WEST BERKELEY PUBLIC LIBRARY: A CASE STUDY IN ZERO-NET ENERGY LIGHTING DESIGN

Max Pierson[1]

INTRODUCTION

Designing lighting for zero-net energy buildings poses unique and fascinating design problems. Beyond the challenge of providing lighting loads on the order of .1W/sqft[2], these projects require toolsets beyond the typical scope of a lighting design consultant, including detailed controls design and photometric predictions of available daylighting. These new roles are part of a broader trend in lighting design as, driven by new code requirements and a general push towards high-performing buildings, lighting design is becoming a more technical, metrics-driven profession. There's a delicate balancing act here, and indeed we have the same responsibility to these projects as any other: lighting that is comfortable and functional for the occupants, that supports the architectural gesture, and that is available within the project budget. So the task is not simply to design the absolute minimum energy density (although yes, also that), but rather to identify ways in which all of these constraints may be harmonized, and embrace the collaborative and iterative workflow that these projects demand.

---

1. Max Pierson is the principal designer at Minuscule, a lighting design practice based around using new technologies and techniques to pursue a more integrated approach to building. He lives in San Francisco with his cat, Uncle Claudius.
2. For comparison, the allowed wattage under ASHRAE 90.1-2013 is 1.19W/sqft.

This case study is written for architects, engineers, owners and others that want an overview of the lighting design process for ultra-low energy density buildings. I'll gloss both the absolute basics and the more esoteric technical details in favor of discussing practical techniques that we used successfully to further the project goals, and the trade-offs we confronted.

KEYWORDS

Lighting Design, Zero-Net, Public Space, Daylighting

ABOUT THE PROJECT

West Berkeley Public Library is the newest branch library of the BPL system. The project totals some 9,700 square feet and occupies the same site as the former library it replaced, a narrow south-facing lot on University Avenue.

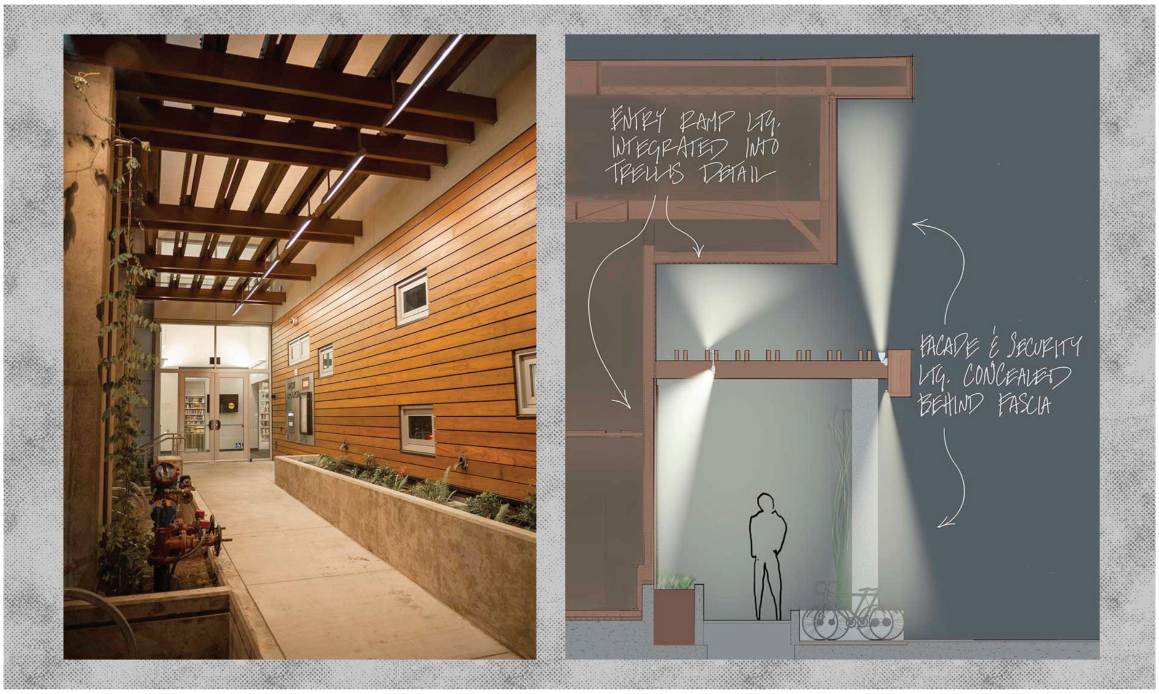
It opened in December 2013, and has been certified as Zero-Net Energy by the New Building Institute, and awarded a BDA Good Design award, and an Illumination Award of Excellence for lighting design, for "significant contribution to the art and science of lighting design."

Image courtesy of Mark Luthringer (www.luthringer.com).

NEIGHBORHOOD PRESENCE

West Berkeley Public Library, like most libraries, provides extensive programming for adult, ESL classes, readings by authors, a venue for community meetings, internet access for people who would otherwise have none, a place to vote, and of course a nice place to spend an afternoon studying or reading.[3] The local library is better viewed as machine for community support rather than a building to house books. Given that, the project's architectural goals of civic presence and approachability were mission-critical, not wish-list items that can be value engineered away.

The library sits on a larger commercial thoroughfare, and the design team wanted the building to have a civic presence at night. Since the interior finishes were quite light, preliminary photometric calculations indicated that during night-time hours the interior of the library could appear as glowing from within, and we added some uplight in the entry atrium to supplement this effect. Thus having gotten most of our night-time presence 'for free', we only had to add about 300W of exterior facade lighting to fill out the rest of the building and balance the brightness of the interiors. Since the facade lighting can be turned off at the same time as the interiors after curfew, the energy impact is minimal.



SAFETY AND SECURITY

For security reasons, we wanted to create a subjective sense that the exterior entry was brightly illuminated. However, these lights would be on all night, and so could have a large impact on energy usage. Further, the emerging consensus among lighting designers is that the traditional approach of lighting the ground to a minimum number of footcandles is ineffective: More Illuminance ≠ More Security. And, we've all been in places where this concept has been applied with special zeal, resulting in glare and an overall institutional feel. In general, security is enhanced by providing vertical footcandles at face level, an illuminated perimeter without dark corners, and managing contrast ratios.

3. See Joshua Prince-Ramus's TED Talk on the O.M.A.-designed Seattle Public Library for a great presentation of the programming needs of a modern library.

We implemented this concept by washing the wall behind the entry path and allowing the light to bounce into the area, which does double-duty as part of the facade lighting presentation. Since the back wall of the entry area is evenly illuminated from end to end, there are no dark corners, and because the vertical surfaces are washed with light the space 'feels bright.'

A HUMAN SCALE

In contrast to the streetside presentation, for the interiors the design team wanted to create an atmosphere of approachability, human in scale. However, the main room is a double-height space some 90' long and 35' wide, which was further complicated by enormous skylight wells running across the space. The spacing of the skylights precluded overhead pendant lighting for anything other than decorative purposes, and the energy density goals of the project made this approach unattractive in any case.

We harmonized these disparate constraints by bringing the lighting to the task, providing high quality task lighting in reading areas and at the book stacks. This greatly reduced the wattage required to achieve the desired lighting levels, while also keeping the lighting at a human scale. Since the walls were mostly covered with book shelves, the task lighting at the stacks gave us wall washing 'for free', which helped to manage the contrast ratios for visual comfort of the patrons. Since the second-story finishes were generally white, and the first-story finishes were generally darker in value, a relatively small amount of uplight was all that was needed to prevent the space from feeling subjectively dark and cavernous.

The skylight wells forced us into creative choices in the lighting design, as the most typical location for luminaires to be mounted is, of course, the ceiling. Where there weren't

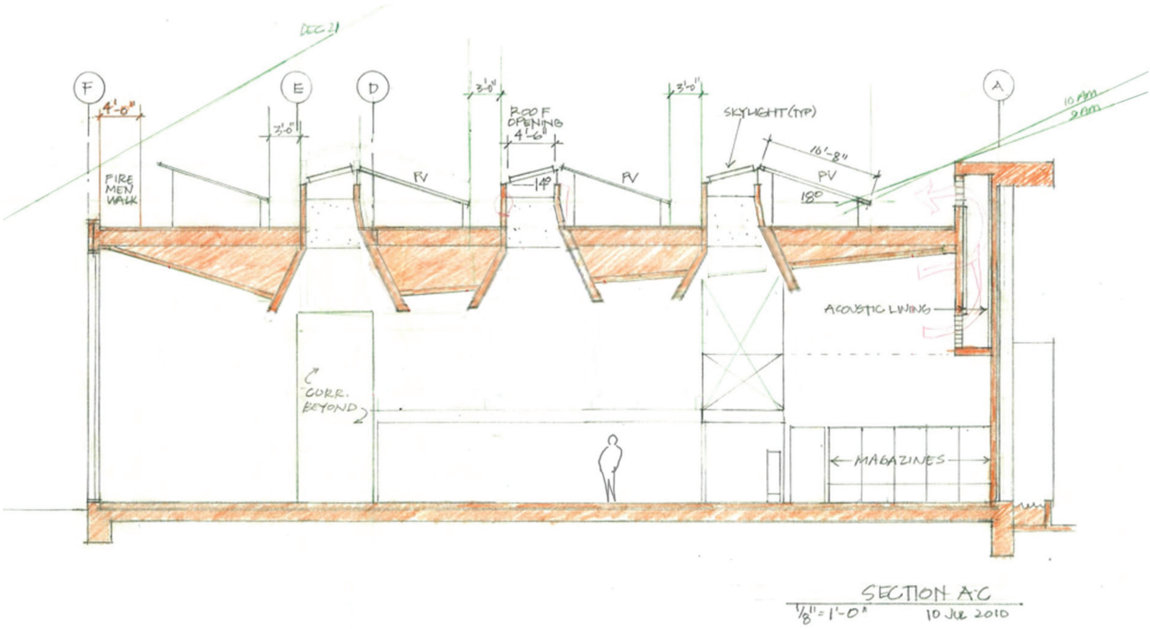
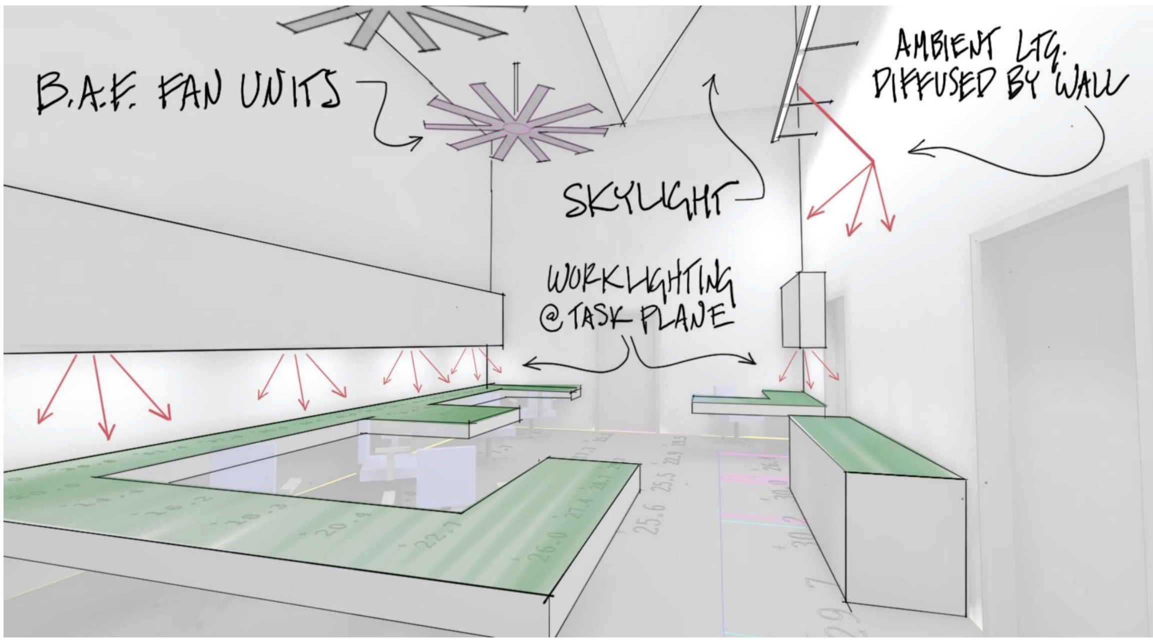


Image courtesy Ed Dean

skylight wells, there were enormous B.A.F. fan units. We couldn't put lighting above the fans, because it would have created strobing in the space below, and we couldn't put lighting below the fans, because it would cause strobing shadows on the ceilings above.

The staff team room was a particularly challenging space in this respect. A long, narrow room with a high ceiling, with a skylight well on the right half of the room and B.A.F. units on the left, it required relatively high light levels at the task plane and visual comfort for the staff working in the room.



Team room lighting. Note the lack of available ceiling mounting due to B.A.F. units and skylight well.

After considering a number of options, we took our inspiration from the daylight coming from the skylight well, and put a linear wall washer on the tall wall on the right. That allowed us to use a high-efficacy fixture, but because we're bouncing the light into the space off the white wall, the lighting is pleasantly diffused. We supplemented the ambient light level with a linear task lighting mounted to the underside of the upper cabinets. The energy density is low because we're not lighting the entire floor area to the relatively high levels needed for office tasks, and the staff are able to individually adjust their worklighting to suit their personal preference.

LIGHTING CONTROLS DESIGN

In the present state of energy codes (and thus LEED), the yardstick used is the total connected lighting load as if every luminaire in the space was switched on at full power, with perhaps some credits given for installing lighting controls. This has the advantage of (relative) simplicity, and as a broad brush it does a reasonably good job at producing energy efficient designs. At .7W/sqft connected load, WBPL is some 40% below the allowed wattage for both Title 24-2008 wattage and ASHRAE 90.1 2007, which would make it a high-performing building by any standard.

However, .7W/sqft is still a far cry from the .1 to .2 W/sqft that is typically required in a zero-net project. While I certainly was willing to eliminate design solutions that were not energy efficient from consideration, I'm not willing to compromise the quality of the design for the sake of energy efficiency—in this as in any project type our approach must be humanistic. So if we've already lowered the connected load as much as possible, and we're not willing to make the occupants get by with less light, we need to find a way to turn the lights off when they're not needed. Hence, zero-net energy lighting design is a lot more about providing daylighting and good controls design than the choice of fixture specification.

Surprisingly, lighting controls design isn't typically in the scope of the lighting designer,[4] but this status quo of dividing fixtures and controls between two consultants is impractical for achieving zero-net. But, lighting controls design isn't all that difficult. The way I approach it is to group the fixtures up by control zone, and then for each zone, identify which controls capabilities are required:

Occupancy Sensing. Remember that badly designed controls will be defeated by the occupants, and nothing is more annoying than lights that switch off when they shouldn't. Except for the likes of single occupancy restrooms and janitor closets, occupancy sensors work best on the ceiling plane. Dual-technology sensors should be used for most applications (the ones mounted on the lighting fixtures themselves don't work very well), and in rooms with more than a few occupants I like to use two sensors so that if either can see an occupant, the lights stay on. At WBPL, almost every space has occupancy sensing, except for the main room where we felt that having some of the lights in the large room switching on and off would be distracting, and the energy savings marginal.

Task Tuning. Given manual dimming controls, many people will choose a level below full power to work under. This works particularly well for task lighting and private offices that do not require multiple occupants to come to a consensus on light levels.

4. "By Engineer."

Daylight Sensing. I'll talk at length about the daylighting design of the library later in the article, but the main thing to understand about daylight automation is that it requires ongoing fine-tuning to be successful. Lighting controls manufacturers have started offering commissioning as a service contract model rather than a one-time startup fee.

Stack lighting photometric study

Controls system typologies may be broadly divided into standalone, panel, and distributed systems. A good model for a standalone system is a switch and occupancy sensor in a restroom—there's no real advantage of having the sensor communicate with the building-wide control system. In a panel system, there's a central relay or dimmer panel with a processor, and the wiring for all the sensors and fixtures homerun to that point. Since you're thus potentially running a lot of wire back and forth, panels work better where you've got relatively large control zones with a lot of fixtures in each zone. Finally, in a distributed system, each fixture and sensor is semi-autonomous with an onboard processor, so that each fixture can be individually addressed and programmed—e.g. DALI or Lutron's Ecosystem. Distributed systems tend to be the flagship in a product line, but the cost can be higher as you're adding a unit cost for each fixture, even if you're going to program them all to do the same thing.

All of these approaches have their merits, but the biggest problem that all lighting controls systems face is that as staff turns over, the know-how and motivation to continuously commission the controls for optimal performance is often lost. For this reason, the best controls system is always the simplest system that will do the job.

For WBPL we were particularly concerned about burdening the staff with a system so complicated that they wouldn't take ownership of it, and decided on a simple switching panel system that can do on-board dimming and daylight response. Most of the smaller interior spaces are stand-alone with a simple occupancy sensor. With daylighting available in most of the spaces and savings from occupancy sensors, we were able to project a .56W/sqft lighting power density during night-time hours and .066W/sqft during daytime hours.

Sunlight in the space in early morning, from an early design iteration.

DAYLIGHTING

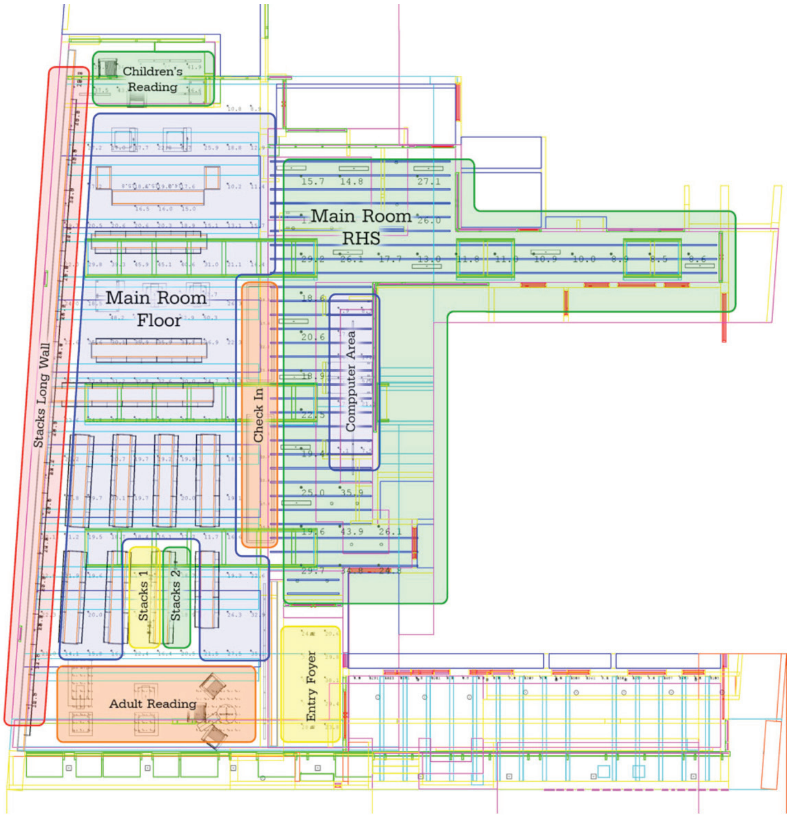
So if daylighting is to be an integral part of zero-net energy lighting design, it's worth examining how to plan for it as part of the lighting design in a practical way. On WBPL, the geometry of the building shell, fenestration, and shading devices was more or less fixed before I began work on the electric lighting design (by the architect with support from Berkeley-based Loisos and Ubbelohde), but there were aspects of the daylighting behavior that had direct implications on my work, such as:

- The contrast ratios present in the space, to assess if supplemental electric lighting might be required even during periods of abundant daylighting to mitigate perceived 'dark' areas.
- Which luminaires in the space would benefit from daylighting responsive controls, and which fixtures within daylight areas can be zoned together as one control unit.
- The value added benefit of dimming or multi-level switching via daylight harvesting control; i.e. how many hours per year daylight would be provide some but not all of the necessary lighting in the space.
- An estimate of the total yearly lighting energy usage.

I was also interested in using this project to research some concepts related to daylighting in a general way. The question of what specific conditions may be taken as typical of the universe of possible conditions within a space is of particular concern for daylighting, as endless combinations of time of day, time of year, and weather conditions are possible.

As a first step both in daylighting and electric lighting, we can divide up the library into types of tasks. In this case, there are a few broad categories:

- Circulation areas, where the light level requirements are not particularly high, and a wider range of contrast ratios between one area to another may be tolerated;



A simplified view of the lighting program for the main room.

- Reading task areas, where higher levels at a horizontal workplane are required, and uniformity must be carefully managed.
- Secondary task areas such as computer use and check-out, where workplane lighting is required but the requirements are perhaps not as stringent as reading areas
- Stack lighting, so that spines of books on shelves can be read.
- The entry foyer, which is a transitional area between indoor light levels and outdoor light levels.

It's helpful to be as granular in this analysis as the space programming allows, as it allows us to concentrate lighting wattage where it will do the most good. We might begin with the following methodology:

1. Set up some representative times, e.g. 9am and 3pm on the spring equinox, and perhaps also some outliers such as the summer and winter solstice, and hit Calculate;
2. Make coffee and write some emails;
3. When the calculation finishes, make adjustments to the design and/or calculation model and repeat, time allowing.

And, as a first pass that's not a bad approach. Any daylight study is necessarily a gross simplification. As an incremental increase in accuracy can easily result in a doubling in calculation time, it's clear that the art here is in choosing what shortcuts we can take, what details will not contribute to the accuracy of the calculation and may safely be omitted. In any case, let's look at what this gives us for one area, the reading area located near the front of the main room, which is adjacent to a large south-facing curtain wall.

All values in footcandles

Reading Area light levels in various conditions				
	Average	Max	Min	Max:Min
Winter Solstice, 12pm	998	2859	111	8:1
Vernal Equinox, 9am	124	170	60	3:1
Vernal Equinox, 3pm	558	2521	208	12:1
Summer Solstice, 12pm	175	213	114	2:1
Electric Lighting	40	150	15	10:1

This is a very simple data set along the lines of the LEED IEQ 8.1 daylighting credit, but it still tells us some useful things. Firstly, interior levels in daylit spaces can easily be ten times the electric lighting levels, and vary by hundreds of footcandles depending on the time of day. So while electric lighting recommendations tend to be built around average light levels, daylighting requires a more holistic approach. Secondly, the maximum light level of 2500+ fc in some times tells us that there's some direct sun penetration into the space, and we might want to know how often that occurs. Thirdly, we might ask why the average light levels in the winter are eight times more than summer—if anything we'd expect the opposite.

So that's some helpful information, but it's clear that we need to dig a little deeper. For this project, I set up the computer to run a calculation for every half hour of the day, at one month intervals, for clear sky, partly cloudy, and overcast conditions. That added up to about 600 radiance calculations, or about two weeks of processor time on a fast quad-core machine. Maybe not practical for every project, but I wanted to capture the entire space of conditions that might occur, and sky conditions in Berkeley are highly variable so it's a good example for a case study. Anyway, at the end of it, I had a metaphorical stack of hundreds of text files. Just so you can see what the raw data looks like, here's one example: (top, page 35)

In of itself, not very useful, and I had 600 more just like it. I needed a way to combine and analyze the data, and for lack of any better solution I wrote custom lisp scripts that run in a Linux shell and open each file, search for the data I want, and then dump the information into one massive spreadsheet, where I could actually start to work with it. I mention all of this to make the point that we need better, more accessible daylighting modeling tools.

As things stand, the software learning curve involved in running a daylighting analysis of any sophistication makes it economically feasible to offer as a design service for only a few specialty firms. For example, if you'd like to run a Spatial Daylight Autonomy (sDA) + Annual Solar Exposure (ASE) calculation as described in the latest LEED v4, you're looking at running perhaps a hundred radiosity calculations of 30 minutes each[5], then writing a script to format the data into something you can work with, and if the envelope changes your results are void. You can see why the business model is problematic.

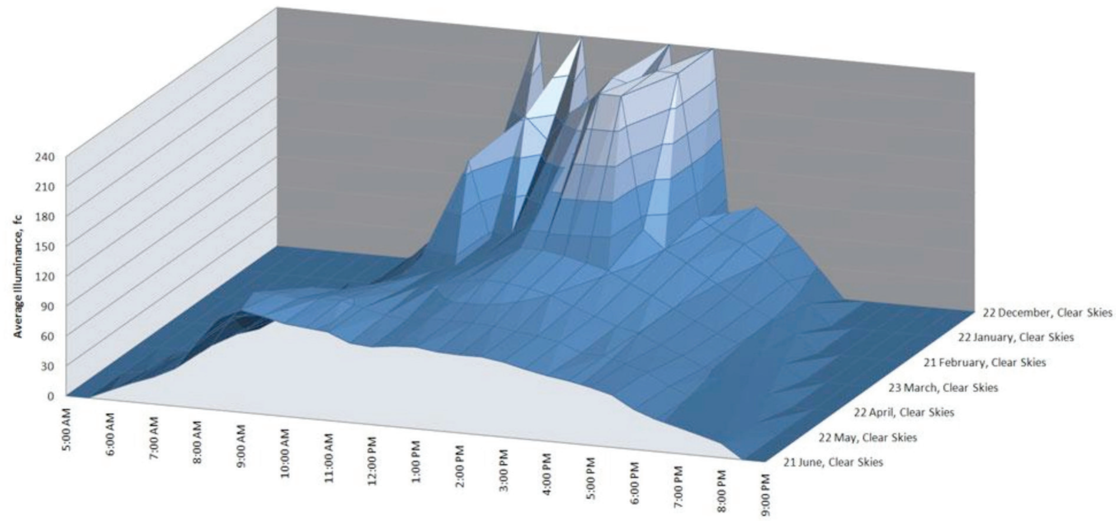
5. It's true that processors get faster and cheaper all the time. But even if you get the calculation time down to 5 minutes per, you're still looking at over eight hours just of processor time. I'm told that the next generation of daylighting software will allow you to purchase time on a small supercomputer and model daylighting in near-real time.

Sample_355.txt - Notepad

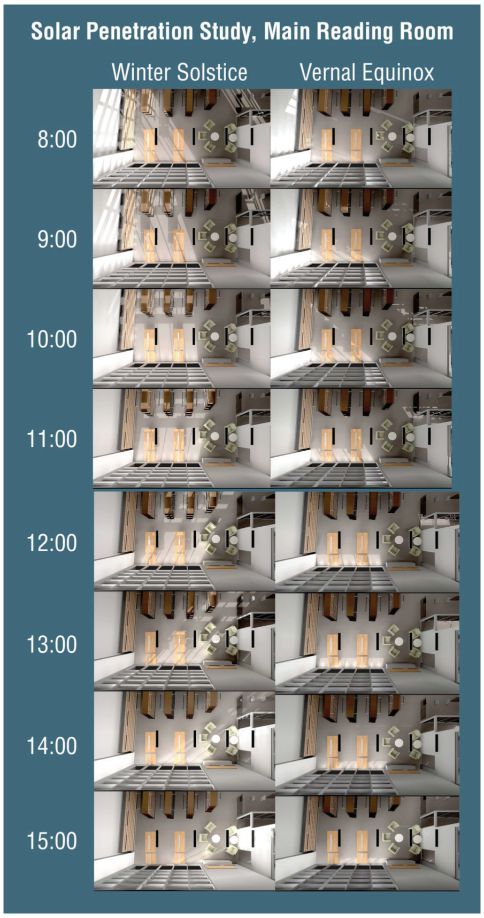
File Edit Format View Help

```
Study Name      Cloudy addition
Site Name       West Berkeley
Site Latitude   37
Site Longitude  122
Site Compass    90
Sky Conditions  Overcast
Electric Lighting       Off
Date    21-Jan-2011
Time    1:30:00 PM
Daylight Savings        True
AGi32 File      West-Berk-Lib-main-room_DMcG_09-12-10 Rev5-Copy-36355_s18.AGI
RGB Image File(s)       Cloudy addition_s18_RGB_v1.jpg
Numerical Summary
Label   Desc.           Avg     Max     Min     Avg/Min Max/Min DF      %Over
Main Room RHS           20.21   104.178 1.333   15.55   80.15   N.A.    N.A.
Floor                   46.94   81.4683 11.4118 4.12    7.15    N.A.    N.A.
Books Long Wall         35.95   53.5988 13.4706 2.66    3.97    N.A.    N.A.
Books Adult Stack 2     24.67   32.0335 17.9582 1.37    1.78    N.A.    N.A.
Check in 1_Surface_5    65.2    78.9625 58.9453 1.11    1.34    N.A.    N.A.
Check in 2_Surface_5    74.8    88.6694 62.1152 1.2     1.43    N.A.    N.A.
Computer Area           10.05   17.8209 4.8548  2.05    3.63    N.A.    N.A.
Adult Reading Workplane 64.9    86.8844 38.3764 1.69    2.26    N.A.    N.A.
Childrens reading area  107.25  148.480 73.2779 1.46    2.03    N.A.    N.A.
Center Reading Section  67.87   74.7299 61.6744 1.1     1.21    N.A.    N.A.
Childrens stack north   64.77   65.8824 63.8799 1.01    1.03    N.A.    N.A.
Childrens stack south   25.77   26.1559 25.3036 1.02    1.04    N.A.    N.A.
Front Wall_1_1_19       14.25   182.295 .0149   0       0       N.A.    N.A.
Entry Vestibule         47.55   58.4884 25.735  1.85    2.28    N.A.    N.A.
Adult Stack 1           23.96   27.4066 19.4622 1.23    1.41    N.A.    N.A.
```

Average light levels on stacks in adult sections



Anyway, now that we have this larger data set, let's see what it can tell us. For one, we can look for outliers in otherwise uniform data, which would tell us if there's an anomaly that perhaps warrants further study. For example, in the above graph of average light levels, there's a uniform 30-90fc on the stacks over daylight hours, and some big spiky jumps in the middle of the day during winter hours (which, the prior vernal equinox study would have missed altogether). This is where renderings are really helpful, as they allow us to zoom in on a particular phenomenon and really understand what's happening.



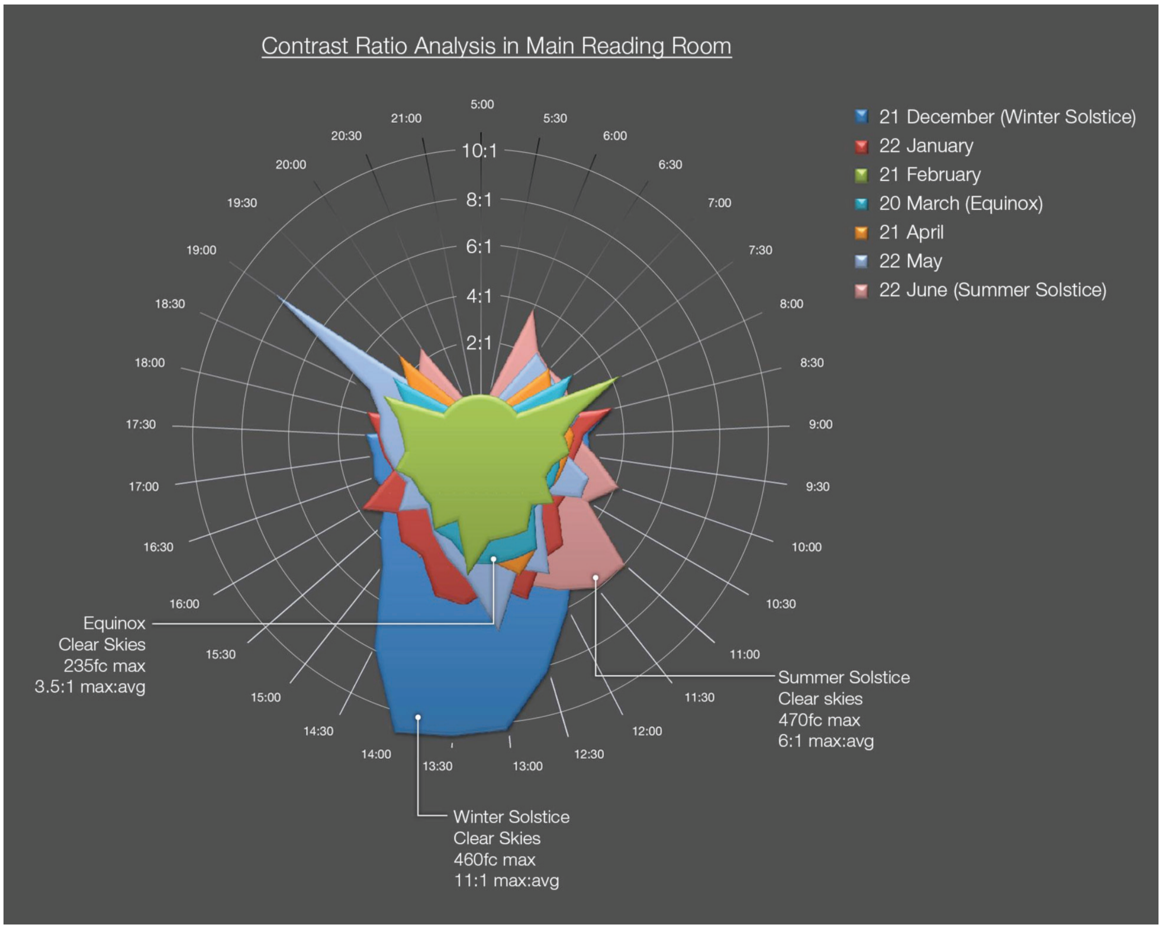
I've been presenting this behavior in an investigative way, but of course it's a designed feature to allow sunlight in via the south-facing main window during winter months when it could help with heating, and block it during summer months when the additional heat load is undesirable. This is accomplished via exterior horizontal louvers on the front of the building.

It's also a reminder that while we can engineer things to death, there's often a simple low-tech or no-tech solution available. In this case, sunlight is blocked during the periods of greatest intensity by the horizontal louvers (low tech), and in other times there is seating available both in the sun and away from it so patrons are able to pick a comfortable location for their needs (no tech). The built space is pleasantly dynamic and maintains a connection between interior and exterior.

SUNNY DAYS VERSUS OVERCAST DAYS

Most daylighting programs can model sky luminance based on historical data sky luminance data recorded at the nearest weather station. It's useful to know the typical behavior, but it's also useful to know the range of values that can occur on a non-typical day. One way of asking this question is, what is the maximum variation between a sunny and overcast day?

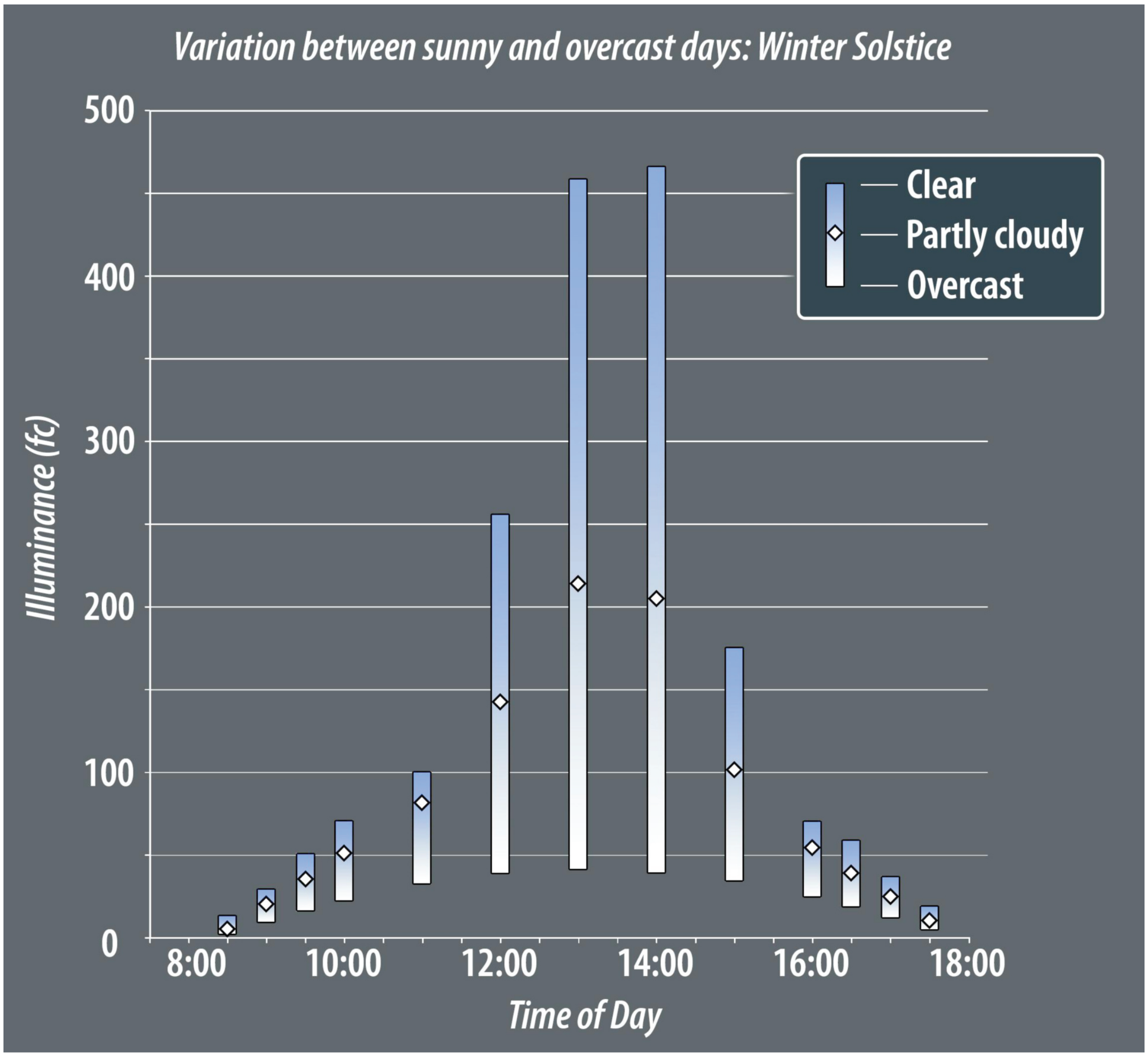
Image courtesy of Mark Luthringer (www.luthringer.com).



In the chart above, the hours of the day are represented clockwise around the center—the summer months begin earliest and end latest. The distance from center is the contrast ratio between a sunny day with CIE Clear Sky, and an overcast day with CIE Overcast sky. We can see at a glance that most of the values are between 2:1 and 3:1, i.e. light levels on a sunny day will be between 2 to 3 times light levels on a cloudy day.[6] The exception is in winter months when some direct sun is allowed into the space, where there can be 10x the difference in light levels or more. Here's a detail of that winter solstice condition:

Speaking as someone who's coming into daylighting from a background in electric lighting design, it's hard to conceptualize a threefold variation in daily light levels, much less a tenfold variation. With electric lighting, it's very easy to design to 10fc or 35fc and know that light level will be consistent from day to day. I can't imagine telling a client that on some days, the lighting I've designed will be 5fc, and on other days 50fc, but that's the situation we're in with daylighting.

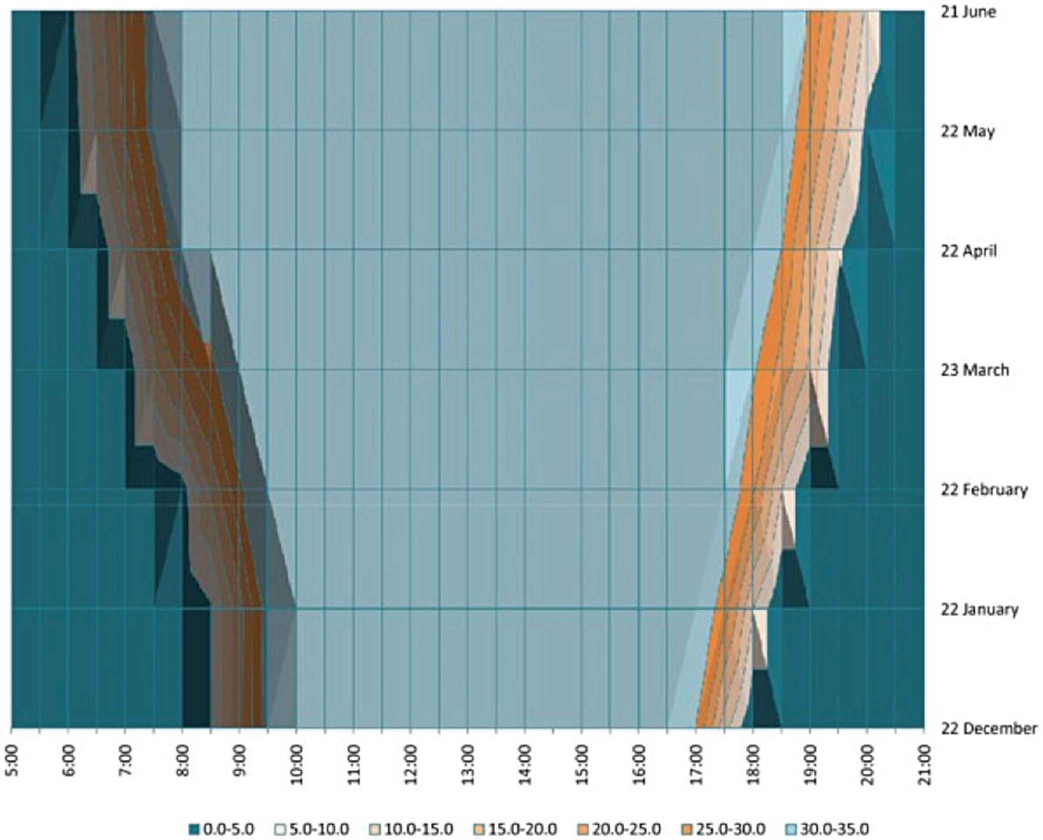
6. Readers who are photographers may be familiar with the Sunny 16 method of exposure estimation, which assumes a doubling in exposure time between sunny and cloudy conditions.



COST VS. BENEFITS OF DIMMING:

One question that came up in the design process was the cost/benefit of dimming vs. switched daylight harvesting. It might seem like dimming daylighting controls are always preferable to switching, but keep in mind that dimming daylighting response is only useful when there will be some daylight, but not enough to reach the target light level. Dimming controls often need commissioning after project close-out to fine-tune them for best performance, and when not working properly can be distracting. Lighting controls that are a nuisance will be defeated by the occupants. So the question of whether dimming controls are worthwhile can be stated: for how many hours per year is there some daylight, but less than our target light level? For example, in the computer use area we might target 30fc average.

In the graph on page 39, time of day is plotted horizontally vs. time of year, with contour lines for footcandle levels. Daylight levels above the 30fc target are in light blue, and where there's no daylight contribution it's plotted in dark blue. The area where dimming would save energy over switched daylight harvesting is shaded in orange, and it works out to about an hour in the morning and an hour at night. However, the planned operating hours of the library were 10am to 6pm, so we're already above the target light



Lighting levels throughout the year, with values > 0fc but < 30fc in orange

level in the morning by the time the library opens, and the library would close before the lights ever turned on in the summer. On the basis of this type of analysis we were able to be selective in choosing which fixtures would benefit from dimming controls.[7]

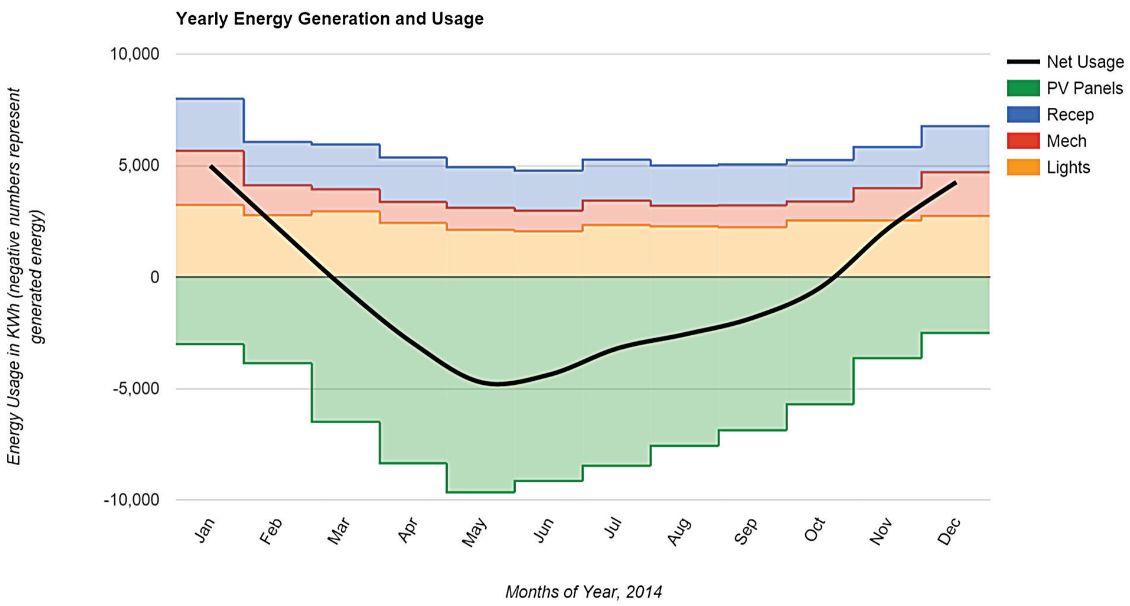
FORECASTING TOTAL LIGHTING POWER CONSUMPTION

Lastly and perhaps most importantly, a large-scale data set like this can be used to forecast actual yearly energy utilization, as opposed to the connected load model of most energy codes which assume that every light is turned on all the time. Which is particularly relevant to projects targeting zero-net, as the onsite energy generation must be sized to the expected load.

It turns out, however, that this is a fairly complex calculation. For each of the areas where we had specified daylighting controls, we identify a target light level, and count the number of operating hours where the light level due to daylighting is below threshold. We then multiply by a wattage factor, which may be a fractional amount of the total electric lighting load if dimming controls are utilized. Summing all the hours times the wattage for all the different areas we arrive at a total number of expected KWh for lighting per year. That gets added to similar totals for areas with occupancy controls, but without daylighting controls, and so on.

7. Of course, the trend in energy codes is to require dimming everywhere, and the transition to LED means that this can be had relatively cheaply and easily. In 2010, it wasn't so.

Anyway, after a lot of subtotaling and checking and re-checking, my calculations projected an "ideal" lighting energy usage of .93KWh/sqft per year—i.e., if all of the lighting controls were completely dialed in so that we're getting the maximum benefit of daylighting and occupancy sensing. The engineering team independently projected a 1.13KWH/sqft per year, which is probably a more attainable figure. And, we were both way off: the actual lighting energy density for the library's first year of operation was 3.16KWh/sqft, indicating that in the first year of operation the lighting controls weren't performing as well as they should be.



Energy usage and consumption for the first year of operation. Data graciously provided by the Office of Energy and Sustainable Development of the City of Berkeley.

There's a takeaway here and it isn't that energy usage forecasts are useless. We're used to thinking of building sustainability features as a capital cost, it's also an operational cost—i.e., the ongoing cost of monitoring and fine-tuning systems for optimal performance. In fact, after a round of post-occupancy commissioning, the lighting power density has been reduced significantly versus the prior year, and the ongoing trend is downward.

To give some context, according to DOE figures, the national average energy use for libraries is 27KWh/sqft.[8] Assuming 30% of that is lighting, we're at 8KWh/sqft, so the 3KWh/sqft for WBPL is already drastically lower than the status quo. The energy savings to be had by good daylighting design are clearly orders of magnitude greater than the energy savings due to efficient electric lighting design alone. That's something to contemplate at a time when LED lighting is maturing as a technology: we're not going to see the kind of improvements in lumens per watt efficacy that we've seen in the last ten years in the next ten years.

8. According to the DOE Commercial Building Energy Consumption Survey (CBECS).

CONCLUSION

This is an amazing time to be a lighting designer. At the time of specification in 2011, the most efficient source available for general interior lighting was linear fluorescent. We can become dazzled by the ability of LED to deliver the same amount of light with ever less wattage (and perhaps a bit frustrated that our lighting is obsolete by the time the building is finished!), but the really revolutionary idea is the way lighting can be folded into the architectural gesture in a way that was never possible with traditional sources. We can move beyond lighting the entire space indiscriminately to the desired light level, and put lighting where we want it, when we want it. We can stop thinking of lighting as a building system installed into the architectural envelope, like sprinklers or mechanical, and think instead of a unified presentation of architecture and light.

This shift comes at a ripe time for architecture, as we move past thinking of buildings as a static enclosure that isolates inside from outside, in favor of an organism that mediates between the two environments while always preserving the connection between them. The technology changes but our goals do not; lighting that serves and inspires.