The Tales of Three Museums
Liliana O. Beltrán, Ph.D., Texas A&M University

Abstract: This paper presents the assessment of the lighting conditions of selected exhibit areas in three museums located at the same site, the Dallas-Fort Worth Cultural District. These museums are the Modern Art Museum by Tadao Ando (2002), the Kimbell Art Museum by Louis Kahn (1972), and the Amon Carter Museum by Philip Johnson (1961, 2001). Each of the museums presents different lighting conditions to exhibit their art collection. This study focuses on specific galleries that include daylight as a source of illumination. Each selected gallery is examined; assessed on the site; simulated using state-of-the-art lighting tools; and evaluated according to good lighting practice: light exposure, glare, and ultraviolet radiation.

Introduction
Light in museums is necessary to enhance and view museum objects; but at the same time, if not properly controlled, light can harm and reduce the life of the museum artifacts. To improve the quality of illumination in museum galleries, daylight has been reintroduced after many windowless galleries were built. Daylighting compared to most electric light sources has more potential to harm susceptible objects, and represents a challenge for designers to succeed in controlling it. Sunlight can create serious problems in the conservation of museum objects, when window systems are not carefully designed to intercept sunrays at all times.

This paper presents the evaluation of three museums that have many similarities as well as differences, and the reflections about the design of daylighting systems in museums. These museums, the Modern Art Museum, Kimbell Art Museum, and Amon Carter Museum, are located in the Fort Worth Cultural District, next to each other (Figure 1). These museums that include in their collection valuable art work, were designed by three well-known architects, who have used a variety of daylighting systems to illuminate the museum galleries to best accommodate the exhibit’s lighting requirement.

The Modern Art Museum
The Modern Art Museum of Fort Worth was designed by Japanese architect Tadao Ando in 2000-2001. This two-story museum opened its new building at the end of 2002. The museum’s permanent collection consists of more than 2,600 works, including paintings, sculpture, site-specific installations, drawings, prints, photographs, and video and digital imagery. The building is set on eleven acres, including a large reflecting pool and areas of outdoor sculptures. The building has 53,000 square feet of gallery space (Reference 1).

The Modern Art Museum introduces natural light into the galleries through different fenestration systems that include skylights, clerestories with interior and exterior louvers, and side light windows with and without interior screens (Figure 2).
The Kimbell Art Museum

The Kimbell Art Museum was designed by American architect Louis I. Kahn between 1966-1972. The museum has been widely acclaimed by its innovative use of natural light and subtle articulation of space and materials. The museum consists of six bays of 104'-long concrete cycloid shells, divided crosswise into three equal sections (Figure 3). The museum is illuminated by narrow skylights that admit natural light, which is then dispersed by perforated metal reflectors onto the underside of cycloid-shaped vaults and down the walls (Reference 2).

The Kimbell Art Museum introduced novel transparent daylight reflector, which together with the cycloid-shaped roof system introduced a totally new quality of controlled ambient lighting in museums. The success of this innovation inspired a renewed interest in the use of daylighting in art museums and influenced art museum design thereafter.

Amon Carter Museum

The Amon Carter Museum was designed by American architect Philip Johnson in 1961. Initially the museum was conceived as a small memorial structure, its collection grew rapidly and needed additional space. The museum expanded its area in 1964, 1977 and finally in 2001. The current total area of gallery is 28,400 ft² (2,638 m²). The collection of artwork consists of 240,000 objects of mainly paintings, sculpture, photography, and works on paper.

The museum’s main entrance wall consists of an east-facing two-story curtain wall of dark tinted glass with bronze mullions, and with an arched portico in its front. The main entrance leads to a two-story exhibit hall of shell stone, brown teak and a floor of pink and grey granite (Reference 3). Beyond the main area, there are several windowless galleries. Later, a new atrium was included in the layout, which introduced natural light to the core of the new building addition. Towards the south facade there is a gallery that receives natural light through a south-facing window. See Figure 4.
Evaluation of Galleries

Direct sunlight enters to several spaces in the three museums. In two of these museums direct sunlight penetrates in galleries where artwork is displayed, that is the case of the Modern Art Museum and the Amon Carter Museum.

The museums were evaluated through site visits to the museums at different times of the year, interviews with curators and facility managers, photometric measurements (with and without electric lighting), photographic documentation of sunlight penetration using fish-eye photography with the SunPath program (Reference 4), and computer simulations using the ECOTECT and Desktop RADIANCE software to analyse the patterns of sunlight penetration and to calculate illuminance and luminance levels throughout the year. The following section describes the evaluation of each museum.

The Modern Art Museum

Large spans of glass illuminate the main entry lobby (north and south-facing), and the sculpture galleries (east-facing), both are two-story high spaces. Most of the galleries in the first floor are windowless and are mainly illuminated by electric light sources. The subtle transition between the highly illuminated east-facing galleries and darker windowless central galleries is successfully achieved through intermediate galleries and passages. Most of the galleries in the central area of the second floor use toplighting as the main source of illumination in combination with halogen lamps. The illuminance levels in these central galleries are well controlled through a series of internal and external louvers that intercepts most incoming direct and diffuse light rays. Light levels in these galleries do not exceed the 200-lux recommended for oil paintings. Along the west side of the second floor are located seven galleries that are illuminated mainly by side light windows with white interior screens (see Figure 2-right).

Sunlight penetration was observed throughout the year along the west-facing galleries, located on the second floor (see yellow areas of Figure 2-right). Illuminance value measured over an oil painting was between 2,000 and 4,000 lux (Figure 5), which are 10 to 20 times higher than the maximum recommended illuminance of 200 lux for oil paintings, as stated in the “IES Recommended Practice for Museum” (Reference 5). Figure 6 is a fish-eye photo taken from an oil painting’s viewpoint with a sun path diagram, and shows the number of hours the painting is receiving direct sun on its surface. This painting is exposed to direct sunlight mainly during the late afternoon hours between 4:00 and 6:30 PM between the equinox and summer solstice. Many of these west-facing galleries cannot be used to exhibit light susceptible artwork. Several of these galleries had remained empty since the opening of the museum, and few of them only display sculptures made of metal.
The Kimbell Art Museum
At the Kimbell Art Museum direct sunlight penetrates only at the west-facing entry lobby, which has a large span of clear glass. To protect the entrance of direct sunlight on this façade, Kahn extended one module of the vaulted roof and used an array of trees to filter sunlight. Few sculptures are displayed in the lobby, where much of the social and gathering activities take place. In the rest of the museum, sunlight penetration occurs only in small areas next to the narrow openings at the end of the vaulted ceiling, mainly in areas toward the south and west of the building. These discreet sun patches move slowly throughout the day without ever reaching the display areas. The movement of these bright surfaces gives to visitors and museum workers a subtle indication of the sun movement, highly appreciated by them. Figure 7 shows a view of the south wall of the central gallery, where soft reflected light bounces off the metal reflective panels onto the vaulted ceiling. Illuminance levels on the display areas throughout the museum do not exceed 50 lux.

The Amon Carter Museum
Direct sunlight was observed in three different galleries of the Amon Carter Museum: the East-facing gallery (entry lobby), the South-facing (2nd floor), and North-gallery adjacent to atrium (2nd floor),

**East-facing gallery (entrance lobby):**
The main entry lobby to the museum is used as a gallery for the display of oil paintings and metal sculptures. In 1996, Philip Johnson made changes to the museum’s east façade by replacing the glass to a dark tinted one with visible transmittance (Tvis) of less than 5% and UV protection. Even with those modifications and the arched portico, direct sunlight strikes the lobby every morning throughout the year except few days around summer solstice. The fish-eye photo from Figure 8 indicates that the painting receives direct sun year-round for about 55% of the morning hours. The horizontal ceiling of the portico protects the paintings from the sun for about an hour everyday of the year. Figure 9 shows the amount of sunlight penetrating this gallery on March 5 at 9:00 AM. Illuminance levels measured over the paintings at this time reached values of 2,400 lux, which is about 12 times higher than the recommended IES standards for moderately light susceptible display materials. Every night each of the oil paintings of this gallery are covered with boards to protect them from the morning sun and UV radiation. Every morning, the boards are removed from the painting few minutes before the museum open its doors for visitors (10:00 AM).

South-facing gallery (2nd floor):
This gallery is the only one on the second floor that receives natural light directly from a side light window. The gallery is located right over the South entrance to the museum. The gallery displays mainly oil paintings and metal sculptures (Figure 10). The 210-ft²-window area (19.5 m²) has a five-feet (1.5 m) external horizontal overhang, and the visible transmittance (Tvis) of the glass is 12%. The window wall ratio (wwr) of the gallery is 58%, and the window floor ratio (wfr) is 28%.
Direct sunlight inundates the gallery all day throughout the year. Fish eye views taken from the painting’s viewpoint show that it receives direct sunlight between 2:00 and 4:00 PM from November to January (Figures 11 and 12). Illuminance measurements taken over the painting under direct sun reached up to 2,200 lux, which is 11 times higher than the IES recommended standards for oil paintings. The total illuminance-hours during these two hours of sunlight over the painting is around 404,800 lux-hours, when added the illuminance-hours over the painting during the rest of daylight hours 700,000 lux-hours, the total over exceeds the maximum annual exposure to light recommended by IES for oil paintings. Figure 12 also shows that the horizontal overhang blocks sunlight few hours around wintertime, but does not shade enough the window to protect the painting. Paintings in this gallery are exposed to daylight at all times without any device that could help to reduce the illuminance levels over light susceptible artwork.

Figures 13 and 14 show the illuminance levels simulated with the Desktop RADIANCE lighting program in the south gallery on November 28, at 3:40 PM. Simulated illuminance levels were calibrated with the measured illuminance levels during site visits. Lighting simulations were done at different times during the day to evaluate the sunlight patterns in the gallery. Results from these simulations showed that the display areas over the walls receive direct sun in the morning (west wall) and afternoon (east wall) for about two hours around winter solstice.
North galleries adjacent to atrium (2nd floor):
Two of the windowless north galleries of the second floor receive direct sunlight that passes through the high southwest windows of the atrium (see yellow areas in Figure 4-right). Illuminance levels measured over the painting in one of the two galleries on January 19, 2003 (Figure 15) reached an extremely high value of 11,500 lux, which is about 57 times higher than the recommended IES standards for museums. The total illuminance-hour per year over these display areas over exceeds the total exposure limits for moderately light susceptible displayed materials. The fish-eye photo (Figure 16) shows that the painting receives direct sun for one and a half hours in the early afternoon from November to January. The high illuminance levels over the display areas are due to the high visible transmittance of the atrium’s glass ($T_{vis}=59\%$). The glass of the atrium does not have any shading device to intercept the incoming direct sun to the adjacent galleries. To protect paintings from over exposure to light, curators have been rotating oil paintings frequently (see dates on Figures 15 and 16).
Another problem observed in these galleries is the glare that visitors experience while moving through the gallery and to the atrium. Figure 17 illustrates how a visitor has to protect her eyes from direct sun while trying to see the painting and read the sign next to it. This visitor is receiving about 7,770 lux over her eyes when not covered. The extremely high variations of light levels within the field of view of the visitors to these galleries makes them uncomfortable to adjust their eyes to the low light levels over the paintings and to the bright atrium’s glass areas that are within her field of view.

Table 1: Summary of Lighting Conditions at the three museums.

<table>
<thead>
<tr>
<th></th>
<th>Modern Art Museum</th>
<th>Kimbell Art Museum</th>
<th>Amon Carter Museum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunlight penetration on galleries</td>
<td>West-facing galleries</td>
<td>No (entrance of daylight is well controlled)</td>
<td>East-facing lobby</td>
</tr>
<tr>
<td>Daylighting systems (orientation)</td>
<td>Toplighting (north-, south-facing clerestories)</td>
<td>Toplighting (narrow-strip skylights with reflectors)</td>
<td>Toplighting (high windows in atrium)</td>
</tr>
<tr>
<td></td>
<td>Sidelighting (west-facing)</td>
<td>Sidelight high strip windows (east-, west-facing)</td>
<td>Sidelighting (east-, south-facing)</td>
</tr>
<tr>
<td></td>
<td>Windowless galleries</td>
<td></td>
<td>Windowless galleries</td>
</tr>
<tr>
<td>Range of illuminance levels on display areas</td>
<td>50 lux to 4,000 lux (under direct sunlight)</td>
<td>50 lux and under</td>
<td>50 lux (windowless galleries)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Up to 11,000 lux (under direct sun)</td>
</tr>
<tr>
<td>Display objects</td>
<td>Oil paintings</td>
<td>Paper, prints</td>
<td>Oil paintings</td>
</tr>
<tr>
<td></td>
<td>Sculptures (wood)</td>
<td>Photographs</td>
<td>Daguerrotypes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil paintings</td>
<td>Photographs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Watercolors</td>
<td>Sculptures (metals)</td>
</tr>
<tr>
<td>Glazing</td>
<td>Blue tinted, Tvis=59% with white interior screens.</td>
<td>Skylights (polycarbonate with UV filter)</td>
<td>Dark tinted, Tvis=5%, UV protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tinted, Tvis=12%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clear glass, Tvis=60%</td>
</tr>
</tbody>
</table>
Conclusions
The most noticeable problem, in the galleries of two of the museums presented in this paper, has been the sunlight penetration over the displayed museum objects. This fact is harming valuable art collections, and also creating visually uncomfortable environments for visitors. Sunlight penetration occurs mainly in galleries with side lighting windows that face the sun - east, south, and west-; orientations that are the most difficult to control. Even though the time of over exposure is relatively limited, the illuminance levels reached at these times are extremely high, 10 to 57 times the maximum recommended IES standards for light susceptible objects. Dark tinted glass, screens, or small overhangs are not enough measures to block the entrance of direct sun over the exhibit areas at the Modern Museum (west-facing galleries) and at the Amon Carter Museum (east-facing galleries). To control the light levels in these galleries more aggressive changes should be done, like modifying the façade by adding horizontal or vertical shading devices, external louvers, trellises, or trees to filter sunlight. All these modifications could change the image of the building, which may not be acceptable by designers. There are other less intrusive solutions that include the use of miniaturized sunscreens, interior louvers or baffles; or computer controlled dynamic window systems (Reference 6), where direct sunlight over sidelight windows can be intercepted and filtered reducing interior light levels as low as 25 lux or under.

On the other hand the third museum, the Kimbell Art, presents a well thought and carefully designed top lighting system that can introduce adequate light levels throughout the year to accommodate the lighting requirements of exhibits, and at the same time provide a connection to the exterior environment by rendering the galleries with natural light. This museum is an excellent example that it is possible to successfully illuminate museum galleries with daylighting.

If we already know that sidelight windows in museum galleries create many problems to the display of light susceptible artifacts, why are we still including them as a source of illumination in museum galleries? Is it due to the lack of knowledge about solar geometry? Or it is just that architects underestimate the effects of sunlighting in museums? The answers to these questions may not be clear and simple, meanwhile we might be finding museum galleries with sidelight windows with strong sunlight over display areas, such as in two of the three museums presented in this paper (see summary in Table 1). In the meantime, curators and facility managers at these museums have to create means to protect their valuable art collection (i.e. rotating display objects, use boards to cover them on a daily basis, display least light susceptible objects, cover completely the windows with boards or black cloths, among other solutions) (Reference 7). The main goal of this paper was to make us reflect on the way that museums are still being designed, and on how could we make them better to preserve and display artifacts that are important part of human history.

Acknowledgements
This work was supported by a grant from the College Research Interdisciplinary Council of the College of Architecture at Texas A&M University.

References
(2) The Kimbell Art Museum website: http://www.kimbellart.org/
(3) Amon Carter Museum website: http://www.cartermuseum.org/
(4) Pacific Energy Center website: http://www.pge.com/pec/