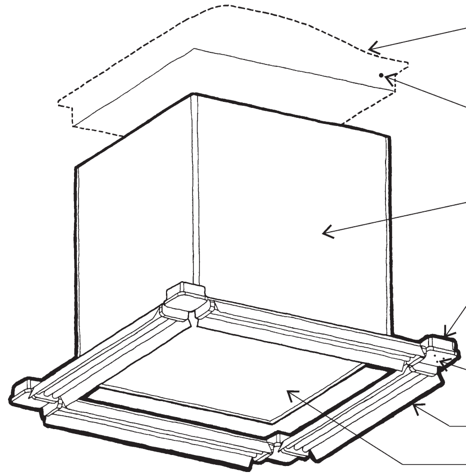
FIELD TEST DELTA

Demonstration and Evaluation of Lighting Technologies and Applications

INTEGRATED SKYLIGHT LUMINAIRE

Contents

Components of the Integrated Skylight Luminaire



Project Profile

The Lighting Research Center (LRC) field tested four prototype Integrated Skylight Luminaires in an industrial setting to determine how the product performs in its intended application. For the field test facility, the LRC chose an open area in a storage and shipping warehouse. The Integrated Skylight Luminaire was designed for this type of high-bay facility, where traditional skylights have had limited success. Often electric lighting is not controlled to take advantage of available daylight. The Integrated Skylight Luminaire was designed to address these issues by pairing diffused daylight and electric light with a photosensor-controlled dimming system that maintains intended light levels in the facility.

Field Test Objectives

Few truly integrated skylight and electric light systems currently exist on the market, and information about their efficiency is limited.[1] Building evaluations have shown that many photosensor-controlled lighting systems do not meet energy savings predictions because of inadequate photosensor design or inadequate commissioning of the electric lighting control systems.[2–5] The LRC tested the Integrated Skylight Luminaire in the field to:

- Test the logistics of installation and maintenance
- Check the functional performance of each component in the integrated system
- Gather employee feedback about the product in its intended setting
- Measure daylight and electric light levels in an actual installation
- Quantify energy savings

Overview of the Integrated Skylight Luminaire

The Integrated Skylight Luminaire combines a skylight, a sunlight diffuser box, and an electric lighting system. A photosensor control system automatically dims or switches electric lights in response to daylight. A portable wireless commissioning device performs initial setup and calibration of the electric lighting system.

The Integrated Skylight Luminaire was developed by the LRC for daylighting in flat-roofed, high-bay buildings such as warehouses, factories, and "big-box" retail stores. High-bay buildings are ideal candidates for skylights because they tend to be single-story, large-volume spaces. Windows cannot deliver daylight to the deep interior of these types of spaces. High ceilings that are typical of these buildings facilitate uniform light distribution throughout the space and minimize the perception of glare from electric lighting systems and skylights.

Product Description

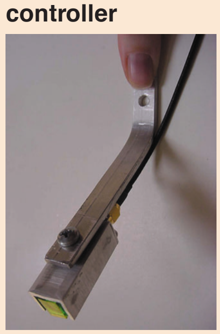
The Integrated Skylight Luminaire consists of a skylight, a sunlight diffuser box, an electric luminaire assembly, and a photosensor with an electronic luminaire controller. A small portable device is used to commission the system and adjust illuminance thresholds to the desired levels.

Skylight and Sunlight Diffuser Box — The Integrated Skylight Luminaire uses both clear and diffuse materials to capture and distribute daylight. This feature differs from traditional skylights, which generally use one or the other. Traditional clear skylights allow direct shafts of sunlight to penetrate, producing a nonuniform light distribution and glare. Traditional diffuse skylights mediate sunlight distribution but reduce light transmittance compared to clear skylights. The Integrated Skylight Luminaire combines the benefits of these materials to maximize daylight collection while avoiding glare.

A standard 4 ft x 4 ft (1.2 m x 1.2 m) double-glazed clear skylight is designed to fit into typical high-bay structural spacing. A 4-ft-high (1.2 m) sunlight diffuser box mounts inside the space below the ceiling. The height of the sunlight diffuser box optimizes daylight collection without interfering with operations in the warehouse. The diffuser modifies the distribution of sunlight so that it more closely matches the electric lighting, easing the transition between electric light and daylight without causing glare (see *Electric Luminaire Assembly*). The side diffusing panels are constructed of white acrylic to maximize diffusion of direct sun. The bottom of the diffusing box is constructed of sandblasted clear acrylic, a material that provides a visual connection to the exterior and allows greater acceptance of interreflected light from the side panels. In northern latitudes, the angle of the sun is rarely high enough to reach the bottom panel, so little diffusion is necessary.

Electric Luminaire Assembly — Twelve linear fluorescent T8 lamps housed in four industrial striplights serve as the electric luminaire assembly. The striplights are arranged in a square configuration 4 ft (1.2 m) below the ceiling and are placed outside of the sunlight diffuser box (rather than inside) to eliminate loss from electric light reflecting off interior surfaces of the diffuser box and back out the skylight aperture. Such light loss would require increased lighting power density for the same illuminance.

Photosensor detects collected daylight and sends information to luminaire controller



The electric luminaire assembly in this prototype is connected to the roof structure, but it is suspended to align with the bottom of the sunlight diffuser box. The electric lighting is designed for step-switching or continuous-dimming control. This prototype has both capabilities. The luminaires are tandem wired, allowing uniform appearance in the space when in step-switch mode. The outer ring of lamps can switch separately from the intermediate and inner rings of lamps. Optional dimming ballasts allow all lamps to be dimmed to the same level.

Photosensor Lighting Control System — The Integrated Skylight Luminaire uses a photosensor and an electronic luminaire controller to automatically reduce the electric light levels when sufficient daylight is available. The photosensor control system was custom designed based on LRC research showing that complicated commissioning procedures and occupant dissatisfaction with the lighting provided were the major barriers to the effectiveness of photosensor-controlled lighting systems.[2,6]

The luminaire controller is housed in one corner of the electric luminaire assembly and is connected by a low-voltage wire to a photosensor mounted in the well of the skylight. The photosensor continually monitors levels of daylight entering the skylight well. Using these data, the luminaire controller continually adjusts the electric light levels based on the amount of available daylight. The luminaire controller turns off the lamps entirely when sufficient daylight exists, a feature that allows significant energy savings. A time delay prevents rapid electric light fluctuations under scattered cloud conditions.

Upon installation of multiple Integrated Skylight Luminaires, the control system of each unit is commissioned separately to correlate measured daylight levels to desired electric light levels.

Commissioning device automates setup and calibration of the luminaire control system (see photo on page 4)

Commissioning Device — The initial setup and calibration of the control system is performed using a wireless portable commissioning device that resembles a remote control for a television set. The commissioning device contains a photosensor and an infrared transceiver (which communicates with the transceiver in the Integrated Skylight Luminaire), as well as buttons used to start the fully automatic commissioning process. The commissioning device also includes buttons for manually overriding programmed functions in the luminaire controller, such as lights off or lights on at full power. Dials on the commissioning device change both the threshold at which lights are dimmed and the amount of overall dimming. These two settings provide a means of altering the balance between energy savings and occupant satisfaction. The amount of overall dimming can be adjusted over a range from a 1:1 trade-off between daylight and electric light illumination levels, to a 3:1 trade-off. At 3:1 trade-off, illumination levels from daylight need to be triple the initial electric light level before the electric lighting is turned off.

A single commissioning device can be used to commission each of the Integrated Skylight Luminaires within an installation. The user places the commissioning device on a horizontal surface beneath the skylight and presses a button to start the automatic commissioning sequence. During commissioning, the luminaire controller measures the photosensor-to-workplane illuminance ratio needed for the open-loop proportional control algorithm used in the controller. If dimming ballasts are used, the Integrated Skylight Luminaire calibrates the dimming control output to the dimming response function of the particular ballast used. This procedure ensures uniform dimming response over the full range of dimming control provided by the ballasts. The luminaire controller can be remotely adjusted to accommodate continuous dimming or step switching.

The commissioning process takes less than 3 minutes per unit and can be accomplished in any amount of daylight by nonexpert personnel. All measurements and calculations are performed automatically by the luminaire controller using the photosensor in the light well of the skylight and the commissioning device on the workplane.

Field Test

Test Site

The Lightolier Distribution Center in Norwich, Connecticut, was the site of the field test. It is a 214,000 ft^2 (19,900 m^2) storage and shipping facility that supplies lighting products to customers across the eastern part of the United States. Pallets of lighting products arrive from Lightolier manufacturing facilities and are stored in vertical racks and horizontal bins before being shipped to customers.

Ceiling heights are approximately 31 ft (9.5 m), with an open bar truss structural system and exposed HVAC duct work and electrical conduits. Racks are 18 ft (5.5 m) in height, with four shelves for shipping pallet storage. A few translucent wall panels are installed in some parts of the building, but most spaces receive no daylight.

The facility operates 18 hours a day Monday–Friday and intermittently on weekends. Thirty employees work the day shift, and five work the evening shift.

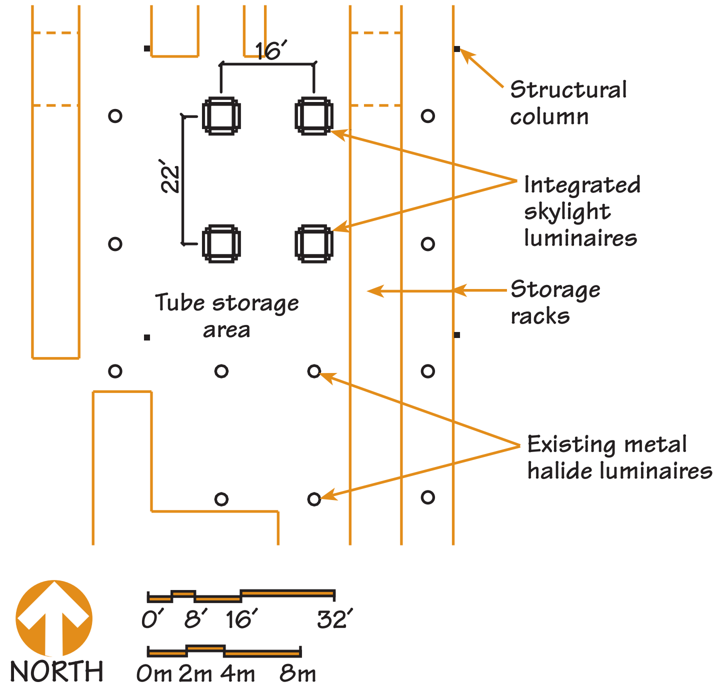
The majority of the existing lighting in this warehouse consists of 400-W metal halide high-bay downlights with a linear aisle-lighter distribution. Mounting locations are spaced approximately 16 ft x 22 ft (4.9 m x 6.7 m) apart.

Installation

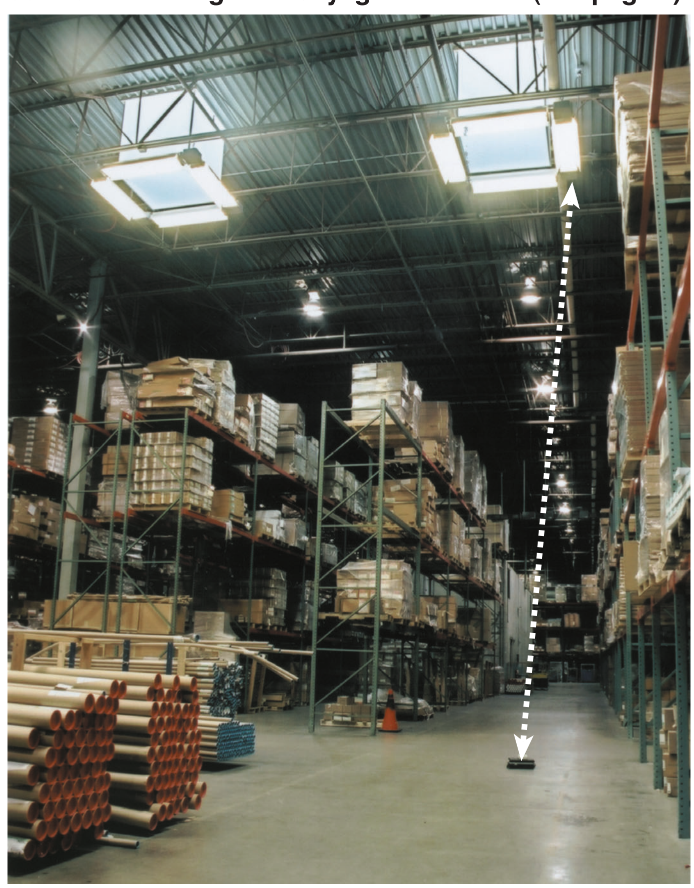
The LRC installed four Integrated Skylight Luminaires in the center of the warehouse, also called the tube storage area, in a location that has no other access to daylight. Four of the existing metal halide downlights were removed, and each replaced with an Integrated Skylight Luminaire. Electric light levels using the Integrated Skylight Luminaires meet or exceed those of the previous 2-year-old lighting system. The space now appears less cave-like because some light is directed toward the ceiling during both day and night conditions.

Page 5 shows the photometric measurements at the field test site. The “daylight only” measurements are not intended to represent the wide range of photometric conditions at various times of day, seasons of the year, and weather conditions. However, the measurements do show the impact of the sunlight diffuser box on light distribution under sunny conditions and that daylight can make a significant contribution to illumination.

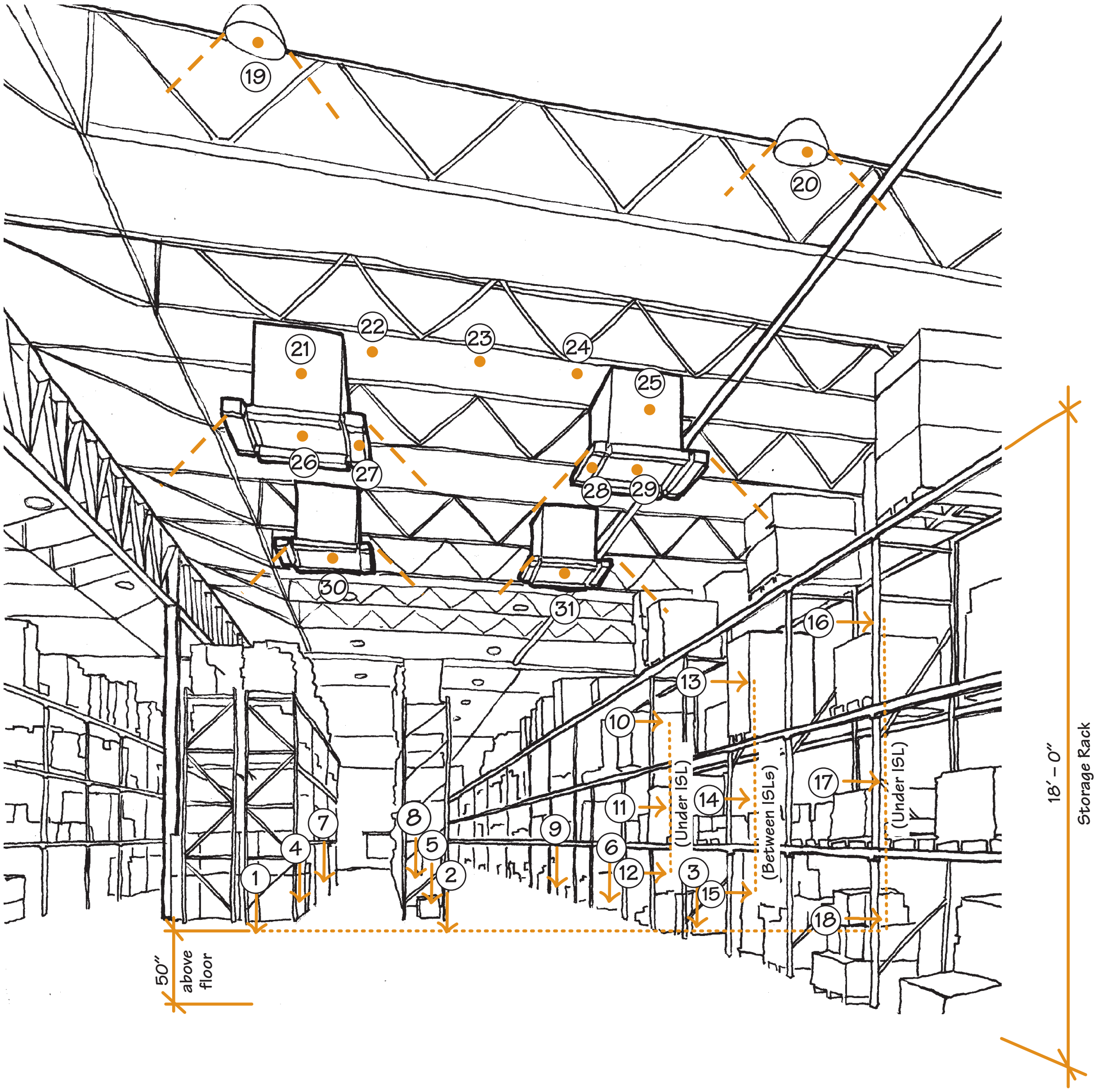
Four units were installed in the tube storage area



Commissioning device communicates with luminaire controller in Integrated Skylight Luminaire (see page 3)



Photometric measurements at the field test site



Measurement location	Horizontal Illuminance (lux) ISL, electric only*	ISL, daylight only**	Previous MH (before retrofit)*	Measurement location	Vertical Illuminance (lux) ISL, electric only*	ISL, daylight only**	Previous MH (before retrofit)*	Measurement location	Luminance (cd/m²) ISL, electric only	ISL, daylight only**	Previous MH (before retrofit)
1	493	240	400	10	320	N/A***	187	19	N/A	N/A	57,000
2	470	220	376	11	230	N/A***	125	20	N/A	N/A	46,000
3	433	237	416	12	180	N/A***	92	21	21	2300	N/A
4	492	324	392	13	270	224	192	22	6	23	4
5	488	202	379	14	243	167	158	23	4	10	3
6	404	336	368	15	184	37	104	24	7	71	3
7	506	212	390	16	360	142	237	25	18	2370	N/A
8	479	161	355	17	240	120	167	26	39	4600	19,000
9	404	N/A***	321	18	188	41	126	27	5060	N/A	N/A
								28	5820	N/A	N/A
								29	38	3500	21,180
								30	45	2750	12,000
								31	42	2600	3500

1 lux = 0.093 footcandle
ISL = Integrated Skylight Luminaire; MH = metal halide luminaires
N/A = not available
* Includes contribution from adjacent MH luminaires, which has added on average 190 lux horizontal and 60 lux vertical to peripheral measurements.
** Daylight measurements taken on a sunny afternoon between 2:00 and 3:00 P.M. in early September. These values do **not** include the contribution of adjacent MH luminaires, which on average would **add 190 lux horizontal and 60 lux vertical** to peripheral measurements.
*** One ISL experienced communications problems (see *Performance of the Electric Lighting* on page 8) and would not override control of electric lights to allow daylight-only measurement.

Methodology

The LRC monitored system performance and energy usage by:

- Conducting an employee survey and interviews to gather occupant observations and feedback about system performance and acceptability
- Retrieving and analyzing energy usage data recorded in the luminaire controller of the Integrated Skylight Luminaires
- Videotaping one of the units to monitor dimming performance under both continuous-dimming and step-switching conditions.

The employee survey was conducted several months after the Integrated Skylight Luminaires were installed to ensure that the employees had ample opportunity to see the system operating in the tube storage area during the daytime and after dark. The survey consisted of a simple questionnaire that provided employee feedback on light levels, visual comfort, and clarity. For comparison, the same questions (except for the daylight-related ones) were asked of the same group of employees about a similar open space, the shipment staging area (not shown in the drawings or photos). The staging area was lighted by conventional 400-W and 1000-W metal halide lamps in high-bay downlights. No windows or skylights were visible in the staging area. Employees were asked to enter the tube storage area during midday to complete the survey. Then the employees were led into the staging area where they completed another copy of the survey, reporting their assessment of the lighting in that area. Some employees also commented on their recollection of nighttime conditions in the tube storage area.

The luminaire controller in each Integrated Skylight Luminaire recorded energy usage at hourly intervals by using an electrically erasable programmable read-only memory chip (EEPROM). Energy usage data were calculated by a predetermined function relating the dimming level to the power demand of the system and integrating over the 1-hour time intervals. The data covering the 8-month test period from March to November 2002 were retrieved from memory chips using the portable commissioning device and were then downloaded to a standard laptop computer for analysis.

Environmental implications of the actual energy usage were estimated using ISO New England's publication, *2000 NEPOOL Marginal Emission Rate Analysis*, which lists New England Power Pool's aggregate emissions in the states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.[7] LRC used this publication to correlate kWh saved to environmental emissions avoided.

The time-lapse video camera captured luminaire and daylight activity of one of the units, recording 1 second of video every 5 minutes, to enable visual verification that the unit dimmed down and finally turned off in response to daylight. Positioned in the foreground of the time-lapse video camera were a clock, an illuminance meter, and a watt meter. The watt meter was directly wired to the luminaire controller of the unit. The illuminance meter enabled the LRC to verify that the control system was appropriately dimming or switching the electric lights.

Tube storage area before and after installation of the

Before installation

After — Daytime with ISL electric lighting on

Integrated Skylight Luminaires (ISLs)

After — Nighttime

After — Daytime with ISL electric lighting off

Field Test Results

Employee Feedback

The employee survey consisted of 10 statements about the lighting in the facility. To complete the survey, employees were instructed to indicate if they agreed or disagreed with each statement. The table on the next page gives the percentage (%) of employees who agreed with each statement.

The results indicated that during the daytime, all the employees questioned thought the Integrated Skylight Luminaires provided good, comfortable lighting that enabled them to easily see what they needed to see. Compared to the metal halide luminaires in this facility, the Integrated Skylight Luminaire was less likely to be considered uncomfortable to look at directly and was much less likely to be considered too bright. About two-thirds (69%) of the employees questioned said they would like to see the Integrated Skylight Luminaire installation extended to the rest of the facility.

"[The Integrated Skylight Luminaire] fulfills lighting requirements better than a single light because it is a larger area of illumination."
— an employee

On the negative side, some employees found the switching of the fluorescent lighting during the day to be disturbing. ("Switching" is the term being used here to encompass dimming down and up, turning off completely, turning back on, and the coordination of these stages among the 12 lamps in a unit, all in response to the daylight levels present in the skylight.)

"The skylights don't work fully in cooperation with each other."
— an employee

Not enough employees were available to answer the survey about the Integrated Skylight Luminaires after dark. Those who were available reiterated that the electric lighting was comfortable and allowed them to see what they needed to see. The fluorescent luminaires were considered more comfortable to look at directly than the metal halide luminaires in the staging area. However, some employees found the appearance of the fluorescent luminaires less attractive at night than by day.

Employee statements about the lighting	Tube storage by day (Integrated Skylight Luminaires in use)	Staging area at any time (all metal halide lighting)
Overall, the lighting is good	16/16* (100%)	11/13 (85%)
Overall, it is easy to see what I need to see	15/15 (100%)	13/13 (100%)
Overall, the lighting is comfortable	16/16 (100%)	11/13 (85%)
The light fixture is attractive to look at	11/15 (73%)	7/13 (54%)
The light fixture is uncomfortable to look at directly	4/16 (25%)	11/15 (73%)
The lighting is sometimes too bright	2/16 (13%)	6/15 (40%)
The lighting is sometimes too dim	5/16 (31%)	4/15 (27%)
The lighting flickers	2/15 (13%)	3/15 (20%)
The lighting creates strong shadows in some areas	0/16 (0%)	4/14 (29%)
The switching of the fluorescent lighting is disturbing	3/16 (19%)	N/A

* Number of employees agreeing with the statement, over the total number who responded to the statement.
N/A = not applicable

"I think they're great. When I come in the morning, they're on and I don't bump into things."
— an employee

Comments made by the employees showed that the connection to the outside provided by the Integrated Skylight Luminaires was appreciated to such an extent that some employees wanted the bottom panel in the diffuser box removed to allow a clearer view of the sky. Others commented that the bottom diffuser panel was essential for safety reasons so that employees driving forklifts were not exposed to disability glare from direct sunlight.

Performance of the Skylight and Sunlight Diffuser Box

The skylights are well-sealed at the roof penetration. The LRC detected no evidence of water leakage. The lower sunlight diffuser boxes were custom-built for this prototype installation, and they did show opportunity for improvement. Insect deposits accumulated in the diffuser box of each Integrated Skylight Luminaire. This indicated that some of the diffuser joints or seams failed, allowing insects to enter the box. Joint or seam gaps may have been the result of temperature fluctuations, which would have caused expansion and contraction of the materials forming the sunlight diffuser box.

> Proposed Solution: Joints and seals of the sunlight diffuser box should allow for thermal expansion and contraction while retaining the seal.

Performance of the Electric Lighting

Several employees commented that the electric lighting in the Integrated Skylight Luminaires sometimes appeared to be malfunctioning. This impression probably occurred because of differences in the operation of the four Integrated Skylight Luminaires. Custom-assembled electronics circuitry in one of the units did behave erratically for most of the evaluation period and may have contributed to this impression. However, two deliberate features of the Integrated Skylight Luminaire's design may have also contributed to the perception of malfunctioning. Every unit is commissioned individually, so for the same daylight conditions, the electric lighting of each unit could be switched at a slightly different time. This feature will be particularly noticeable in step-switching mode, when one unit may have four lamps on while the adjacent unit has eight on. Also, because two units were adjacent to vertical racks in this installation, their commissioning values were slightly different, resulting in different operation.

> Proposed Solution: Switching could be better coordinated by using a master–slave controller. One master unit with a photosensor could send a control signal to a larger group of slave units.

A second aspect of the Integrated Skylight Luminaire's design may have contributed to the perception of malfunction. When in step-switching mode, control of the outer, middle, or inner ring of fluorescent lamps in each unit is determined by independent luminaire controllers. Even if all of the units have one ring of lamps on, the units may each be operating a different ring of lamps (outer, middle, or inner). Although it may appear to be haphazard, switching of lamps was intended to be randomized so that all of the fluorescent lamps would accumulate the same number of hours of use, thus ensuring equal operation time of each lamp to minimize relamping maintenance.

Proposed Solution: It might be more acceptable to occupants either to adopt a time-based, systematic rotation of the switching priority of the fluorescent lamps to minimize relamping maintenance, or to use diffusers below the lamps to conceal switching patterns.

Despite careful attention, the installation experienced premature lamp failures when dimming fluorescent lamps. During the first few months of operation, when the luminaire controllers were set to the continuous dimming mode, several lamps failed and were replaced. Although investigation is ongoing, two electrical issues have emerged as likely causes: 1) poor electrical contact between the lamp and socket, and 2) signal interference in the tandem wiring used in the field test to enable both continuous and step dimming.

Electrical Contact — Extreme end-darkening of some lamps indicated improper cathode heating. The most likely cause was poor or nonexistent electrical contact with one of the two lamp pins at each lamp end. For this prototype assembly, LRC selected off-the-shelf luminaires. The luminaires featured a type of spring-loaded lamp socket that may work fine with instant-start type ballasts, which need only one contact at each lamp end to operate properly. Rapid-start dimming ballasts require two low-resistance contacts at each lamp end to maintain expected lamp life. After LRC replaced the luminaires' instant-start ballasts with rapid-start dimming ballasts, the sockets provided unreliable electrical contact with the two lamp pins. End-darkening occurred even after LRC attempted to improve contact by installing additional spring-loaded cords to keep the sockets firmly in place against the lamp pins.

Proposed Solution: If continuous dimming is used in future Integrated Skylight Luminaire designs, careful attention must be paid to the type of lamp socket. A "knife-edge" socket may be the most reliable.

Electrical Signal Interference —The tandem wiring used in this installation was necessary to be able to demonstrate both continuous dimming and step switching. However, tandem wiring may have contributed to premature lamp failure when using the continuous dimming mode. Since wiring was not done in separate wireways, interference (crossover of signals) may have caused losses in the lamp drive currents to the adjacent wires, which may have shortened lamp life. Separate wireways are especially critical when dimming ballasts are used because of low-level lamp drive and the importance of proper cathode heating current. In both step-switching and continuous-dimming mode, the safety shutdown feature of the dimming ballasts was occasionally falsely triggered in response to interference. Although not a contributor to shortened lamp life, intermittent ballast safety shutdown provided additional evidence of interference problems.

Proposed Solution: When using dimming ballasts, avoid tandem wiring. Otherwise, tandem wiring done in shielded, separated wireways may avoid mutual interference between lamp leads.

Performance of the Photosensor Control System

The time-lapse video data closely corresponded to data recorded by the Integrated Skylight Luminaire units themselves. Apart from the electrical problems discussed above, the fluorescent lights dimmed and switched appropriately and consistently in response to the presence of daylight.

Performance of the Commissioning Device

The LRC verified that the integrated skylight luminaire was easy to commission using the commissioning device. After override functions were used, one press of a button allowed normal operation to resume without having to recommission the unit.

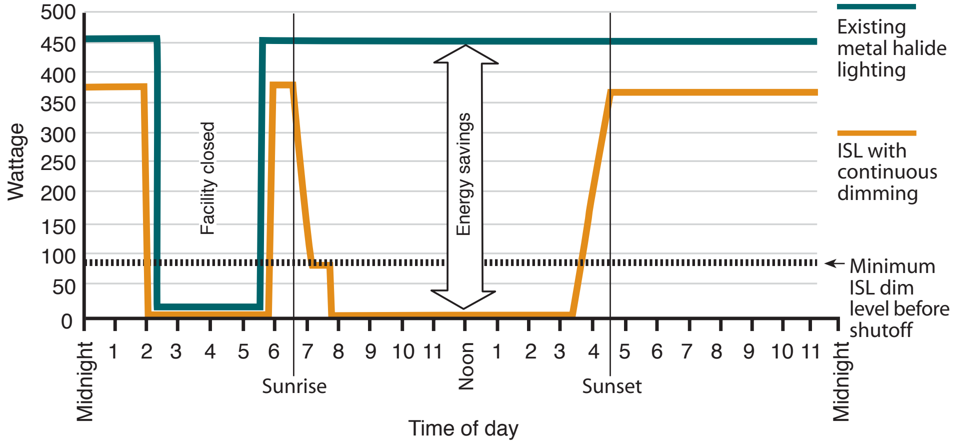
Energy Savings

When sufficient daylight was present, the Integrated Skylight Luminaire turned off the electric lighting rather than maintaining a minimum dim level (see *Typical daily lighting energy use* graph). In this installation, use of the Integrated Skylight Luminaires with their photosensor lighting control systems reduced energy consumption by 40% compared to the previous metal halide lighting (see *Energy savings* graph). If lighting controls had not been used, the energy savings would have been 17% instead of 40%, due to a more efficient luminaire type and reduced ballast losses. Controlling the electric lights in the Integrated Skylight Luminaires provided energy savings of 28%.

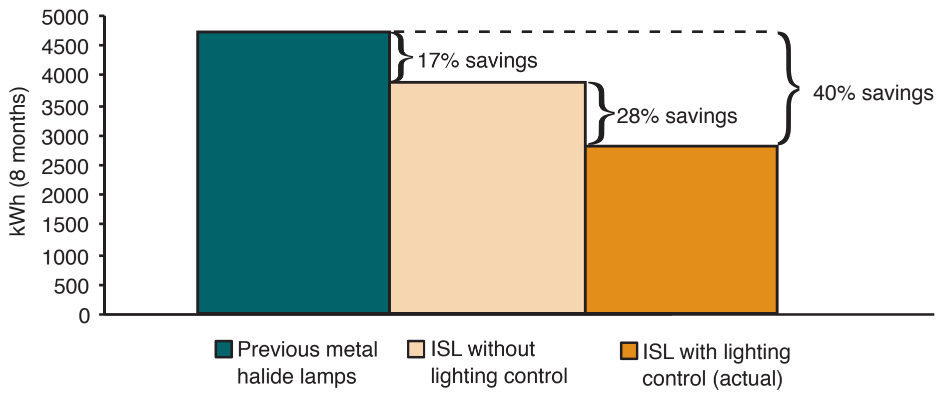
Energy reduction is greatest on sunny days. Since peak electrical demand often coincides with sunny days, the Integrated Skylight Luminaire may offer demand savings as well.

Environmental Implications — The Integrated Skylight Luminaires at the field test site resulted in lower power plant emissions from reduced energy use (see table at right).

Typical daily lighting energy use before and after installation of Integrated Skylight Luminaire



Energy savings from three* Integrated Skylight Luminaires (ISLs) March–November 2002



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

Reduced power plant pollution[7] from 8 months use of three Integrated Skylight Luminaires (ISL)

Pollutant	Emission savings of ISL with lighting control compared to existing MH (lbs)	Emission savings of ISL with lighting control compared to existing MH (kg)	Emission savings of ISL with lighting control compared to ISL without lighting control (lbs)	Emission savings of ISL with lighting control compared to ISL without lighting control (kg)
SO_2	11.7	5.3	6.7	3.0
NO_x	3.6	1.6	2.0	0.9
CO_2	2802	1271	1603	728

Sulphur dioxide (SO_2) is associated with visible pollution (haze) and acid rain. SO_2 is also a direct lung irritant. Nitrogen oxides (NO_x) are a primary cause of ozone production (a main component in smog) and acid rain. Carbon dioxide (CO_2) is a possible contributor to future climate changes, such as global warming.

Glossary

Commissioning — After installation of an automatic lighting control system, the initial process of equipment setup, calibration, input of control settings, and tuning to adjust the system to the actual location and conditions in which it is installed.

High-Bay — Building type with a tall ceiling, often single story, greater than 15 ft (4.6 m) in height, and with an unfinished appearance characterized by exposed structural trusses, ductwork, and other mechanical equipment.

Interference — In this installation, crossover of electrical signals that may occur among adjacent unshielded electrical wires. In general interference is an electrical or electromagnetic disturbance, phenomenon, signal, or emission that can cause malfunctioning or degradation of the electrical performance of electrical and electronic equipment.

Open Loop — Daylighting control strategy in which the photosensor does not monitor the electric light that it controls. The photosensor is either mounted outdoors, or is aimed such that it only receives light from the exterior. A signal proportional to the exterior daylight instructs the control system to dim the electric light by an amount proportional to daylight levels.

Tandem Wiring — Wiring lamps in one fixture to a ballast in another fixture. This method of wiring permits a uniform pattern of illumination when used in step-switching applications.

Transceiver — An electronic device that transmits and receives data.

References

[1] Leslie, R., and J. Brons. 2002. An integrated skylight luminaire: combining daylight and electric luminaires for energy-efficiency. In *Proceedings of Right Light*, 5:269-278. Stockholm, Sweden: Borg & Co.

[2] Bullough, J., and R. Wolsey. 1998. *Specifier Reports: Photosensors*. Troy, NY: Rensselaer Polytechnic Institute.

[3] Maniccia, D. A., B. Rutledge, M. S. Rea, and W. Morrow. 1999. Occupant use of manual lighting controls in private offices. In *Journal of the Illuminating Engineering Society*, 28(2):42-56.

[4] Mistrick, R., C. H. Chen, A. Bierman, and D. Felts. 2000. A comparison of photosensor-controlled electronic dimming in a small office*. Journal of the Illuminating Engineering Society*, 29(1):66-80.

[5] Rea, M. S., and D. Maniccia. 1994. *Lighting Controls: A Scoping Study*. Troy, NY: Rensselaer Polytechnic Institute.

[6] Bierman, A., and K. M. Conway. 2000. Characterizing daylight photosensor system performance to help overcome market barriers. *Journal of the Illuminating Engineering Society*, 29(1):101-115.

[7] ISO New England Inc. 2002. *2000 NEPOOL Marginal Emission Rate Analysis*. Prepared for the NEPOOL Environmental Planning Committee. Table 2, page 7. Accessed on 18 November 2002 at http://www.iso-ne.com/Planning_Reports/Emissions

Findings and Recommendations

Findings

- Significant lighting energy savings can be achieved using the Integrated Skylight Luminaire, even if a facility is occupied long into the night.
- Skylights and electric lighting can be integrated to balance energy savings with occupant satisfaction.
- Employees in a warehouse environment appreciate having the connection to the exterior that skylights provide.
- Commissioning requirements need not be a barrier to the use of photosensor-controlled lighting systems.

Recommendations for Product Development

- When Integrated Skylight Luminaires are used in a large open space and step-switching mode is used, it may look haphazard to have each luminaire controlled separately. Occupants may prefer unified switching patterns.
- Joints and seals of the sunlight diffuser box should allow for thermal expansion and contraction.
- When used with rapid-start dimming ballasts, fluorescent lamp sockets must provide reliable electrical contact with all lamp pins.
- When using dimming ballasts, tandem wiring should be avoided or provided in shielded, separated wireways to avoid mutual interference between lamp leads.
- For reduced product cost, use nondimming ballasts and step switching.

Current Product Status

- The Integrated Skylight Luminaire is not commercially available at time of press. Manufacturers are invited to commercialize this product. The lighting controls system described in this publication was developed by LRC and will be made available to interested manufacturers.

Field Test DELTA
Issue 1
Integrated Skylight Luminaire

January 2003

Field Test DELTA evaluates new energy-efficient lighting products to independently verify field performance claims and to suggest improvements. A primary goal of the Field Test DELTA program is to facilitate rapid market acceptance of innovative energy-efficient technologies.

Program Director: Sandra Vásconez

Project Manager: Jennifer Brons

Product Development and Assembly: Lighting Research Center

Human Factors Interviews: Peter Boyce, Owen Howlett

Reviewers: Andrew Bierman, Peter Boyce, Russ Leslie

Editors: Marilyn Morgan, Virginia Brouns Harrison

Technical Assistance: Jonas Concepcion, David Cyr, Wendy Fujinaka, Nutron Manufacturing

Illustrations: Jonas Concepcion

Photography: Jennifer Brons ("before" and page 3–4 photos); Randall Perry Photography ("after" and cover photos)

Publication Design and Production: James Gross

SPONSORS

Connecticut Light and Power Company (CL&P)

New York State Energy Research and Development Authority (NYSERDA)

CREDITS

Lightolier Warehouse: Bruce Roberts, Lead Mechanic; Cliff Jackson, Warehouse Manager

Lightolier Corporate: William Blitzer, Mete Kantar, Bob Wedekind

CL&P: John Mutchler, Ken Galanto, Sam Fankhauser

NYSERDA: Marsha Walton

Architect: James Vance and Associates Architects

General Contractor: G. Schnip Construction

Skylights: Wasco Products

Luminaires: Lightolier

Dimming Ballasts: Advance Transformer

Equipment Donors: Lightolier, Wasco Products

For publication ordering information, contact:

Lighting Research Center

Rensselaer Polytechnic Institute
21 Union Street
Troy, NY 12180-3590
(518) 687-7100
email: lrc@rpi.edu ▲ www.lrc.rpi.edu

ISSN 1075-3966 Printed on recycled paper.

Rensselaer