Dark Side of Daylighting: Balancing Energy and Lighting

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Course Description

Trends in global warming, population and demographic pressure, development economics, and employment opportunity generate increasing stresses on existing urban centers. New buildings are required to include more rentable space compressed within already stressed volumes.

To design and build within this environment requires flexibility to respond to traditional development pressures, while more nimbly responding to fast-changing climate instabilities and higher urban densities. Designers must anticipate broadly predictable changes in heating/cooling/daylighting resources and loads, while remaining cognizant of existing conditions. Existing buildings, in particular their envelope and mechanical systems, must adapt as they lose daylight access in one direction while being simultaneously exposed to unanticipated reflected radiation from another.

Outline & Learning Objectives

1. Understand the energy impact of buildings and how daylighting techniques can help to reduce consumption.
2. Recognize the negative impacts of unanticipated reflected radiation.
3. Understand how codes and standards are guiding designers to consider daylighting and energy optimization in buildings.
4. Identify strategies and techniques for responding to and reducing unanticipated reflections.
5. Identify new ASHRAE and IECC prescriptions that apply to daylighting, curtain wall glass allocation, and daylight dimming.
6. Preview potential daylighting code impacts on the envelope design.

Outline

- Daylighting – What is it? How do we do it?
- Daylighting and Resilience
- The Dark Sides:
  - Reflections
  - Shading
- Daylighting and Codes

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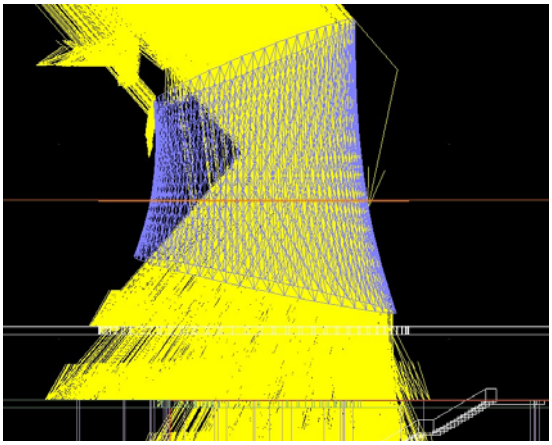
What is daylighting?

The controlled harvesting, redirection, and distribution of sun and ambient (sky) light to the building interior



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Why daylighting?

1. 30% of building operating cost typically directed at lighting energy. Daylighting can reduce this by as much as 50%.
2. Daylighting creates more stimulating environments that increase occupant performance and productivity.
3. Daylighting serves a critical health function in terms of regulation of the body's circadian clock.

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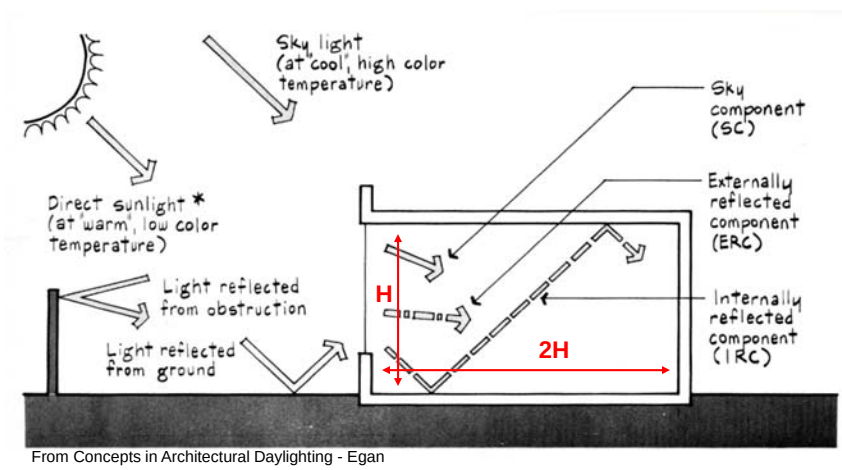
What are the sources and critical features of building daylighting?



From Concepts in Architectural Daylighting - Egan

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Daylighting traditions

Since the Roman Empire, good daylighting has been governed by informed design thinking about the sun's relationship to the site, the building's orientation, aperture size and placement, interior space height and depth, and material selections.

Grand Central Station

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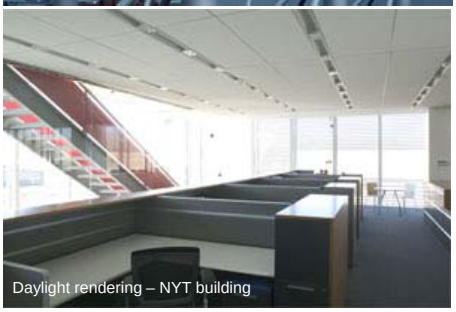
Daylighting (modern) technologies

In the late 20th and 21st century advances in glazing, coatings, reflective materials, shading, and vertical and horizontal deep daylight penetration systems have pushed useable daylight well beyond its 2x the window head height limits, while improved lighting, ballast design, and daylighting controls have optimized the resulting energy benefits and building cost savings.

Heliostat installation – Genzyme Building



Daylight rendering – NYT building

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Model daylighting project

The New York Times building by Renzo Piano:

Lighting energy savings – 56%
Demand charge savings – 13%
Payback DL controls – ~4 yrs
Occupant light satisfaction – 75%
Occupant sense that building contributed to performance – 61%

NYT building – Renzo Piano Architect

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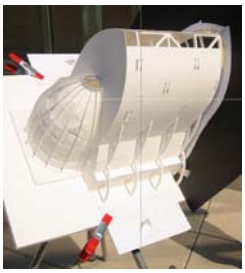
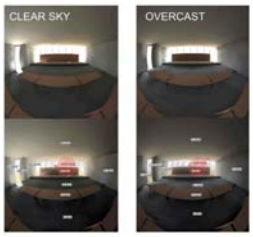
Tools for successful daylighting analysis

1. Rules of thumb (Effective for early planning of simple spaces).
2. Architectural models (Effective for complex spaces, special daylighting challenges, excellent for presentations).
3. Simulation (Only way to accurately, comprehensively, and iteratively account for external context, building orientation, complex geometry, WWR, shading, interior walls and furniture, lighting, and controls and conformance with daylighting codes [ASHRAE and IES] and LEED certification).





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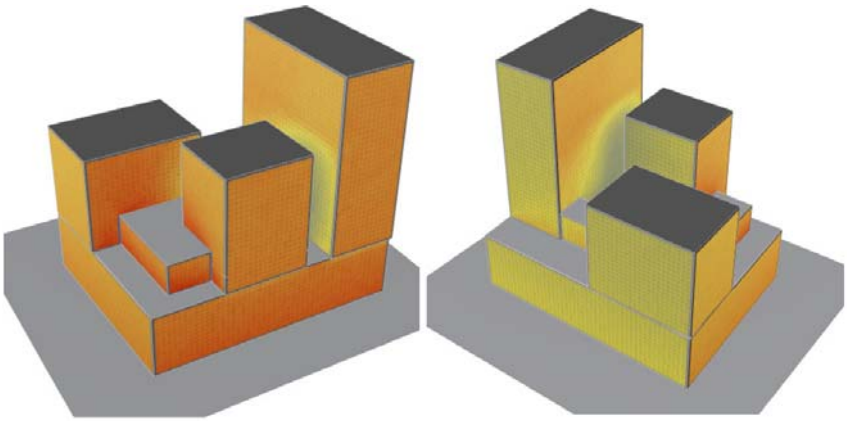
Tools for successful daylighting analysis: simulation



South West View

North West View

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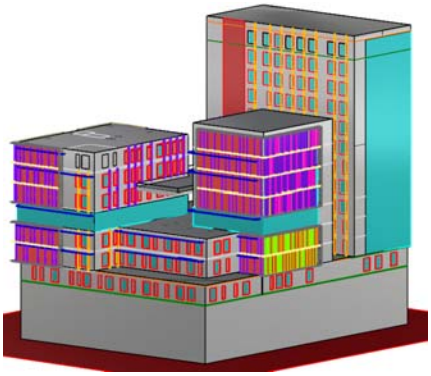
Tools for successful daylighting analysis: simulation



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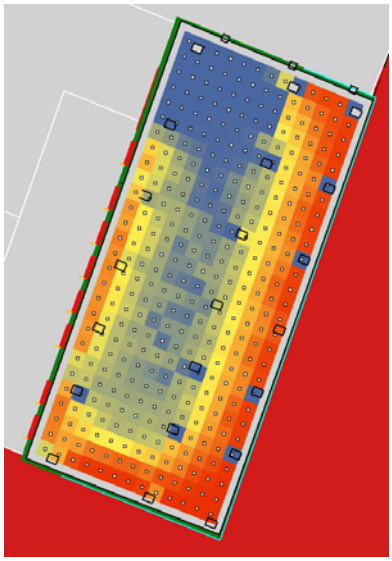
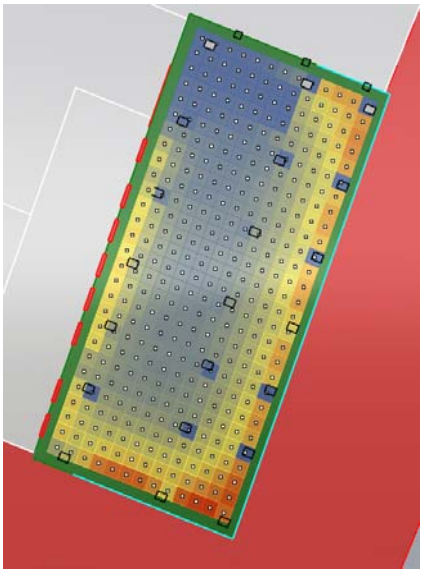
Tools for successful daylighting analysis: simulation





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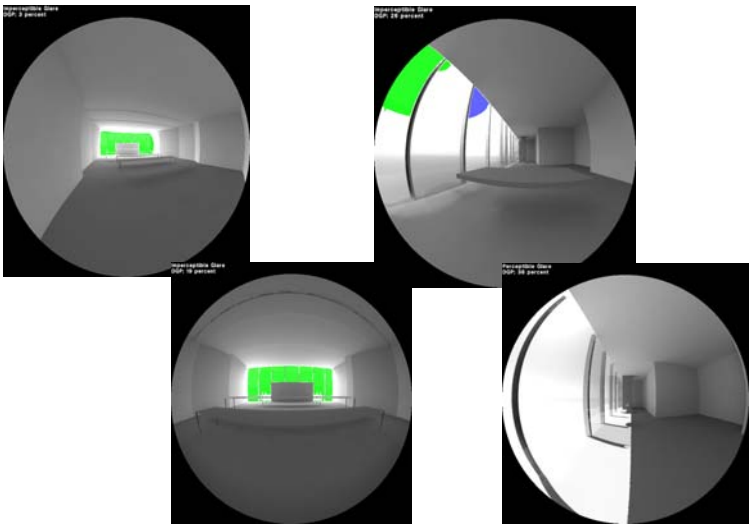
Tools for successful daylighting analysis: simulation



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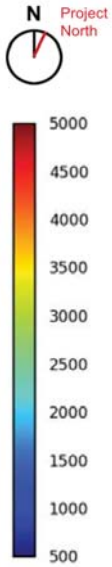
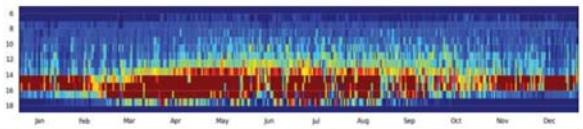
Tools for successful daylighting analysis: simulation

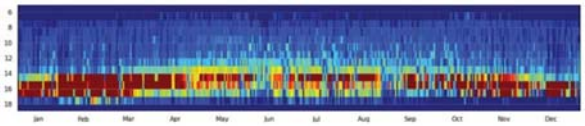


Vertical axis = time of day (sunrise to sunset)
Horizontal axis = month of the year (Jan to Dec)
Colored scale = 500 lux (target) to 5000 lux (overlighting)

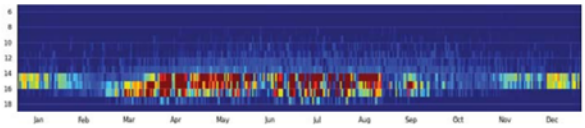
Architect's Design (with shades)



SGH's Design (alternate shades)



Architect's Design (shades and tinted glass)



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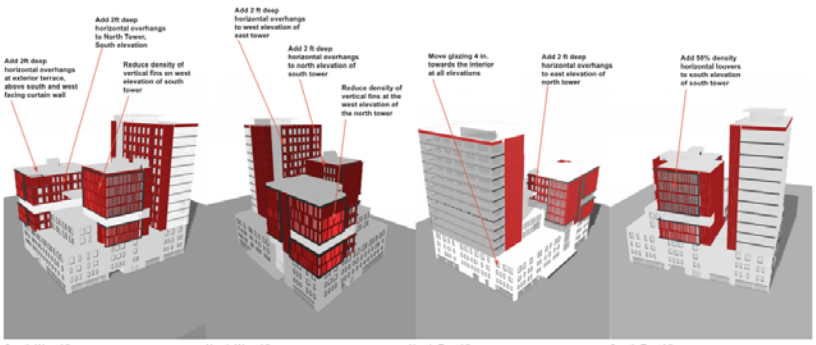
Tools for successful daylighting analysis: simulation



Overall Perspective Views

Perspective views with Alternate Shading Options

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DAYLIGHTING AND RESILIENCE

Manhattan sunset October 29, 2012 (sandy +1) looking south from SoHo

Daylight and resilience: blackouts

Downtown Manhattan

Midtown Manhattan

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Daylight and resilience: blackouts

EMPIRE STATE BUILDING

Blackouts - when the lights go out, well daylighted commercial and residential buildings will function better in terms of wayfinding and exiting. Residential buildings with good daylight will have more extended hours of use.

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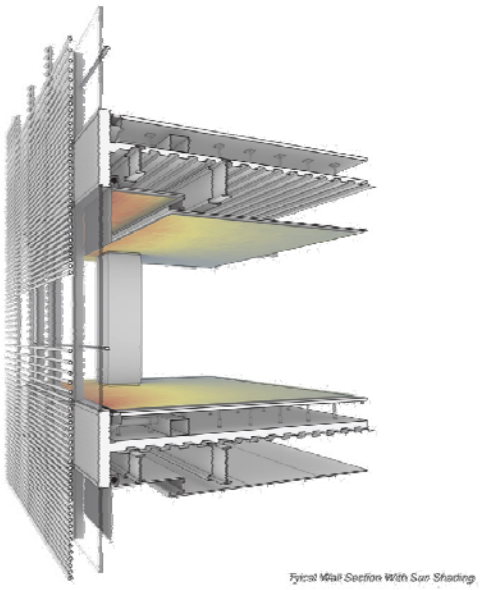
Daylight and resilience: blackouts

As a matter of daylighting design, harvest abundant daylight at the perimeter with generous glazed area and high window head height.

Minimize curtain wall absorption and reflection in the visible spectrum in order to transmit as much useable daylight to the interior.

Maximize ceiling height and reflection.



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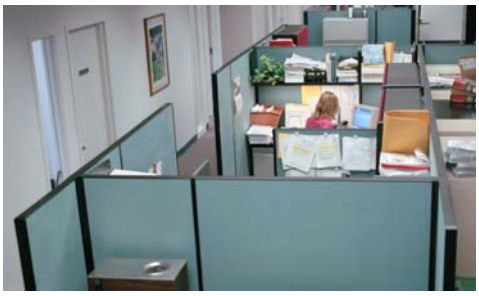
Daylight and resilience: blackouts

Combine low/no partition open office planning with modest daylighting floor plate depth to push daylight to and into the core, in particular in the area of the exit stairs.



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Daylight and resilience: blackouts

Consider light redirecting prismatic glazings, integrated reflectors, and applied films. Shown here: 3M Daylight film applied to clerestory glazing.

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Daylight and resilience: blackouts

Consider horizontal light guides that efficiently transmit daylight gathered at the curtain wall to the core: SunLuminaire™ from SunCentral

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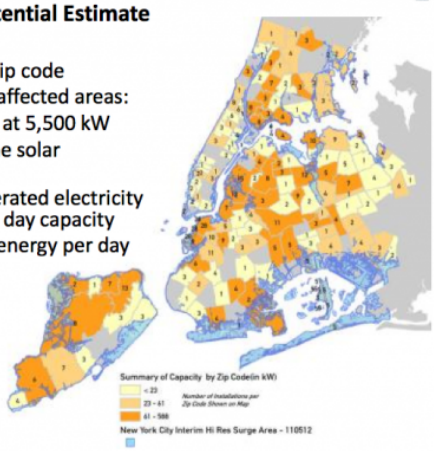
Photovoltaics and resilience

What Solar PV Could Have Provided During Recovery

Emergency Solar Potential Estimate

- PV installations by zip code
- # of installations in affected areas:
  - 281 installations at 5,500 kW
  - Nearly 50% of the solar installations
- On average PV generated electricity at 35% of full sunny day capacity
- 6,500 kWh of solar energy per day



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Photovoltaics and resilience

For PVs to be of useful in a blackout, they will need to immediately switch to an alternate in-house (DC (?)) circuit that will connect to and network essential emergency services such as circulation and exit stair lighting, elevator motor, domestic water supply and fire water pumps, and emergency cell phone charging.

To assure minimal nighttime electric services, battery storage will be required.

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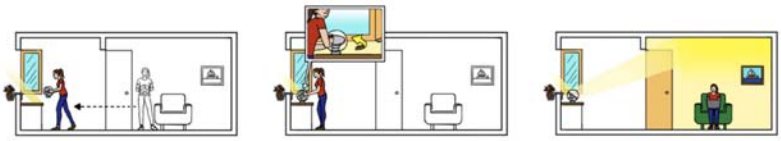
Photovoltaics and resilience



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Resilience and daylight: blackouts

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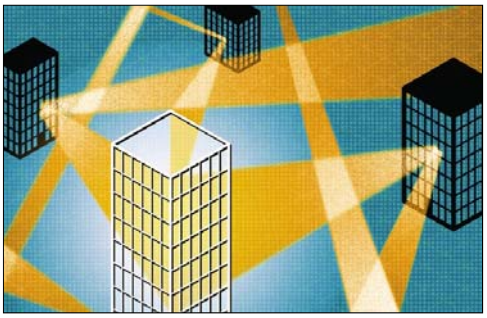
Unanticipated solar reflections

To reduce cooling loads, modern facades are designed to deploy metal panels and high IR reflective glazings to reflect away solar radiation. The problems is that these can then impose unwanted solar gains on neighboring buildings.



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Unanticipated solar reflection – glazing and building form

The Guardian: The Walkie Scorchie Skyscraper

ABC News: Vegas Hotel “Death Ray” Burns Tourist

Low SHGC glass combines with architectural concavity to create a heat-focusing facade

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Unanticipated solar reflection – remediation

The southwest facade of the Disney center (2004) reflected solar radiation. Condo residents across the street closed shades and turned on AC for up to three added hours per day. A city study showed that the building's reflected solar gains could raise temperatures to 138°F in spots. Neighbors, passers-by, and local residents also complained about glare.

The solution was to sand the offending reflector panels so that what had been a mirror reflection became a diffuse reflection.

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Unanticipated solar reflection

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Unanticipated solar reflection – building form and glazing

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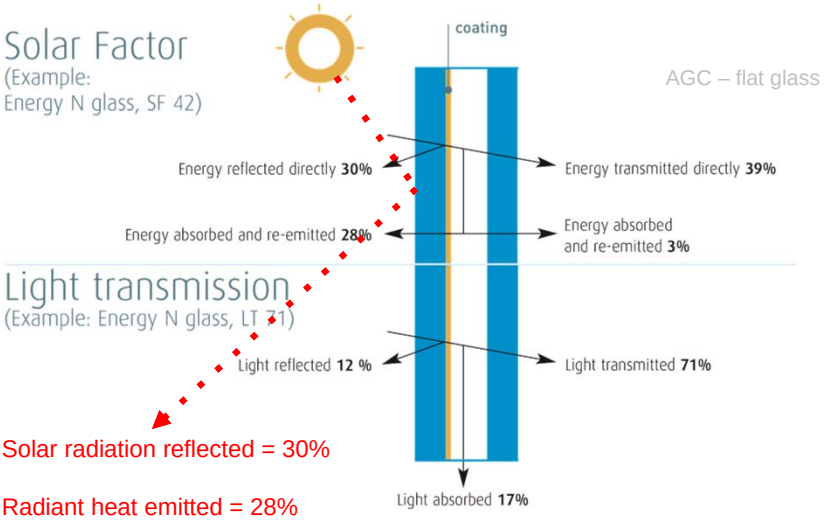
Unanticipated solar reflection – the role of advanced glazings



Solar radiation reflected = 30%

Radiant heat emitted = 28%

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Unanticipated solar reflection – remediation (?) for building and garden

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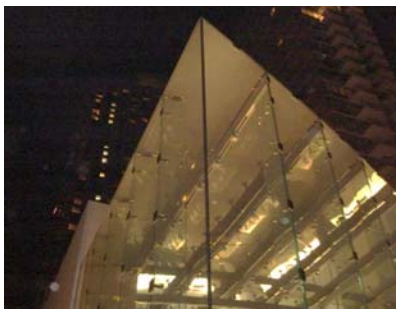
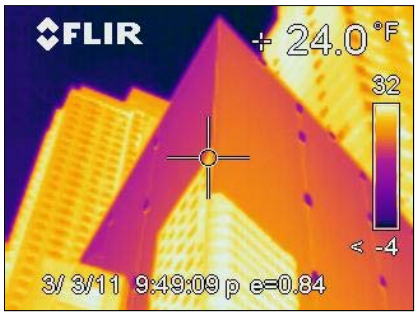
Unanticipated solar reflection – the role in urban heat island





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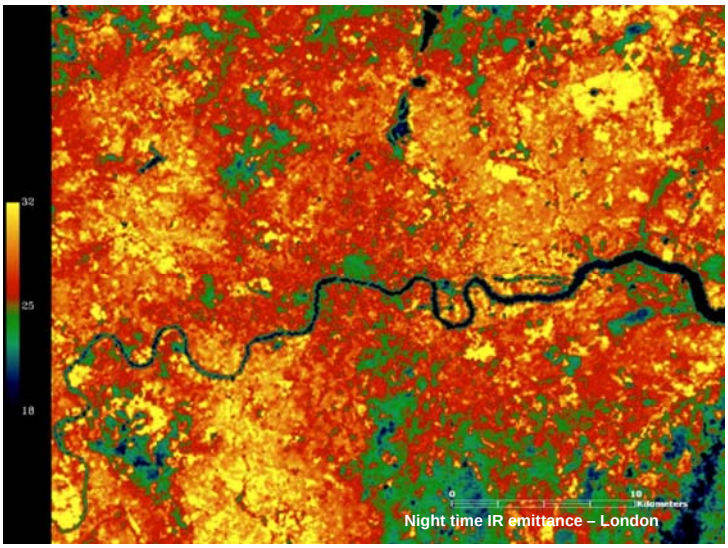
Unanticipated solar reflection - urban heat island effect



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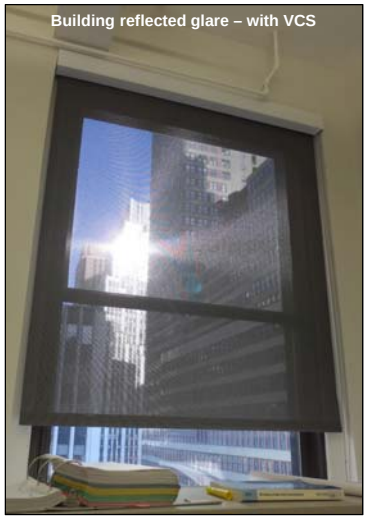
Unanticipated light reflection and glare



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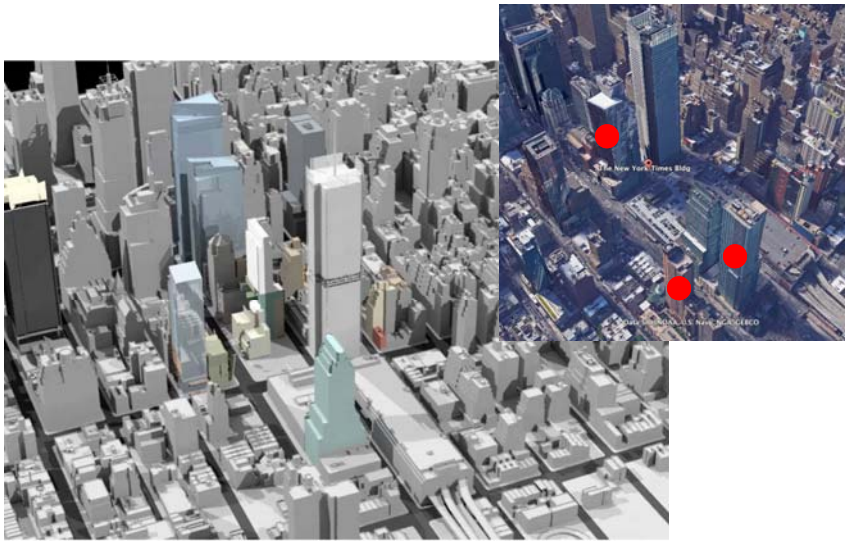
Anticipating future shading's impact on daylight availability



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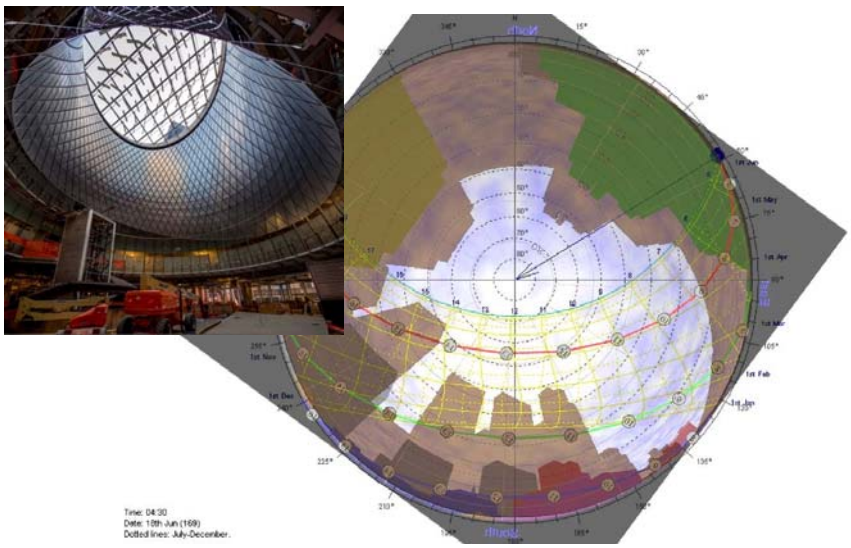
Anticipating future shading's impact on daylight availability



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Shade as matter of NYC public policy: CEQR

Vegetation: the minimum sunlight time necessary for its survival (when there was sufficient sunlight in the future without the project), or a reduction in direct sunlight exposure for existing plantings.

Historic and cultural resources: a substantial reduction in sunlight available for the enjoyment or appreciation of the sunlight-sensitive features of an historic or cultural resource.

Open space utilization: a substantial reduction in the usability of open space as a result of increased shadow.

For any sunlight-sensitive feature of a resource: complete elimination of all direct sunlight on the sunlight-sensitive feature that substantially effects the survival, enjoyment, or, in the case of open space or natural resources, the use of the resource.

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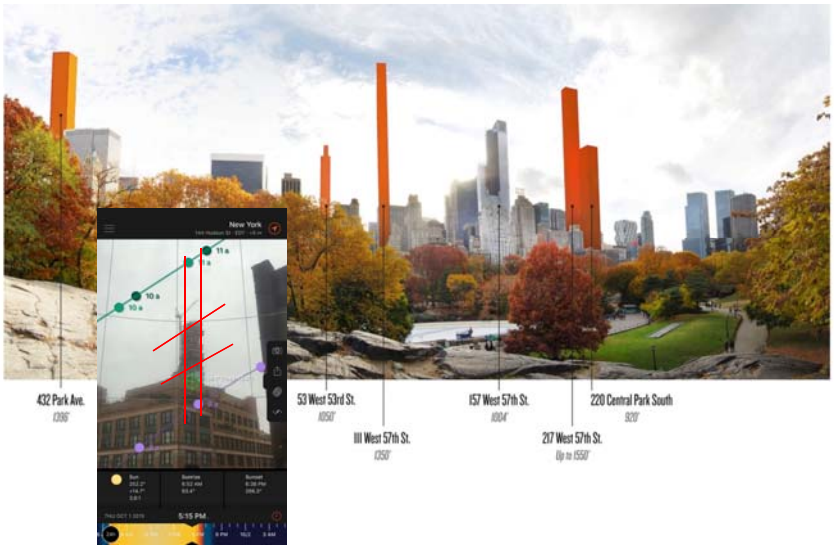
Shade in the public domain



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Shade in the public domain

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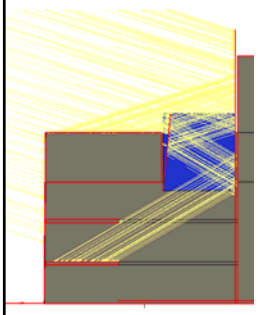
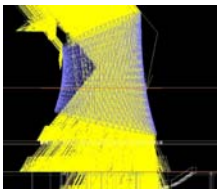
Interior daylight reflected by design



REFLECTOR WALL YORK QUAY PARKING GARAGE, TORONTO – JCDA/CNC



SKY REFLECTOR NET FULTON ST SUBWAY STOP, NYC – JCDA/CNC

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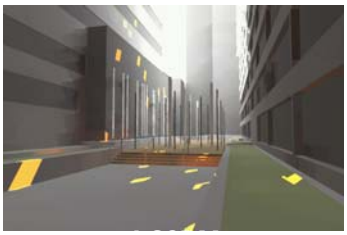
Exterior daylight reflected by design

LIGHT REFLECTORS, SKY MASTS AND SKY RIBBONS, WEILL CORNELL MEDICAL CENTER, NYC – CNC

THREE BUILDING MOUNTED HELIOSTATS TARGETED TO TEAR DROP PARK, BATTERY PARK, NYC - CNC



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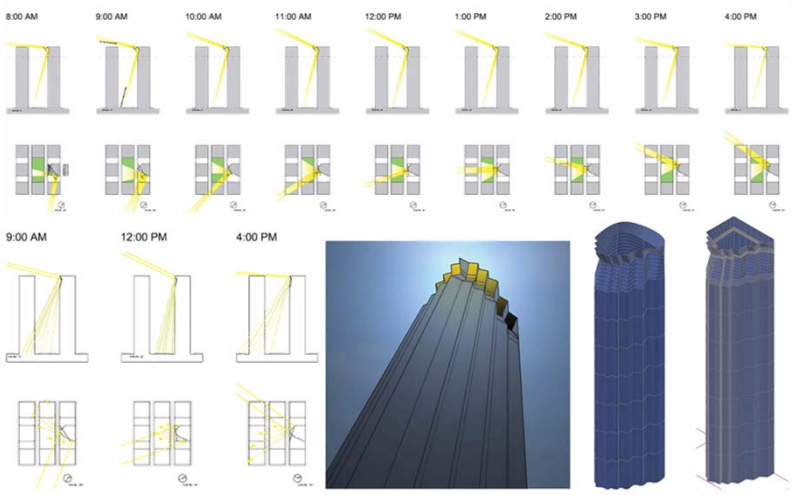
NYC planning department 2012 – compensatory light



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Compensatory light in practice?

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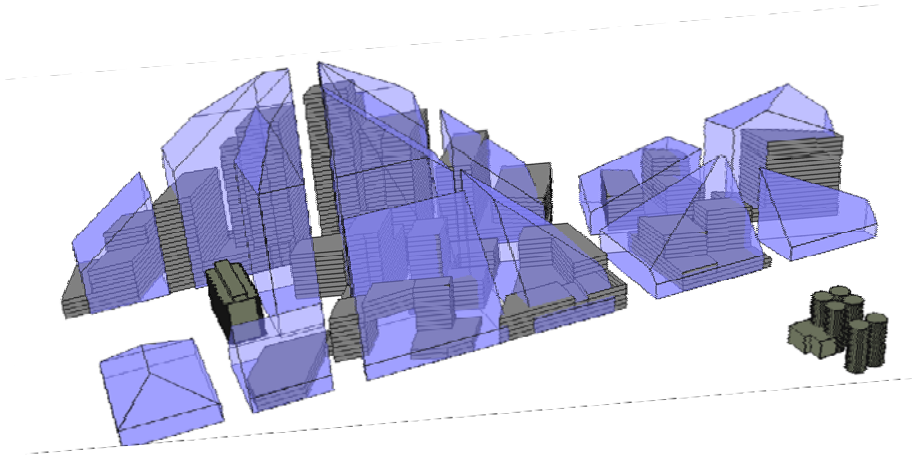
Solar and daylight “sky exposure” planning for Lower Don Lands, Toronto



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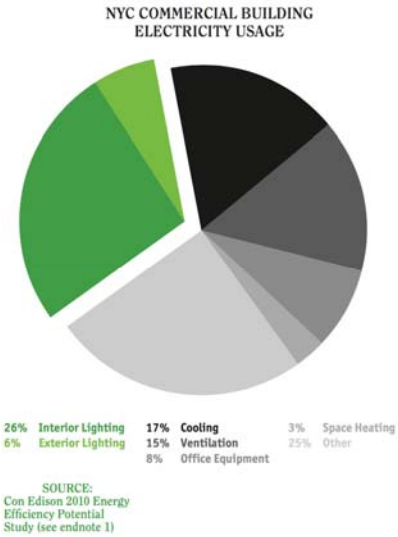
Daylighting and codes: commercial building lighting energy consumption

Lighting electricity consumption stands at 150 billion kwh in the residential sector and almost double that at 262 billion in the commercial sector.

In commercial buildings, lighting is the chief annual operating energy load at nearly 30%. From an energy regulator's standpoint this makes reductions in commercial building lighting a priority target.



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Daylighting and codes: building density and lighting energy use

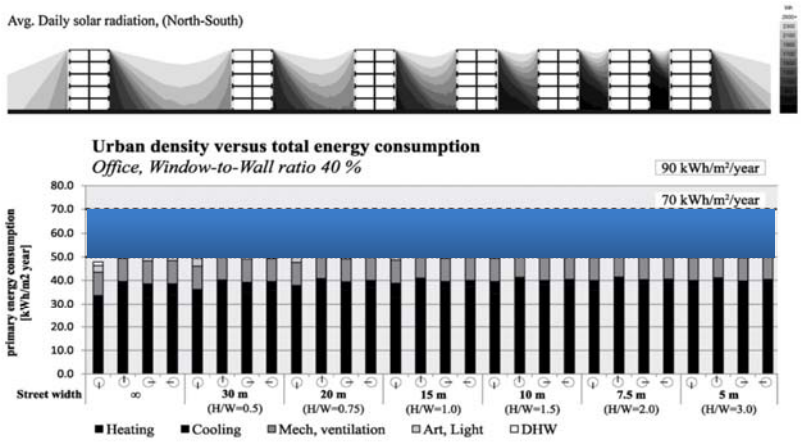

Fig. 8. Total primary energy consumption (kWh/m²/year) for a 5-storey office building as a function of urban density.

The urban canyon and building energy use: Urban density versus daylight and passive solar gains
J. Strømann-Andersen, P.A. Sattrup, Energy and Buildings 43 (2011) 2011–2020

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Daylighting and codes: lighting power density

The 1st regulatory priority has been to focus on ever more restrictive lighting power density (LPD).

Since 1989, allowable ASHRAE/IES 90.1 LPDs for the six sample space uses (blue) in chart on right have dropped by an average of 45%.

Building Type	Maximum Lighting Power Density (W/sq.ft.) Allowed Per Version of the ASHRAE/IES 90.1 Standard				
	1989	1999/2001	2004/2007	2010	2013
Automotive Facility	0.96	1.5	0.8	0.982	
					1.01
Court House	1.44	1.4	1.2	1.05	
Dining: Bar Lounge/Leisure	1.37	1.5	1.3	0.99	
Dining: Cafeteria/Fast Food	1.37	1.8	1.4	0.90	
Dining: Family	1.37	1.9	1.6	0.89	
					.57
Exercise Center	2.07	1.4	1.0	0.88	
Gymnasium	2.07	1.7	1.1	1.00	
Healthcare Clinic	1.44	1.6	1.0	0.87	
					5
Hotel	1.15	1.7	1.0	1.00	
Library	1.29	1.5	1.3	1.18	
Manufacturing Facility	0.96	2.2	1.3	1.11	
Motel	1.15	2.0	1.0	0.88	
Motion Picture Theater	2.07	1.6	1.2	0.83	
Multi-Family	1.15	1.0	0.7	0.60	
Museum	2.07	1.6	1.1	1.06	
					.82
					.21
Penitentiary	1.44	1.2	1.0	0.97	
Performing Arts Theatre	2.07	1.5	1.6	1.39	
Police/Fire Station	1.44	1.3	1.0	0.96	
Post Office	1.44	1.6	1.1	0.87	
Religious Building	2.07	2.2	1.3	1.05	
Retail	2.25	1.9	1.5	1.40	
					.87
Sports Arena	2.07	1.5	1.1	0.78	
Town Hall	1.44	1.4	1.1	0.92	
Transportation	2.07	1.2	1.0	0.77	
Warehouse	1.03	1.2	0.8	0.66	
Workshop	0.96	1.7	1.4	1.20	

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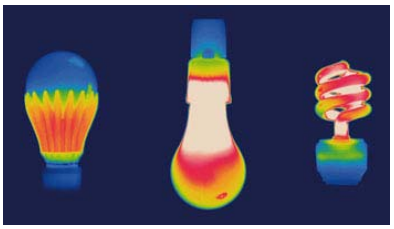
Daylighting and codes: luminous efficacy

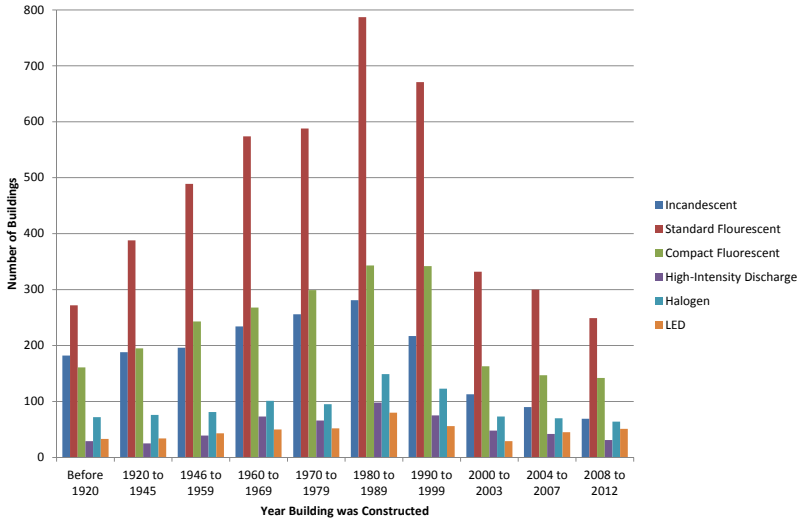
In response to much more demanding LPDs the lighting industry has developed and produced lamps (and housings) with much higher luminous efficacy (output of lumens per input of watts).

Fluorescent lamps, compact fluorescent lamps and LEDs have luminous efficacies that are on average 6x that of an incandescent lamp.



59

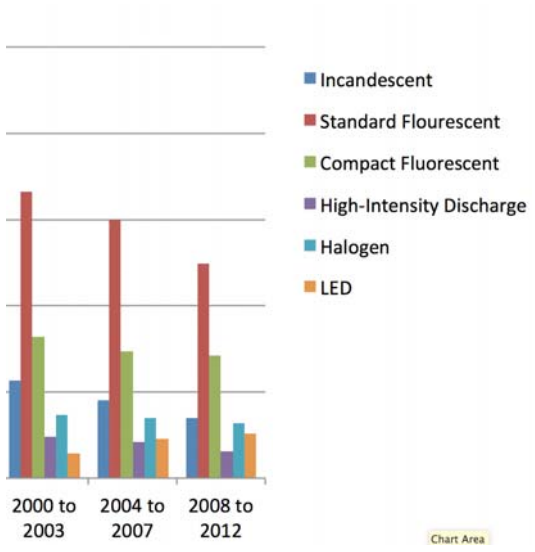
Daylighting and codes: the historic(al) switch in light sources



60

Daylighting and codes: the modern historic(al) switch in light sources

Recent history shows continued drop in the use of all lamp types with the exception of LED.



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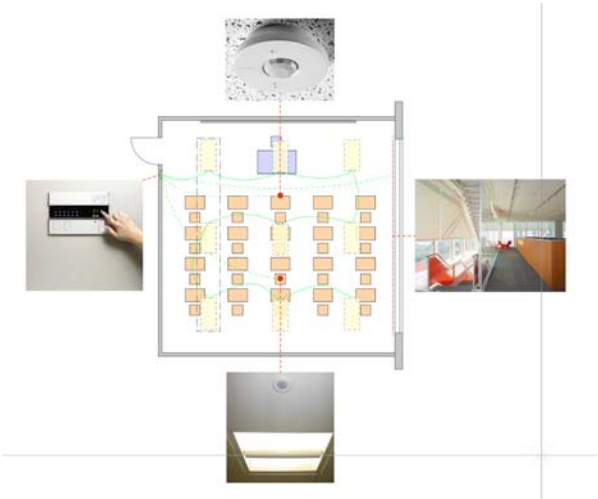
Daylighting and codes: controls to harvest savings from daylight

Daylight sensors, dimming ballasts and dimming control can now efficiently harvest the economic benefit of daylight at the level of the individual light fixture.

Dimming can now operate and fully integrate with automated visual comfort shades and occupancy sensors.



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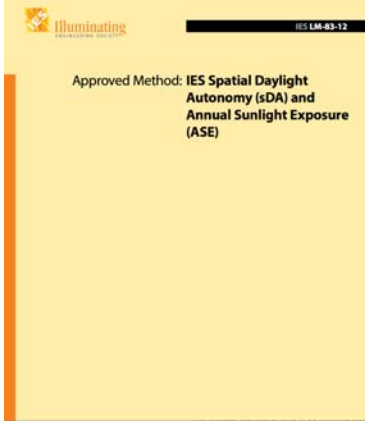
Daylighting and lighting codes – IES LM-83-12 also LEED conformance for daylighting

SPATIAL DAYLIGHT AUTONOMY – SDA 300lux, 50%

sDA seeks to assure a “neutral” value of 300 lux (typical office illuminance) on a 30 in. aff horizontal surface between the hours of 8:00 a.m. to 6:00 p.m. (10 hrs) for 55% of annual daylight hours.

ANNUAL SUNLIGHT EXPOSURE – ASE 1000lux, 250h

ASE describes the potential for visual discomfort in an interior environment. Spaces that exceed ASE (1000, 250h) for 10% of the year are deemed too bright and troubled by reflections and glare.



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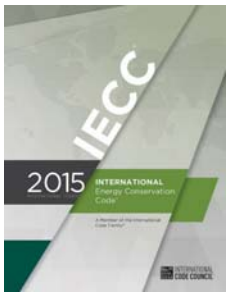
Daylighting and building codes – ASHRAE and IECC

Recent codes version address the entangled issues of how our buildings reap the energy benefits from good daylighting, all while addressing reduced envelope heat gains and losses.

The debate centers on the WWR, presently set at 40% in ASHRAE (2013). This will lead to reduced glass area in our buildings and consequently reduced envelope heat losses and gains. The IECC WWR is presently set even lower at 30%.

This will also result in less daylight. These WWRs are too low: robust penetration and distribution of natural light starts at WWR (50%).



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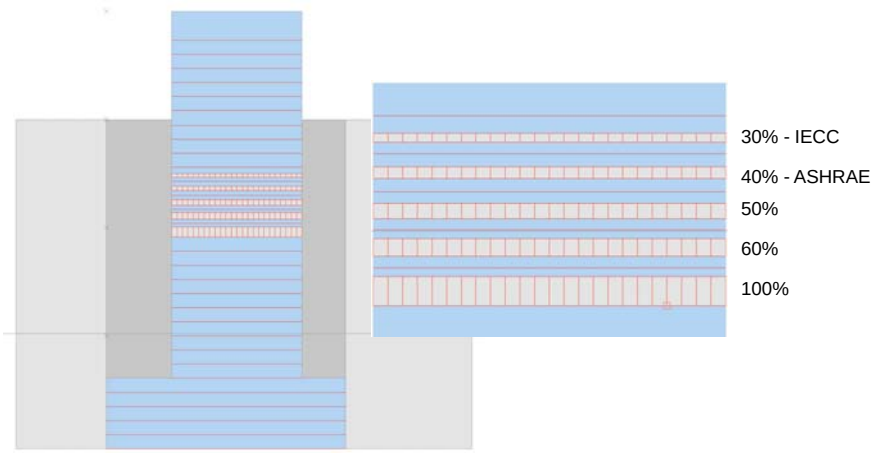
Daylighting and codes – WWR



East and west elevation allowed no more than 25% of total WWR. More allowed with a decrease in the E/W glazing's SHGC.

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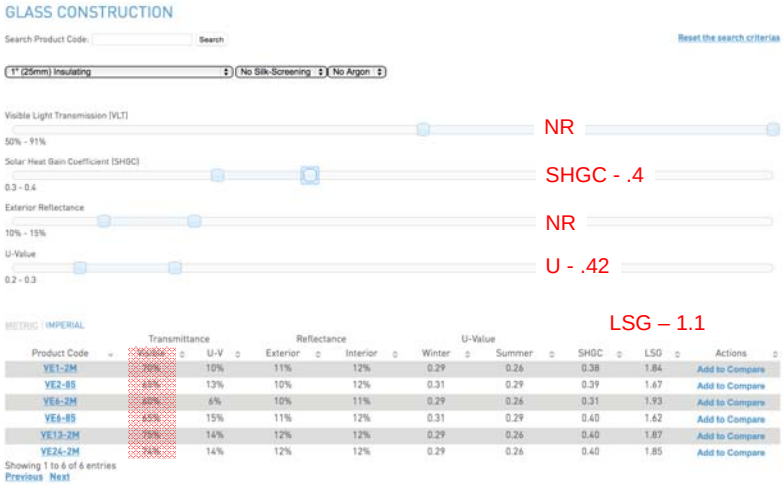
Daylighting and codes – do stringent SHGC requirements lead to low daylighting Tvs?

Boston is in ASHRAE climate zone 5. E/S/W glazing code requirements in red.
For north glazing, an SGHC increase of .05 is allowed.



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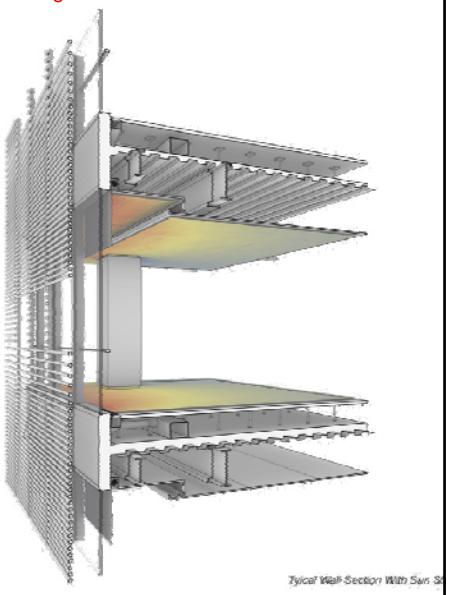
Daylighting and codes – SHGC reductions for shading

ASHRAE: Louvers that provide full glass shading on June 21st would allow for a SHGC multiplier as low as .44, depending on the shade density on the south, east, and west glass. Up to .73 multiplier for north elevation.

IECC: SHGC adjustments for permanent shading devices. Up to 0.64 SHGC multiplier for N/E/S/W orientations.



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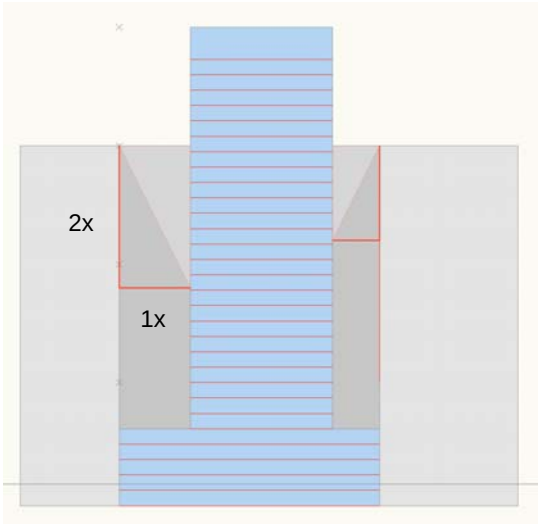
Daylighting and codes – daylight zones and mandatory dimming

ASHRAE: If the distance to the opposing building is less than 2x the height to its parapet (red outline), daylight control zones will be mandatory and will require daylight dimming.



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Daylighting and codes – daylight zones and mandatory dimming

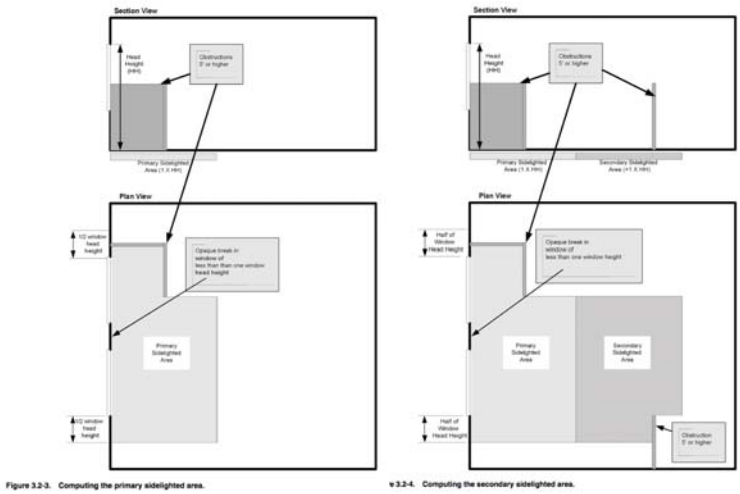

Figure 3.2-3. Computing the primary sidelighted area.

e 3.2-4. Computing the secondary sidelighted area.

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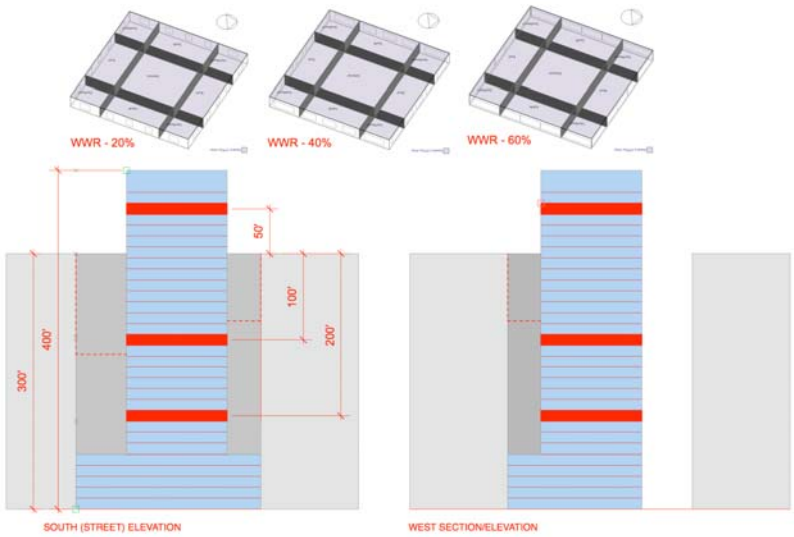
Daylighting and energy in practice – a reconnaissance



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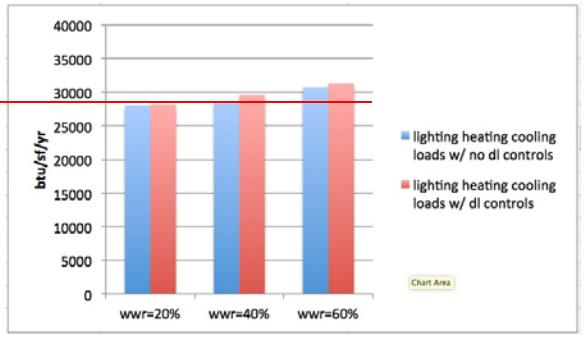
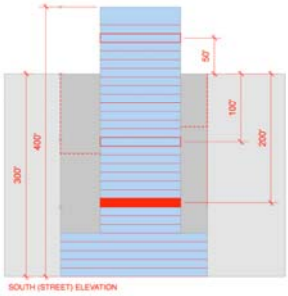
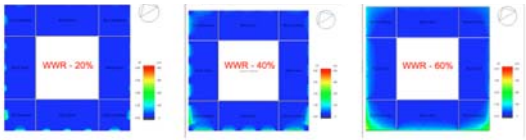
Daylighting and energy in practice – a reconnaissance

Baseline EUI







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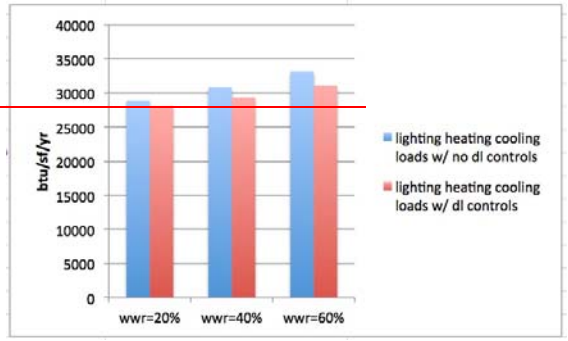
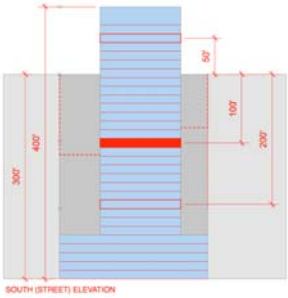
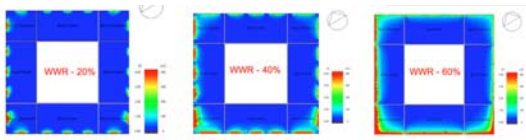
Daylighting and energy in practice – a reconnaissance

Baseline EUI







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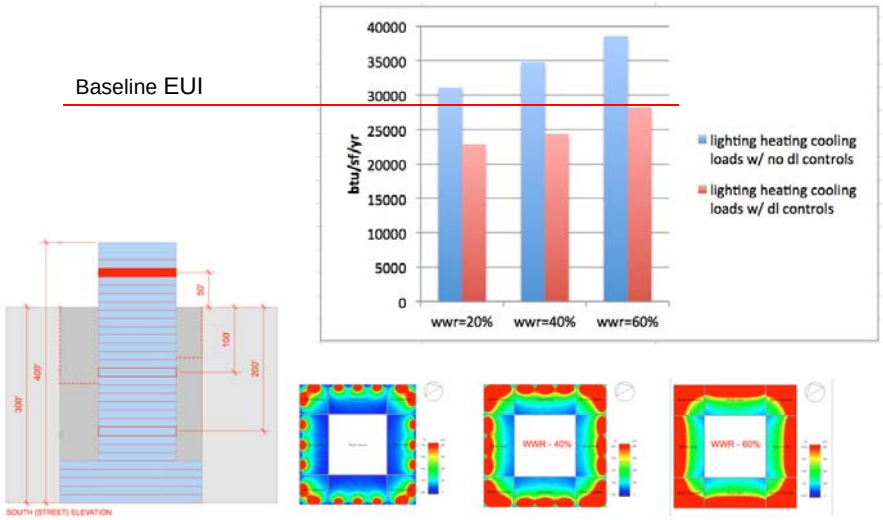
Daylighting and energy in practice – a reconnaissance



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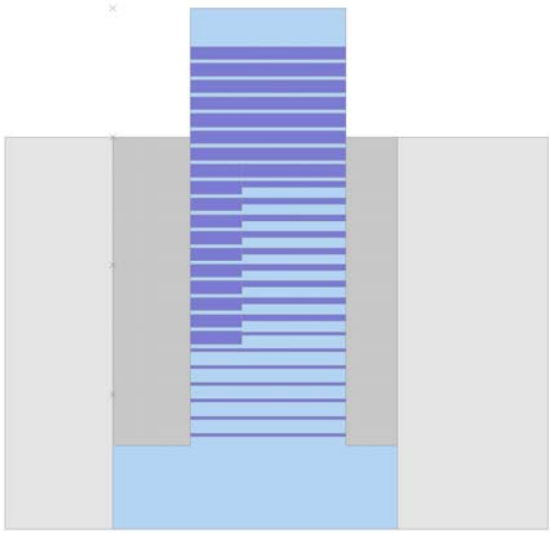
Daylighting and energy in practice – design implications and opportunities



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Summary

- Daylighting is a simple concept, but to work effectively, it must engage building form, orientation, curtain wall glass area and type, daylight and shading technologies, interior layout, materials, electric lighting and dimming controls. Daylight design decisions must be comprehensive.
- To analyze, track, and guide design decisions, parallel energy and daylighting simulations offer the best way to balance their sometimes cooperative, sometimes competing demands.
- During a blackout, daylight, assisted by PVs, can provide in depth light for emergency exiting and services.
- Daylighting design decisions need to identify and address large scale negative consequences, in particular external reflections and shading, but also lesser externalities such as vibrations and noise, snow accumulation/ice formation, wind vortices, and street noise amplification.
- Current codes and standards have now taken the preliminary step to legitimize and incorporate daylighting by making daylighting controls mandatory. Whether the code language and constructs confuse or fruitfully engage remains to be seen. Have patience.
- Code requirements will put more daylight into our buildings and focus our design thinking on the relationship of building to light. The sky is the limit – and that is a fact.

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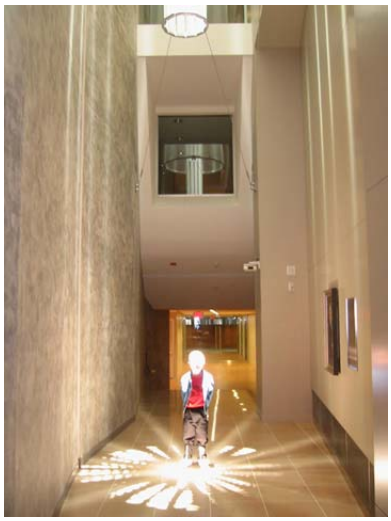
Coda: Daylight and Wellbeing?

Over the last 15 years, multiple research teams have confirmed that our circadian clock, the one that times our daily biological rhythms from sleep to defecation, is cued by light at 460 nm. That's in the dark blue part of the visible light (daylight) spectrum.

The main building and design implication is that daylight is not just about lux on the work surface but also plays a key role in our health and well being.

How soon before ASHRAE comes out with a minimum CCC (circadian clock coefficient) as part of the glazing code?



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