Successful Daylighting Techniques and Technologies

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Daylight Dividends Focus Groups

- **Portland, OR**: Architects, Engineers, Designers
- **New York, NY**: Architects, Engineers, Designers
- **Charlotte, NC**: Owners, Developers, Managers
- **Des Moines, IA**: Owners, Developers, Managers
- **Orange County, CA**: Designers, Owners, Developers, Managers
Daylight Dividends
Focus Group Results

- Top three perceived benefits
  - Occupants’ feeling of well-being
    - Comfort
    - Feel good about self
    - Like being outdoors
    - Productivity
  - Energy savings
  - Improved aesthetics

- Primary barriers
  - First cost and cost effectiveness
  - Problems with technologies
  - Building’s site location
  - Added design/financial risk
  - Inconsistency in daylight availability across the building and during the course of the day
Building Form– Letting the Light In

- Bring light in high
- Use light color surfaces
- Diffuse the sun
- Bring people to the light
- Switch off the electric lights
Side Lighting

- Rule of thumb:
  - Effective daylight penetration ($D$) = $1.5x$ window height ($H$)

Daylight penetration increases with window height.
Side Lighting

- DELTA Portfolio: DeGraff St. Industrial Center, Office and Small Manufacturing
  www.lrc.rpi.edu/programs/delta/publications/publicationsDetails.asp?id=141&cat=14

Clerestory Lighting

- DELTA Portfolio: SONY Disc Manufacturing, Administration and Support Spaces
  www.lrc.rpi.edu/programs/delta/publications/publicationsDetails.asp?id=173&cat=12
Side Lighting

- DELTA Portfolio: Sacramento Municipal Utility District, Office Building
  - www.lrc.rpi.edu/programs/delta/publications/publicationsDetails.asp?id=139&cat=12
  - High occupant satisfaction
  - 8% savings by daylight
  - $56K yearly energy savings

Top Lighting

- DELTA Portfolio: Sacramento Municipal Utility District, Office Building
  - www.lrc.rpi.edu/programs/delta/publications/publicationsDetails.asp?id=139&cat=12
  - Splayed Skylights
Top Lighting

- Rule of thumb:
  - Skylight spacing ($S$) = 1 to 1.5 x ceiling height ($H$)

Electric Lighting Control

Harvesting the Energy Savings:
Switch or Dim the Electric Lights
Daylighting and Energy Savings

- Market penetration is poor
- Less than 1% of new construction uses photosensors

TomoTherapy, Inc.
Madison, Wisconsin

- T-5 HO lamps in direct/indirect lighting fixtures with dimming electronic ballasts
- LPD = 1.0 watts/ft²
- Long payback of dimming ballast and daylighting controls

www.lrc.rpi.edu/programs/daylighting/pdf/TomoTherapyCaseStudy.pdf
Fluorescent Lamps Weren’t Designed for Dimming

- Compatibility issues exist to dim without degradation to lamp life?

Dimming T8 Fluorescent System Problems

- Lamps (broken electrodes)
- Luminaires (improper wiring, disconnected wires)
- Ballasts (failing, low input voltage, lack of power)
- Installation (lamps not rotated into place, discontinuity in electrode heating circuit)
- Troubleshooting procedure
Simplifying Daylight Technologies

- Automatic on/off
- Designed to retrofit
- Low cost

DaySwitch Energy Savings Potential

Energy savings comparison of systems in open office plans for different cities

- Albany NY: 15%, 24%, 37%
- Sacramento CA: 12%, 19%, 35%
- Portland OR: 14%, 22%, 37%
- Charlotte NC: 17%, 28%, 39%
- Phoenix AZ: 13%, 29%, 34%

Systems compared:
- DaySwitch
- DaySwitch and AutoBlinds
- Perfect dimming
Daylight Dimming

- Wireless, remote sensor
- Self-commissioning
- Occupant preference adjustment

Commissioning time < 3 minutes in most cases

Sponsor: Connecticut Light and Power

Daylighting Controls: Making Them Work

- Proper selection of the correct controller for the design situation
- Proper location of the controls
- Proper adjustment to ensure correct operation
Specifier Reports: Photosensors

October 2007

Trends

- Photosensors part of lighting control or whole building control system
- Interface with load shedding or occupancy sensing
- Added features (such as remote controls or remote interfaces) for simpler adjustments and commissioning procedures

No one product satisfied all requirements or was fully adaptable to different installations

- Complex products perform no better than simple products
- Products tested perform no better than those tested ten years ago at meeting the design criteria: constant workplane illuminance
## Control Characteristics and Features Matrix

The matrix below indicates when a characteristic is important to consider with a particular product type.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Open Loop Switching Systems</th>
<th>Open Loop Dimming Systems</th>
<th>Closed Loop Switching Systems</th>
<th>Closed Loop Dimming Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of response</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
<tr>
<td>Spectral response</td>
<td>HD</td>
<td>HD</td>
<td>HD</td>
<td>HD</td>
</tr>
<tr>
<td>Spatial response</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
<tr>
<td>Deadband</td>
<td>MH</td>
<td>—</td>
<td>MH</td>
<td>—</td>
</tr>
<tr>
<td>Compatibility with applicable temperature and humidity conditions</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
<tr>
<td>Ballast and component compatibility - manufacturer should list compatible ballasts and the components necessary to make a complete operating system</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
<tr>
<td>Power requirements - operating voltage, input and output current must be clearly indicated</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
<tr>
<td>Number of ballasts the device is able to control</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
<td>MH</td>
</tr>
</tbody>
</table>
Visual Discomfort

- People will take action to reduce or eliminate daylight if it causes discomfort or increases task difficulty
  - Maniccia et al., 1999
Auto Blind Concepts

- Manual anytime
- Auto open once per day
  - East facade: afternoon
  - West and south facades: evening
- PV or mechanical device: no wiring required

Auto Blind Energy Savings Potential

<table>
<thead>
<tr>
<th>Time clock switched</th>
<th>Automatic switching</th>
<th>Perfect dimming</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>100%</td>
<td>63%</td>
</tr>
<tr>
<td>100%</td>
<td>86%</td>
<td>50%</td>
</tr>
<tr>
<td>50%</td>
<td>76%</td>
<td></td>
</tr>
</tbody>
</table>

Integrated Skylight Luminaire (ISL)

- High bay applications
  - “Big box” retail
  - Warehouses
  - Light industrial
- Demo in Norwich, CT

Sponsored by:
New York State Energy Research and Development Authority
Connecticut Light & Power

ISL Design Criteria

- Meet manufacturers’ and owners’ concerns
- Automatically capture energy savings
- Glare control; no harsh shadows
- Know it is daylight
- Work under clear and overcast skies
- Easy to install, commission, and maintain
- Use simple, low cost technology
- Applicable to many buildings
Integrated Skylight Luminaire

Lighting Controls Options

Continuous Dimming:
All lamps are dimmed at the same time until they turn off

Step Switching:
Rings of lamps are turned off; balance lamp life of each ring
Commissioning Procedure

Integrated Skylight Luminaire

Before installing ISLs

After installing ISLs (daytime)

After installing ISLs (nighttime)
Energy Savings

Energy Savings from Three* Integrated Skylight Luminaires
Spring, Summer, Fall 2002

- Previous metal halide
- ISL without dimming control
- ISL with dimming control (actual)

*Note: Data were available for three of the four units, including both step dimming and continuous dimming operation.

Benefits Beyond Energy
Daylighting Benefits Beyond Energy

- Report reviewed by blue ribbon panel
  - Enhancing Productivity
  - Daylight & Health
  - Daylight & Finance
  - Misunderstandings


The Biophilia Hypothesis

- Innate need to be in contact with nature?
- The one reason why windows are inherently superior to electric lighting
Preference for Windows

“90% of people say it is important or very important to have windows in their office.”

Preference for Windows

- As long as people are thermally comfortable and do not lose privacy
Finance

- A wall containing windows costs more to construct and maintain than one without.
- Windows have a positive effect on the rental value of a space.
  - Office space with windows = $15-$20/ft²
  - Office space without windows = $12-$17/ft²

Is View a Factor in Price Structure?

<table>
<thead>
<tr>
<th></th>
<th>% &quot;yes&quot;</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hotels (n=21)</td>
<td>48%</td>
<td>$15-70/night for those that price by view</td>
</tr>
<tr>
<td>Apartments/Condos (n=15)</td>
<td>87%</td>
<td>One condo reported $15,000-25,000 increase with view</td>
</tr>
<tr>
<td>Offices (n=22)</td>
<td>73%</td>
<td></td>
</tr>
</tbody>
</table>


Task Performance/Productivity

- More light gives better task performance
- Better vision for seniors/people with low vision
- Good color characteristics
The Circadian Connection

- Physiologically, daylight is an effective stimulant to the circadian system
- The impact of daylight on task performance and health operating through the human circadian system?

Building Design/
Case Studies
Building section: roof monitor, skylights, flower diffusers
35 Skylights

2 Roof Monitors
Design Concept:
Roof Monitor

- Diffuse block and diffuse direct sunlight.
- Clustering the interior ceiling provides a smooth brightness transition.
- Higher light levels to draw people into these areas: produce, back of store.
- Diffuse solution: no direct sunlight below monitor.
- Baffles for visual interest as daylight pattern progresses across them.

12-month Progression...
Inspiration

Design Evolution
Design Concept:
Integrated Sky Light

Lamp petal
T8 Fluorescent Lamps

Leaf from customer’s logo/identity
used as a branding tool

North Elevation

Proposed window height: 18'-10"

Loading dock
West Elevation

Proposed window height: 18'-10"

Proposed window height: 11'-10"

West Corridor Daylight Study

Natural light brightens the hallway while small light shelves eliminate direct sun glare.
Daylight transmits through to men’s room

Base Case 1

- No skylights
- Developer’s sidelighting
- Energy cost: $527,366/yr
  - Base Case 1 meets ASHRAE 90.1-2004 requirements
  - Whole-building method used for lighting
  - For retail store, 1.5 watts/ft² for general overhead lighting
  - Additional 1.6 watts/ft² for task lighting in retail area
Base Case 2

- 35 skylights
- Efficient electric lighting
  - Base 1 Energy Cost: $527,366
  - Base 2 Energy Cost: $444,215
  - Savings: $83,151

LRC Alternate 1

- 53 skylights
  - Base 1 Energy Cost: $527,366
  - LRC Alt 1 Energy Cost: $442,497
  - Savings: $84,869
LRC Alternate 2

- 35 skylights
- 2 roof monitors

  - Base 1 Energy Cost: $527,366
  - LRC Alt 2 Energy Cost: $442,180
  - Savings: $85,186

LRC Alternate 3

- Improved sidelighting

  - Base 1 Energy Cost: $527,366
  - LRC Alt 3 Energy Cost: $443,135
  - Savings: $84,231
LRC Alternate 4

- 35 skylights
- 2 roof monitors
- Improved sidelighting

  - Base 1 Energy Cost: $527,366
  - LRC Alt 4 Energy Cost: $441,133
  - Savings: $86,233

More light, less energy!
Smith Middle School

- Built in 2001
  - 637 students
  - 135,764 ft²
  - 54% daylit

Daylighting Strategy

- Integrate daylighting into the building’s design
  - South-facing wall windows employ light shelves
  - Minimize east- and west-facing windows
Daylighting Strategy

- Integrate the daylighting strategy into the building’s design
  - Utilize south-facing roof monitors
  - Use unevenly spaced cloth baffles to eliminate glare
Daylighting Strategy

- Wall-mounted luminaires are used where the roof monitor meets the ceiling
- Drop-in, three-lamp, parabolic troffers are used in the drop ceiling

Gymnasium uses daylighting

Main hallway

Daylighting awareness program
Lighting Controls

- All fixtures use dimming ballasts; each class room uses closed-loop photosensors and control panels
- Motion sensing is through a dual technology (ultrasonic and infrared) controller

Control Scheme
Lighting Controls Installation

Commissioning the System

- Too many parts and controls
- Quote from the maintenance supervisor: “Commissioning was a pain in the @$%&!”
- Expensive to replace dimming ballasts
  - $90 vs. $20 for standard ballast
Building Costs

- Total incremental daylighting cost: $158,098
  - $1.23/ft² over entire building (about half is daylit)
  - Includes roof monitors, light shelves, lighting controls, cloth baffles, etc.
- Reductions in peak cooling load (78 tons) and lighting needs reduce the daylighting incremental cost

Energy Savings

- Reduction in annual lighting energy of daylit spaces: 70%
- Reduction in annual cooling energy: 19%
- Increase in annual heating energy due to reduced internal heat from lighting: 20%
Paying for Daylighting

- Incremental cost: $1.23/ft²
- Annual lighting & cooling savings: $0.33/ft²
- Annual heating cost increase: $0.04/ft²
- Total annual energy savings: $0.29/ft²
- Simple payback: 4.2 years

Building Occupant Satisfaction

- “They like it.”
- Teachers love the amount and quality of light
- There is a feeling of spaciousness
- Principal uses the daylighting design as a selling point to attract teachers to work at the school
- Students and teachers find the lighting better here than at other schools
- One teacher said, “I thought I died and went to heaven when I came to work here.”
Lessons Learned

- Daylighting must be integrated into total building design from the beginning
- Teachers believe there are less behavioral problems and there is more motivation to learn due to daylighting
- The cost of replacement dimming ballasts must be factored into any economic analysis of daylighting
- Awareness and management support is critical to energy savings

Daylight Dividends
CASE STUDY

Harmony Library
Fort Collins, Colorado

www.lrc.rpi.edu/programs/daylighting/pdf/HarmonyLibraryCaseStudy.pdf
Design Strategy

- Clerestory glazing
  - Overhanging roof eaves
  - Neutrally-tinted glass
    - 22% visible transmittance
Design Strategy

- General lighting
  - Low ambient luminance
  - Augment with task lighting as necessary

Design Strategy

- Initial control scheme
  - Did not meet design intent
  - Complex for users
  - Upgraded after one year

- New control system
  - Two main components
    - Relay-based automatic switching system
    - Lighting scene module
Lighting Scenes

- Pre-programmed scenes
  - Opening
  - Public
  - Pre-shutdown
  - Night
- Scenes automatically switched according to programmed schedule

Open-loop Switching

- Roof-mounted photosensor
- Operates non-dimming ballasts
  - Minimizes hardware costs
Photosensor Operation

- Photosensor kept lights off most days, April 2004
  - Intermittent on/off cycling on overcast days (5 of 31 days)
  - Few complaints about cycling

Energy Savings

- Roof photosensor controls nearly 50% of lighting watts in main areas
Occupant Satisfaction

Window Comfort Reports

<table>
<thead>
<tr>
<th>Percentage of responses agreeing</th>
<th>Too dark</th>
<th>Dark</th>
<th>Comfortable</th>
<th>Bright</th>
<th>Too Bright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower windows (sunny) n=38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower windows (cloudy) n=34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof windows (sunny) n=35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof windows (cloudy) n=34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Occupant Satisfaction

Electric Lighting Questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use table lamps? n=39</td>
<td>26%</td>
<td>41%</td>
</tr>
<tr>
<td>Notice switching? n=39</td>
<td>74%</td>
<td>26%</td>
</tr>
<tr>
<td>Is switching distracting? n=38</td>
<td>89%</td>
<td>11%</td>
</tr>
<tr>
<td>Electric lights too bright? N=39</td>
<td>92%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Lessons Learned

- Well-designed buildings reduce reliance on blinds for sun shading
- Task lighting helps low ambient lighting design condition
- Dark tinting on windows is not objectionable on sunny days

Lessons Learned

- Switching is noticeable, but not offensive
  - Sometimes confusing (Is it closing time?)
- Switching can save energy costs and avoid initial expense of dimming ballasts
- Public facilities need simple lighting scenes that can also be automatically switched off on schedule
Online Resources

- Available at www.daylightdividends.org and www.lrc.rpi.edu/programs/NLPIP/index.asp

Thank you.