Daylighting at Stonyfield

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[See Also: Notes on Constructing a Daylighting Model]

Introduction

This paper reports the results of a comparison of skylights vs. south-facing roof monitors for daylighting the north wall zone of a 10,000 square foot office building near Manchester, NH. This effort was part of ARC Design Group's (John Abrams, Marc Rosenbaum, PE, Bruce Coldham) integrated approach to design which seeks to create high quality human environments through excellence in ecological design. The office space is being retrofitted into an existing steel framed, 18 foot high warehouse, with a party wall to an industrial facility on the north side; therefore, no daylight is available through the north wall. A design goal was to have the interior daylit on overcast as well as clear sky days because, in the NH climate, the sky is overcast 50% of the year — a goal intended to enhance the interior working environment more than to save electrical energy. Specifically, we aimed to achieve at least 20 footcandles (fc) at the workplane with 1,500 fc of exterior ambient daylight. Since the south wall is sixty feet from the north wall, it was clear that some form of toplighting would be required to achieve this throughout the interior space.

To test toplighting strategies, a physical model was constructed and tested. Simultaneously, the building's annual thermal performance was modeled with Energy-10 hourly simulation software, and its peak heating and cooling load performance was modeled with the Carrier Corp. Hourly Analysis Program (HAP).

The zone being tested consists of a bank of offices adjacent to the north wall. Each office has a transparent ceiling at about 10 feet. The high roof ensures that no direct beam light can reach the office workplanes — most of the light delivered is reflected off of the north wall above the offices. Apertures were built into the roof of the model, and several skylight and south-facing roof monitor configurations were tested in both clear and overcast conditions.

Physical Model Construction, Instrumentation, and Testing Table

The model was built of 1/2" thick corrugated cardboard (base and roof), and 3/16” thick Gatorfoam board (walls). All Gatorfoam was painted black on the exterior to achieve complete opacity to light, and the actual finish on the interior was used to exactly simulate the reflective quality of that surface. The cardboard roof surface was painted white since we intended to replace the roof membrane and chose a white product to enhance reflectance to the monitors. We modeled the center two bays of this four bay building (60 feet north-south by 160 feet east-west), creating a model of 30 inches by 40 inches by about 10 inches high. Glazed openings were modeled with a low-e film called Solis made by Southwall Technologies to closer approximate the effect of glazing in the actual building. The visible light transmission of Solis is 70%; we measured 64% with our light meters in the field. An observation port just large enough to insert a wide-angled camera lens into was built into the west wall, allowing qualitative viewing of the daylighting inside the model and the taking of photographs. This had a light-tight flap.

Inside the model the north offices and some interior cubicles were constructed. We took measurements in all three of the distinct daylighting zones - a cubicle near the south wall, a cubicle in the center, and in one of the north offices. The model had a channel through which we could slide the sensor of our light meter mounted on a block to approximate the level of a desk workplane. A second light meter was mounted on the roof of the model to measure the ambient light levels. In each model orientation, measurements were recorded for each of the three interior positions, and the exterior light level.

Instrumentation consisted of two hand-held light meters with independent sensors attached by a coiled cord. The meters were both cosine-corrected and color-corrected. One meter, used for the ambient light readings, allowed us the option of setting for daylight as opposed to other light sources. (A full sun, clear sky condition reading was 13,000 fc which we considered surprisingly high).

The table built for model testing was based on a scheme which we learned about from our daylighting consultant, Bob Osten at Lam Partners in Cambridge, MA. The platform on which the model sits is constructed at a fixed tilt corresponding to the latitude of the building, and this tilted assembly can rotate relative to a second tiltable platform. A gnomon is fixed to the model's roof, and is used in conjunction with the tiltable platform to orient the model to the time of year being tested (allowing a full year's worth of testing to be done on any given day of the year.) Once the model is oriented to be at solar noon on the desired day being modeled, the tilt can be fixed, and all other hours of the day can be measured and observed by simply rotating the model. This is a delightful way to observe the progression of the sun through the building during a day.

This process requires two people to set the testing table to its proper orientation, and two people to collect and record simultaneous data (exterior and interior) illumination levels —(we were surprised at how great was the variation in the sky's illumination what, to our eyes, appeared as a stable sky condition). Nonetheless, for a design team that is not supported by a hefty research grant nor has the budget to hire a fully equipped daylighting consulting firm, this is one way to do worthwhile daylight modeling.

Testing Results

Initial testing showed that monitors with overhangs performed poorly in the overcast conditions, and that substantially more aperture was needed even with monitors without overhangs than with skylights to obtain satisfactory overcast performance. The monitors which were tested most extensively had apertures 77% larger than the apertures of the skylights.

The test results were then corrected for seasonal variations in solar intensity and luminous efficacy, intended glazing products, and ambient light level variations during testing. The glazing envisioned for the skylights was the SC75 product made by Southwall Technologies, chosen for it's low U value (U = 0.17), low solar heat gain coefficient (SHGC = 0.34) and relatively high visible light transmission (Tvis = 0.61.) This glazing has one of the highest luminous efficacies (Tvis/SHGC) available, so it is good for letting light in while rejecting heat. The glazing projected for the south-facing monitors was a high transmission, argon-filled low-e (U = 0.26, Tvis = 0.75, SHGC = 0.56.)

Table 1 reports corrected values for footcandles measured on the workplane in clear sky conditions for an equal amount of glazed aperture.

	Skylights	*Monitors*
Summer 9 am	136	72
Summer noon	172	98
Equinox 9 am	77	79
Equinox noon	127	135
Winter 9 am	7	15
Winter 10 am	36	65
Winter 11 am	58	99
Winter noon	69	121
Overcast - 1500 fc	20	8

Note that the skylights out-perform the monitors as expected in the summer, they both have similar performance at the equinoxes, and the monitors work best in the winter. However, to achieve our goal of good lighting in overcast conditions (aiming for 20 fc on the workplane with 1500 fc exterior horizontal illumination - a Daylight Factor (DF) of 1.33%), the monitors require 2.4 times as much aperture as the skylights. This substantially increased aperture would allow the monitors to yield light levels 1.3 to 5 times higher than the skylights in clear conditions, but such elevated levels are unnecessarily high for normal office activity. It seemed as though skylights would be a better choice, but it remained to be seen what their effect would be on the building's thermal performance. We were worried in particular about their effect on peak cooling load.

Thermal Modeling

The thermal models incorporated enough skylighting or monitors to provide 20 footcandles of light on the workplane when the ambient horizontal light level was

1500 footcandles — about 10% of the floor area illuminated for the skylights, and about 24% of the floor area for monitors.

	Skylights	Monitors
Annual Heating Fuel Use	140 MMBTU	126 MMBTU
Annual Heating Cost	$730	$653
Annual Cooling Energy Use	7629	8278
Annual Cooling Energy Cost	$941	$1,027
Total Annual H/C Energy Cost	$1,671	$1,680

Table 2 shows the results of the Energy-10 modeling of the entire building.

Space heating cost was $5.20 per million BTU. Electrical cost was $0.09 per Kwh, and $8.00 per KW demand charge.

The Energy-10 results showed that the annual heating and cooling energy cost for the building was the same for either strategy - approximately $1675. The version with monitors produced a lower heating consumption (126 vs. 140 MMBTU) and a higher cooling consumption (8278 vs. 7629 Kwh) than the version with skylights.

Peak heating and cooling costs were modeled with HAP from Carrier Corp. These results are for the zone which includes the toplighting being modeled. This zone was by far the largest zone in the building, representing 5000 square feet of floor space, and virtually all of the roof and south-facing glass. Results of the modeling are shown in Table 3.

	Skylights (SHGC = 0.33)	*Monitors* (SHGC = 0.43)	*Monitors* (SHGC = 0.55)
Total Cooling Load, KBTU/hour	156.6	172.2	184.5
Sensible Cooling Load, KBTU/hour	136.3	152.9	166.5
Zone Peak Occurs	July @ 2 pm	Oct @ 2 pm	Oct @ 2 pm
Heating Load, KBTU/hour	177.4	189.8	188.4
Air handler CFM	5390	6630	7133
Solar Loads	43520	100950	111723

Two different glazings were looked at for the monitor case. Analysis with HAP showed that peak cooling loads (157 vs. 185 KBTU) and peak heating loads (177 vs. 188 KBTU) were lower with the skylit version - the increased aperture, reflective roof, and somewhat higher solar heat gain coefficient of the monitor glazing lead to this result. Note that the peak cooling with the monitors occurs in the fall (even though an economizer was included in the model), whereas the peak with the skylights is in mid-summer. In some situations this may necessitate a space conditioning system which can provide cooling to some zones while providing heating to other zones. Solar loads reported include all the other glazing in this zone, which includes about 910 square feet of south-facing glass, 60% of which is well-shaded in the summer.

Conclusion

Conventional wisdom tells us that monitors are preferable to skylights in this climate. The conclusion of the design team was that skylights were preferable to monitors in this application. This unexpected result is clearly dependent on the goal of a daylit work environment in the overcast condition - if the daylighting system is optimized for clear day conditions, the monitors are a better choice. The solution we arrived at is not necessarily the one which produces the lowest annual total energy cost, when summing heating, cooling, and lighting loads. However, with state-of-the-art artificial lighting design, the electrical savings which can be achieved by daylighting continue to be diminished. Therefore we believe that the beneficial effect on the working environment is the primary goal of daylighting, and it should be extended to as many hours of the work year as can reasonably be achieved without paying undue penalties for increased energy use or initial construction cost. The solution arrived at through this work will produce modest energy savings and an increased workplace quality.

The modeling indicates that *advances in glazing technology* which allow good visible light transmission while rejecting a large portion of the solar heat gain will enable us to achieve a skylight solution yielding similar annual energy costs, lower peak loads, and lower construction cost than the monitors.