Lighting Design with Efficiency

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A special presentation of the Energy Center of Wisconsin

Daylighting for Lighting Geeks

Some of the following slides were developed in conjunction with the California Collaborative for High Performance Schools and included input from James Benya, Charles Eley and Lisa Heschong.

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A Renewed Interest in Daylighting: The Next Major Design Challenge

- Makes interior spaces more pleasant and appealing
- Recognized as a significant aid in academic performance.
- Can provide significant energy cost savings.
  - Peak savings tend to occur at peak demand and peak rates
- A very large percentage of California schools are in nearly ideal climates for daylighting
  - Minimum temperature differential indoors to outdoors
  - Very high daylight availability

What is “Daylighting Design”?

- Designing spaces to use diffuse light from the sky.
- Use daylighting to provide the PRIMARY illumination within a space.
- Design the electric lighting system to SUPPLEMENT the daylight.
  - Make sure it is turned off when not needed.
  - Provide adequate light when no daylight is available.
- Includes the design of architectural and interior elements such as light shelves and shades to control daylight quantity and quality.

Symantec R&D Education Campus

HOK Architects

What is NOT Daylighting?

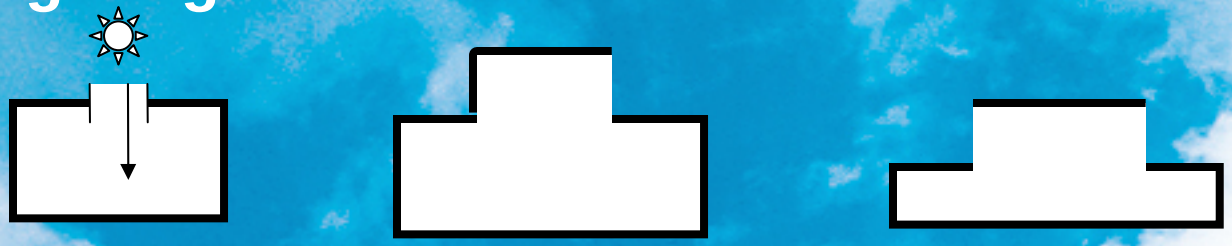
- Too much daylight – a solar oven
- Incorrectly massed and oriented buildings
- A building with good daylight illumination BUT the electric lights burning away.

Direct sunlight is not good daylight

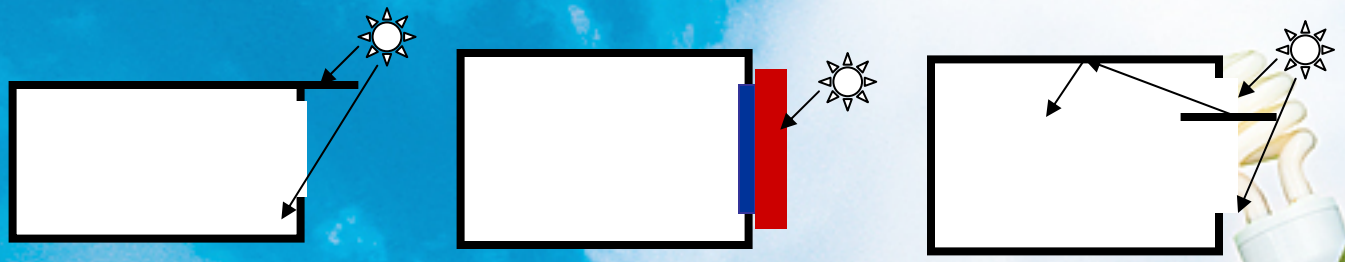
- Too bright, causing contrast and visual comfort problems.
- Significant infrared radiation causes local thermal discomfort
- Does not diffuse the light, making use of electric lighting necessary and increasing the cooling load

Basic Types of Daylighting

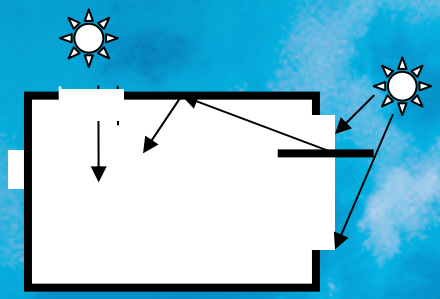
Toplighting



Sidelighting

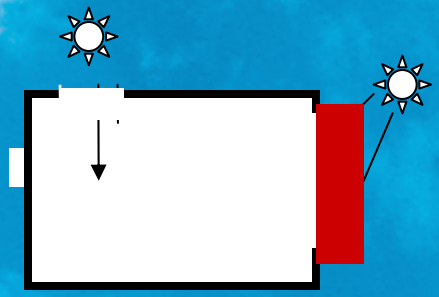


Some Combined Types of Daylighting

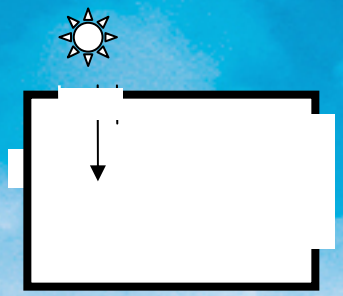


Sidelighting + Toplighting

Light shelf positioned to prevent solar gain during cooling season. South exposure only.



Vertical fin positioned to prevent solar gain until end of school day. East or west exposure only.

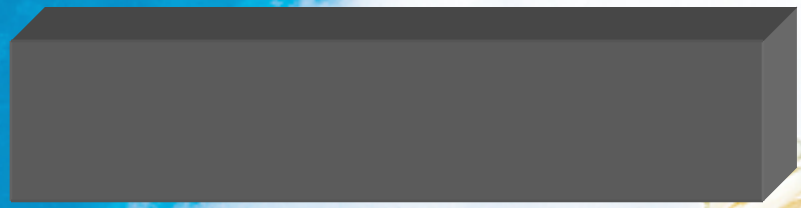


North façade – no additional shading is needed.

Basic Principles of Solar Orientation

Worst Exposure

- North and south ends provide minimum interior light
- East and west sides tend to introduce too much light and heat
- East and west sides require complex shading systems
- Shading often requires blocking view glazing



Ideal Exposure

- North side can introduce a maximum of diffuse daylight
- South side can be passively shaded most of the year without blocking view glazing
- East and west sides can have minimal fenestration

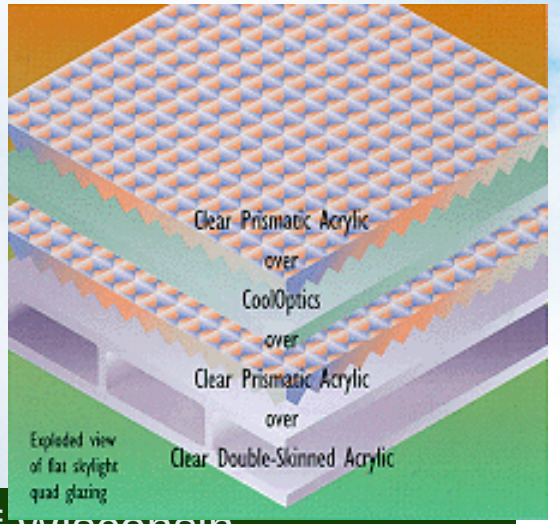
Basic Daylighting Design Principles

- Passive Solar before anything fancy
- Allow NO direct sun penetration, except in circulation spaces.
- Diffuse the light broadly through diffusing glazing and/or shading.
- Introduce daylight as high as possible.
- Use light colored surfaces.
- Keep brightest surfaces out of line of sight.
- Provide blinds or louvers where there is potential for glare.
- Only use diffuse glazing above eye level.
- Provide specific shading for audio-visual control.

Skylights – Simple and Reliable Daylight

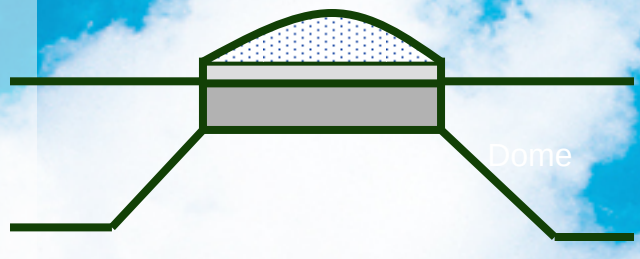
Consider skylights whenever possible in single story buildings and the upper level of multi story buildings. Use diffuse or prismatic skylights in most cases. Skylights with internal louvers are an excellent option for light level control but add cost.

- Proper sizing needed. Use SkyCalc or equivalent.
- Consider modern skylights using prismatic refractors, specular throats and other technologies to increase efficiency, allow smaller skylight to floor ratio (SFR).
- "Cool" skylights with low-e type filtering now available – check them out.
- Skylights are:
  - Effective all day long.
  - Effective under sunlight or cloudy skies.
  - Comparatively inexpensive.
  - Relatively independent of building orientation.



Skylight Keys to Success

- Don’t use clear skylights
  - Consider prismatic and diffusing options
  - The higher the Visible Light Transmission, the smaller the skylight needs to be.
  - Possibly use a skylight with a low-e layer, especially in desert and warmer climates
- Assuming 60% VLT, match skylight size to mounting height. (If using larger skylights, use lower VLT)
  - 4 sf to about 12-14’
  - 8 sf to about 16’
  - 12 sf to about 20’
  - 16 sf to about 30’
- Provide a white splay for the skylight
  - Total area at least 4x the area of the skylight
  - Angle approx. 45 degrees



Deep Splayed Well

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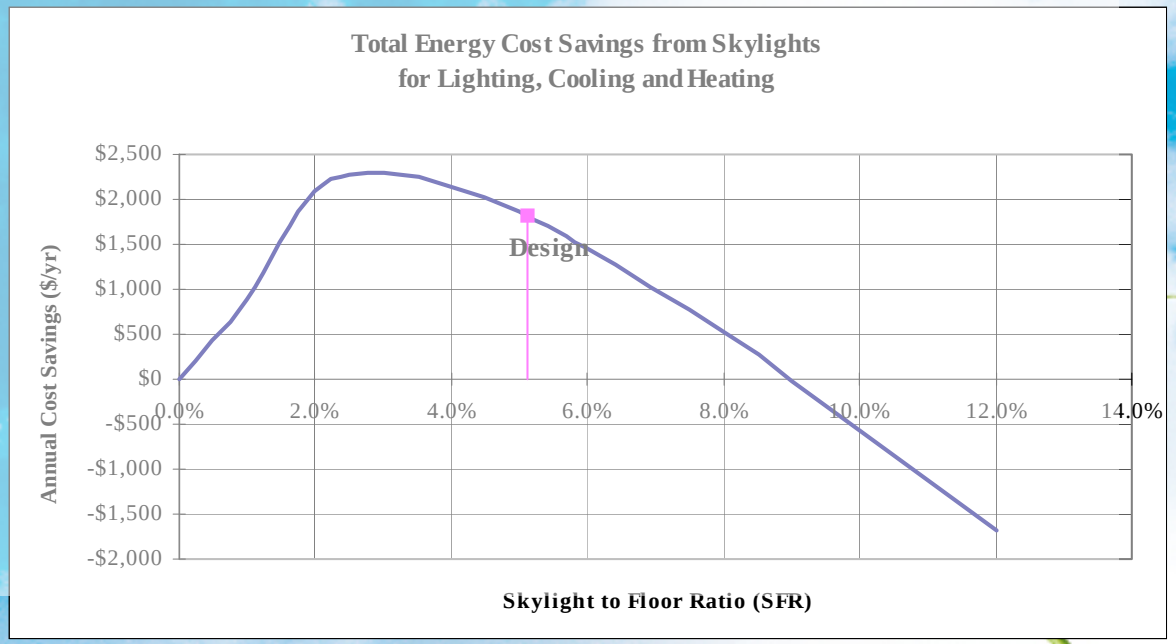
SkyCalc

- Skylight design tool
- Standard Excel Spreadsheet Template
- Readily available data for most of California Climate Zones
- Built-in basic lighting calculations, energy cost analysis, and other useful information
- Makes skylight sizing quick and easy
- Accounts for
  - Heating
  - Cooling
  - Lighting
  - Energy Rates
  - Occupancy/use



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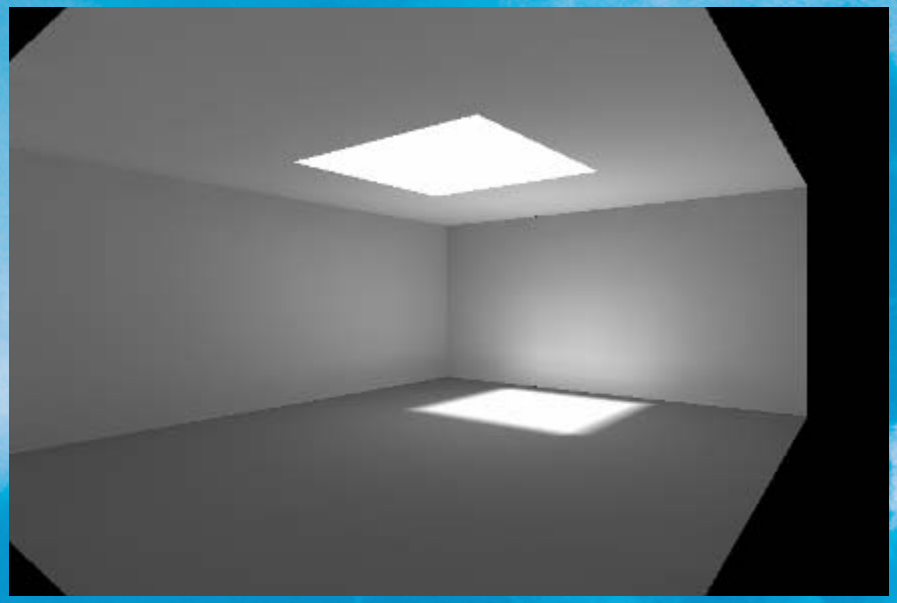
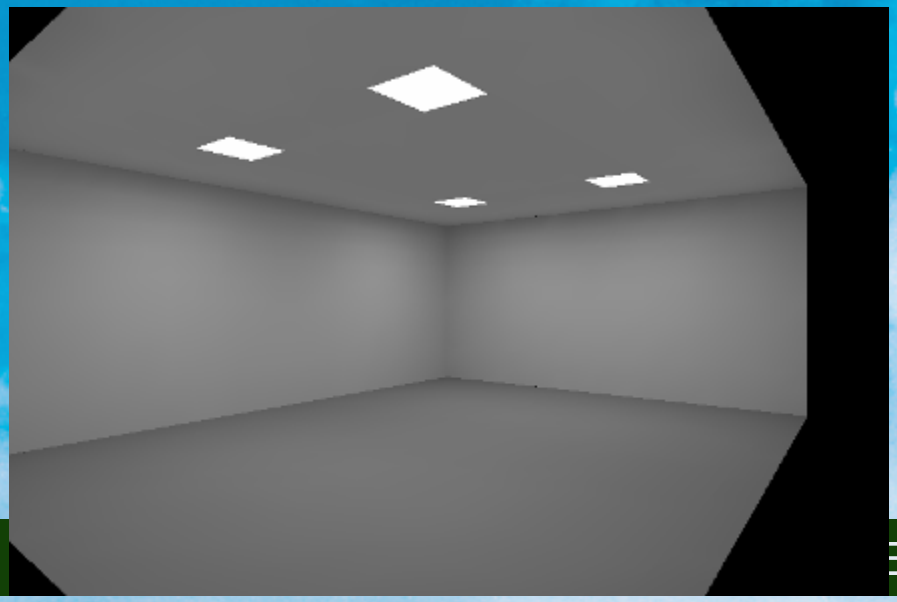
Classroom Design Using SkyCalc





PROJECT: Washington School for the Deaf

Typical small classroom 20 x 25, 10’ ceiling

Original Daylight Concept

Single Center Skylight 8’ x 8’ clear. Total of 64 SF (12.8% SFR) with VLT =50%

Average light level: 604 fc (equinox clear)

Peak light level: 3928 fc

Typical light level: 80-100 fc

Minimum light level: 63 fc

Recommended Daylighting Revision

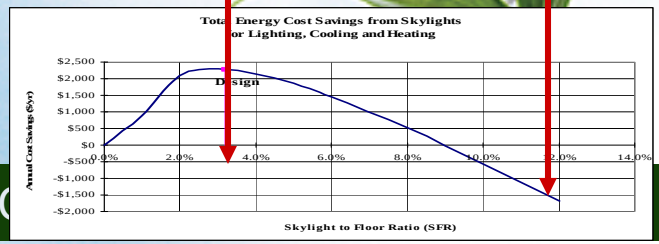
4 diffuse skylights, 2’ x 2’ , total of 16 SF (3.2% SFR) with VLT=50%

Average light level: 121 fc (equinox clear)

Peak light level: 172 fc

Typical light level: 80-100 fc

Minimum light level: 72 fc



Two Gymnasiums Using SkyCalc (~ 4% SFR)

Four large (8’ x 16’) skylights 50% VLT 4% SFR

Average light level 200 fc (equinox clear)

Maximum light level 335 fc

Minimum light level 83 fc

Twenty small (4’ x 4’) skylights 60% VLT 3.33% SFR

Average light level 142 fc (equinox clear)

Maximum light level 172 fc

Minimum light level 80 fc

(Calculations for Sacramento)

Skylights with Shading

An optimal design for a 1440 SF Large Classroom. “Daylight dimming” using internal louvers in the skylighting system permits very low interior light levels suitable for AV uses.

Salida Middle School, Vella Campus

Ken Kaestner, Architect.

CRITICAL COMMENTS

With skylights, increasing the skylight to floor ratio (SFR) can improve performance under cloudy skies as long as the reduced insulation of the roof doesn’t matter much (temperate climates). Partially dimming the daylight can be used to reduce solar gain on sunny days.

BUT…a skylight with closed louvers still has solar gain. Be sure to consider this fact when evaluating

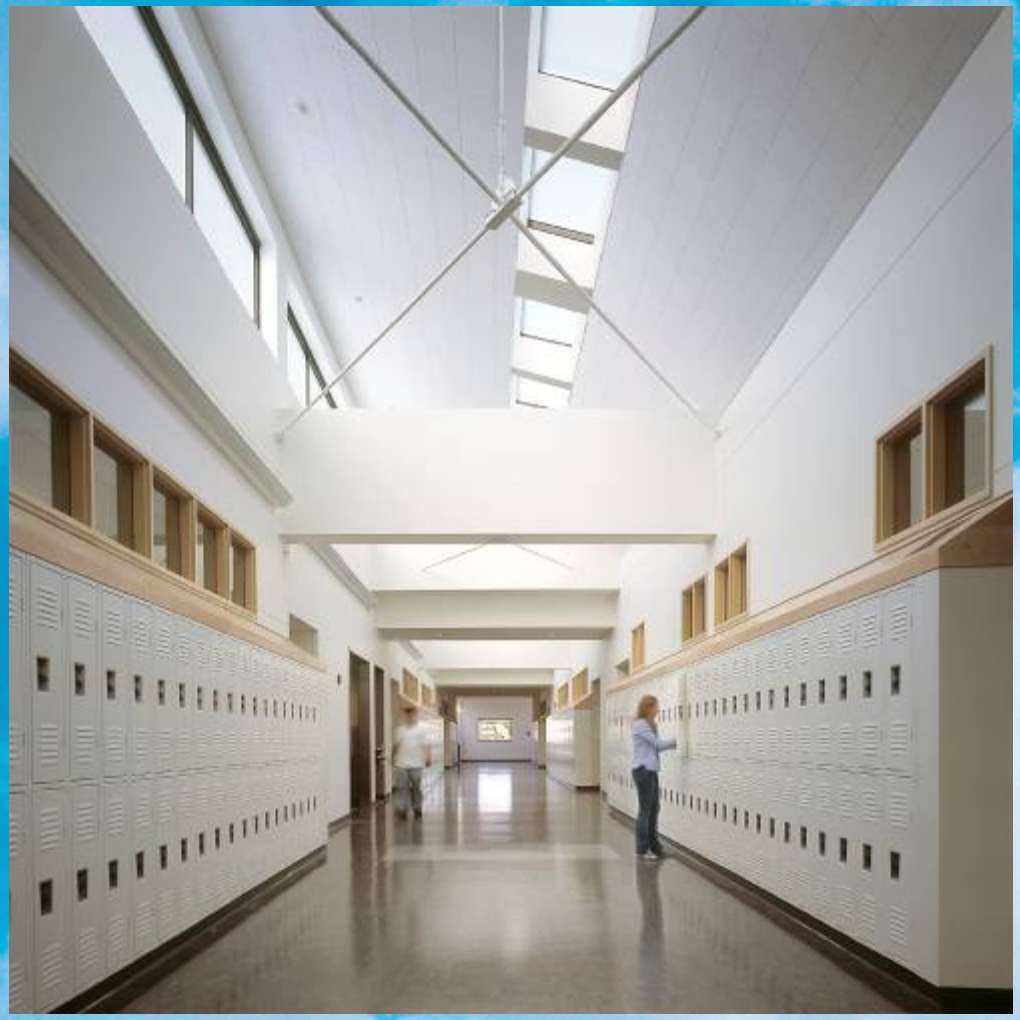
North Facing Clerestory

- North facing clerestories produce excellent daylight with minimum risk.
- Can be relatively large (10-20% fenestration to floor ratio)
- Ceiling should be white to reflect light and to reduce contrast between building and sky

South Facing Clerestory

- A unique design that must be carefully designed and executed
- Not suited for sites with long cooling seasons.
- Approx. 10-12% fenestration to floor ratio
- Ceiling must be white
- Baffles or other diffusing media must be used to prevent direct viewing of the sun.
- Overhang must be designed to cut-off direct exposure during the cooling season.

Skylights + Clerestory



North Clackamas High School

BOORA, Architects

A technique that works under all weather conditions and all times of year.

CRITICAL COMMENTS

1. **In cooling climates, this may not be best for spaces with occasional use like corridors.**
2. **Borrowed light panels are used to introduce daylight into adjacent spaces. Do not rely upon borrowed light to "daylight" those spaces.**

Sidelighting

- Consider using windows to provide daylight when toplighting is not practical.
- Solar orientation is critical. Windows must be shaded on the south, east and west faces. Light shelves with combination clerestory/view windows can be used on the south face. Window walls and high clerestory windows can be clear on the north face – on the east, south and west faces, shading is needed.
- East and west facades – especially west – can be partly shaded with vertical shades as well as horizontal.
- Two side lighting is much better than one side.
- Shaped ceilings can improve the performance of sidelighting.

The pluses and minuses of windows

PLUS

- View is **highly** desirable. May have benefits as great as those of any form of daylighting, even if task light levels are not provided
- Can produce useable task light levels.
- Less concern over insulating value than skylights.
- Less problems with leaks than skylights.
- North exposures are generally benign

MINUS

- Subject to extreme solar heat gain and localized discomfort for periods of the day.
- Significant seasonal variations.
- East and west exposures are very difficult to address and generally require shading for both glare and solar gain control
- South exposures are easier but still require control of solar gain and glare.
- .Windows get covered with “stuff”.

South Sidelighting with Shelf and Angled Ceiling

North Clackamas High School

BOORA Architects

CRITICAL COMMENTS

1. **Note the shaping of the ceiling. This improves indirect daylight penetration.**
2. **This only works on the south façade and on sunny days.**
3. **Classroom orientation should be such that the teaching surface is on the side wall.**
4. **Glare control blinds might be required for sunny winter days.**
5. **Marginal in climate zones 10-15.**

East or West Sidelighting

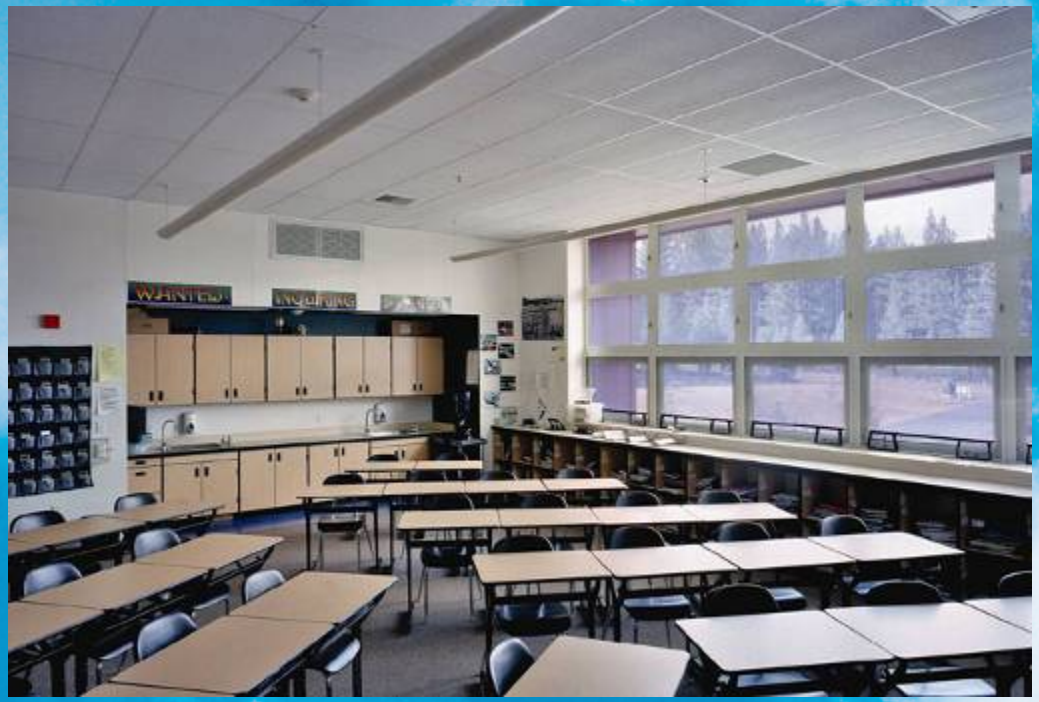
The Sidwell School

Kieran Timberlake Associates

CRITICAL COMMENTS

1. **East and west facades are problematic, especially in sunny climates.**
2. **The fins are designed to prevent direct solar penetration after 9AM and before 3PM during the cooling season.**
3. **Glare control blinds will be needed.**
4. **Not recommended for Climate Zones 10, 14 and 15. Marginal in 12 and 13.**

North Sidelighting



Alder Creek
Elementary School

Lionakis
Beaumont Design
Group

CRITICAL COMMENTS

1. **Reduced insulation is a major consideration. In a temperate climate this window wall can have a lot of glass.**
2. **Low-e glass is only needed when ground plane reflections are an issue. Used low-e glass when viewing large heat islands or hot ground planes, e.g. desert.**
3. **In the summer, some early morning and late afternoon direct sunlight can occur at northern latitudes.**

Combining Daylighting Strategies

- **Skylights + Clerestories**
  - No view
  - If the clerestory faces north, a very high performance combination
- **Skylights + Windows**
  - Offers view
  - As long as the problems of windows are addressed, works extremely well.
- **Clerestories + Windows**
  - Offers view
  - Also a good solution if the window's problems are resolved and the clerestory faces north.
- **Skylights + Clerestories + Windows**
  - Offers view
  - Another good solution but needs to address window issues – and the clerestory needs to face north.

Clerestory + Window

Oakridge High School

A special presentation of the Energy Center of Wisconsin

Related Daylighting Design Considerations

Structural Issues

- Roof penetrations
- Additional reinforcing

Classic Concerns

- Noise Control.
- Safety and Security.
- Air and Water Leakage.
- Condensation.
- Fire Protection.
- Visual Privacy.
- Maintenance and Replacement.

Daylighting Analysis Tools – Physical Models

- Use of Scale Models
  - Best studied under both an artificial sky (diffuse light) and heliodon (direct solar radiation) in a lab.
  - Can also be studied outdoors if you know what you're doing
  - Need to be ½"= 1' or larger scale.
- Benefits of Model Methods
  - Hands on three dimensional study
  - Daylight scales perfectly
  - May allow reconfiguration
  - Allows understanding of what works and why
- Disadvantages of Modeling
  - Accurate results require proper models, skill, and good instruments.
  - Don't try this at home

A light meter adapted for outdoor model analysis

Daylighting Lab, [illegible] California Edison

Daylighting Analysis Using Computer Simulations

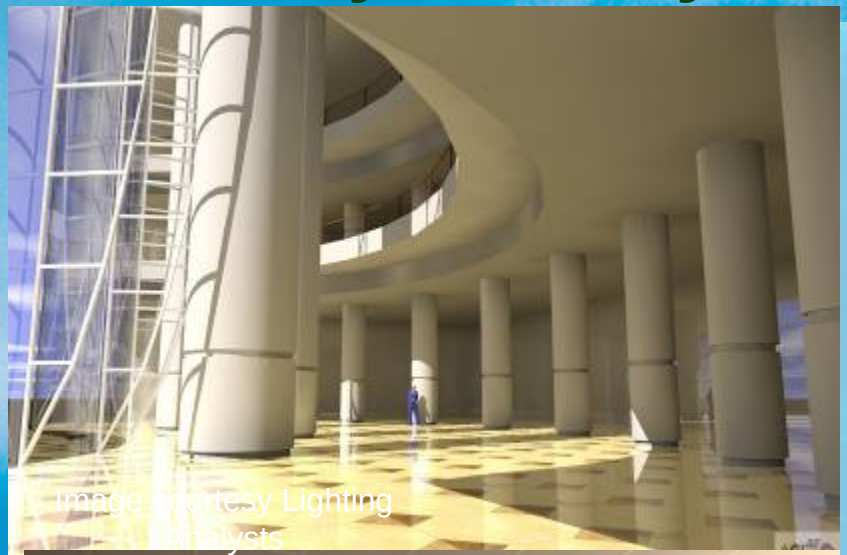
Modern lighting software permits daylighting analysis as good as any model

- Quick 3-D modeling
- Rapid analysis under many conditions
  - Time of day
  - Time of year
  - Weather condition
  - Different glazing conditions
- Benefits
  - Flexibility in modeling variety of daylighting conditions
  - Ease of modeling design iterations / refinements
  - Accurate modeling of surface characteristics
  - Flexibility in automating annual visual and numeric calculations
- Challenges
  - Requires adequate computer equipment and software
  - Requires general computer knowledge and expertise in software

Simple Radiosity Analysis

- Simple models deliver quick results.
- Easy to create, fast to run
- Examples of a south facing classroom with sidelighting employing a light shelf, with higher transmittance for the clerestory glazing and lower transmittance for the view glazing
  - Top, winter, no shade
  - Middle, winter, with glare shade
  - Bottom, summer, no shade

Radiosity with Ray-trace Highlights



- More complex models require more input and analysis time.
- More learning curve, longer to run
- Allows combined electric/natural lighting designs
- More compelling images
- Examples
  - Top, atrium lobby daylighting, using AGI32
  - Bottom, classroom with sidelighting and horizontal blinds, using Lumen Designer

Ray-tracing software

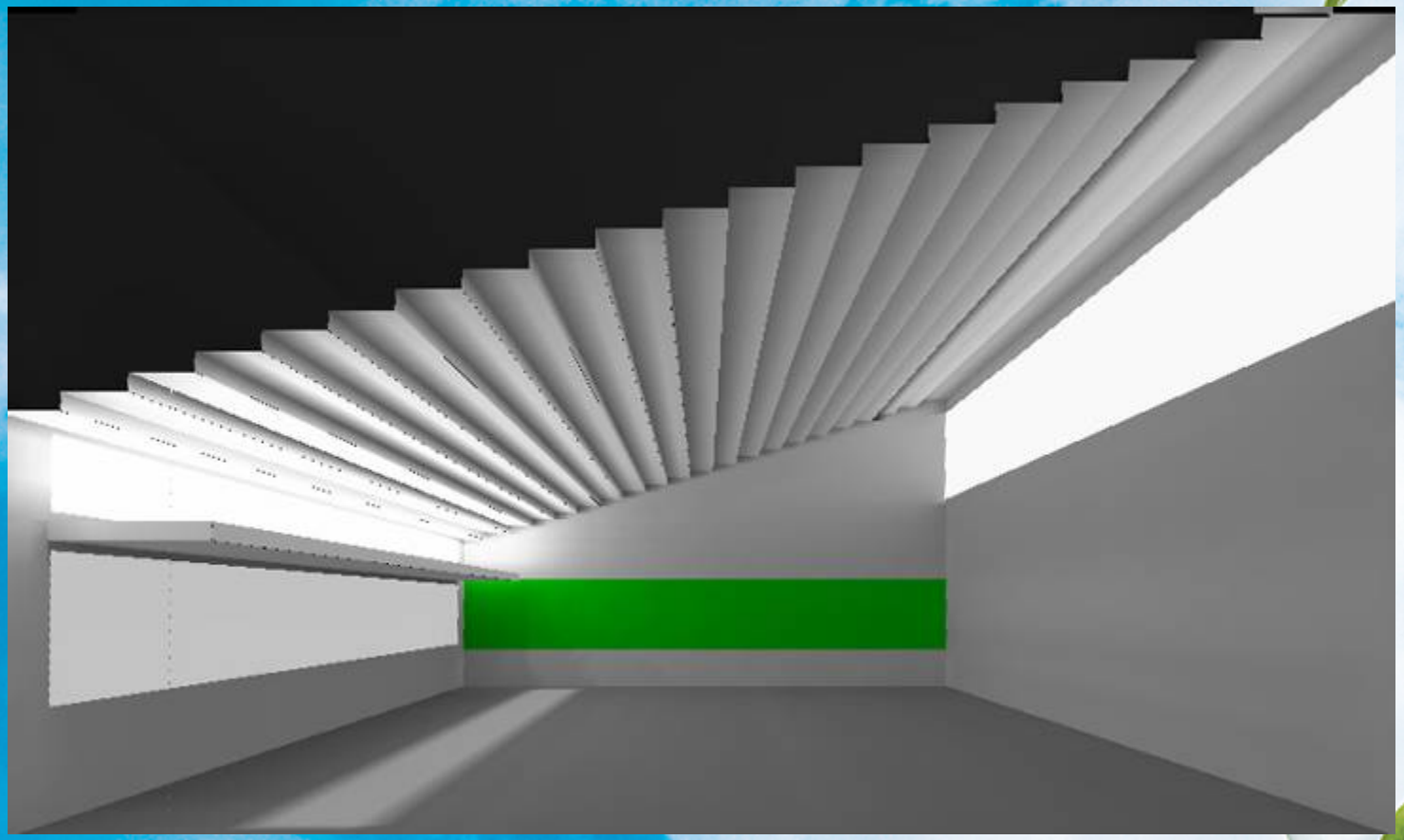
Images courtesy of Architectural Energy Corp.

- Much more complex models require even more input and analysis time.
- Significant learning curve, potentially taxing to the computer resources of most offices
- Most compelling images – if you spend the time, you'll get the picture!
- Poor, geeky user interface more suited for IT than Architecture
- Performance: Radiance is the king of the hill

Other Software to Consider

- **DAYSIM** A free annual daylighting analysis program based on the Radiance engine. Complex, but may be a very useful tool once the analyst has experience.
- **SKYCALC** Shown earlier, a free desktop tool when skylights are the only daylight source.
- **ECOTECT** A Radiance interface designed specifically for daylighting analysis. Incorporates weather data and a host of other improvements not part of the original Radiance engine.
- **SPOT** A Radiance engine optimized for daylighting sensor placement analysis, can provide a number of other Radiance based calculations. Free.
- **OPTIC** A free program from LBNL determines the optical characteristics of standard and custom combinations of glazing system elements
- **WINDOW** Another free program from LBNL determines the thermal characteristics of standard and custom combinations of glazing system elements

Example: Radiosity analysis, north facing clerestory, south facing window with shelf and glare shade



December, sunny, noon. Daylight is 189 fc average, 500 max, 73 minimum. This analysis used Lumen Micro and took 20 minutes to construct and execute.

Tubular Daylighting Devices

- Range of sizes from 8” to 22” diameter
- Reflective, flexible tubes.
- Collector at top, diffuser at bottom.
- For active interiors such as offices and other small spaces, approx 75-150 sf per tube.
- For interior spaces with minimum lighting requirements, can also be used with wide spacings

Achieving the Daylight Credit

- **Option 1 Single Point in Time Analysis**

  This method is best suited for the analysis of complex daylighting systems using point-by-point computer programs like Lumen Micro, Lumen Designer, AGI32, and Radiance. It can also be studied using a physical model.

- **Option 2 Daylight Saturation Percentage (DSP) Analysis**

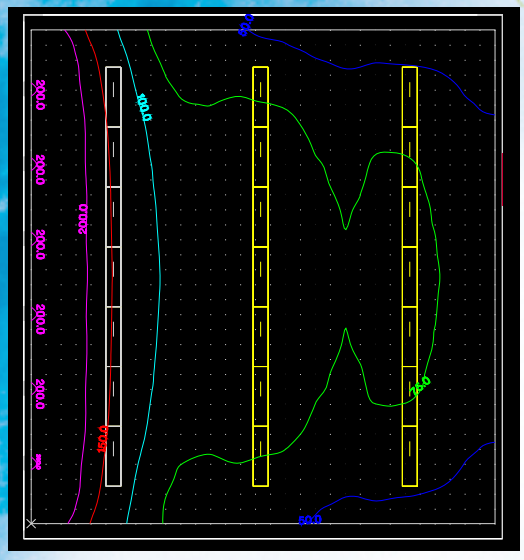
  This method is best suited for using daylighting analysis programs like DAYSIM and SPOT and for complex analysis using Radiance.

- **Option 3 Daylight Factor Analysis**

  This method is best suited for analysis of schools that will be in predominantly cloudy climates or have all north facing glazing. This is the LEED 2.1 method and it is not very good for most of USA's climate zones.

Single Point in Time Analysis – Computer Option

- Computer analysis for the room at 12:00 Noon on 3/21
- Criterion: achieve at least 25 footcandles throughout the room in the task plane (don't consider a 4' border around the room)
- Advantages:
  - Permits fast analysis
  - Sunny days can be used if desired
  - Allows full consideration of shading systems
- Disadvantages
  - Does not address seasonal and weather variations very well.



Single Point in Time Analysis – Model Option

- Model analysis for the room at 12:00 Noon on 3/21
- Criterion: achieve at least 25 footcandles throughout the room in the task plane (don't consider a 4' border around the room).
- Advantages:
  - Permits model analysis without a lab
  - Allows full consideration of shading systems and other external elements
- Disadvantages
  - Requires accurate ½" = 1' scale model or larger
  - Requires calibrated instrumentation and accurate calibration of daylight conditions.

Break

Go Get Some Daylight