Toplighting for the Tropics

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ABSTRACT: This paper presents the findings of a study that investigates the daylight performance of traditional and innovative toplighting systems to maximize the energy savings by offsetting the electric lighting and air conditioning requirements during peak hours. This study also includes the daylight distribution of different systems’ spacing and their effects in the energy consumption of the proposed toplighting systems. The toplighting systems were designed for Lima, Peru (latitude 12°S). The studied toplighting systems include skylights with diffusing glazing; clerestories and roof monitors with external shading devices; and skylights with splay wells, reflectors and diffusers beneath aperture. The RADIANCE ray-tracing lighting software and the EnergyPlus energy analysis computer program were used to model, simulate and analyse the daylight and thermal performance of the different toplighting systems. Results showed that roof monitors with North- and South-facing glazing, achieved the most uniform and highest illuminance levels. The skylights with splay wells and reflectors beneath aperture achieved the most efficient overall performance: even illumination (~500 lux), reduced glare, and low summer solar heat gains. Results confirmed that toplighting systems with good solar control and reflective surfaces can save energy by providing adequate daylight illumination in buildings so that electric lights can be turned off during peak hours.

Conference Topic: Low Energy Architecture
Keywords: daylighting, energy-savings, toplighting, solar control, Peru

1. INTRODUCTION

Historically, toplighting systems have been widely used. We can find examples worldwide that range from small openings to large glazed areas. Roof monitors were the traditional toplighting systems in Lima’s architecture during the past four centuries. Examples of these systems can be found in convents, libraries and old colonial courtyard houses.

Optimum sizing and placement of toplighting systems have been studied and recommended for locations in high latitudes based on local climatic conditions and solar geometry [1]. However, locations near the equator with year-round bright skies around the zenith, and high potential to introduce high illuminance levels to single-story buildings and top floors, have not been investigated. The potential to use toplighting systems in Lima is fairly high, since more than 95% of buildings are single- and two-stories. Currently, toplighting systems are not being used as often as in the past. Nowadays, sidelight windows are the most common source of illumination in interior spaces. Toplighting systems provide many advantages compared to sidelight windows in low latitudes: (a) high illuminance levels, (b) uniform illumination throughout large floor areas, (c) low luminance ratios, (d) controlled solar heat gains, (e) low ratios of window area per floor area for similar illuminance levels with sidelight windows, and (f) easy integration in existing buildings.

2. CLIMATE

The toplighting systems were designed specifically for a low latitude location in the southern hemisphere: Lima, Peru (12° South). The climate of Lima is characterized by a hot and humid summer season and a relatively mild winter. Day and night temperatures have small differences. The number of maximum hours of sun occurs during the summer season ranging from 55% to 65% of sunlight availability. The two predominant sky conditions are the clear and overcast skies.

Figure 1: Lima’s weather: (top) solar, heating and cooling degree hours, (bottom) monthly diurnal average temperature.
3. TOPLIGHTING SYSTEMS

Four toplighting systems were designed specifically for Lima’s climatic conditions: diffusing skylight, sawtooth clerestory, roof monitor, and skylight with interior reflectors/diffusers.

In all the designs, the goal was to improve lighting quality, control excessive daylight illuminance levels, and maximize the energy savings, compared to conventional diffusing skylights. The glazing area of each toplighting system was sized to minimize heat gains in the space. The systems were designed using the local construction materials. All the designs included high performance glazing, such as spectrally selective clear glass (visible transmittance, $T_{vis} = 0.77$). The reflectances of interior surfaces were: walls 45.1%, floor 21.7%, and ceiling 80%.

3.1 Diffusing Skylight
The base case skylight has a small aperture of 0.15m horizontal diffusing glazing ($T_{vis} = 0.77$).

![Figure 2: Detail of diffusing skylight](image)

3.2 Sawtooth clerestory
The sawtooth clerestory is designed with a north-facing vertical glazing of 0.95m high and a sloped ceiling surface of 90% reflectance. The glazing is protected from the direct sun by external vertical and horizontal shading devices.

![Figure 3: Detail of sawtooth clerestory](image)

3.3 Roof Monitor
The roof monitor is designed with north- and south-facing glazing of 0.55m high with external vertical and horizontal shading devices for sun control.

![Figure 4: Detail of roof monitor](image)

3.4 Skylight with Interior Reflectors and Diffuser
The skylight with reflectors is similar in dimensions to the base case diffusing skylight. The main difference is the set of interior reflectors and diffusers that hangs underneath the small aperture. The reflectors are coated with a highly reflective specular film (97.5%). The glazing is a clear spectrally selective glazing to let sun rays over the reflectors at most times of the year. Splay wells are included near the aperture to increase the entrance of sunlight.

![Figure 5: Skylight with interior reflectors and diffuser.](image)

4. METHODOLOGY

The RADIANCE ray-tracing lighting software [2] was used to model, simulate and analyse the daylight performance of the different toplighting systems. The EnergyPlus [3], building energy analysis computer program, was used to evaluate the thermal performance of each toplighting system. Comprehensive sets of computer simulation were used to simulate annual daylight and energy performance.

The modelled space is 15m wide, 25m long and 4.5m high. The spacing of the toplighting systems was 1.5 times the height of the space. The spacing of 1 time the height of the space resulted in much higher illuminance levels at the cost of higher cooling loads. The design objectives of the systems were to maximize daylight efficacy, increase uniformity and to minimize solar heat gains during summer months.

5. EVALUATION

5.1 Daylight Performance
The most even workplane illuminance distribution is achieved with the roof monitors and skylights with reflectors. Illuminance ratios achieved with roof monitors and skylights with reflectors did not exceed more than 1:2 throughout the year. Maximum recommended illuminance ratios for uniform illumination are 1:5 [4]. Annual average illuminance under clear sky conditions at 12:00 PM was 1,650 lux with roof monitors and 450 lux with skylights with reflectors. The roof monitor has the highest average daylight factor (2.8%) while the skylight with reflectors has the lowest (0.4%), as shown in Table 1.

Figures 6 to 9 show the illumination within a single-story space during the summer solstice (Dec. 21) at 12:00 PM. It is noticeable the uniform light distribution over the floor with the roof monitors and skylights with reflectors compared to the two other systems. Figures 10 to 11 depict illuminance levels along the centre of the space with the four systems at the solstices and equinox, at 12:00 PM. The highest illuminance ratios are achieved with the diffusing skylight 1:20 on Dec. 21. The sawtooth clerestory achieved also a fairly uniform distribution, 1:3 on Dec. 21 and 1:2 the rest of the year.
Table I: Daylight factors of the four toplighting systems.

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<tr>
<td>Average</td>
<td>0.5</td>
<td>2.7</td>
<td>2.8</td>
<td>0.4</td>
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<tr>
<td>Min.</td>
<td>0.1</td>
<td>1.5</td>
<td>2.1</td>
<td>0.3</td>
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<tr>
<td>Max.</td>
<td>1.5</td>
<td>3.3</td>
<td>3.1</td>
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Figure 6: Radiance images of diffusing skylights on Dec. 21, 12:00 PM, (bottom) false color image.

Figure 7: Radiance images of sawtooth clerestories on Dec. 21, 12:00 PM, (bottom) false color image.

Figure 8: Radiance images of roof monitors on Dec. 21, 12:00 PM, (bottom) false color image.

The CIBSE code [5] establishes that spaces with uniform light distribution should have the ratio of minimum illuminance to average illuminance more than 0.8. The two systems that achieved higher ratios throughout the year were the roof monitor (0.64) and skylight with reflectors (0.61), while the sawtooth clerestory (0.5) and diffusing skylight (0.3) achieved lower ratios.

Figure 9: Radiance images of skylights with interior reflectors and diffusers on Dec. 21, 12:00 PM, (bottom) false color image.

Figure 10: Illuminance level on Dec. 21, 12:00 PM, clear sky conditions.

Figure 11: Illuminance level on Sep. 21, 12:00 PM, clear sky conditions.
5.2 Thermal Performance

Indoor average temperature with all toplighting systems remains fairly similar year-round, with slightly hotter temperatures (<0.5°C) during the summer season (Figure 13). Solar heat gains introduced by roof monitors and sawtooth clerestories were twice the amount introduced by the two skylights during the hottest months (Figure 14). During the coldest months the solar heat gains introduced by all the toplighting systems were about the same (Figure 15). Heat losses during the coldest months are four times higher using the roof monitors and clerestories than the two skylights systems (Figure 16).

6. CONCLUSION

Results showed that the skylights with reflectors have the best overall daylight and thermal performance of all the systems. They introduce uniform light throughout the space (~500 lux) with minimum solar heat gains and heat losses. Roof monitors provide the most uniform and highest illuminance levels. However, they also introduce the highest solar heat gains during the cooling season of all the toplighting systems evaluated. Toplighting systems with adequate solar control and appropriate use of reflective surfaces can provide both good daylight illumination and energy savings.

7. REFERENCES