatically turn off or dim the electric lights when daylighting is available.

EQ1.1.R4 Any diffusing glazing shall be located above the line of sight for the teacher and the students.

Source: CHPS Best Practices Manual Volume III – Criteria, www.chps.net/

credits, the school must have 75 percent of the spaces with 40 percent continuous DA. There are currently no other solar control or uniformity requirements. Some simulation tools afford users the opportunity to easily verify compliance and document the CHPS NY daylight credit.

Other Applications

Although not currently implemented as a metric in a building rating system, additional examples of dynamic daylight metrics exist and have been used by researchers in the daylighting community (see Notes section). Two are included for comparison purposes.

Useful Daylight Illuminances (UDI)

As the name indicates, UDI calculates the total number of occupied hours that "useful" daylight enters a space at a select point. Useful daylight is defined as providing ambient light at the workplane at illuminance levels between 100 lux to 2,000 lux (9fc to 185fc). Above 2,000 lux, heat gains and glare become potential problems.

Potential UDI metrics give thresholds using bins (too low, useful, and too high) for certain percentages of the workplane. It is dynamic in the sense that it requires an annual calculation capturing design variables such as occupancy and climate. UDI differs from the DA calculation method because it bins hours based on saturation instead of summing the saturation ratios.

SPOT DA

In addition to documenting the LEED SPT and CHPS daylight credit compliance paths, the Sensor Placement + Optimization Tool or SPOT™ simulation software (see sidebar) gives a unique daylight report. The metrics used for the report are a combination of Continuous and Maximum DA. The Continuous DA thresholds require that 60 percent of the workplane meet 40 percent saturation for "Adequate," 60 percent saturation for "Good," and 80 percent saturation for "Excellent" remarks. In addition, a prerequisite using an upper saturation limit of one percent Maximum DA for five percent of the workplane is used to penalize glare potential.

Daylighting Metrics Summary

The table on the next page summarizes the metrics and calculation methods discussed in the previous section.

Daylight Calculation Parameters

Dynamic calculation methods provide a palette of metrics that are adaptable to any type of space. Specific variables are important to understand as they relate to the dynamic calculation methods. These parameters include location and climate, time frame, shading element automation, design illuminance, and spatial considerations.

Parameter Definitions

Location and Climate

Location - including global position and space orientation - and climate affect daylighting due to sun angle, typical weather conditions, and other sky factors such as turbidity or cloudiness. Dynamic daylight metrics account for this variation in the annual daylight simulation by

Daylighting Metric Definitions

Metric	Calculation Method Parameters*	Scale Description	Criteria	Path	Program
Single Point in Time	Max to Min Illuminance Ratio and SPT, sunny equinox at noon	Emax: Emin Prerequisite Area%	≤ 8 : 1 Area % point thresholds here Eavg [fc] ≥ 25fc	1	CHPS-CA
Daylight Saturation Percentage	Continuous DA with 40fc and Incremental DA with 400fc	[(DSP40 - 2 x DSP400) [%]]avg	Area weighted average DSP point thresholds	2	CHPS-CA
Daylight Factor	DF, cloudy climate	Area %	Area % point thresholds where DFavg[%] ≥ 2%	3	CHPS-CA
Daylight Autonomy Ratio	Continuous DA using design illuminance	Area %	75% area must have ≥ 40% DAR, pass/fail	1	CHPS-NY
Glazing Factor	DF variation	Area %	75% area must have ≥ 2% Glazing Factor, pass/fail	1	LEED-NC
Single Point in Time	SPT, sunny equinox at noon, modeling or measurement	Area %	75% area must have ≥ 25fc, pass/fail	2	LEED-NC
SPOT Daylight Autonomy	Continuous DA and MaxDA using design illuminance	MaxDA %, binned prerequisite DA %, binned	≤ 5% area > 1% MaxDa 60% area compared to stacked %DA bins	-	None
Useful Daylight Illuminances	Annual hour binning for various saturation levels	UDI hours %, binned	Undetermined	-	None

*Other prerequisites exist but those listed are critical to the calculation method.

Source: Architectural Energy Corporation

using local weather files, such as TMY2[8] data, to determine cloudiness and sky luminance over the course of a typical year. This variable has synergy with occupied times because if spaces are occupied only in the afternoons and typically cloudy in the design location, then daylight-dependent design solutions may not prove to be optimal.

Time Frame

The time frame variable applies to the annual simulation, though it can be an important consideration in the design extreme metrics as well. The question is whether or not an occupancy schedule should be used as a mask to all of the daylight hours in the year. One paradigm says that a space should be designed for future flexibility meaning that a full annual

schedule (or the annual peak for static metrics) should be used in the simulations to account for worst-case scenarios. Another viewpoint is that this often results in over-design or a mismatched design between daylight and architecture as viewed by the occupant. Also, the descritization, the technique of grouping by selected values, of the schedule is a variable. The more fine-grained, the longer the annual simulation time will take and the more accurate the results.

Shading Element Automation

As part of the dynamic daylight metric category, DA calculation methods can incorporate different shading element scenarios based on design or assumed user patterns. For example, if interior window shades are implemented in the design of a south-facing open-office space, then the shades can be automatically controlled by a timer or photosensor, manually controlled by occupants, or fixed in place. If the shades are manually controlled, users can be defined as passive or active. The passive user will close the shades once glare is a problem, and leave the shades closed the majority of the year. The active user will open and close the shades as daylight changes. From a modeling perspective, designers can simulate active users as similar to a photosensor. However, modeling users as active is an ideal assumption that many designers advise against to prevent an under-daylit space. Also, it is advisable to avoid manual controls as part of the primary design, occupant behavior is too erratic to depend on users to properly and consistently control shades.

Design Illuminance

Daylight design illuminance can vary based on task type or intended electric lighting integration. For example, 50fc of daylight might be required for the task and ambient illuminance in a library lobby whereas only 20fc of daylight might be needed as an ambient supplement in an art gallery lobby. The two scenarios will yield different DA results, even if the interiors and location and orientation are the same.

Spatial Considerations

The spatial variable in this context refers to the location of the measurement points. Measurements are typically taken at points in an

evenly spaced grid such as two feet or four feet, assuming a workplane height of 2.5 feet above the finished floor. Specific requirements may be defined by a building rating system's metrics. Separate grids can be used in the same space if varying design illuminance criteria exist. The definition of a calculation grid is common to almost all of the daylight metrics. However, the ability to assign separate grids in a common space to different design criteria is unique to dynamic daylight metrics.

Daylight Autonomy Example

The following example uses the DA calculation methods to show how the inclusion of the discussed calculation variables allow a metric to address the different design goals for successful daylighting design. The goals addressed are Daylight Quantity for Illuminance, Daylight Quality for Uniformity, and Daylight Quality for Direct Sun.

- Daylight Quantity – Perform a base DA calculation for occupied hours using a continuous summing method, the space's design illuminance, and representative climate data, along a grid of points representing the critical task surfaces. The continuous summing method is selected because it is useful when addressing the usability and functionality goal, if lighting controls are used. Partial daylight saturation allows for the benefits described in the introduction, especially electric lighting energy savings through multi-level switching or dimming.

- Daylight Quality (Uniformity) – Require that a minimum percentage of the daylit space's workplane points meet the given level of daylight quantity as measured by the base DA. The threshold might vary depending on the activities occurring in the space. Threshold recommendations for a classroom application are given later in this brief.

- Daylight Quality (Direct Sunlight) – Perform a MaxDA calculation for occupied hours using the incremental summing method and representative climate data, along a grid of points representing the critical task surfaces.

Metric Comparison

The following table summarizes the capability of the defined metrics to account for select design goals and variables in the design of a classroom. The table shows that dynamic daylight metrics are the most robust because the majority of the design goals and variables are addressed. The notes in the table indicate some parameters are not clearly defined for some metrics. Whether or not and how a parameter is included is often open to interpretation.

Table 1: Daylighting Metrics versus Design Parameters in Classrooms

	LEED		CHPS CA		CHPS NY	OTHER		
	GF	SPT	SPT	DF	DSP	DAR	UDI	Spot DA
Metric Type	Static				Dynamic			
Design Goals								
Quality, Direct Sun			X		X		X	X
Quality, Uniformity			X^1		X^1		X	X
Quantity, Illuminance	X^1	X^1	X^1	X^1	X^1	X	X^2	X
Quantity, Cost								
Usability and Functionality					X	X	X	X
Architectural Integration								
Design Variables								
Surface Properties		X	X	X	X	X	X	X
Space Orientation		X	X		X	X	X	X
Location and Climate		X	X		X	X	X	X
Time Frame					X	X	X	X
Shading Element Automation			X^3		X^3	X	X	X
Design Illuminance						X		X
Spatial Considerations		X^1	X^1	X^1	X^1	X	X	X

[1] Does not allow for variable criteria based on project conditions or design goals
[2] Dictates a broad range of acceptable illuminance, not allowing for metering of a specific daylight illuminance target required for space programmed tasks.
[3] Louvers or blinds must be located between glazing to be considered as a parameter in the calculation.

Source: Architectural Energy Corporation

Classroom Daylighting Example

Analysis of daylight conditions in a classroom is presented below to illustrate the use of metrics and criteria by various building rating systems. The example represents a north-facing classroom and was selected for its simplicity. The calculation parameters that are held constant throughout the example include simulation settings, space geometry, and surface properties. The dimensions of the classrooms are 30 feet by 32 feet, the wall thickness is eight inches, and the window-to-wall ratio is 37 percent. The surface properties are given in **Table 2**.

Table 2: Model Surface Properties

Model Element	Characteristic
Floor Reflectance	20%
Wall Reflectance	60%
Ceiling Reflectance	75%
Ground Reflectance	25%
Mullion Reflectance	50%
Lightshelf Reflectance	50%
Overhang Reflectance	50%
View Window Transmittance	36%
Daylight Window Transmittance	50%

Source: Architectural Energy Corporation

The simulation tool used to generate the example is the SPOT software. It was selected because the interface allows for a visualization of the calculation variables, and the metric reports are a built-in function, which allows for comparison of the results. The software uses RADIANCE as the underlying engine with a Microsoft® Excel interface. Other simulation tools may produce similar results. A list of simulation tools is referenced in the next section.

Six simulations were run, each with a cumulative change in the calculation variables, described previously in the Dynamic Daylight Metrics Section. **Table 3** outlines the simulation variations. The calculation grid remained constant for all six variations, as this parameter affects both dynamic and static calculations.

Table 3: Simulation Descriptions for Classroom Daylighting Example

Variation #	Variable*	Description
1	Base Case	• North-facing classroom • San Francisco, CA • Traditional school schedule • No shades or blinds • 40fc design illuminance • 4-foot calculation grid spacing
2	Orientation	• 45 degrees east of north
3	Location	• Boulder, CO
4	Time Frame	• Year-round school schedule
5	Shading Element Automation	• Automatic shades based on exterior photocell
6	Design Illuminance	• 20fc design illuminance

*All changes in calculation variables are cumulative for the variations.

Source: Architectural Energy Corporation

Test Case Variations, Calculation Process

Geometry and Surface Property Modeling

While geometry and surface property can be accurately represented in a physical model, a computer model is more convenient for running parameter variations. **Figure 1** shows the room geometry for the Base Case example.

Figure 1: Basic Model
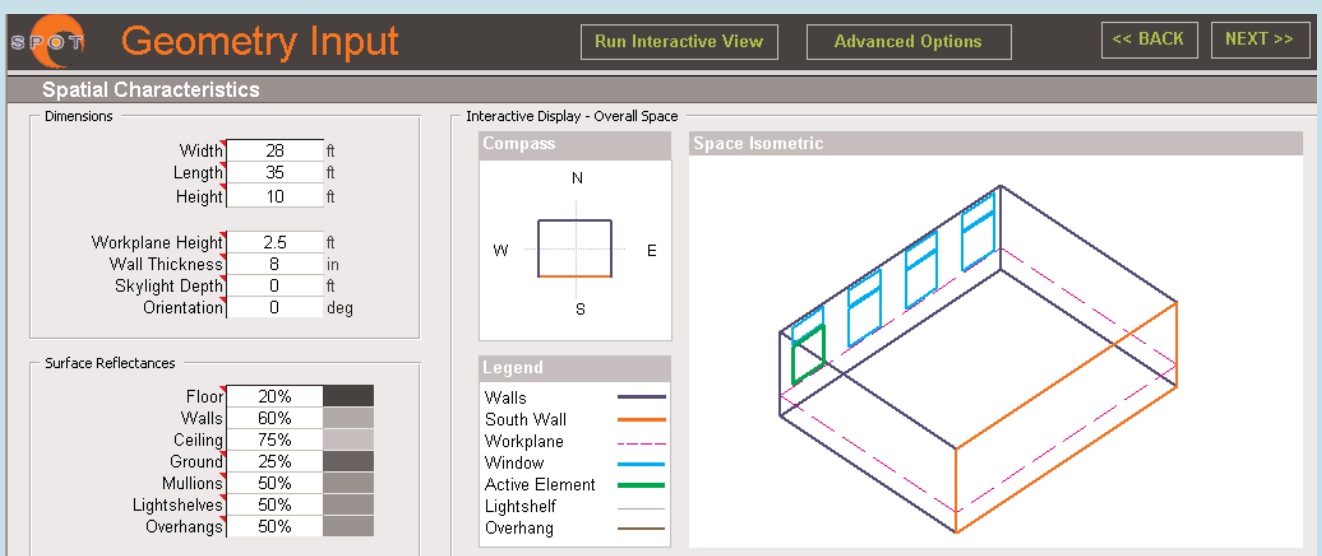
Source: Architectural Energy Corporation

Fenestration Modeling

In addition to basic geometry and room surfaces, glazing geometry and visual properties must be modeled as shown in **Figure 2**. Window treatments and transmittance values may be inputted. Advanced Options provide additional inputs, if desired, for use-defined shade controls.
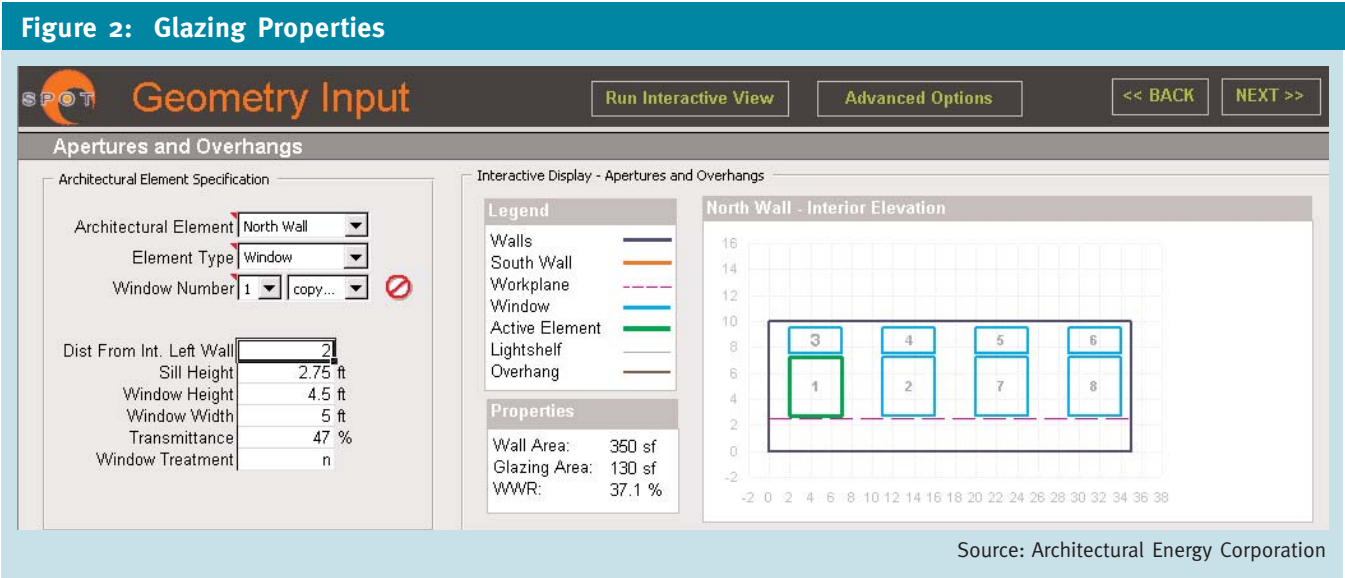

Figure 2: Glazing Properties

Source: Architectural Energy Corporation

Calculation Options, Including Temporal and Spatial

The default RADIANCE parameters in the software are used for the comparison calculations. Calculations were developed for each month of the year (the year is assumed to be symmetric). Only March, which includes the equinox, is necessary for the SPT calculations, and only one cloudy condition calculation is necessary for the DF calculation. However, all months are included for a fine-grained temporal calculation of the dynamic daylight metrics.

Location and Schedule

As mentioned in the Location and Climate section, TMY2 data is a common resource used to determine typical daily weather variations. The SPOT software allows for the use of TMY2 or Energy Plus Weather (EPW) files to scale the hourly daylight conditions calculated using the CIE sunny and overcast sky models. This portion of the input (**Figure 3**) also allows for the definition of both a daily and annual occupancy schedule. Only the occupied times of the day and year are included in the dynamic metric calculations.

Figure 3: Site and Schedule

Source: Architectural Energy Corporation
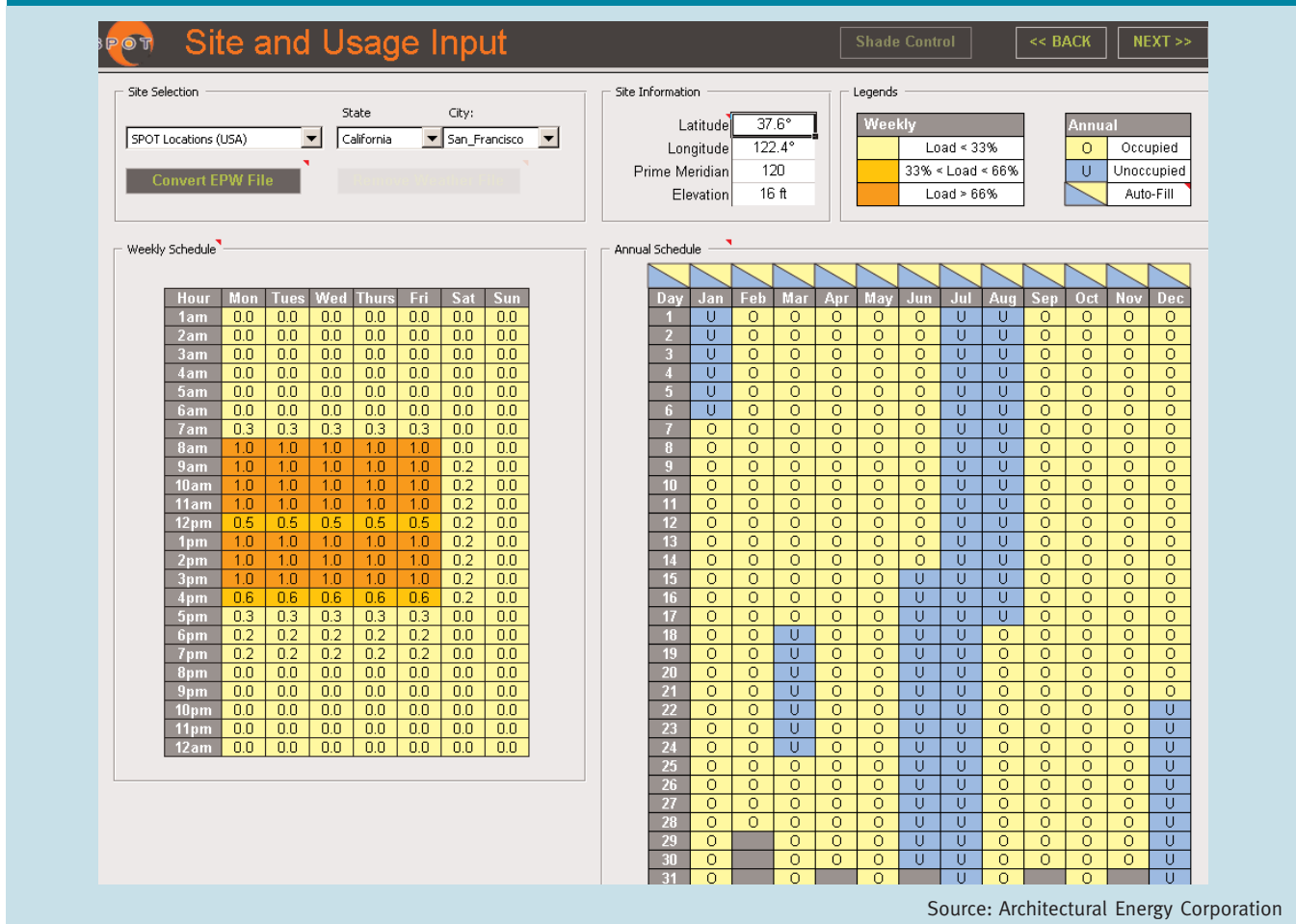
Shading Options

Although shading element automation is not included in the calculation for the Base Case, it is a user-interface input included in Variation #5. Modeling of shading elements is important, because the selection of the inputs may result in significant variations in the results. Shade control can be fixed, manual, or automatic. Automatic control can rely on time schedules or photosensor control. This software only allows for fixed or automatic control types, though other programs such as Daysim allow for active and passive manual control. Each temporal increment of the annual calculation will be performed with shades up or down depending on the algorithm result, whether it is based on time or exterior illuminance. A wall-mounted, northeast-facing photocell along with 850fc signal is used in the automatic up/down shade control algorithm for Variation #5.

UNDERSTANDING DAYLIGHT METRICS

Design Illuminance

Electric lighting results are not directly relevant to the daylight metric calculations with the exception of the design illuminance that is used to determine the desired proportion of electric light to daylight in the space. Most daylight metrics criteria aim for full daylight saturation of the space. An alternative is to split the electric lighting and daylighting contributions into a task and ambient approach.

Preliminary Daylight Results

Using an annual simulation engine, daylight illuminance on the workplane can be determined for each time of the day, year, and for each sky condition requested with the input. The results (**Figure 4**) allow for inspection of the daylight contribution per electric lighting zone.

Figure 4: Daylight Illuminance Results

Source: Architectural Energy Corporation
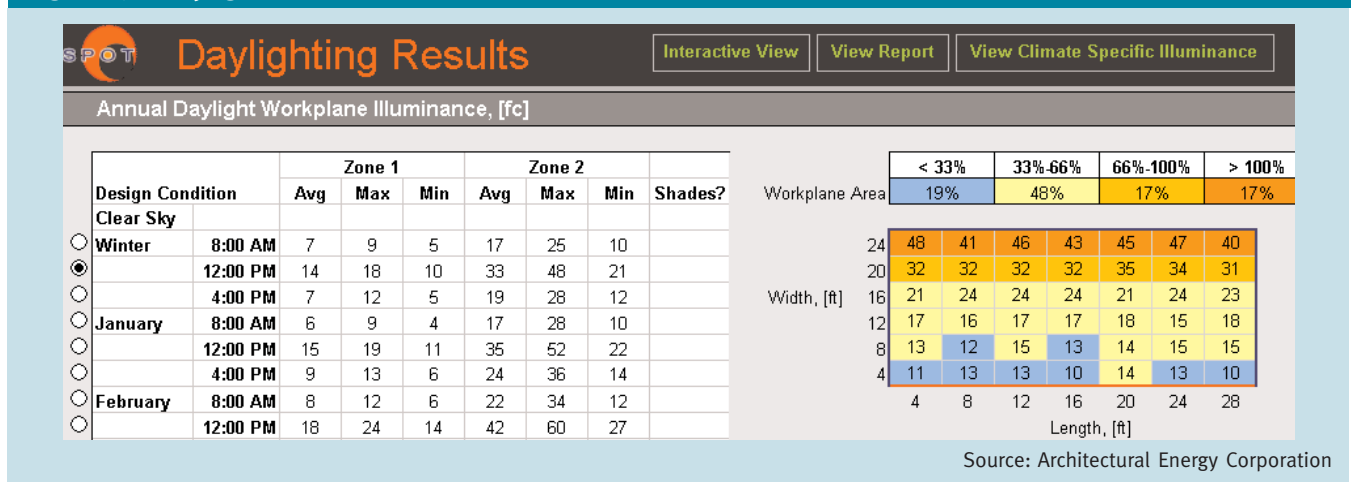
Daylight Metric Reports

Daylight Metric Reports were generated by the software for all metrics discussed in this Design Brief with the exception of the LEED Glazing Factor and Useful Daylight Illuminances. The reports are shown on the following pages. The first metric, Single Point in Time for CHPS (CA), is presented in **Figure 5** and provides a space summary. It shows the crude workplane illuminance distribution for a sunny equinox sky at noon with the resulting average illuminance and maximum-to-minimum ratio. The results show a smooth distribution from the perimeter to the core of the space resulting from the north sky.

Daylighting Report

CHPS (CA) - Single Point in Time ▼   PRINT   << BACK

CHPS(CA) -Single Point in Time- Daylighting Report

Space Setup Summary

Isometric View

Space Properties			Element Description			Prerequisite Checks	
Dimensions			Apertures	Overhangs	Lightshelves	Direct Sun Check (R1)	
Width	28	ft	North Wall				Pass
Length	35	ft	4 4.5ft x 5ft 47%			Skylight Control (R2)	
Height	10	ft	4 2ft x 5ft 65%				Pass
Wp Height	2.5	ft				Daylight Sensors (R3)	
Wall Thickness	8	in					Pass
Skylight Depth	0	ft				Diffuse Glazing (R4)	
							Pass
Surface Reflectance						Workplane Height (30in AFF)	
Floor	20	%					Pass
Walls	60	%				Grid Spacing (4ft x 4ft max)	
Ceiling	75	%					Pass
Ground	25	%					
Mullions	50	%					
Lightshelves	50	%					
Overhangs	50	%					

Design Performance

Workplane Annual Daylight Illuminance

Zone	Average	Maximum	Avg:Max
1	15 fc	43 fc	3
2	41 fc	200 fc	5

Workplane Illuminance (fc) - Sunny Equinox at Noon

□ 0-5   □ 5-10   □ 10-15
■ 15-20 ■ 20-25   □ 25-30
■ 30-35 ■ 35-40   □ 40-45
□ 45-50 □ 50-55   ■ 55-60

Avg Illuminance:
36 fc

Max to Min Ratio:
4 : 1

Evaluation: **Pass**

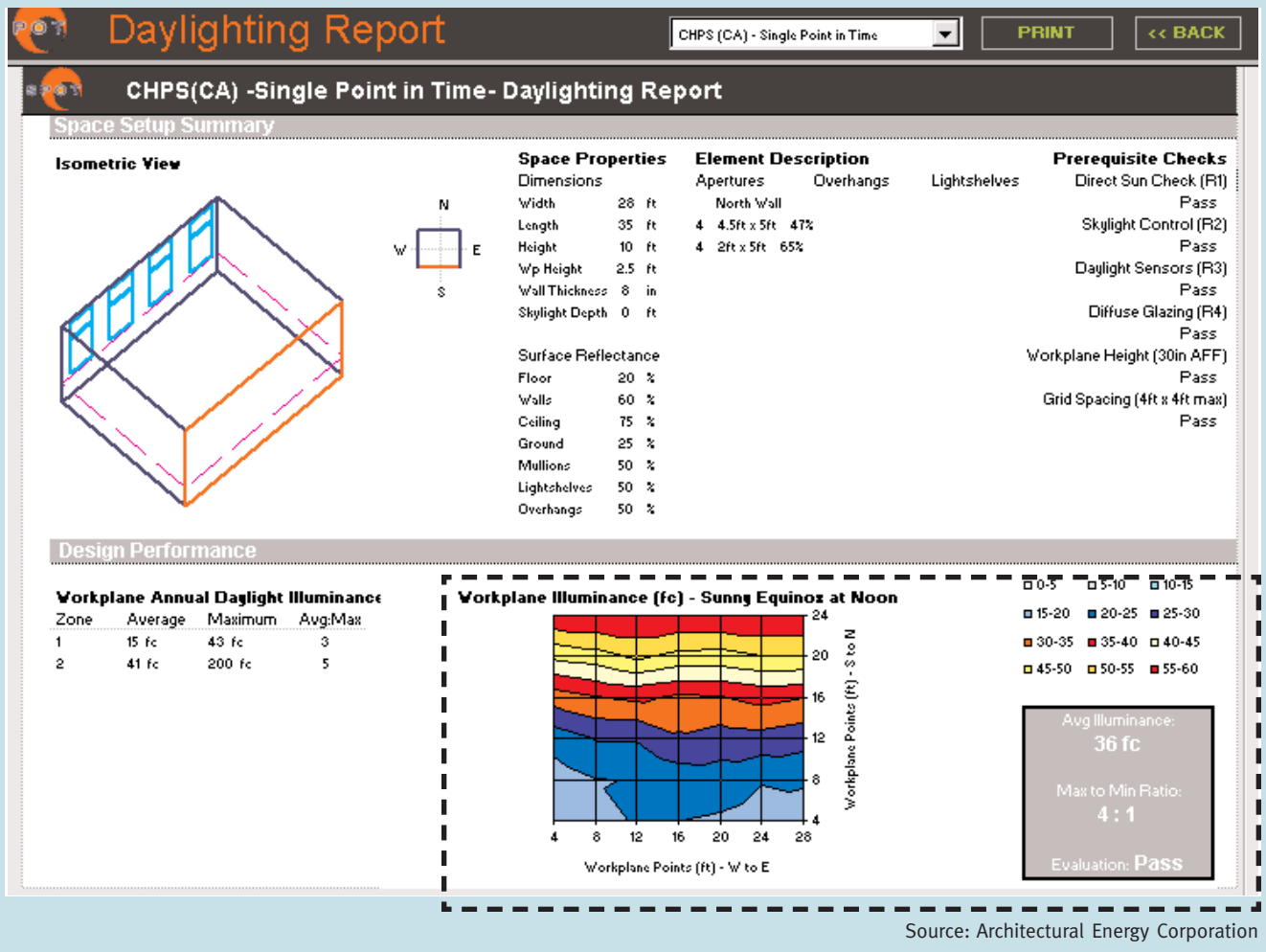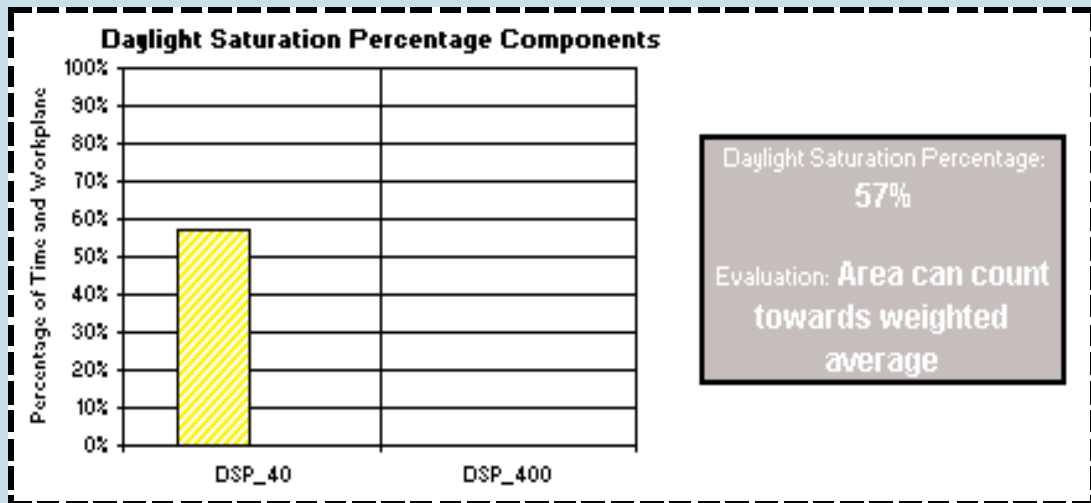Source: Architectural Energy Corporation

Figure 6 gives a bar plot representation of the DSP equation components. The saturation for 40fc is adequate and direct sunlight is negligible. The resulting DSP can count towards a full building-area weighted average to be compared against point total thresholds.

Figure 7 shows the DF for CHPS CA at 1.8 percent. The DF result is the same for the Base Case and for all variations. The room geometry and properties do not allow for quite enough daylight to meet the two percent criterion.
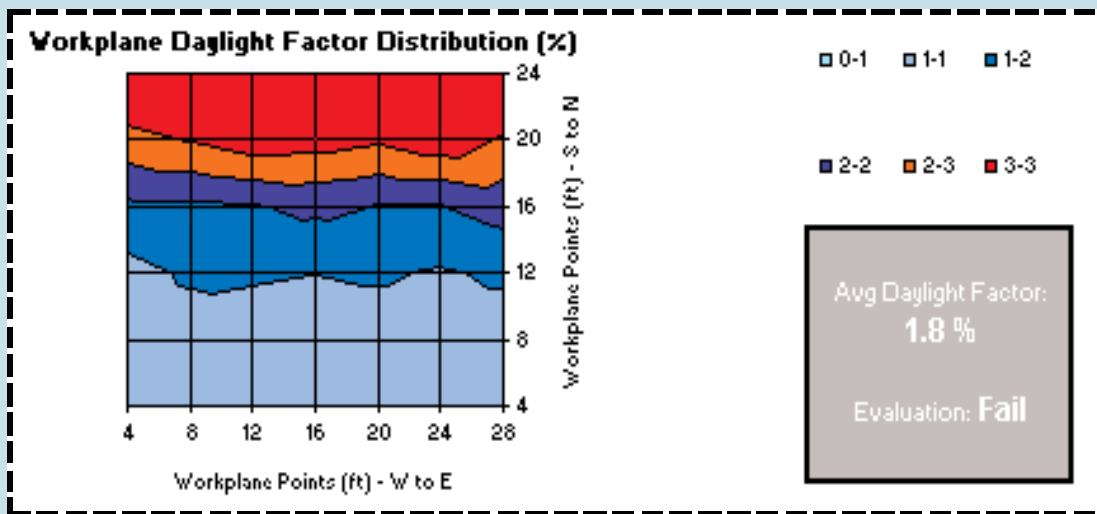
Figure 6: DSP – CHPS CA
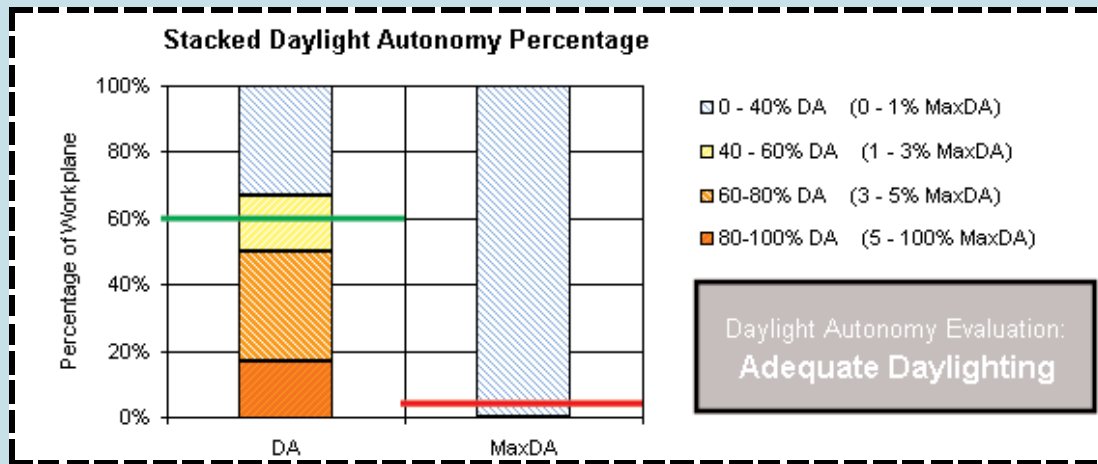

Source: Architectural Energy Corporation

Figure 7: DF – CHPS CA

Source: Architectural Energy Corporation

The SPOT DA results, shown in **Figure 8**, are presented in the form of a stacked bar chart. The left bar gives the binned Continuous DA results and the right bar gives the binned MaxDA results. The lines across the bars show the criteria for sufficient daylight saturation and avoidance of direct sunlight as related to the percent of workplane area respectively for DA and MaxDA.
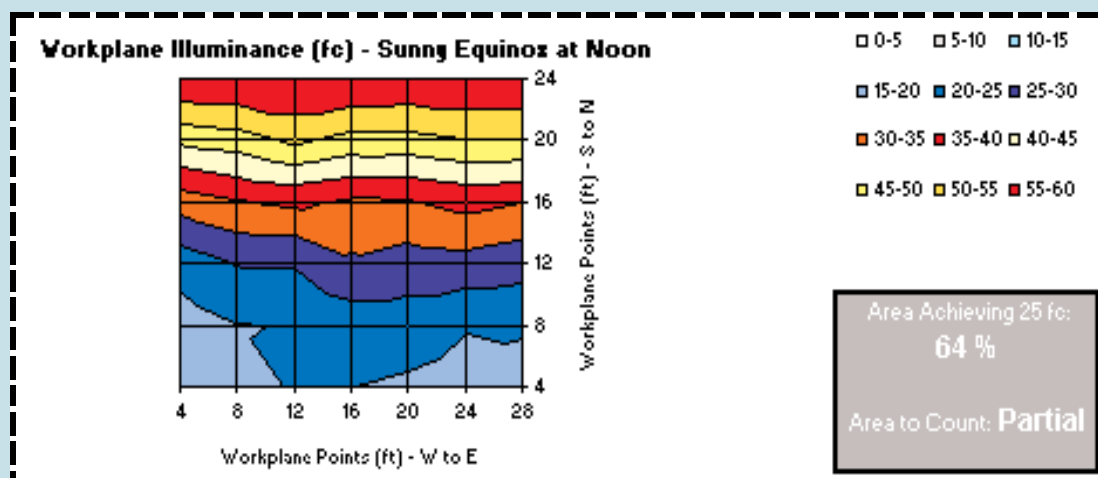
Source: Architectural Energy Corporation

The final report image shown in **Figure 9** is for the LEED Single Point in Time metric. The illuminance distribution plot is the same as for the SPT – CHPS, though the transformation of point data for the metric is different. Again, the LEED option only counts the percent of the workplane with illuminance above 25fc. A minimum of 75 percent of the total building area must meet this threshold to attain the daylight credit. Partial area can be counted for each space (criteria differ for small offices).

Figure 9:   SPT – LEED Results

Source: Architectural Energy Corporation

Test Case Variations, Summarized Results

For the parameter comparisons in **Table 4**, point results are given as though one classroom represents the typical school design. In a true whole building calculation, all required areas would be included in the calculation and summed appropriately for a program credit/point total.

The DF-CHPS CA column is highlighted to reiterate that the daylight factor is the quintessential example of a static metric, as its results do not change with any of the calculation parameter variations. The orientation results also are emphasized to show the variability of results among the metrics. The variation is due mostly to the thresholds instead of the calculation results for this example. The SPOT DA thresholds are meant to be dynamic with the project design goals. The DSP credit method is currently under review, therefore a metric cannot be accepted or disregarded based on the current thresholds.

The classroom example and the resulting metric comparisons are not intended to make a statement about any one metric or threshold. Rather, this exercise is intended to give a general sense of the capabilities of the various metrics and an understanding of the differences for lighting designers and energy consultants. Also, the example illustrates how the dynamic metrics represent more complete benchmarks.

Table 4: Calculation Parameter Variations, Metric Results

Cumulative Parameter Variations	SPT-CHPS CA	DSP-CHPS CA	DF-CHPS CA	SPOT DA	SPT LEED
Base Case	36fc average 4: 1 min to max ratio 4 Points[2]	57% average DSP 2 Points	1.8% average DF 0 Points	60% of area at 40%-60% DA ‹ 5% area above 1% MaxDA Adequate	64% of area ≥ 25fc 0 Credits
Orientation	40fc average 5: 1 min to max ratio 4 Points	61% average DSP 3 Points	1.8% average DF 0 Points	60% of area at 40%-60% DA › 5% area above 1% MaxDA Reevaluate	67% of area ≥ 25fc 0 Credits
Location	38fc average 5: 1 min to max ratio 4 Points	72% average DSP 3 Points	1.8% average DF 0 Points	60% of area at 60%-80% DA › 5% area above 1% MaxDA Reevaluate	67% of area ≥ 25fc 0 Credits
Time Frame	38fc average 5: 1 min to max ratio 4 Points	74% average DSP 3 Points	1.8% average DF 0 Points	60% of area at 60%-80% DA › 5% area above 1% MaxDA Reevaluate	67% of area ≥ 25fc 0 Credits
Internal Shading	38fc average[1] 5: 1 min to max ratio 4 Points	74% average DSP[1] 3 Points	1.8% average DF 0 Points	60% of area at 40%-60% DA ‹ 5% area above 1% MaxDA Adequate	67% of area ≥ 25fc 0 Credits
Design Illuminance	38fc average[1] 5: 1 min to max ratio 4 Points	74% average DSP[1] 3 Points	1.8% average DF 0 Points	60% of area at 60%-80% DA ‹ 5% area above 1% MaxDA Good	67% of area ≥ 25fc 0 Credits

[1] Does not change from previous variation because only louvers or blinds fixed between glazing are to be considered in the calculation.

[2] Note that all point totals assume modeled design is the same for all classrooms in the school, which is not a likely reality. This is only for comparative purposes.

Source: Architectural Energy Corporation

Calculation Tools

Many tools exist to aid in the process of weather file creation, initial design checks, and full annual daylight simulations. Some of the most widely used include ADELINE, AG132, Daysim, Daylight 1-2-3, EPS-r, Lumen Micro, RADIANCE, and SPOT.

The most useful tools for dynamic calculations such as Daylight Autonomy are those that have an annual simulation engine. The software tools that exist in this capacity are RADIANCE interfaces. This is due to the accuracy of RADIANCE daylight simulation and the flexibility in manipulating the output. Daysim, Daylight 1-2-3, and SPOT are RADIANCE interfaces that allow for the calculation and documentation of Daylight Autonomy because of their inherent annual simulation processes. SPOT software has options for calculating all of the different Daylight Autonomy methods used in current sustainable building rating systems. Daysim and Daylight 1-2-3 DA results are typically presented in a graphical format as a workplane distribution, which is equivalent to the SPOT DA method of presentation.

Other lighting software packages exist that allow for workplane illuminance calculations under daylight. The output from programs such as AGI32 and Lumen Micro can be used to calculate DA, though the process is somewhat tedious for gathering annual data unless an automation method is developed.

Conclusion

For design teams, it is important to understand the many facets involved in balancing the quantity and quality of daylight into a given space. Calculation tools that simulate daylighting design and calculate the various metrics provide designers with methods of prediction and benchmarking against varying design concepts. While no one metric will be able to speak to all of the design goals for successful daylighting, each metric has its place to assess specific design issues at different places in the design process. The more robust dynamic daylight metrics are more telling of the successes and failures of a design as design goals and parameters change. Dynamic metrics are still in their infancy, and further development and testing is needed to establish concrete methods and benchmarks. The metrics will continue to evolve as the daylighting community and, in particular, the IESNA daylight committee grapples with determinants of daylight visual quality and quantity. More innovative daylighting design, specific to space use, is on the horizon.

FOR MORE INFORMATION

Publications and Web Sites

CHPS Best Practices Manual: Volume II: Daylighting and Fenestration Design Chapter, www.chps.net

Energy Design Resources, Daylighting Design Brief and other daylighting tools, www.energydesignresources.com/category/daylighting/

Illuminating Engineering Society of North America (IESNA): IESNA Lighting Handbook, 8th edition, www.iesna.org

LEED™-NC 2.2 Reference Guide: Indoor Environmental Quality Credit 8: Daylighting, www.usgbc.org

Southern California Edison Classroom Lighting Guide, www.sce.com/RebatesandSavings/DesignandEngineering/SCEClassroom LightingGuide/

The Daylite Site, various resources, www.thedaylightsite.com/

Calculation Tools

AGI32 Lighting Design Software: www.agi32.com/

Daylight 1-2-3: www.daylight1-2-3.com/

DAYSIM Daylighting Analysis Software: irc.nrc-cnrc.gc.ca/ie/lighting/daylight/daysim_e.html

Ecotect: www.ecotect.com/

Lumen Micro: www.lighting-technologies.com/Products/LumenMicro/LM.htm

RADIANCE: radsite.lbl.gov/radiance/

SPOT: www.archenergy.com/SPOT

Notes

1. www.lrc.rpi.edu/programs/daylighting provides link to a variety of studies although it is not an exhaustive reference.

2. [ASHRAE/IESNA] American Society of Heating, Refrigerating and Air-Conditioning Engineers/Illuminating Engineering Society of North America]. ASHRAE/IESNA 90.1 2004. Standard - 2004 - Energy Standard for Buildings Except Low-Rise Residential Buildings.

3. Commission Internationale de l'Eclairage (CIE) developed a series of mathematical models of ideal luminous distributions under different sky conditions.

4. Association Suisse des Electriciens. 1989. E´ clairage inte´rieur par la lumicˇre du jour. Association Suisse Des Electriciens, Swiss Norm SN 418911, Zurich.

5. Reinhart C.F. 2002. Effects of interior design on the daylight availability in open plan offices. In: Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA. USA.

6. Rogers 2006 Rogers Z. 2006. Daylighting Metric Development Using Daylight Autonomy Calculations in the Sensor Placement Optimization Tool. Boulder, Colorado, USA. Architectural Energy Corporation.

7. Rogers 2006. Best estimate of acceptable threshold determined through a series of examples. Refining of threshold is an ongoing process.

8. Weather data provided by the federal government for 237 U.S. locations, derived from a 1961-1990 period of record. Data sets are hourly values of solar radiation and meteorological elements for a one.