Daylighting Symposium White Paper

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WHITE PAPER

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1. Executive Summary

This whitepaper (1) summarizes the latest, significant, wide-ranging research on the human imperative and value proposition for daylighting in buildings, (2) documents a public gathering called the Daylighting Symposium that convened industry leaders who met in attempt to advance daylighting in buildings, and (3) makes bold recommendations, based on items 1 and 2, on ways California can move forward in support of daylighting in buildings, primarily as it pertains to energy modeling.

Today, people spend more than 90 percent of their lives indoors, so it is vital that buildings are designed to promote and preserve the comfort, productivity, and health of its occupants. Recent studies have shown that daylighting, which renders a space with highly desirable, natural, full-spectrum light and provides views to the outside world, can be an effective, low-energy design strategy, and can also provide significant health and well-being benefits to its occupants. Several research studies (Loftness, et al. 2003) have shown that daylighting in buildings can reduce the need for mechanical heating and cooling and peak energy usage, increase property value and positively impact occupant health. Studies on human productivity (Heschong Mahone Group 2003c) have shown that access to daylight can increase productivity, promote higher sales in retail stores, and increase learning in classroom environments.

In Title 24 Part 6, key daylighting aspects have been evolving for many years. The code has mainly focused on prescriptive daylighting measures that identify daylighting for its value as an energy efficiency feature. These prescriptive measures have included guidance on daylight distribution, glare mitigation, and encouraging the use of advanced daylighting techniques. However, a performance-based daylighting approach that gives building designers a full range of flexibility on daylight design has not yet evolved.

A challenge in bringing in new, climate-based, daylighting metrics, and a performance-based approach to Title 24, Part 6 has been the limitations with CBECC-Com, the code compliance software for Title 24, Part 6, which does not cohere to current best practices and lacks a detailed daylighting simulation engine.[1] The software currently uses the split-flux daylighting simulation method which was developed considering computational power and daylighting design from the early 1980s. Today, the split-flux method is broadly regarded as insufficient for informing daylighting design. Additionally, the ability to accurately model daylighting in a space is required to calculate the new climate-based daylight metrics, and to incorporate many of the daylighting features and devices used in modern daylit buildings, such as light shelves and light redirecting louvers. These are important in helping building designers mitigate glare and develop comprehensive daylighting designs. Most importantly, the software currently cannot capture daylight quality metrics, such as daylight autonomy, which supports designers in evaluating the benefits of daylighting.

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[1] Recent daylighting research led by the California Energy Commission's (Energy Commission) Public Interest Energy Research (PIER) and the Investor-Owned Utilities (IOUs) and guided by the International Illumination Engineering Society (IES) has developed new, climate-based, daylighting metrics, which are now being widely used by the building industry and in voluntary building standards, such as U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program. These metrics are an important energy efficiency strategy and are designed to identify and encourage well-daylit buildings from the occupant's perspective.

Detailed daylighting simulation engines, such as Radiance, have evolved over time and can be incorporated into existing Title 24, Part 6 compliance tools. However, there are key technical and functional issues that need to be discussed and resolved first with stakeholders and the California Energy Commission (Energy Commission).

On April 29, 2019, the Statewide CASE Team, in partnership with the National Electrical Manufacturers Association (NEMA) Daylight Management Council (DMC), hosted the Daylighting Symposium in Sacramento, California. There were 36 attendees, including researchers, architects, daylighting equipment manufacturers, practitioners, software developers, California regulators, and utilities. Experts from the daylighting industry presented on topics including: glare management, the state of daylighting in California, valuing daylight and view, commercial daylighting case studies, dynamic light-redirecting technology, health benefits associated with daylighting, predicting the performance of automated glare management systems, and designing for comfort and productivity. The Daylighting Symposium pooled some of the latest research on the benefits of daylighting in buildings and presented successful applications of daylighting design from leading design practitioners. Throughout the Symposium, there were also fruitful discussions on existing issues related to daylighting, potential solutions to these issues, and how to engage all important stakeholders in the future. The overall intent of the Daylighting Symposium was to establish some industry consensus around productive paths moving forward in support of daylighting in buildings in California.

These discussions during the Daylighting Symposium, along with additional research, have made it clear that there are several actionable next steps that could be taken to help address the shortcomings associated with daylighting. These include:

- Moving secondary daylit zone requirements from prescriptive to mandatory requirements;
- Modeling buildings with many similar spaces together to make user inputs of representative spaces easier;
- Streamlining plan checking and verification by providing field inspectors a list of inputs from the daylighting software; expediting these checks via mobile apps; and
- Reducing simulation runtimes by utilizing cloud and server-based workflows.

These potential improvements can help address some of the technical and functional issues of introducing a performance-based daylighting approach and a detailed daylighting simulation engine, like Radiance, into Title 24, Part 6 and CBECC-Com.

A viable, yet bolder alternative approach could be to use a certifying procedure that tests third-party simulation software for its fidelity to the compliance rulesets. The advantage to this method is that the Energy Commission would no longer be responsible for the ongoing development of CBECC-Com. However, the methodology to implement this approach is still under discussion by the industry and the approach would require a significant change in direction for the Energy Commission.

This white paper and the Daylighting Symposium are in no way intending to bypass the Energy Commission’s traditional public stakeholder engagement process. They are ultimately supplemental efforts in support of broad industry coordination and collaboration.

2. Daylighting Value Proposition

Maximizing a building’s value and comfort for its occupants, while minimizing its energy expenditure has been a goal for building owners and designers alike. Daylighting in buildings provides a way to achieve this by bringing natural light into the built environment through windows and skylights. When done correctly, daylight can displace the use of daytime artificial lighting, resulting in energy savings and peak demand reduction. At the same time, daylight also renders the space with highly desirable, natural, full-spectrum light and views to the outside world, which add significant value for the occupant by providing a healthy indoor environment that protects wellbeing and provides visual comfort.

For these reasons, designing buildings with ample daylight should be an easy decision. It should be the norm and not the exception in building design. In fact, up until the early twentieth century, the standard way to design a building was to ensure that the entire building floor area was fully daylit. However, the advent of electric lighting and affordable electricity changed the way architects and building owners saw and valued daylight.

Designing with daylight can be a complex task. It requires understanding changing sun positions, predicting the potential for glare, and correctly sizing the daylight aperture and glass properties to prevent overheating. When viewed purely as a way to deliver the desired quantity of lumens into a space, electric lighting offers designers a much easier, simpler design process. This thinking brought about a trend in building design with smaller, darker windows, and over-designed electric lighting, especially in the latter half of the twentieth century. These buildings were hailed as "new-age" and "advanced" in their day, as they showcased the flexibility of electric lighting designs. However, over time, the lack of natural light and connection to the outdoors became synonymous with negative connotations like "sick-building syndrome" (Heschong and Roberts 2009). Researchers started to hypothesize that low illumination levels and restricted access to outdoor views were directly linked with circadian dysfunction, which in turn has serious negative health consequences for building occupants.

Perceptions have changed today and with advances in technology, it is now possible to design buildings that maximize the health benefits of daylight and views, more accurately predict and mitigate glare, and save energy. We can reverse the trend that led to buildings with poor indoor environment quality and move towards a future with healthy daylit buildings.

2.1 Daylighting and High Efficacy Lighting

At the start of the twenty-first century, there was a significant up-tick in electric lighting efficiency. High efficacy sources, like LED lighting, made it possible to deliver the same amount of lumens of light in a space using much less energy than older sources, like incandescent and fluorescent lamps. Moreover, LEDs also became less expensive over time, making them a compelling choice for lighting in building. Figure 1 provides a chart from the United States Department of Energy's (DOE) Solid-State Lighting Research and Development Report from 2013 and shows that LED lighting has decreased in cost while increased in efficacy, which makes them a very attractive solution to efficiently light a building.

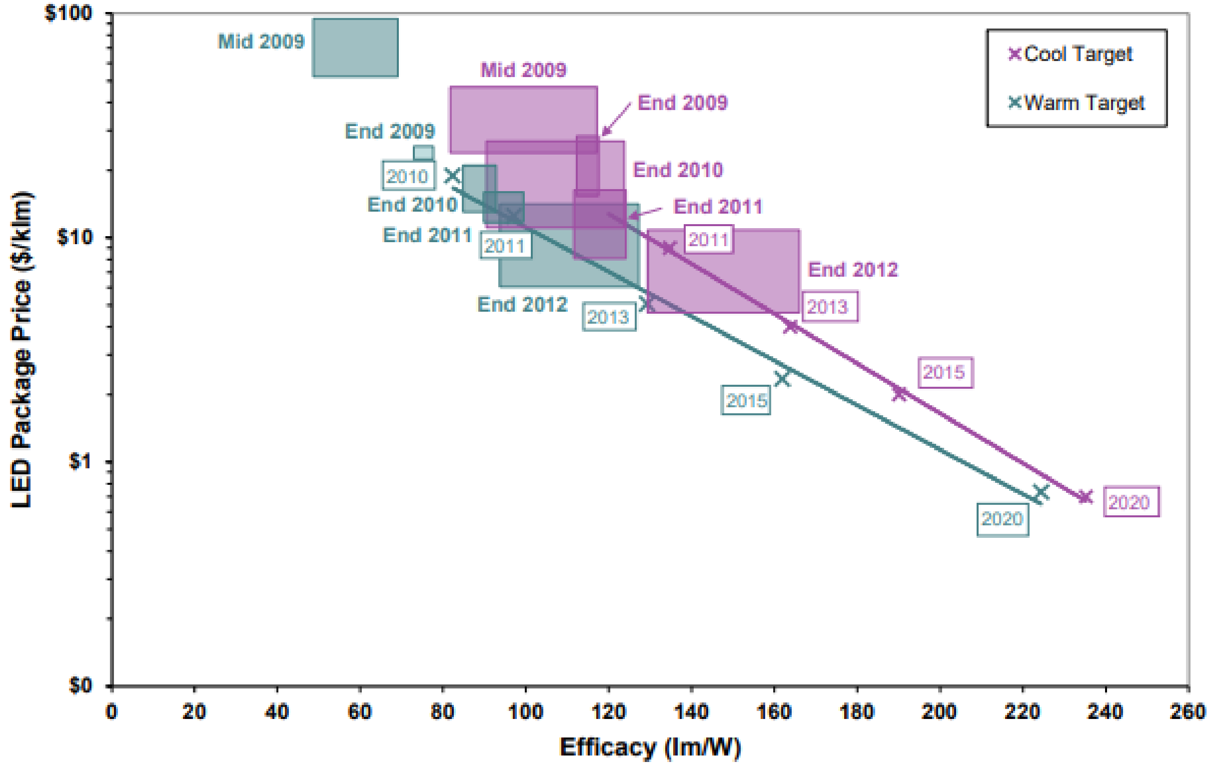

Figure 1: LED efficacy and cost trends during the previous decade.

In fact, building professionals began to question whether building codes should even include daylighting requirements, if lighting continued to become more efficient and less expensive. Should energy efficient buildings be built with small, dark windows because LEDs can light the space more efficiently?

This argument misses the wholistic benefits of daylight improving occupant health and wellbeing, and misrepresents daylight as purely a way to deliver desired quantity of lumens into a space. This key advantage that daylight has over any form of electric lighting is addressed later in more detail. However, even based purely on lighting efficacy, there is still reason to choose daylight over a highly efficacious artificial lighting source like LED.[2]

Figure 2 shows another graph from DOE's Solid-State Lighting Research report from 2017 showing that while LED sources are becoming more efficient, the luminous efficacy has a theoretical maximum of about 250 lumens per watt (lm/W).

To compare the efficacy of an electric lighting source (measured in lumens of light per watt of electricity) to daylighting, we consider the equivalent watts of heat that are brought into a space through a spectrally selective glazing (like a window or skylight) for every lumen of daylight delivered. Daylight's efficacy varies by time of day and the source. If daylight is coming directly from the sun, it is less efficacious than if it is reflected from the sky or clouds or outside objects. The highest efficacy for daylight (light from the sky through a spectrally selective window) is the maximum value of 250 lm/W

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[2] Lighting efficacy in terms of is delivering light with the least watts of energy, or watts of heat when referring to daylight.

(Konis and Selkowitz 2017). This makes daylight from the sky as a source the most efficient way to light a space. With direct sun as the source (light from the sun through a spectrally selective window), the efficacy can go down to about 150 lm/W as seen in Figure 2, which is still comparable to high efficacy LEDs available in the market today.

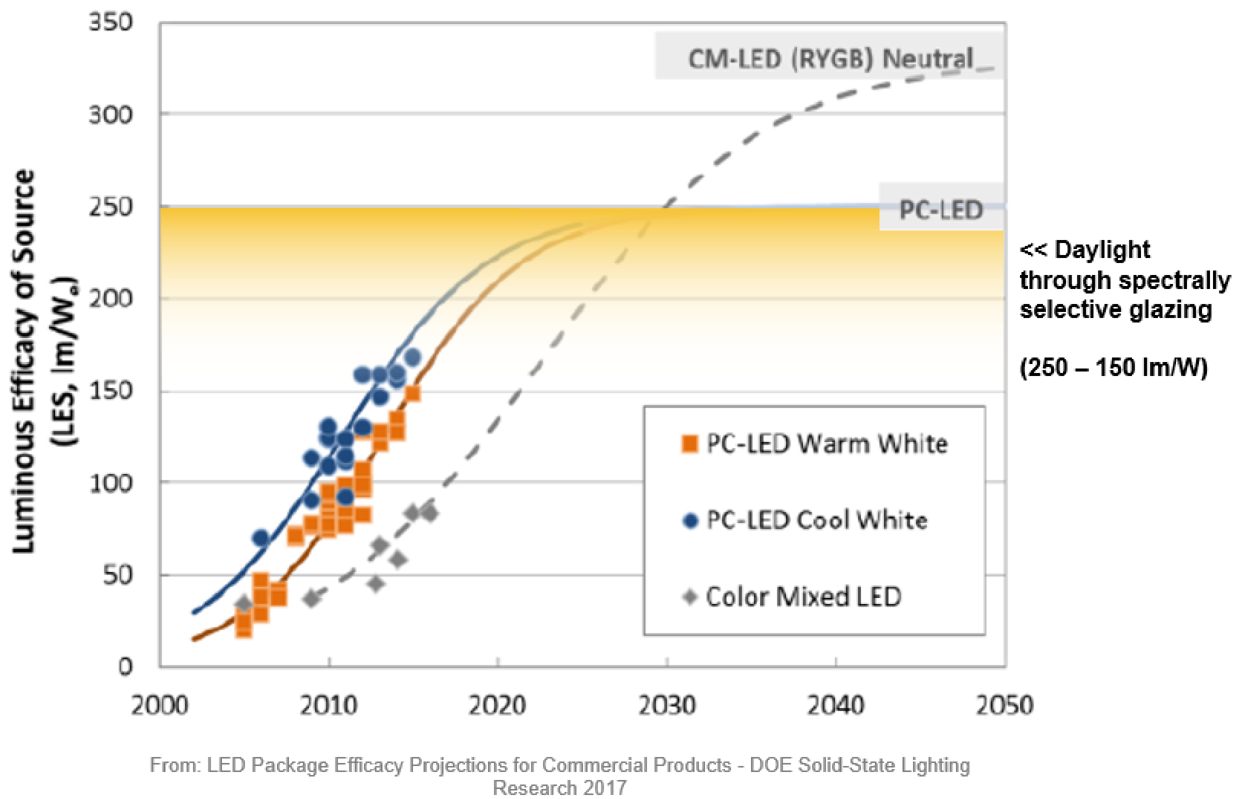

Figure 2: Luminous efficacy of LED lighting sources over time.

2.2 Health and Well-Being Benefits

As discussed, daylighting is perhaps the most energy efficient source of light for a building, even compared to the latest electric lighting technology. However, there is an even more compelling reason why daylighting should be an integral part of the way we design buildings which is protecting the health and wellbeing of occupants.

Buildings are more than mere shelters designed to keep occupants safe and protected. They serve a greater function of providing an indoor environment where occupants can be comfortable, productive, and healthy. With more than 90 percent of modern lives spent inside buildings, this function of protecting occupant wellbeing is as critical as any other building function (Klepeis 2001). In recent years, as focus in the building community has shifted towards reducing greenhouse gas emissions through the reduction of energy used, it has become crucial for a building's indoor environment to deliver this health and comfort with the least energy expenditure.

Air quality is one aspect of the indoor environment, whose impact on human health has been well studied and understood. Minimum outdoor air ventilation and air quality standards for buildings have been published (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 and 62.2) which set criteria, against which, efficiency standards for buildings, like ASHRAE 90.1 and Title 24, Part 6, have been developed. When it comes to the indoor visual environment, however, researchers have only recently understood that indoor environments, where a lack of daylight results in low illumination levels and limited outdoor views, can have significant health and productivity implications. Studies from biologists have found that "light is the most potent entraining signal" (Reppert and Weaver 2002) for the part of the human brain responsible for maintaining internal (circadian) clocks. That, in turn, coordinates aspects of behavioral and physiological rhythms, ranging from blood pressure and immune functions (Altun and Ugu-Altun 2007) to a feeling of well-being and happiness (Young 2007). Serotonin, a neurotransmitter responsible for these functions, is triggered by exposure to blue light (like from a blue sky). Conversely, melatonin, its hormonal counterpart, is triggered by darkness. Along with exposure to daylight, access to outdoor views has also been shown to provide health and cognitive benefits.

This is evidenced in a more direct and tangible way from results of research on the relationship of daylight and human productivity. Multiple research studies on human factors and the built environment show evidence of strong correlations between daylight and occupant productivity. Three such studies funded by the Energy Commission and supported by the California Investor Owned Utilities identify a link between daylight and better student performance (Heschong Mahone Group 2003b), higher retail sales (Heschong Mahone Group 2003a), and higher office worker productivity (Heschong Mahone Group 2003c). Several other well-regarded studies (Loftness, et al. 2003) have shown that well daylit environments, especially those that are free of disturbing glare, can result in increased productivity.

Studies have shown daylight's connection to occupant health, wellbeing, and productivity. This is an active research topic but the evidence to date provides compelling reasons for daylighting in buildings being considered a requirement in the same way as we require air quality standards to maintain a livable and healthy indoor environment.

2.3 Building Standards Recognizing the Importance of Daylighting

This recent realization of the importance of daylighting in delivering a healthy and productive indoor environment is evidenced in the recent changes in voluntary building standards like WELL and the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED). The WELL building standard is the first to acknowledge and require "circadian lighting" with its inclusion of the unit Equivalent Melanopic Lux (EML) – a more apt way to measure exposure to light as interpreted by the human eye's photopic vision. Beginning with LEED v4, the USGBC recognizes the merit of calculating spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) by awarding an additional point for these features. sDA and ASE are new daylight metrics that are correlated to occupant's satisfaction and comfort levels with the amount of glare-free daylight in a space.

WELL and LEED are two examples of recent recognition of the importance of daylight in buildings and represent the first steps in the direction of encouraging architects and designers to take on the complexity that comes with designing well-daylit buildings. They are likely to evolve over time as more research is made available on daylighting's impact on human health and wellbeing, and as tools such as daylighting simulation software become more capable.

While these leading-edge building standards are moving towards a greater recognition of daylighting in the built environment, energy codes such as IECC and ASHRAE 90.1 have tried to move the building envelope code towards smaller, darker windows. Proposals that restrict the window-to-wall ratios from a maximum allowable of 40 percent to 30 percent push towards smaller window areas and decreasing window solar heat gain coefficient (SHGC) requirements without a minimum visible transmittance (VT) requirement to promote darker windows.

There is enough evidence from past building trends to demonstrate that optimizing the energy equation, while ignoring the human impact of those optimizations, will result in buildings that the occupants will eventually reject. These proposals have been backed by engineering calculations that do not factor in the need for daylighting for health and human needs of occupants. In fact, buildings can easily be designed with ample daylight using large, clear windows, and still meet or exceed energy codes and reach zero-net-energy status.

To develop prescriptive code that is more wholistic, alternate methods to evaluate a building's performance that goes beyond the simplistic metric of window-to-wall ratio have been proposed (Levitt, et al. 2018). These approaches present a more nuanced argument which factor in daylight metrics, energy savings, and whole building performance, and should be considered by code bodies.

3. Current Status of Daylighting

3.1 History of Daylighting in Title 24, Part 6

To understand where and why there are certain gaps in the current state of daylighting, a review of the history of daylighting in Title 24, Part 6 is helpful. This history reveals the trajectory of daylighting measures and approaches so it can also be helpful in determining how the path of this trajectory might continue going forward. The daylighting code in Title 24, Part 6, has been evolving throughout the years to address key aspects of daylighting.

3.1.1 Legacy code and the split-flux method

By 2005, the Title 24, Part 6 code included mandatory requirements for daylighting in the primary daylit zone for many spaces. Half of the lighting power in this zone required controls that reduced the light output of luminaires by at least 50 percent. Mandatory requirements must be met whether a prescriptive or a performance compliance pathway is chosen.

Prescriptively, there were power adjustment factors (PAFs) for windows and skylights that let designers install higher lighting power densities (LPDs) than the maximum allowed prescriptive LPDs. The value of the PAFs depended on the light transmittance and area of fenestration. Large low-rise spaces directly under ceilings higher than 15 feet prescriptively required skylights and daylighting controls and the requirement for daylighting controls changed from daylit areas greater than 250 square feet to total luminaire power greater than 120 watts,

Under the performance path, projects could use a building energy modeling software based on DOE-2[3] to show compliance. In this software, projects could either use the PAFs as multipliers to lower the modeled lighting power, or the installed daylighting control could be directly modeled by the software.

[3] DOE-2 is a building energy modeling engine created by the Department of Energy. There were many interfaces created that provided more user-friendly interfaces for this engine. Software with the DOE-2 engine were widely used for many years as energy modeling software to show compliance with Title 24, Part 6's and ASHRAE 90.1's performance paths.

For directly modeling daylighting, the compliance software was limited in comparison to modern daylighting simulation software. It could model only three types of skies: clear, partly-cloudy, and overcast. Additionally, only 20 different solar positions were modeled to approximate the annual range.

Figure 3 is an illustration of the split-flux method that the software uses to calculate the daylight level in the space. In this method, rays are traced from the outdoor sky and sun, into the daylit space, and onto a reference point. Rays that come through the window from a downward angle land onto and reflect off of the floor and lower half of the walls. Rays that come through the window from an upward angle land onto and reflect off of the ceiling and upper half of the walls. Thus, the daylight flux is split between the upper and lower halves of the space.

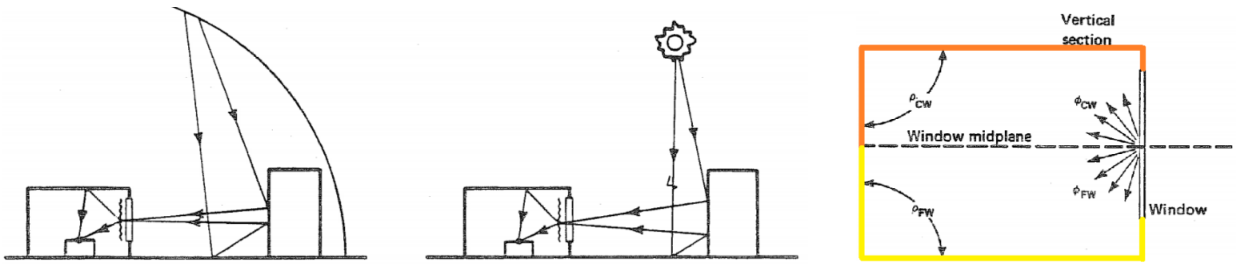

Figure 3: Split-flux method sky and sun paths and interior reflections.[4]

Each of these halves uses an area-weighted average reflectance of all the surfaces as a net reflectance spread out over the whole surface. With the upper and lower reflectance and the paths of the daylight rays, the total daylight onto a reference point is calculated. This reference point is used for both the daylighting control of electric lights and occupant glare. The metric used for glare is the daylight glare index (DGI), which is appropriate for diffuse skies.

The split-flux method was validated against scale models and a more accurate simulation engine under the limited sky conditions discussed above. Studies showed that it over-predicted the interior inter-reflected daylight, especially after multiple bounces in deeper spaces (Winkelmann 1983).

In terms of modeling the physical characteristics of a daylit space, the split-flux method only contains two modes to model windows: transparent glazing or shades drawn over transparent glazing. If glare at the reference point at a particular hour is too high, the shading is modeled as completely drawn, if not, the shades are completely opened.

There was little change for the 2008 Title 24, Part 6 code cycle. Instead of minimum light output, a minimum two-third power reduction was required for daylighting controls. In the performance method, the skylit daylit zone was required to be directly modeled in the software and combinations of controls were allowed to receive credit via schedules. These schedules were wattage-weighted averages of individual control schedules that appeared the Nonresidential Alternative Compliance Manual (ACM).

3.1.2 Moving from credits to requirements and introducing CBECC-Com

[4] Adapted from graphics from (Winkelmann 1983). Orange room surfaces have the area-weighted average reflectance of all surfaces above the window midplane. Yellow room surfaces have equivalent reflectance for below the window midplane.

A big push in daylighting occurred in the 2013 Title 24, Part 6 code cycle. Window daylit zones were redefined in terms of window height, which effectively increased their area. Primary and skylit daylit zones totaling at least 75 percent of the floor area became mandatory for large enclosed spaces. Additionally, the threshold for requiring mandatory controls in daylit zones was effectively lowered. These controls had to be stepped, and, if the daylight in the space reached more than 150 percent of the setpoint, the lighting power had to lower to at least 65 percent of total lighting power.

Prescriptive PAF credits were eliminated to make way for prescriptive requirements and the secondary zone now required daylighting controls. An area-weighted visible transmittance (VT) requirement for windows replaced of visible light transmission PAFs. These two requirements greatly boosted the daylighting energy savings.

In this code cycle, the California Building Energy Code Compliance for Commercial buildings (CBECC-Com) software was created for the performance method. In this software, EnergyPlus replaced DOE-2 as the building energy model simulation engine.

EnergyPlus had been developed for many years as the more powerful successor to DOE-2, but the split-flux method of DOE-2 remained as a daylighting simulation method. However, EnergyPlus also contained an alternate daylighting simulation method called the DELight calculation. While more accurate than DOE-2, this method also had its own shortcomings.

The DELight calculation uses the radiosity method which is an improvement over the split-flux method. First, the radiosity method divides all surfaces into sub-surfaces and calculates the reflection for each of these areas, in contrast to split-flux which calculates only two areas (upper and lower). Second, the DELight calculation can also model complex fenestration systems (CFSs).[5] The split-flux method only allows modeling for transparent glazing systems.

However, the DELight calculation does not calculate glare, and correspondingly does not close occupant shades in the model when there is too much glare. In addition, the complex fenestration calculations are "under development" (University Of Illinois And The Regents Of The University Of California 2015).

Even the advantages of the DELight calculation are moot in terms of CBECC-Com as it was ultimately not implemented in CBECC-Com. The older, split-flux method was used with primary and secondary daylit zone adjustment factors to compensate for the split-flux method's aforementioned error with depth.

3.1.3 Glare mitigation

There was no change to address daylighting in the 2016 Title 24 code cycle, but in 2019, PAFs were added again to encourage good daylighting and were given for louvers, light shelves, and clerestories.

This is important because louvers and light shelves block direct sunlight which is a prominent source of glare. However, unlike overhangs, louvers and light shelves do not simply block direct sunlight. They also provide a path for that light to enter the space in a useful way because light bounces off their

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[5] CFSs utilize surfaces to redirect light from the direction it might normally travel through transparent glazing. Examples are louvers which use reflection off opaque surfaces to block and bounce light in a diffuse manner, or films which use small features on transparent media to refract light towards another direction. CFSs are most commonly utilized with transparent glazing as in the case of an exterior louver in front of glazing or a transparent film applied onto glazing.

surfaces and this diffuse daylight then enters the space. Diffuse light is softer, with much less potential for glare than direct sunlight, making it a more ideal source for daylighting.

Glare mitigation provides a sort of warranty on calculated energy savings because when glare occurs, how occupants will respond is not strictly predictable. If an occupant chooses to close blinds over a window to block the glare, electric lighting savings reduce drastically as compared to a window whose blinds are open. If glare can be minimized, the predicted daylighting savings can have greater consistency and reliability.

A credit for clerestories was also added which helped to encourage larger daylit areas. These larger daylit areas provide views and sunlight deeper in the space, corresponding to health and productivity benefits, as discussed previously.

Because of the limitations of the split-flux method, louvers could not be directly modeled in the ACM. As a result, credits for the technology could only be provided via PAFs in the performance method.

3.2 Pros and Cons of Current Status

With the evolution of Title 24, Part 6, key factors that promote well-daylit building designs have been incorporated into the mandatory and prescriptive sections of the code, including:

- Amount of daylight (visible transmittance for both windows and skylights)
- Distribution of daylight (good daylit area coverage, haze values and clerestory PAF)
- Glare mitigation (louver and light shelf PAFs)

However, these aspects can still be refined as the market evolves and better products become more cost-effective.

In terms of the performance approach, the compliance software has not yet evolved to keep up with the market. On the upside, the split-flux method provides a relatively fast daylighting calculation for CBECC-Com users. With this method, users can directly simulate daylighting in lieu of PAF multipliers or weighted schedules.

While this split-flux method has been validated to some extent, this validation was performed under limited conditions as discussed above. The room adjustment factors discussed previously are an attempt to compensate for daylit spaces that differ from the validated cases.

It also uses DGI, which is an older glare metric. To reiterate, this was developed for diffuse sky conditions. On the contrary, newer metrics such as the Daylight Glare Probability (DGP) exist, which has a larger research sample and is based on both diffuse and direct sun glare.

sDA, the metric for daylight quality used extensively in the industry, cannot be modeled with EnergyPlus' split-flux or DELight method. The split-flux and DELight methods do not allow for enough reference points to calculate sDA.

As another downside, CFSs which use advanced daylighting devices such as the louvers introduced into the prescriptive path cannot be modeled with the split-flux method. Therefore, including louvers in the performance path means reverting back to PAF multipliers. The values for these PAFs were calculated with the intent of conservative universality, applying a low, approximate savings value to compensate for the unknowns of spaces. As such, they are inexact. Performance path modeling models the actual space. More precise calculation of savings can be performed if louvers can be directly modeled in this way.

The split-flux method used in CBECC-Com was developed in 1983. It was developed in consideration of the available computational power at that time and in consideration of the daylighting design and products of that time. At this point, 35 years later, the design and products have changed. Computational power has increased to the point that more modern daylighting simulation software can be reasonably utilized. These can model a wide range of sky conditions, room geometries, and, because of their higher resolution and larger capacity for reference points, can calculate modern glare and daylight quality metrics. They can also model CFSs giving designers more flexibility to create better daylit spaces.

The split-flux method used in CBECC-Com has provided relatively fast daylighting simulations for many years. When it was introduced, it was a move forward as it allowed direct simulation of daylighting in lieu of PAF multipliers or weighted schedules. However, daylighting simulation has developed more capabilities since then. Providing these capabilities in CBECC-Com will allow more accurate simulation, more flexibility in daylighting designs, and better feedback on comfort and health.

4. Daylighting Symposium

4.1 Coordinating the Daylighting Symposium

Recognizing the importance of continuing discussions on daylighting with contributors from all sectors, the Statewide CASE Team began working closely with the NEMA DMC in Fall 2018 to plan the Daylighting Symposium event. The group agreed that the three main objectives of the Daylighting Symposium would be to:

1. Help accelerate market adoption of proven, cost-effective daylight management technologies and practices, by offering a respectful environment for planning & coordination;
2. Present relevant case studies that convey the state of daylight management and glare mitigation in current practice, and identify opportunities to improve daylighting design and operational success; and
3. Inform overall prioritization of daylighting measures for the Title 24, Part 6, 2022 code cycle and beyond.

Through this collaboration, the working group determined that the best path forward would be to hold several case studies and discussion sessions led by a variety of experts specializing in different areas of daylighting. A questionnaire was developed and sent to contacts who might be interested in presenting case studies with the intent being to better understand which case studies fit best into the theme of the Daylighting Symposium.

Using contacts and outreach from both the Statewide CASE Team and NEMA DMC, an official invite was delivered to 89 people, but less formal invites were also forwarded to potential attendees. Despite the relatively short planning period, 43 people registered for the Daylighting Symposium and 36 people attended. The Daylighting Symposium was an all-day event held on April 29, 2019 held in Sacramento, California, with a dinner and social hour held the night before, also in Sacramento. The attendees included a variety of stakeholders and daylighting experts, including Energy Commission staff, manufacturers, national laboratory staff, and public university faculty. See Appendix E: Daylighting Symposium Materials for the full list of attendees as well as the questionnaire and invitation that were sent out.

4.2 Agenda for the Daylighting Symposium

The agenda for the Daylighting Symposium included both presentations from and discussions between various stakeholders, culminating with two simultaneous working sessions at the close of the day to discuss daylighting. The following presentations and case studies were given:

- Valuing Daylight and View. Presented by Lisa Heschong
- Daylighting Commercial Buildings: Case Studies and Simulation Models. Presented by Eleanor Lee, Lawrence Berkeley National Laboratory
- Dynamic Light-Redirecting Technology: One Look into the Future. Presented by Luis Fernandes, Lawrence Berkeley National Laboratory
- What's on the Horizon and What's Sunsetting? Presented by Kevin Van Den Wymelenberg, University of Oregon
- Predicting the Performance of Automated Glare Management Systems to Inform Design. Presented by Daniel Glaser, LightStanza
- Lessons Learned from Two Acclaimed Daylit Buildings. Presented by Daniel Huard, Global Green Tag Americas, LLC, and National Fenestration Rating Council
- Integrated Daylighting and Glare Control System: Designed for Comfort and Productivity. Presented by John Crowley, Rollease Acmeda

There was also a panel discussion titled: "What is working? What needs to change?" Panel participants included:

- Michael Holtz, LightLouver LLC
- Zack Rogers, Daylighting Innovations
- Andrew McNeil, Kinestral Technologies Inc
- John Crowley, Rollease Acmeda
- Mudit Saxena, Vistar Energy

At the close of the day, two separate discussion sessions were held:

- Design and Application
- Codes and Standards

The Design and Application session focused on areas of daylighting that could become new case studies and needed further discussion. The Codes and Standards session focused on how daylighting is addressed in current energy codes and could be improved. Please see the Daylighting Symposium notes in Appendix E: Daylighting Symposium Materials for a detailed summary of discussions at both sessions as well as summaries from all the presentations and discussions.

4.3 Key Takeaways

The presentations and subsequent discussions at the Daylighting Symposium brought up important considerations to keep in mind when integrating modern daylight simulation capabilities into CBECC-Com.

Michael Holtz noted that there is sometimes a disconnect between occupant-centered design and codes because of the need to prove a code change is cost-effective. He emphasized that designers need flexibility and suggested that the prescriptive path could be eliminated entirely. Based on this, it is important to think about creative ways to update codes, so they adhere to protocols while also ensuring that designers have the flexibility to design buildings with occupant needs at the front of mind.

Lisa Heschong noted that occupant comfort and convenience should come first to help motivate energy savings and carbon reduction. In her words from her experience, “The view is the task.” As such, comfort metrics should be thought of as primary needs. This challenges the traditional thought pattern that energy savings need to come first, because daylighting is such an essential part of occupant comfort in buildings. Lisa Heschong also noted that it may be time to think about moving from an energy metric to a carbon metric.

With regard to specific daylighting case studies, Eleanor Lee remarked that occupant health and well-being is already driving daylighting performance today. Both she and Luis Fernandes commented on emerging technologies that were very occupant-focused. The technologies presented by Eleanor Lee, Luis Fernandes, and John Crowley produce complex daylighting over the space, and over daily and seasonal time periods. The space- and time-dependent daylight levels, comfort, and daylight quality benefits of these technologies could not be captured by the split-flux method. They require more sophisticated algorithms.

Daniel Glaser highlighted the importance of using the full computational power of software to model daylighting and the need to refine and validate annual sunlight exposure. This is possible now because modeling is advanced enough and no longer a limiting factor.

Kevin Van Den Wymelenberg stated that daylighting designers should be viewed as healthcare providers. He echoed similar sentiment to Lisa Heschong when he stated that occupants like “daylight in the space, not in the face.” His presentation informed the group about cutting-edge research on the positive effects that daylighting has on reducing pathogens like harmful bacteria when daylight exposure is increased. He cited numerous studies about daylighting reducing hospital stays, increasing sales, and increasing school performance.

Kevin also made a clear point that daylighting designers and researchers cannot afford to work in a silo of their own. It is important to engage with stakeholders who may not traditionally be considered for daylighting code discussions. For instance, daylighting imparts many health and wellness benefits which invoke a need to engage with the medical industry. By ensuring that a wider breadth of stakeholders are a part of the discussion, we can ensure that all the different benefits of daylighting are properly being addressed. Kevin talked about high-dynamic-range (HDR) imaging and simulation for daylighting and glare controls. An innovative technology he discussed was task glare control. These could only be simulated with modern daylighting simulation.

Liam Buckley commented that the Daylighting Symposium functioned more as a technical conference than a symposium with a proposed goal. He also noted that, because CBECC-Com doesn’t model all daylighting details, it gives similar daylighting savings for Proposed and Standard Designs, disincentivizing good daylighting design. He suggested removing or reducing daylighting in the Standard Design to counter this. He further suggested that Proposed Designs in the 2-D (simplified) modeling approach not be given any credit because that approach lacks any daylighting design details.

He also recommended that the ACM be allowed to account for interior windows leading to daylit spaces. In addition, he stated that the ACM rule that requires that the geometry of the skylit zone "will be the same" as the geometry of the skylight, over-extends the skylight zone for skylight shapes that have corners. Finally, he stated that the ACM rule that reduces the height of windows in the Standard Design windows to maintain a maximum 40 percent window-wall-ratio is ambiguous for non-rectangular windows.

For more details about working with stakeholders outside of the traditional daylighting industries, see Section 5.4. Additionally, see Appendix E: Daylighting Symposium Materials for detailed notes from the Daylighting Symposium.

5. Next Steps

For CBECC-Com to incorporate all the daylighting quality, comfort, and health benefits discussed in section 4.3 and to accurately model technologies introduced there, CBECC-Com will need to be able to incorporate modern daylighting simulation algorithms such as Radiance, Radiosity, or multidimensional lightcuts.

While it is possible to incorporate modern daylighting simulation into CBECC-Com, this is not going to be without its challenges. Incorporating modern daylighting simulation into compliance software requires careful thought to the software's usability. The software that implement these algorithms need to ensure that the tasks, expectations, and goals of the user are met, providing the user with a smooth workflow and timely feedback. To outline an approach to achieve this user-friendly goal, a detailed roadmap for incorporating modern daylighting simulation into CBECC-Com is given in this section.

Alternatively, instead of updating CBECC-Com to incorporate modern daylighting simulation software, developing a verification process for daylight modeling software could be the correct path forward. This approach would relieve the Energy Commission's burden of developing and maintaining compliance software as well as allow the use of third-party modeling software that meets the specific ruleset criteria.

Regardless of which path forward is chosen, the daylighting community will benefit from reaching out to and including new collaborators who can bring new perspectives into daylighting conversations.

5.1 Workflow

Providing users of CBECC-Com with a smooth workflow is prudent to its usability. To achieve this, it will be critical to keep inputs to a minimum and minimize the changes from current practices.

5.1.1 Daylit space versus thermal zone

It is common for energy models to model several rooms as a single heating, ventilation, and air-conditioning (HVAC) thermal zone, ignoring interior walls. This will not be valid for modeling daylighting, because any spaces that have daylighting should be modeled as they will be built. This will require the detailed geometry approach in CBECC-Com.

However, many spaces in a building can have similar dimensions and orientations such as the same office layout along a façade or for multiple floors. For those situations, it's possible for a single, representative space to be simulated. The daylight quality and daylighting energy savings would be calculated for that space and would be valid for all the similar spaces. Multipliers would then be used to calculate the project-wide energy savings. Using this technique, modeling input time is reduced.

CBECC-Com already has the ability to use multipliers and to join multiple spaces into a single thermal zone, so no new features would need to be added to CBECC-Com.

5.1.2 Selection of Daylighting Devices and use of ASHRAE LM-83 defaults

The final change to the workflow for CBECC-Com users is the selection of any optional daylighting devices they are including in the project, such as louvers or light shelves. This could be included in a drop-down menu on the fenestration construction tab along with entries for the required daylighting device properties, such as geometry and reflectance.

Note that the above sections discuss all of the foreseen changes to the user workflow of CBECC-Com. No further inputs would be required from the user. For the interior reflectance of floors, walls, ceilings, exterior walls, exterior ground, etc. ASHRAE LM-83 values would be used.

5.1.3 Compliance

CBECC-Com's outputs are used in the compliance process. These outputs could be extended to provide a visual way to verify that advanced daylighting design inputs match the project's construction documents.

CBECC-Com can be modified to output plan and elevation views of daylit spaces. These plan and elevation views could show the dimension and placement of walls, windows and daylit zones. They could list all the daylit spaces they represent per section 5.1.1, window visible transmittance and any daylighting devices. The views could even include non-daylighting features such as U-factor, SHGC,[6] and possibly even wall or other envelope features to ease verification of those requirements. This might reduce the need for other forms and provide a faster, visual way for verification.

At plan check, these outputs could be matched against the construction documents, providing a highly visual way to verify the geometry, window properties, and daylighting devices. Field verification would not be necessary for space geometry because, when constructed, it would be highly unusual for the dimensions and placement of walls or windows to be significantly different than specified in the construction documents. An example compliance form is shown in Figure 4.

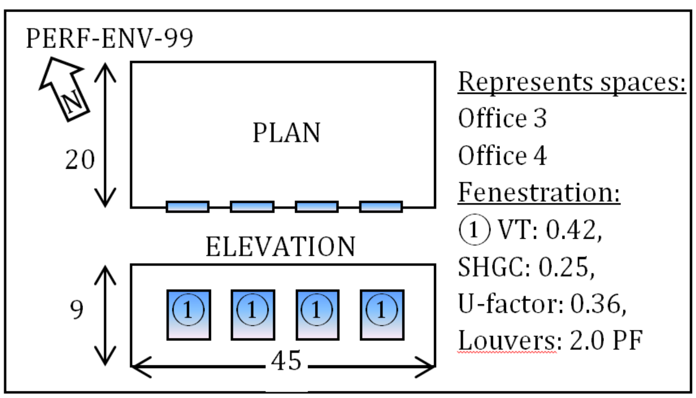

Figure 4: Example compliance form.

Daylighting devices can be verified in the field as is currently done. For louvers or fins, the software outputs would give the geometry and reflectance. These would be verified in the field. For Daylight

[6] The Solar Heat Gain Coefficient (SHGC) is a metric characterizing the transmittance of infrared radiation (heat) through fenestration.

Redirecting Devices (DRDs),[7] the manufacturer and model could be given on the software outputs, again, to be verified in the field.

Per feedback from the Daylighting Symposium, a further refinement for field verification could be the use of smartphone apps that could be created to verify geometry, manufacture labels, or bar codes.

5.1.4 Summary

Rather than inputting every space, only those projects that wished to use advanced daylighting would need to input a 3-D model. These projects would only input representative spaces and would use multipliers to capture the impact of those representative spaces on the entire project.

To verify the validity of the daylight simulation, plan checkers would match CBECC-Com's outputs of plans and elevations to the construction documents. EnergyPlus, CBECC Com's energy modeling engine, already has the capability to export Data Exchange Format (DXF) files that are readable by many popular computer aided design (CAD) programs. These outputs could even be used to verify other envelope features. Finally, for field verification, these same outputs would list the geometry or manufacturer's make and model of any daylighting devices. Per feedback from the Daylighting Symposium, these checks could be made easier by the creation of mobile apps.

5.2 Timely Feedback

One of the first concerns when proposing the use of modern daylighting simulation tools is the speed of calculation. Energy modelers are often on tight schedules so minimizing the time between inputs and outputs is a critical factor. There are several, very detailed techniques discussed below that can be used to achieve this, but these detailed techniques would be handled by software with the intent that they would go unnoticed or would actually enhance the user experience.

5.2.1 Server-based computation

Performing calculations on a server can achieve a large reduction in run-time and can improve the user experience of feedback time. With a server-based computation there are several advantages, including:

- Running the daylighting simulation in the background while the user is busy inputting other CBECC-Com parameters.
- Maintaining a results database that can re-use results from the same or previous projects if the characteristics are similar enough.
- Tailoring software to leverage hardware to utilize advanced computational techniques using powerful server processor power and memory.

The first step to creating a detailed geometry model in CBECC-Com, is importing the building's geometry created from third-party 3D modeling software. After this, the user fills in the remaining inputs for space functions, lighting, HVAC, etc.

While the user is fills in the remaining inputs, daylighting simulation will run in the background on a server with this geometry. This will prevent the user from having to unnecessarily wait on the

[7] DRDs are highly-engineered devices that change the direction of light as it passes through them. Typically, they will take incoming daylight and redirect it upwards towards the ceiling. This tends to reduce direct sun glare in occupant's view.

daylighting simulation, resulting in a smoother workflow experience. The space daylight levels are returned to the local computer where CBECC-Com would convert them into electric light dimming schedules and comfort or health metrics.

While running the simulation in the background could be done on the user's computer some modern daylighting simulation engines leverage multiple processors to speed up the processing time. If this were done on the user's computer, it would slow down other tasks running on the user's computer. Also, the user does not need to leave their computer powered on for simulations run on a server. Users could be offered the option to run the simulation on their local computer.

In tandem with the above technique, the daylight simulation results would be stored on a server database. In this way, when the user checks for compliance, it would not need to re-run the daylighting simulation every time because it would simply pull the results from the server. Results would only need updating if the user changed an input that affected the daylighting of a space. These inputs would be: geometry of the space or windows, window visible transmittance properties, or the area's space type. Modifying the geometry would be unusual if a project was already at the stage of checking for compliance.

Extending the database to keep results after a project completed would be an advantage as well. Future projects, even from other companies, might have similar spaces, and instead of those spaces needing to run daylighting simulations, results could be pulled from similar spaces in the database. To account for these situations, criteria would need to be set to determine what would qualify as sufficient similarity between spaces.

In the long term, the database results could even be used to calculate mandatory daylighting savings. These are currently not modeled in the performance path. These savings affect the HVAC energy so not including them in the model is inaccurate.

Servers with known, powerful processors and large memory capacities would provide additional benefits in contrast to running energy modeling on a personal computer. User computer hardware is unknown. If servers are chosen based on pre-determined hardware specifications, certain computational techniques can be used in a reliable way because software can be tailored to take advantage of them efficiently. Parallel processing would allow multiple calculations at a time. Run-length encoding (a type of compression) would ensure memory and processors are not overloaded and would efficiently use data. If a high-powered graphics processor was included on the server, Accelerad could be used to speed up calculations. Accelerad has versions of Radiance commands that reduce computation times by tens to over a hundred times.

Models can be uploaded and daylight level results downloaded as compressed text files and are not expected to require large bandwidth. As an example, the entire set of 2016 CBECC-Com Title 24 Prototype Models is only 174 kilobytes when compressed.

The entity in charge of the maintenance of the server will need to be determined. Possibilities are the Energy Commission or the California Investor-Owned Utilities. Alternatively, server time can be bought from some technology companies. However, the methodology for implementing any of these alternatives will need further investigation. If modern daylighting simulation is used only when BSDFs are required for modeling daylighting devices, then server traffic is expected to be minimal at first, but gradually growing over time as these technologies become more common.

5.2.2 Selective illuminance calculation

Illuminance results are needed to calculate sDA for daylight quality and daylighting control of electric lights for energy savings.

To maximize speed while maintaining the accuracy of simulations, a selective approach can be used to calculate illuminance. In this approach, the needs of the simulation determine which series of commands are sufficient to meet the desired accuracy. The Radiance simulation engine is given as an example.

For transparent glazing, the simplest and fastest approach can be used. In this approach, a matrix representing the view from the reference points and an annual sky matrix are created. With these two matrices, Radiance calculates the daylight arriving at all reference points for all hours of the year in a single command. This is sometimes called the “single-phase method.”

For CFSs, more matrices are needed. A daylight matrix is added to represent the transmittance of light from the annual sky matrix onto the CFS, and a matrix to represent the transmittance of light through the CFS is also added. This is called the Bidirectional Scattering Distribution (BSDF). In this “3-phase method,” these matrices are again used in a single command to calculate the daylight arriving at the reference points. The 3-phase method takes more time to calculate than the method for transparent glazing but adds the capability to efficiently simulate CFSs.

To calculate daylight for highly-engineered daylighting devices with small features, specular transmittance or reflectance such as DRDs, the 3-phase method is not sufficient. More steps and calculation time are required. This is achieved using 5-phase method. The 5-phase method uses two 3-phase runs and a high-resolution direct sun matrix calculation. The 5-phase method is the most accurate technique of those discussed. However, it is also the most time-consuming by a significant margin as it requires matrix additions and two more annual matrix calculations.

By matching the simulation needs to the fewest, least computationally expensive Radiance commands, longer simulation times only occur when required. Further details on these methods are given in Appendix A: Matrix methods for daylighting.

5.2.3 Selective glare calculation

Glare calculations determine when blinds are closed in a daylighting simulation. When blinds are closed, less daylighting enters the space. Daylight quality and energy savings are lowered. For sDA the horizontal illuminance data is sufficient to calculate its glare metric, but for energy savings a glare metric such as DGP that can capture vertical illuminance and contrast glare from a hypothetical occupant viewpoint is preferable.

The matrices used in the single- and 3-phase methods create coarse representations of real daylighting. They are sufficient to calculate the illuminance of a reference point from daylight but are not sufficient to accurately calculate the luminance and size of light sources within view of the reference point.[8] This is an issue because DGP needs this luminance and size.

However, there exist two other forms of DGP that have been shown to correlate well with a full DGP calculation, depending on the characteristics of the daylight of the space: the simplified DGP and the

[8] Illuminance can be thought of as how much a reference point is lit up by all the light sources around it. It’s the sum of all the light arriving at it. Luminance can be thought of as what the reference point sees when it looks out. It sees the individual brightness of the sources of light.

enhanced simplified DGP (Wienold 2009). If we combine these forms of DGP into a selective enhanced simplified DGP, the speed to calculate glare for all hours of the year can be greatly reduced. This selective enhanced DGP simplified (seDGPs) technique would select the form of DGP appropriate for the characteristics of the daylight of the space for a given hour. Details are given in Appendix B: Selective enhance simplified DGP.

Image files can be created directly from the 5-phase method for which glare metrics such as DGP can be directly and fully computed. However, as mentioned, it is also the most time-consuming by a significant margin.

5.2.4 Summary

Using a server to run simulations can increase computation speed by leveraging powerful, predictable server hardware. Additionally, using a selective approach to computations minimizes calculation time while maintaining accuracy. Combining these two techniques together can greatly reduce feedback time for users of CBECC-Com.

5.3 Software

5.3.1 Selection for CBECC-Com

Various wrapper software exist which facilitate the inputs for modern daylighting simulation engines. These software can ease the transition away from the split-flux method of CBECC-Com. The capabilities and features of these software need to be considered to appropriately select one.

The goals of adding advanced daylighting in CBECC-Com include calculating a daylight quality metric for health reasons and calculating electric lighting levels for annual energy savings. Practically speaking, this translates to considering the following features of the software:

- Does the software perform climate-based annual simulations? These simulate a realistic daylight experience for occupants of the space under all predicted weather conditions.
- Does the software calculate comfort and daylight quality metrics?
- Can the software control blinds by glare metrics on an hourly basis? This captures the change in daylighting level when blinds are closed by occupants in response to glare.
- Can the software model BSDFs so that CFSs can be modeled?
- What is the licensing of the software? Proprietary software will require coordination with the owners of the software. Open-source software can be modified in perpetuity at the discretion of the Energy Commission.

Details of the research into available software are summarized in Appendix C: Literature review.

Research showed Accelerad, RadianceIES and LightStanza to be notable products. Some of this was re-enforced by presentations at the Daylighting Symposium. As mentioned above, Accelerad can be used with most Radiance implementations and is open-source. RaidanceIES already integrates Accelerad. LightStanza offers a user-friendly interface combined with a user-friendly, powerful and fast simulation engine but is proprietary.

Other top candidates are considered to be Honeybee[+] and OpenStudio's implementation of Radiance. Their features meet the minimum requirements, and for any shortcomings, they can be modified in perpetuity at the discretion of the Energy Commission because they are open-source software.

Honeybee[+] has a slightly larger and more advanced feature base, namely ASE and the 5-phase method. However, looking to other aspects to aid in the decision, OpenStudio may have a larger advantage.

OpenStudio is in fact already integrated into CBECC-Com. The CBECC-Com 3D model workflow starts with importing models from OpenStudio, and when a user begins a compliance run, CBECC-Com exports the model to OpenStudio for the compliance calculations. Thus, OpenStudio is already an integral part of CBECC-Com and tools already exist for sharing data as well as importing and exporting between the two.

Additionally, OpenStudio already has server-based computing capability built in. In fact, all OpenStudio runs are server-based[9]. As a bonus, if the OpenStudio Radiance measure is stored on the server, it protects the source code[10].

5.3.2 Certified compliance rulesets

An alternative to selecting specific software for CBECC-Com is to instead use a certifying procedure that can test software for its fidelity to the compliance rulesets. This approach is similar to the one taken by ASHRAE Standard 140 to certify Building Energy Model (BEM) engines. The advantage of this method is that the Energy Commission would no longer be responsible for selecting software and methodologies for, not only daylighting, but for the performance method as a whole. The development and maintenance of software would be in the software market's hands. This would relieve a large burden from the Energy Commission.

An approach for this certification of software that is being investigated by the DOE is to test software's fidelity to the translation of models to a standard schema. This schema is a file format that contains all model building descriptors (e.g. U-factor).

To begin the process, a series of input models are created in the standard schema. These models are intended to cover a representative range of the code, including less likely cases in the code. To achieve certification, software must show that their ruleset implementation translates the input models to proposed models and baseline models that accurately follow the ruleset.

This certification procedure also potentially requires a reference implementation of the ruleset in order to generate proposed and baseline models from large numbers of user models. These "reference" models would provide a means for aiding in verification and for discussing disputes.

There are some hurdles to overcome for this method. Methodology will need to be developed that ensures that the translation of models to and from the schema truly represent the internal calculations performed by the software. For instance, if software shows that their baseline wall has a U-factor of 0.082 Btu/(hr x ft^2 x ºF) in the standard schema, but in fact performs internal calculations with a U-factor of 0.001 Btu/(hr x ft^2 x ºF), this would falsely represent compliance.

A universal model schema will require wide acceptance. This could be difficult as a universal schema approaches the possibility of inter-operability among different software. Inter-operability would allow

[9] When run on a personal computer, OpenStudio considers that computer the server.

[10] The OpenStudio Radiance measure, like all OpenStudio measures is written in Ruby. Ruby is an interpreted programming language. Interpreted programming languages use an interpreter to directly read the source code to perform computations. Interpreted languages could be altered if not protected.

users to move models easily from one software to another and is not generally a feature that software companies pursue.

To avoid the controversy of inter-operability, in lieu of certifying software, simulation reports could be validated for each project. In this approach, software would output reports in a reporting schema. This reporting schema would require less detail than the modeling schema and would have the advantage of also allowing for verification of proposed and baseline modeling results, not just modeling building descriptors. DOE and ASHRAE are currently pursuing this approach via a new standard "Evaluating Ruleset Implementation in Building Energy Modeling Software."

5.3.3 Explore an Energy-Use Intensity Based Standard

As mentioned previously, Michael Holtz firmly supported eliminating the prescriptive compliance path in favor of an energy-use intensity (EUI) based standard. This EUI-based standard would require only that buildings stay below a specified energy-use per area. This limit would be determined from energy model simulations that used measures that are not only cost-effective, but also reflect market tendencies and reasonable advancements in the field. Further exploration can be seen as prudent as it is a means to get more energy efficiency measures into Title 24, Part 6 without the burden of proving cost-effectiveness. This would however require a major change in the current compliance process including issues with the Warren-Alquist Act.

5.3.4 Summary

Upon examination of the alternative software options, LightStanza, Honeybee[+]'s implementation of Radiance, and the OpenStudio Radiance measure seem to be good candidates. They run climate-based annual simulations, have daylight quality metrics, can control blinds based on glare, and use BSDFs. However only Honeybee[+] and OpenStudio are customizable in perpetuity at the Energy Commission's discretion because they are open-source software projects. The OpenStudio Radiance measure may have a larger advantage in that OpenStudio is already an integral part of CBECC-Com. Additionally, adding features to the OpenStudio Radiance measure may be an easier transition than incorporating Honeybee[+] into CBECC-Com.

A second approach could instead use a certifying procedure that can test any software for its fidelity to the compliance rulesets. The advantage of this method is that the Energy Commission would no longer be responsible for selecting software and methodologies for the performance method as a whole. However, the methodology to implement this approach is still under discussion by the industry and the approach would require a significant change in direction for the Energy Commission.

5.4 Make New Friends

Daylighting has significant non-energy benefits that touch upon several other disciplines ranging from biology to medicine to health and safety. It is important to engage with stakeholders who may not traditionally be considered for daylighting code discussions. To realize the benefits of good daylighting, we need to reach out and form new relationships. As Kevin Van Den Wymelenberg put it, "We need to make new friends." These new stakeholders could not only come from familiar organizations such as ASHRAE and the Illuminating Engineering Society but might also come from medical associations such as the National Institutes of Health, the American Medical Association, or the Center for Disease Control and Prevention. With the knowledge these experts offer, better informed decisions can be made, and the benefits of good daylighting can better be realized in building and how codes may help make that happen.

New potential stakeholders to bring into the daylighting discussion include:

- Medical and health professionals and researchers
- Microbiologists
- Daylighting software developers
- CAL-OSHA

5.5 Overall Approach

Bringing all the elements together, the overall proposed approach can be described as follows. First, CBECC-Com should be modified to utilize the OpenStudio Radiance measure. This is facilitated by the fact that OpenStudio is already integral to CBECC-Com. Then, a server should be set up to run the OpenStudio Radiance measure for CBECC-Com that can leverage hardware advantages to speed up the calculation time.

The workflow for a CBECC-Com user follows the steps below. A flowchart of the process is given in Appendix D.

1. If the user wishes to add advanced daylighting features to their model, they input 3-D geometry and daylighting devices into an OpenStudio model.
2. The user imports the model into CBECC-Com.
3. CBECC-Com uses the model's parameters to select the type of Radiance calculations:
    a. Single-, 3- or 5-phase for illuminance, and
    b. seDGPs or 5-phase for luminance and glare.
4. The OpenStudio Radiance measure is run immediately in the background, on the server, while the user is busy inputting other parameters into CBECC-Com.
5. The Radiance results are stored on the database. These results are also stored indefinitely for future projects which may have similarly daylit spaces.
6. When the user finishes the remaining inputs and wishes to perform a compliance run, the sDA and daylighting control illuminance level are input into the compliance check.
7. If the sDA is not adequate, the project does not comply. If the sDA is adequate, the daylighting control illuminance is used to calculate the electric lighting savings from daylighting. The rest of the performance compliance follows current procedures.
8. For any modifications to daylighting properties (e.g. space or window geometry, window properties, control type) the process returns to step 3.

Alternatively, a certified automated compliance ruleset procedure could be pursued. The implementation would be:

1. Creating a building model schema in agreement with stakeholders.
2. Creating a reference ruleset software.
3. Creating a set of test models for the reference ruleset software including models with "edge-case" features of the code.
4. Outputting proposed and baseline buildings for the test models.
5. Applicant software would input the test models and output proposed and baseline buildings per their implementation of the ruleset.
6. If the proposed and baseline buildings from the software match exactly the proposed and baseline buildings from the reference ruleset software and the software is shown to model building physics adequately under ASHRAE 140, then the software is certified as performance method compliance software.

7. Certified performance method compliance software can then submit for Title 24, Part 6 compliance in the same fashion that CBECC-Com currently does.

The details of this approach have not yet fully been developed. The full details of this approach would require coordination with the DOE and other industry stakeholders to arrive at agreement on the model schema and other factors. Therefore, a finalized, overall approach is not presented here.

Finally, incorporating more stakeholders into daylighting conversations is advantageous regardless of which software path is chosen. These non-traditional participants can help steer discussions towards new ideas and to the discovery of new daylighting benefits.

6. Conclusion

With the many health and cognitive benefits that daylighting adds to a building, it is clear that daylighting is a critical design aspect in buildings to help promote occupant comfort, productivity, and health. While the Title 24, Part 6 code has been evolving to address key factors, the compliance software has not evolved to keep up with the market. The split-flux method is outdated, the software needs to be able to model daylighting devices such as louvers, and the software needs to capture daylight quality metrics. We have outlined several actionable items to fix these problems throughout this paper, including: moving secondary daylit zone requirements from prescriptive to mandatory requirements, using multipliers rather than inputting every space, using the daylighting software's outputs to match plans and elevations, leveraging server hardware, incorporating Radiance or developing a software verification methodology, and including new collaborators into daylighting conversations. Ultimately, it will take the work of many daylighting stakeholders to realize these changes, but the result will truly underscore the importance of daylighting for all.

Appendix A: Matrix methods for daylighting

The single-phase method uses matrix multiplication to calculate the daylighting in a space. In this approach a matrix representing the view from the reference points is created. This view matrix contains a list of net light transmittance factors. Each factor corresponds to a direction of view from the reference point. In this way, the net light transmittance from any direction can be calculated. An annual sky matrix is also created. This is similar to the view matrix except that it represents the level of luminance output by the sky and sun for all directions, and, for all hours of the year. With these two matrices Radiance calculates the daylight arriving at all reference points for all hours of the year in a single command. The equation for the single-phase method can be written as:

$$1\Phi = V \times S$$

Where:

- V is the matrix looking outward in all directions from a reference point and all the transmittances and reflectances of walls and fenestration.
- S is the matrix of daylight shining down from the sun and sky.

For CFSs, such as louvers over windows, more matrices are needed. The annual sky matrix is created as before, but another matrix is also created to represent the transmittance of light from the annual sky matrix onto the CFS. This is called the daylight matrix. Then another matrix to represent the transmittance of light through the CFS is needed. This is called the Bidirectional Scattering Distribution (BSDF). The BSDF captures the complex transmissions and inter-reflections within the CFS. Finally, the view matrix is created as above. The calculation is as follows:

$$3\Phi = V \times BSDF \times D \times S$$

Where:

- V is the matrix looking outward in all directions from a reference point and all the transmittances and reflectances of walls, fenestration and the BSDF.
- BSDF is the matrix of net transmittance through a CFS.
- D is the matrix looking outward in all directions from fenestration and all the transmittances from the sun and sky.
- S is the matrix of daylight shining down from the sun and sky.

In this “3-phase method” these matrices (sky, daylight, BSDF and view) are again used in a single command to calculate the daylight arriving at the reference points, but this time with four matrices. The 3-phase method takes more time to calculate than the method for transparent glazing but adds the capability to simulate CFSs.

To calculate daylight for highly-engineered daylighting devices with small features, specular transmittance or reflectance such as DRDs, the 3-phase method is not sufficient. More steps and calculation time are required. This is achieved using 5-phase method. The steps can be summarized as follows:

$$5\Phi = 3\Phi - 3\Phi_{\text{direct sun}} + HR_{\text{direct sun}}$$

Where:

- 3Φ is the 3-phase method is run as above.
- $3\Phi_{direct\ sun}$ is the 3-phase method above except with an annual sky matrix with only direct sun[11].
- $HR_{direct\ sun}$ is a more accurate annual direct sun contribution using a high-resolution BSDF with a high-resolution direct sun matrix.

The 5-phase method is the most accurate technique of those discussed. However, it is also the most time-consuming by a large margin as it requires matrix additions and two more annual matrix calculations.

[11] Corresponding direct daylight and view matrices are also created but only considering the direct sun. These take less computation time as the bouncing of daylight of surfaces in the interior space is ignored.

Appendix B: Selective enhance simplified DGP

If the daylight in a space is diffuse, a simplified form of DGP (DGPs) can be used (Wienold 2009). Diffuse conditions exist in a space when direct sun is either not within view of the fenestration, when a diffuse shade covers the entire fenestration, or when a daylighting device blocks direct sun (e.g. when the sun is above a louver's cutoff angle). DGPs only requires illuminance so data from the single- or 3-phase method can be directly used.

However, diffuse conditions do not account for all hours of the year. Sometimes direct sun is within view of the fenestration and daylighting devices do not block it. For direct sun, the enhanced simplified DGP (eDGPs) can be calculated (Wienold 2009).

Calculating eDGPs requires creating an image of the view from the reference point using a very accurate sky. This adds computational steps, some of which are also computationally expensive. But per the eDGPs procedure, the bouncing of daylight off interior surfaces does not need to be calculated. This greatly reduces the computation time to create the image. With this image, a contrast term can be calculated using the illuminance from the single- or 3-phase method along with the luminance results from the no-bounce, direct-sun contrast image.

The speed to calculate glare for all hours of the year can be greatly reduced if we combine these techniques into a selective enhanced simplified DGP (seDGPs). The selection process follows the below steps. Figure 5 illustrates the steps.

- If the sun below the horizon, DGP is 0.
- If the sun is above the horizon but not within view of the window or is blocked by a daylighting device, use the single- or 3-phase illuminance results to calculate DGPs.
- If the sun is above the horizon, within view of the window and not blocked by a daylighting device, use the single- or 3-phase illuminance and also create a contrast image to calculate eDGPs.

seDGPs can be used for transparent glazing and daylighting devices such as opaque louvers and fins with diffuse surfaces. These devices have large features and clearly defined angles at which direct sunlight is blocked. Radiance can accurately create a high-resolution, direct-sun contrast image for eDGPs for these cases.

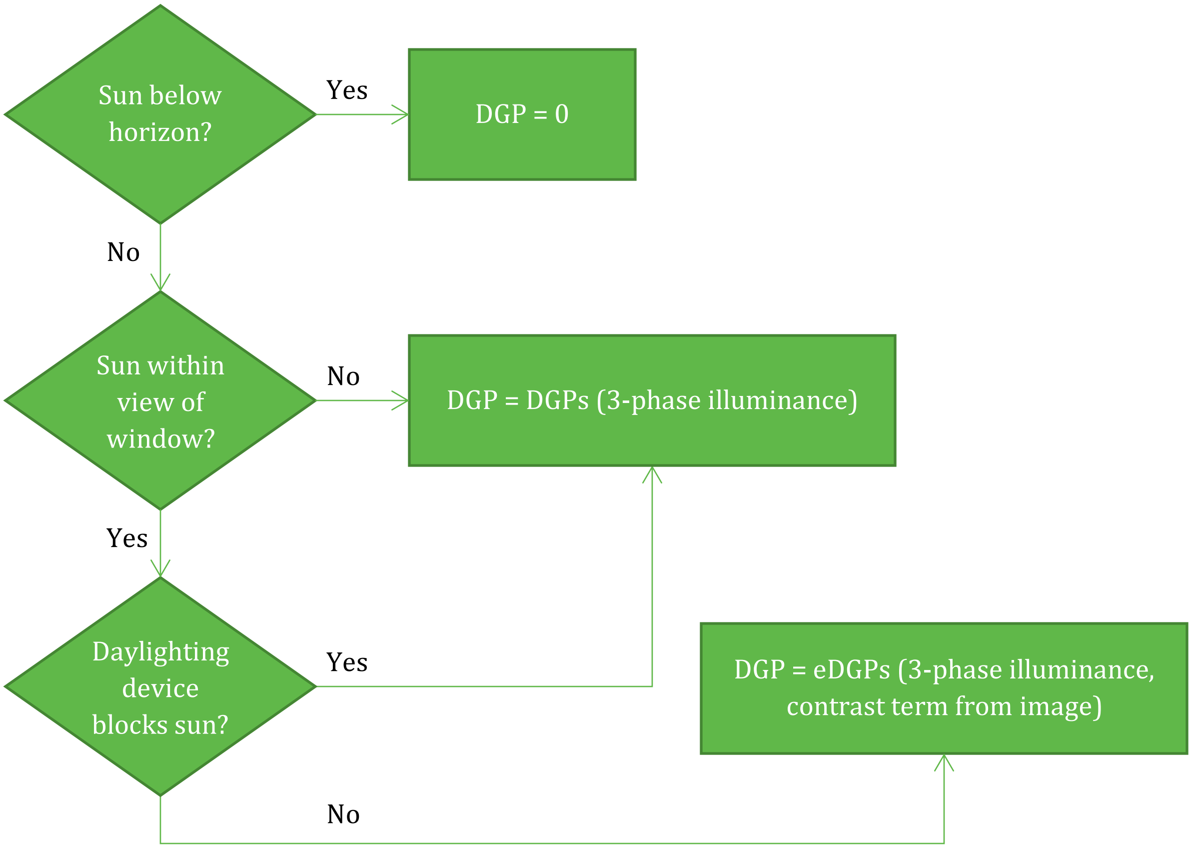

Figure 5: Selective enhanced simplified DGP flowchart.

Appendix C: Literature review

Table 1 shows the results of the literature review of available software. Software that could not perform annual simulations or could not use BSDFs were eliminated without further consideration and do not appear in the table. This includes the current CBECC-Com implementation of the split-flux method, the multidimensional lightcuts algorithm of Insight, and many implementations of Radiance.

Table 1: Advanced Daylighting Software Features

Software	Annual Daylight Quality Metrics	Hourly Glare Metrics (Blinds Control ✔)	Accuracy Comment	Speed Comment	Licensing
EnergyPlus: Simergy COMFEN DesignBuilder OpenStudio Honeybee[+]	None	None	The radiosity algorithms are under development.	The radiosity method requires fewer calculation steps and is therefore faster than ray-tracing methods.	Open source
OpenStudio	DA cDA UDI sDA	DGPs ISP[12] ✔	Radiance 3-phase Low-resolution sky.	Parallel processing. Server-based computing.	Open source
Honeybee[+]	DA cDA UDI sDA ASE	DGP DGI ISP ✔	Radiance 3-phase 5-phase High resolution sky.	Parallel processing.	Open source, but EnergyPlus integration requires proprietary software (Rhino).

[12] Illuminance setpoint (ISP) closes blinds when a threshold illuminance occurs at a reference point.

Software	Annual Daylight Quality Metrics	Hourly Glare Metrics **(Blinds Control ✔)**	Accuracy Comment	Speed Comment	Licensing
LightStanza	sDA ASE	LM-83[13] ✔ DGPs DGP	Radiance 5-phase Pier reviewed paper in progress shows good correlation with real spaces.	Parallel processing. Multi-server processing. Many other optimization techniques.	Proprietary
RadianceIES	UDI ASE sDA Photocell illuminance statistics	LM-83 ✔ **<u>Single-hour point-in-time:</u>** CIE, UGR, DGI, CGI, VCP and DGP	Radiance 3-phase **<u>Validation:</u>** 1989-99 'gherkin' building in London Sub-hourly daylight harvesting, including for ILFI Certified (ZNE) buildings	Accelerad GPU parallel processing Flexible sky resolution and discretization **<u>Workflow:</u>** Geometry GUI gbXML import/export Automated baseline: Title 24, ASHRAE 90.1, IECC, Florida Energy Code, NECB for Canada Parallel processing of proposed and baseline	Proprietary

[13] LM-83 closes blinds when more than two percent of the floor area of a space has an illuminance greater than 1000 lux considering only direct sunlight.

Appendix D: Flowchart of Radiance OpenStudio Compliance (ROSCo) in CBECC

Figure 6 shows user workflow in green and CBECC-Com and Radiance automated processing in purple.

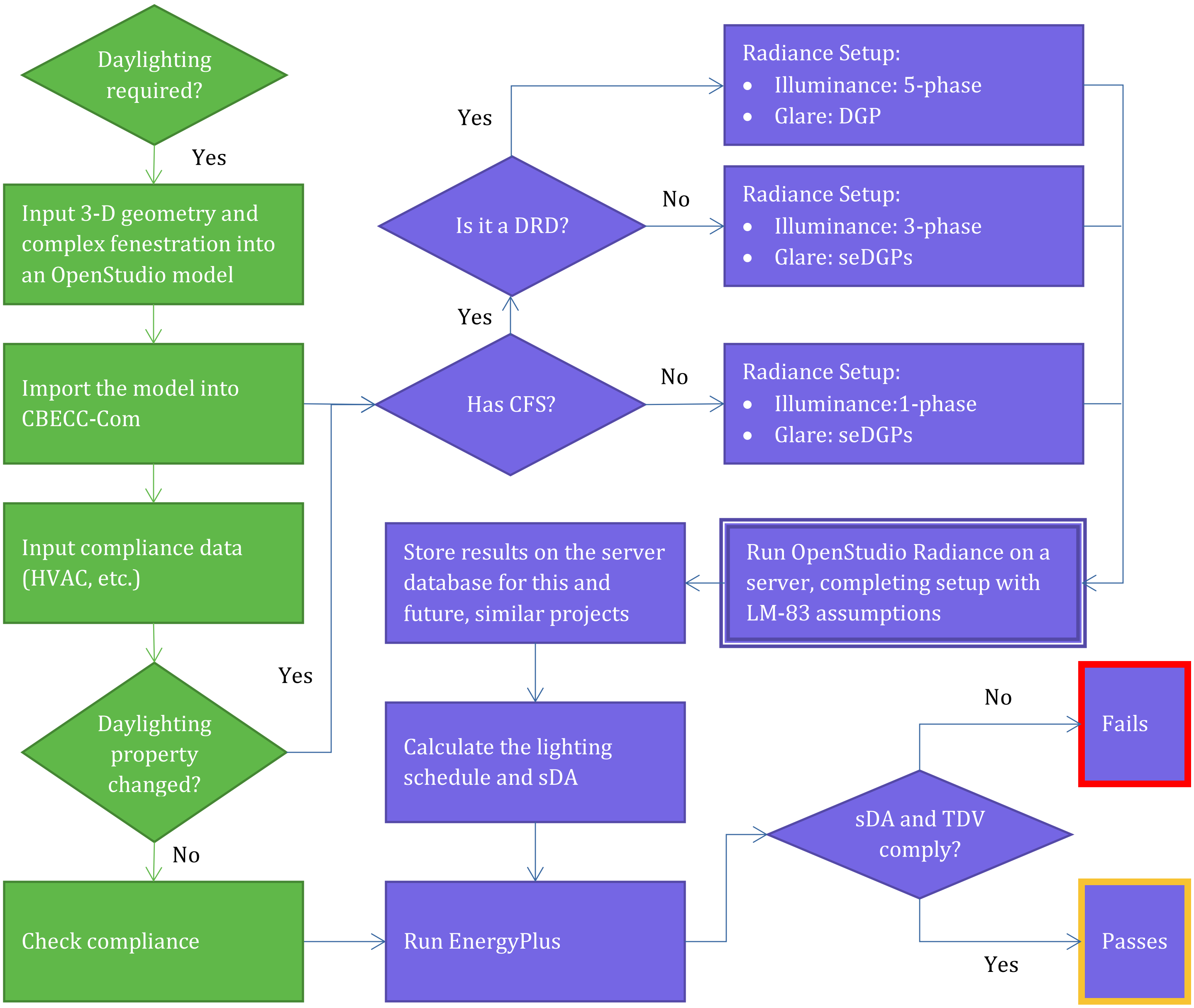

Figure 6: Radiance in CBECC flowchart.

Appendix E: Daylighting Symposium Materials

Event Invitation

Figure 7 shows the invitation that was sent to potential attendees of the Daylighting Symposium.

2019 Daylighting Symposium

When
April 29
Symposium: 8am-5pm

Where
Kimpton Sawyer Hotel
500 J St
Magnolia Ballroom
Sacramento, CA 95814

Contact Info:
Christopher Uraine
510-482-4420 x243
info@title24stakeholders.com

Register Now!

Please join the California Investor-Owned Utilities, in partnership with the National Electrical Manufacturers Association Daylight Management Council, for the 2019 Daylighting Symposium. The Symposium will provide a forum for invited industry experts, academics, agency representatives, and manufacturers of daylighting building products and systems. Participants will explore daylight management solutions that address glare mitigating through the design, evaluation, application, and operation of manual, passive, or automated systems.

The overall objectives of the Symposium are to:

1. Help accelerate market adoption of proven, cost-effective daylight management technologies and practices, by offering a respectful environment for planning & coordination.
2. Present relevant case studies that convey the state of daylight management and glare mitigation in current practice, and identify opportunities to improve daylighting design and operational success.
3. Inform overall prioritization of daylighting measures for the Title 24, Part 6, 2022 code cycle and beyond.

Breakfast and lunch will be provided the day of the event. For attendees arriving the day before, SCE will be hosting an additional optional daylighting planning & coordination meeting over dinner. We look forward to seeing you at the Symposium!

Please click the link above to RSVP. Registration closes on April 19th!

Figure 7: Daylighting Symposium invitation.

Questionnaire

The screenshots below show the questionnaire that was sent out to potential presenters for the Daylighting Symposium.

2019 Daylighting Glare Management Symposium - Request for Case Studies

Survey Overview

The NEMA Daylight Management Council (DMC) and the California Statewide Utility Codes and Standards Team are seeking to identify Case Studies of finished daylit spaces that document how manual, passive, or automated daylight management solutions were applied to manage daylight penetration and optimization through fenestration apertures. The Case Studies will document the design issues as they were addressed during conceptual design, analyzed through simulation and predictions to refine design decisions, implemented through design development and system integration, implemented during construction, and assessed through post occupancy evaluation. The goal is to broadly share your experiences, clearly articulating what worked and what didn't, to further our collective learnings, and help develop future best practices for glare control in daylit spaces.

Design Team Representatives for selected Case Studies will be invited to attend a one-day Daylighting Symposium to actively discuss industry initiatives and programs that are needed to improve the successful implementation of daylighting management design technologies. The Symposium is scheduled to occur in Sacramento, California on Monday, April 29, 2019.

Survey Responses must be submitted no later than Wednesday, April 12, 2019.

Please note: If a Project Owner does not support the publication of this (your) project as a potential Case Study, then there is no need to fill out the questionnaire as the end goal is to publish resulting Case Studies and Best Practice learnings in a public forum.

OK

1. Case Study Project Details

Project Name:	
Project and Space Type(s) Daylit:	
Project Location:	
Project Date of Completion and/or Occupancy:	
Name of Design Team:	

2. Design Team Lead Contact

Name	
Company	
Address	
Address 2	
City/Town	
State/Province	
ZIP/Postal Code	
Country	
Email Address	
Phone Number	

3. What were the objectives / performance goals of the system design? (Brief responses preferred.)

4. Provide an overview of the automated daylight management system (such as automated shading systems, venting windows/skylights, electric lighting controls) including the issue(s) being mitigated, objective of system, design/simulation process, integration with other systems, installation, commissioning, and post-occupancy results. (Brief responses preferred.)

5. What factors were utilized in the final Operation Control Methodology and/or Sequence of Operations? Check all options that apply.

- ☐ Glare
- ☐ Occupancy
- ☐ Light Level
- ☐ Electric Light Status
- ☐ HVAC Status
- ☐ Venting Windows/skylights for Natural Ventilation and Cooling
- ☐ Preservation and Clarity of View
- ☐ Solar Heat Gain
- ☐ Other (Examples: Seasons, sun position, time of sunrise/sunset, indoor or outdoor temperature, indoor air quality). Please explain.

6. What factors were considered to support the design solution? Check all options that apply.

- ☐ Economics – First Cost
- ☐ Economics – Operating Cost (Energy & Maintenance)
- ☐ Pre and/or Post-occupant Survey
- ☐ Other (Please explain how this was accomplished)
- ☐ Energy Codes
- ☐ Energy/Sustainability/Wellbeing Standards

7. How was the potential for glare predicted and/or assessed? (Check all options that apply.)

- ☐ Designer Experience
- ☐ Space Modeling & Simulations
- ☐ Building Owner Concerns and/or Experience
- ☐ Occupant Concerns and/or Feedback
- ☐ Other (please explain)

8. Did the installed system function as planned?

- ○ Yes
- ○ No

9. Did the installed system resolve the issues that you were attempting to address?

- ○ Yes
- ○ No

10. Was the project featured in an article or case study / presentation?

- ○ No
- ○ Yes! (Please provide a discription of where the project was featured and/or provide links to online references.)

Meeting Notes

The meeting notes that were circulated to all Daylighting Symposium attendees are shown below.

Meeting Notes

Posted July 4, 2019

Daylighting Symposium

Meeting Information:

Meeting Date: April 29, 2019
Meeting Time: 8:00 am – 5:00 pm
Meeting Host: California Statewide Utility Codes and Standards Team

Presentations from the 2019 Daylighting Symposium are available here on Title24Stakeholders.com

Meeting Attendees:

Last Name	First Name	Email	Affiliation
Abear	Teren	teren.abear@sce.com	Southern California Edison
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Chau	Thao	thao.chau@energy.ca.gov	California Energy Commission
Crowley	John	john.crowley@rolleaseacmeda.com	Rollease Acmeda
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Froess	Larry	larry.froess@energy.ca.gov	California Energy Commission
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Uraine	Chris	curaine@energy-solution.com	Energy Solutions, Representing Statewide Utility Codes and Standards Team
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Weaver	Scott	scott.weaver@acuitybrands.com	Sunoptics Skylights
Werner	Heidi	hhauenstein@energy-solution.com	Energy Solutions, Representing Statewide Utility Codes and Standards Team

Meeting Agenda:

Topic	Presenter	Time
Welcome	Heidi Werner	*8:40 – 8:50*
Glare Management in Daylit Spaces	Neall Digert	*8:50 – 9:00*
State of Daylighting in California	Mudit Saxena Eric Shadd Chris Uraine	*9:00 – 10:15*
Valuing Daylight and View	Lisa Heschong	*10:15 – 10:45*
Case Study # 1: Daylighting Commercial Buildings: Case Studies and Simulation Models	Eleanor Lee	*11:00 – 11:30*
Case Study # 2: Dynamic Light-Redirecting Technology: One Look into the Future	Luis Fernandes	*11:30 – 12:00*
What's on the Horizon and What's Sunsetting?	Kevin Van Den Wymelenberg	*12:10 – 1:00*
Case Study # 3: Predicting the Performance of Automated Glare Management Systems to Inform Design	Daniel Glaser	*1:00 – 1:30*
Case Study # 4: Lessons Learned from Two Acclaimed Daylit Buildings	Daniel Huard	*1:30 – 2:00*
Case Study # 5: Integrated Daylighting and Glare Control System: Designed for Comfort and Productivity	John Crowley	*2:00 – 2:30*
Panel: What is working? What needs to change?	Michael Holtz Zack Rogers Andrew McNeil John Crowley Mudit Saxena	*2:45 – 3:30*
Working Sessions	Everybody	*3:30 – 4:45*
Recap and Next Steps	Heidi Werner	*4:45 – 5:00*

Key Points and Action Items

1. Daylighting has a strong correlation with improved productivity, cognitive ability, and health.
    a. Health is driving the demand for daylighting in buildings.
    b. People value daylighting and views over other features in high-performance buildings.
2. Daylighting controls save energy and can be cost-effective even with high efficacy lighting sources.
3. "Make new friends": We should be thinking about the advantages of daylighting that are less obvious. For example: daylighting and its effects on indoor air quality as evidenced from reduced microbial growth in spaces with higher daylight levels; daylighting and higher levels of occupant satisfaction with space, etc.
    a. Industries should be encouraged to work together to develop solutions (blinds, windows, PV, controls, interior design).
    b. Daylighting has value beyond reducing energy use, which building codes need to recognize.
    c. Engage people that might not normally participate in daylighting conversations.
4. We should not forget about installation, commissioning, and user experience.
5. How can we promote daylighting in existing buildings?
6. Daylighting is an essential tool to get to zero net energy (ZNE) and zero emission buildings (ZEB).
7. More education is needed for all market actors including architects, lighting designers, builders, building managers, and code officials.

Meeting Notes

Introduction **Heidi Werner**

Key messages from presentation

- The Statewide Utility Codes and Standards Program has several sub-programs. This symposium is being sponsored by the coordination and planning sub-program that aims to encourage market acceptance by coordination with emerging technology initiatives, voluntary programs, and code and standards advocacy.
- During this session, we encourage people to share their ideas. The thoughts we hear today will not necessarily feed directly into a code change proposal for the building codes.
- Nothing we are discussing today replaces the California Energy Commission's rulemaking process for building code opportunities.
- Send comments or ideas to anyone on the Statewide CASE Team or to info@title24stakeholders.com.
- We encourage people to keep an eye on the following websites to track progress on proposed code changes for the 2022 California Energy Code:
    - Statewide Utility Codes and Standards Team's Title 24 Website: Title24Stakeholders.com
    - California Energy Commission's 2022 Title 24 Rulemaking website: https://www.energy.ca.gov/title24/2022standards/

No discussion on this topic

Glare Management in Daylit Spaces **Neall Digert**

Key messages from presentation

- The human visual system drives lighting (electric or daylight) design, whether it is for vision, task visibility, visual effect, or space perception.
- Excessive luminance ratios result in visual discomfort and glare, causing occupants to "react".
- Glare Management is key to achieving daylighting energy savings, reducing building carbon footprints, and enhancing occupant health and satisfaction.
- Daylighting drives people to act and communicate.
- Daily light and dark patterns, combined with the changing spectral content of daytime daylight, drive our circadian cycle.
- Daylighting is the artful application of our daylight resource (sun and sky).
- Today's daylighting solutions are dynamic, and occupant "activity", which is driven by comfort and satisfaction, determines annual building system performance.
- Daylight analysis is dynamic and there should be processes to integrate codes and standards to apply savings that do not have a standardized process, and that support dynamic performance metrics and ratings.

No discussion on this topic

State of Daylighting in California **Mudit Saxena, Eric Shadd, Chris Uraine**

Key messages from presentation

- Daylighting, when done correctly, is still the most efficient way to light a space, despite advances in LEDs.

- Buildings need to provide comfort, function, and protect occupants' health and well-being. Daylighting in buildings provide a connection to outside which is linked to higher productivity and increased occupant health.
- The ZNE building we want to encourage and build in the future needs to be designed with the wellbeing of the occupant as its central focus, which leads to daylit designs.
- Tools are available to increase daylighting, including advanced daylighting technology, and simulation software.
- Codes need to set the correct daylighting goals and encourage effective designs. This can be achieved by increasing innovative prescriptive daylighting compliance options, and bringing Radiance into CBECC-Com.
- Statewide CASE Team develops cost-effective proposals based on stakeholder outreach, research, and analysis. They present proposals to the California Energy Commission.

Discussion

- Will Vicent: Do you have any early thoughts on how a process, like integrating Radiance, might be enforced? How would we verify that the designs created in Radiance would be installed?
    - Eric Shadd: Plan checker could check designs with plan in OpenStudio. Plan check may be sufficient because it is unusual in my experience for building space dimensions to be built differently than the approved plans.
- Jon McHugh: The current compliance software has some tools for evaluating daylighting. Energy analysts voted for two dimensional (2D) approaches to allow for easy data entry.
    - Mudit Saxena: What is the burden we are putting on user to use the three dimensional (3D) performance path and is it worth their time and effort? Designer and their team should decide - if they want full credit for daylighting then they would opt to model in 3D, taking on the extra burden.
- Jon McHugh: Power Adjustment Factors (PAFs) are conservative because they are not looking at every permutation of orientation. Looking forward to 2030 and ZNE buildings, are we anticipating that our standards use the simple approach of minimal compliance and that advanced implementations are used to reduce the size of the solar photovoltaic system?
    - Mudit Saxena: There are two paths for compliance: prescriptive and performance. PAFs (prescriptive) should continue to get stronger and encourage innovative daylighting designs. The performance path should allow people to experiment with daylighting to push for ZNE and that are occupant-centric. There is opportunity to advance both paths.
- Michael Holtz: There is a disconnect between Mudit's occupant-centered design presentation and the methodology that the California Energy Commission uses to demonstrate that a proposed code change is cost effective. Designers should have the flexibility to use any means to achieve the desired energy budget. There should only be a performance path and the prescriptive path should be eliminated. Designers are using software anyway to create the design drawings that are needed to comply with the code.
    - Mudit Saxena: There is a disconnect, and we are open to challenging the way we think about codes. Codes should reflect the change in the market. However, the process for changing the code is difficult and there are constraints on certain requirements.
    - Michael Holtz: As soon as you say a measure needs to be "cost effective", then you are tied into a certain regulatory process, which then directs you into a certain type of code requirement. We need to reexamine the cost effectiveness requirements and methodology.
    - Lisa Heschong: We should move from an energy metric to a carbon metric.

- Daniel Glaser: Software should also be performance-based. Meaning, we should be choosing software that performs well. California should think about performance-based software rather than only relying on open-source software.

Valuing Daylight and View **Lisa Heschong**

Key messages from presentation

- Daylighting provides resiliency – buildings can still function after fire, flood, earthquake, blackouts, etc. Provides higher leasing turnover and higher sales.
- Daylight and window views have health and cognitive benefits, and are inherently tied to circadian rhythm, eye health, cognitive mapping, and creative incubation. This affects occupant well-being in a positive way. Hence, it is crucial that daylight be provided to us in our buildings by design.
- People are drawn to look out windows often (i.e. the view IS the task).
- Occupant comfort and convenience (horse) helps "pull" the energy savings and carbon reduction (cart), and it should not be the other way around.
- Need to think about how to continue daylighting conversation on a regular basis and who will lead that charge?

No discussion on this topic

Case Study # 1: Daylighting Commercial Buildings: Case Studies and Simulation Models **Eleanor Lee**

Key messages from presentation

- A lot of progress is needed to meet greenhouse gas emissions goals, and daylighting can help achieve them.
- Daylighting devices are still complicated and there are pros/cons to all technologies. Choosing depends on client needs and application.
- Health is driving performance today. We want to enable industry to use whatever tools are out there to achieve highest performance.
- Ways to help drive daylighting industry include provide feedback loop to industry on products, development of standardized product database, development/validation of occupant.

Discussion

- Neall Digert: When looking at traditional shades, we look from top down. However, sometimes glare comes from the ground up (for example, opaque hardscape outside is causing glare).
    - Eleanor Lee: Just finished a study where lower shade was transparent and upper portion was louver. It did cut glare.

Case Study # 2: Dynamic Light-Redirecting Technology: One Look into the Future

Luis Fernandes

Key messages from presentation

- Building automation is becoming more occupant focused.
- Dynamic light-redirecting blind system being developed at LBNL that modifies blinds geometry to maximize daylight and minimize glare.
- Prototype developed uses a variable slat geometry instead of a variable gap, but the same effect can be achieved with either strategy.

- Nothing precludes some blinds from being mounted in the exterior or interior. There are a lot of advantages to exterior mounting. Also, could mount within Insulated Glass Unit (IGU).

Discussion

- Mudit Saxena: Before commercialization, any plans for increasing slat angle (instead of changing distance between slats or increasing slat widths)?
    - Luis Fernandes: Ideally, more attracted to changing spacing between slats, but both configurations scale. One issue is you're not using all the slats all the time, so some slats would need to be stored and managed.
- Daniel Glaser: What is good daylighting?
    - Luis: Want to have enough daylight without any glare. We were looking at getting as much useful daylight as deep into building as possible without glare.
- Lisa Heschong: Your metric of performance seems to be deeper daylight penetration, but what about occupant reaction to this? Specifically, opaque at the upper level so can't see the blue sky, etc.
    - Luis Fernandes: Nothing comes down into eyes of occupants. Area (7-9 ft) is precluded by shading systems so if we are limited to just improving existing buildings, this is an improvement (seeing blinds versus just seeing opaque window).
    - Eleanor Lee: When it's overcast, the system will retract. We found that people enjoy outside views. We found that there was some aversion to (permanent) view obstruction.

What's on the Horizon and What's Sunsetting? — Kevin Van Den Wymelenberg

Key messages from presentation

- Daylighting designers are healthcare providers.
- Air inside is often more toxic than other air.
- We have been working with biologists and architects. Some companies are developing architectural probiotics.
- Research on the bactericidal effect of daylighting has a long history. A recent study shows daylighting may be killing stuff that doesn't look like us, encouraging things that look like us.
- We've been looking to technology to solve indoor environmental quality issues but need to work with nature, not try to create impossibly sterile environments.
- People value daylight and views over anything else inside a building.
- California leads the United States and the United States arguably leads the world in many aspects.
- There are many studies that show daylight reduces hospital stays, increases sales and increases school performance.
- In 2016 only six buildings met the AIA 2030 challenge. In 2017 that increased to 11 (only 175 out of 20,000+ architectural firms reporting).
- Illuminating Engineering Society (IES) and others should talk about daylighting as an equity issue.
- What is sunsetting?
    - Energy-efficiency driven market
    - Single-point quality metrics
    - Lighting as only supporting function
- What is on the horizon?
    - Carbon driven market

- Climate-based annual quality metrics
- Daylighting as equity and health issue (Bridges between health care spend and construction/energy spend
- High Dynamic Range (HDR) based analysis and simulation, blinds and electric lighting in control loop

- Research needed in human factors affecting/affected by daylighting: blinds operation, visual comfort, circadian rhythms, delight.

No discussion on this topic

Case Study # 3: Predicting the Performance of Automated Glare Management Systems to Inform Design — Daniel Glaser

Key messages from presentation

- New building codes should not think that computer modeling will be too slow and so code should be dumbed down. Modeling is advanced enough that code should reflect this.
- Ideally, the software allows you to try different design strategies and see how they work (e.g., standard glass, dynamic glass, overhangs, automated shades, redirecting films, light shelfs).
- Software can look at every hour of the day and find the absolute worst glare conditions. The tools now can look through the data for you. We are no longer limited by the time required to complete computations.

Discussion

- Will Vicent: To what extent have both spatial daylight autonomy and annual sunlight exposure been validated in the field and what work should be done in the future to validate those two metrics?
    - Lisa Heschong: Not enough, but spatial daylight autonomy has been validated by Christoph Reinhart at MIT.[14] Annual sunlight exposure is even more behind, but Kevin is leading the efforts on how it can be refined and improved. We are far away from being able to represent glare and visual comfort metrics in the field.
    - Daniel Glaser: We need to refine things and push forward today.

Case Study # 4: Lessons Learned from Two Acclaimed Daylit Buildings — Daniel Huard

Key messages from presentation

- Four things that I see that need to be improved:
    - Transparency
    - Sustainability
    - Resiliency
    - Wellness
- We saw great improvements in bi-facial solar PV generation due to reflective surface below plus more comfort from occupants.

No discussion from this topic

[14] Study found here: https://www.tandfonline.com/doi/abs/10.1080/15502724.2014.929007

Case Study # 5: Integrated Daylighting and Glare Control System: Designed for Comfort and Productivity **John Crowley**

Key messages from presentation

- Case study included daylight redirecting devices for upper third of windows and shade/vision/glare control for bottom two-thirds.
- How do we deal with existing buildings? There isn't a lot of new construction every year, but most of our effort and attention goes into new buildings.
- Barrier of daylight seems to always be cost of implementation, lack of standardization.

Discussion

- Jon McHugh: Did you evaluate the baseline to see how often the blinds are being manually opened and closed? What is the human factor of how people are using shades?
    - John Crowley: Yes, we did consider this. We put in lighting and controls and did monitoring. We are installing shades now, which will allow us to see impacts of lighting and controls versus shades.
- Lisa Heschong: This is the first system I'm aware of that integrates solar PV, battery charging, and wireless controls. What are advantages and challenges?
    - John Crowley: One advantage is that in developing these PV arrays, we can start generating electricity even at low light levels. Though, developing a solar PV system that will trickle charge shades has been challenging.
    - John Crowley: People have been hesitant about wireless controls. However, wireless is now reliable up to a point where it can be used in such applications. Removing wires reduces the project cost significantly. There was $1 million savings from using wireless instead of using wired in a specific large building we are working on. Installation costs depend on location.
    - John Crowley: One challenge is how often do people move shades up and down.
    - Rahul Athalye: Does that $1 million include commissioning in the system?
    - John Crowley: The $1 million was the incremental labor and installation cost, which varies by location. The legacy product distribution model presents a challenge.
    - John Crowley: There is a mark-up in every step of the supply chain. Breaking out of the traditional supply chain model can reduce costs significantly but doing so is challenging.
- Luis Fernandes: Have you looked at how different flat finishes impact the daylighting?
    - John Crowley: This can be optimized, but most slats manufactured today are colored the same on both sides. We color one side to be matte white and one side to match décor of building.
- Mudit Saxena: Have you thought of collaborating with other companies who may have already solved these issues and refined parts of the system (e.g., wireless controls)?
    - John Crowley: We are completely open to collaborate and would love to learn how to leap frog beyond where we are. We welcome the expertise from others to make improvements.
- Mudit Saxena: What is your commercialization plan? How would you achieve scale?
    - John Crowley: Our strategy is to develop a kit of parts that can be used by a wide variety of end users. However, the bigger goal is to address how to break out of the traditional product distribution model.

Panel: What is working? What needs to change?
Michael Holtz, Zack Rogers, Andrew McNeil, John Crowley, Mudit Saxena

- Neall Digert: Two questions: What is working? What needs to change?
- Michael Holtz (architect perspective):
    - Daylighting is the purposeful use of sunlight to meet the illumination requirements of occupants in an architectural space. Design equals building system performance and human performance, therefore, design needs to address both. The successful integration of daylighting into commercial buildings is still generally pretty poor. Architects tend to think that more glass equals better daylighting, without consideration of uniform daylight distribution and elimination of glare.
    - *What does work?*
        - There are a few top and side-daylighting products, such as the LightLouver Daylighting System, that effectively and uniformly distribute daylight while eliminating glare. Designers also have a number of excellent daylight simulation tools that can help them develop an effective daylighting design, but unfortunately, are not used as often as they should.
    - *What needs to change?*
        - Architects, engineers, and lighting designers need more education about daylighting. They are not well informed about basic daylighting design principles and how to apply them in commercial building design.
        - Codes should include mandatory performance-based daylighting requirements. This is a health issue, not just an energy issue.
        - Codes should focus on implementing daylighting in the existing building stock.
        - Need to consider code compliance through daylight simulation tools.
        - All of this is irrelevant unless we immediately address climate change. We must focus on reducing greenhouse gas emissions.
- Zack Rogers (energy engineer and modeler perspective):
    - *What works?*
        - Simulation software and tools work. There is room for further refinement but the software and tools we have are effective. We have the means to do the analyses that are required to develop intelligent daylighting design.
        - There are some proxy glare metrics that are working, but we need more research and development to establish better glare metrics.
    - *What needs to change?*
        - Passive and static solutions are simpler and should be used more. Dynamic systems with integrated controls are great, but passive strategies are a more resilient design.
        - We need more accurate estimates of energy savings from daylighting. Perhaps photosensor-based analyses could be useful?
            - John Crowley: There are lighting products that have integrated sensors. Could you use integrated sensors within lighting products to reduce redundancy?
            - Zack Rogers: Potentially.
- Andrew McNeil (adaptative fenestration manufacturer perspective):
    - *What works?*

- Although daylighting is not required by code, there is a demand to incorporate daylighting into buildings. Rarely are there architects who do not want daylighting.
    - Daylighting products are readily available.
  - *What needs to change?*
    - Delivery system: struggling with the product distribution chain and mark-ups.
    - Interoperability: we would like more information about how daylighting products interact with HVAC and lighting system.
    - Customer education: it is important for customers to understand daylighting strategies and how to apply technologies appropriately. How do you bring people who are not deeply involved with the daylighting community?
- John Crowley (attachment mindset for adaptive control perspective):
  - *What is working?*
    - There is a lot of collaboration happening to turn decorative products into performance products. Industry is recognizing that the issues we are dealing with are much larger than the part (shading industry, window industry).
    - I have been impressed with the amount of information that is available to demonstrate the value of daylighting.
  - *What needs to change?*
    - Health and wellness is an enormous opportunity because that's what people relate to.
    - We need better education.
    - I've been impressed by all the information that makes the case of why daylighting is good, but I have been unimpressed with how that information gets deployed to help designers and industry understand how to implement daylighting.
- Mudit Saxena (codes and compliance perspective):
  - *What is working?*
    - Compliance rates are getting better
  - *What needs to change?*
    - We need higher rates of compliance. How do we do that? Do we need a new structure so that code compliance be further improved?
    - Neall Digert: The typical mindset is that codes and standards impede innovation, but the rigors of going through checks and balances of codes and standards has pushed everyone to collaborate. The question is how to shorten the checks and balances.
    - Mudit Saxena: Correct. Another way to think about it is not as another constraint but as an opportunity to innovate. Codes is an opportunity to encourage technologies and challenge designers. Reward the correct solution and simplify.
- Will Vicent: We have a consensus that there's a climate emergency, and a trend of designers in the industry being overwhelmed with compliance. What's the single thing we can do in daylighting to address climate?
  - Mudit Saxena: Codes are too complex. We should simplify them and make them more digestible. Codes should convey the desired outcome more clearly.

- John Crowley: In commercial and residential sectors, there is an opportunity to harvest energy savings through exterior shading. There is a lack of awareness in how to implement exterior shading economically and effectively. We need a low-cost option to improve daylighting and reduce cooling demand that will benefit a broad swath of the community.
- Andrew McNeil: There is an aversion in the construction industry to trying new things. How can you encourage the construction industry to try new things? More demonstrations to experience the solutions and eliminate the fear of doing something new. People need to experience and not be afraid.
  - Mudit Saxena: Codes have PAFs to encourage people to try new things. We need to continue this and bring more examples of daylighting for people to see.
- Zack Rogers: Prescriptive code stifles innovation and is more complex to navigate. Move towards performance-based codes. For example, an energy use intensity target.
- Michael Holtz: Take knowledge we have and use it. We need to address existing building stock. We need a climate change metric, and we need to get rid of cost-effectiveness requirements.

Working Sessions **Everyone**

Design and Application

Objectives and Discussion Topics:

- Identify topics or presentations that could become a case study
- Identify or refine changes to best practices
- Identify topics or concepts that should be future symposia topics

Discussion Notes:

- Anything that we want to learn more about?
  - Would be helpful to hear more about the retrofit project that John Crowley presented. There is funding within the current project to develop case studies.
  - More information about wireless controls
  - More information about exterior retrofit possibilities
  - More information about health motivators
  - Daylighting and resilience
    - Daylighting retrofit is also a resiliency and reliability retrofit
    - Earthquake preparedness
    - Might be able to get staff time on National Fenestration Rating Councilor collaboration with CSA International Well Building Institute
    - Resiliency is wonderful. How does this change the dialogue about daylighting?
      - Perhaps there is a code option of daylighting for egress.
    - If a space is daylit, including egress, then the space will have lighting if a power outage occurs in the day
  - We should change the way we are thinking about metrics.
  - Should we be thinking about illuminance within the space, or should we value the view out the window? The “task” that we are valuing is the view out the window.
    - If there is a window at eye height, the purpose or “task” is the view. It is okay to increase lighting to reduce glare and enhance the view.
  - Light from two angles; top-light + sidelight

- Case studies
  - Need case studies that document successes and failures
  - HMG conducted a study 20 years ago that looked at top-lit spaces (funded by Southern California Edison). This study was replicated for sidelit spaces in the northwest (funded by the Northwest Energy Efficiency Alliance). It would be valuable to update that analysis.
- Key take away: education is needed – Architects, Lighting Designers, Interior Designers.
  - We need information on how to do daylighting. Are case studies the right approach? What about daylighting pattern guide?
  - Collect information from outside of the United States.
  - Consider a committee to reach these user groups.
    - Example: attend NeoCon and co-host an event with The Shade Store as an approach to access interior designers.
    - Codes and standards are effective as a convener. We bring groups of people together. If we can get the Utility Team to think about their stakeholder engagement not just "how do we get our code change proposal adopted", but as a means to work through design and technology challenges.
    - Health and wellness is a means to get people to care about daylighting.
    - Building ratings systems (e.g., Well) is another "hook" / marketing approach.
  - How much collaboration has happened with American Institute of Architects (AIA)?
- Best practices
  - Is it best practice to dim-to-off if there is sufficient daylight?
    - Yes. It is okay to turn lights off.
  - ASHRAE allows dimming to 20 percent. There are significant energy savings associated with dimming all the way to off, but lighting designers were concerned about dimming all the way to off because people come into the room and try to turn the light on. When it doesn't turn on, people think something is broken and they complain to the maintenance facility. There are also claims that people like some lighting other than daylighting. What would help people understand when it is okay to dim-to-off and when it is appropriate to dim to some level other than off?
    - Bi-directional illumination from daylight is critical.
    - Education; there is not enough information.
    - Could look at case studies with auto-off based on occupancy.
- Supply chain issues – probably need to address this in some other way than a case study.
- Future symposium topics (especially to encourage new people to the table):
  - Health, wellness, and light.
    - Using and designing natural light to help circadian rhythm.
  - What is our goal? Symposium is a means to an end. What is the end? Are we chasing the problem? What is the problem?
    - The problem is that 63 percent of people say they do not have access to daylit space and one-third of office space has access to daylight.
  - Builder perspective; why aren't people buying into daylighting?
  - Daylighting and education
  - Retrofits – how do we daylight spaces in existing buildings?

- Are we using the right metrics? When the daylighting community talks about metrics, we lose the attention of other industry representatives (designers, architects, and interior designers).
    - Define the daylighting industry's metric circadian stimulus through daylighting.
        - Engage the Department of Defense
    - Part of the issue is too much light at night.

Codes and Standards

Objectives/Discussion Topics:

- Radiance into California Building Energy Code Compliance Commercial (CBECC-Com)
- Current daylighting requirements in Title 24
- What's working and what's not?
- Areas for improvement or alignment with ASHRAE, IECC and Title 24?

Discussion Notes:

- Codes and standards need to:
    - Address grid harmonization
    - Reexamine payback and cost-effectiveness: need to account for non-energy benefits.
    - Examine ways to make daylighting mandatory in all building codes.
- Radiance needs to be incorporated into CBECC-Com.
    - CBECC-Com currently limits a number of creative daylighting designs to be modeled for compliance. This serves as a dis-incentive for such daylighting solutions, which are critical to achieve ZNE buildings, Bringing Radiance daylight modeling capability to CBECC-Com, this can be resolved.
    - How will Radiance be incorporated into CBECC-Com?
        - CBECC-Com may interface with other modeling tools.
    - Need a simple way for compliance checkers to confirm measures are installed properly compared to how they are modeled.
        - Need to determine which daylighting items need field verification and what doesn't.
        - Is there a way to develop software to make field verification easier?
        - One possibility is to have CBECC-Com output plans and elevations of spaces. The Plan Checker could match these dimensions with the Construction Documents.
    - How can you determine daylighting baseline to compare improved daylighting design?
        - Daylight metrics such as Spatial daylight autonomy (sDA) and Annual Sunlight Exposure (ASE) may be used for this purpose.
- Field Verification
    - Education of acceptance test technicians (ATTs) and inspectors is crucial
    - Need to support the development of daylight code compliance tools
    - New acceptance testing with procedural and metrics in line with other acceptance tests should be developed
        - Need to keep in mind that inspectors are already heavily burdened
        - Spot checks to encourage compliance. These spot checks have already been implemented for the daylighting devices in the 2019 Standard.
- Should daylighting for its health and wellness benefits be included in a different part of Title 24? Other than Part 6, which is an energy conservation code? Could it be part of CALOSHA?

    - No, since Title 24, Part 6 is an "energy efficiency" code and not an "energy conservation" code, it can have a health benefit as part of the code. Daylighting should follow the precedence set by minimum outdoor ventilation requirement, which is a health benefit but is included in Part 6, a minimum requirement for daylighting should be part of Title 24 Part 6.
- How do we account for human factors (closed blinds/glare)?
    - Good metrics exist on these, being worked on by IES.
    - What more resources are needed to get better data?

Recap and Next Steps **Heidi Werner**

Action:

- Respond to survey[15] that aims to collect a list of buildings where daylighting has been demonstrated well and should have a case study. Ideally there is data to document the results.
    - Demonstrate successes and failures.
- Continue to engage with the Statewide Utility Codes and Standards team as we develop code change proposals for the 2022 code cycle.
- Make the Daylighting Symposium a regular (annual) event
- Continue to share your ideas by sending input to info@title24stakeholders.com

Pictures from Event

Figure 8 shows the layout of the room during the event. This picture was taken during a presentation by Eric Shadd.

[15] https://www.surveymonkey.com/r/WFTCJ7V.

Figure 8: Layout of room with presenter.

Figure 9 shows one of the working session discussions at the end of the Symposium. This working session was led by Neall Digert.

Figure 9: Working session discussion.

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