Illuminating Art Using a Daylight System at the Broad Contemporary Art Museum

Introduction

In February 2008 the Broad Contemporary Art Museum (BCAM) opened on the campus of the Los Angeles County Museum of Art (LACMA). Designed by the award winning architect, Renzo Piano, the three-story building features 72,000 square feet of gallery space, a distinctive red escalator that transports visitors to the third-floor main entrance, and a horizontal roof composed of glass panels and saw-tooth skylights that channel north light into the third floor galleries while excluding direct sunlight (Figure 1).

The use of diffuse natural light to illuminate the third floor galleries is one of the defining features of the building and was purposely incorporated into the design to take advantage of the varying intensity and color of natural light to enhance the visitor viewing experience. In this paper, the authors will review the design of the roof lighting system and present an assessment of its overall effectiveness using environmental data collected over the past two years. The practical implications associated with recent changes in museum architecture to take advantage of diffuse natural light to illuminate artwork will be discussed in terms of the changing nature of exhibition and conservation practice.

Broad Contemporary Art Museum

Designed in the shape of a truncated "H", each floor of BCAM consist of two, 10,000 square foot galleries separated by two corridors which are used as additional gallery spaces and also function as foyers. All utilities including the passenger and freight elevators are housed in the central core which separates the main galleries on each floor. The

Figure 1 Third floor gallery ceiling construction

main gallery spaces on each floor are free of support columns and measure over twenty two feet tall giving the galleries of sense of openness and a loft-like appearance. With the exception of the first floor, humidified air is delivered through an underfloor, air-distribution system to achieve appropriate environmental conditions within the galleries.

A key element of the design of the BCAM building is the use of natural light as the primary means of illuminating the third floor galleries. To accomplish this objective a roofing system was designed using north facing skylights to allow diffuse light to enter the galleries and external motorized shades to reduce the overall amount of light transmission into the galleries to a level appropriate for the display of moderately light sensitive works of art based on current museum standards for cumulative light exposure for "old master" oil paintings. Conservation standards and practices vary from museum to museum but typically limit paintings to illuminance exposure of 30 foot-candles (ftc). Since the potential for visible light to degrade light-sensitive objects is a function of the cumulative effect of light intensity over time, these instantaneous guidelines are often multiplied by 3,000 annual hours operation to yield annual allowances of 45,000 -90,000 ftc-hrs.

This approach eliminates the need to provide constant illumination at a specified light level and takes advantage of the varying intensity and color of natural light when viewing works of art.

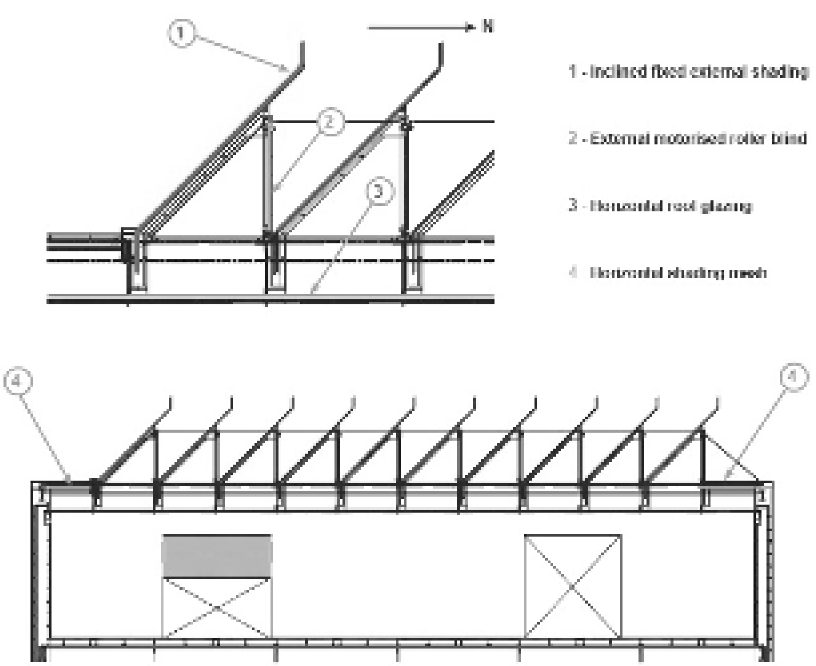

Figure 2 Third floor roof construction

Design of third floor roof system

The BCAM roof consists of a series of north facing skylights placed in a saw-tooth pattern at ten foot intervals which allows diffuse north light to enter the gallery (Figure 2). The roof system consists of a number of layers: (a) inclined fixed external shading; (b) external motorized roller blinds; (c) horizontal roof glazing panels and (d) horizontal shading mesh.

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Inclined fixed external shading

These white panels are inclined at 45 degrees and are open to the north to allow diffuse north light to enter the building. Their orientation prevents direct sunlight entering the gallery for most of the year, but allows reflected diffused sunlight through. In addition, the panels have a matte finish to reduce specular reflections. Gloss measured on the panels at the angle of incidence of 60 degrees is 2 gloss units. For painted surfaces, gloss measurements less than 10 gloss units at 60 degrees are considered matte.

External motorized roller blinds

The external motorized blinds serve three functions. The blinds diffuse early morning and late afternoon summer sun that can pass through the inclined fixed shading panels. They also provide a further degree of control of natural light levels within the gallery when the museum is open. When fully deployed, the blinds also reduce the amount of daylight entering the galleries when the museum is closed thereby reducing unnecessary exposure of art to light.

Horizontal roof glazing

Low iron insulating glazing units provide the weatherproofing layer. Low iron glass is used to maximize color rendering, therefore minimizing the distortion of the color of natural light transmitted into the gallery. Clear polyvinyl butyral (PVB) interlayers are also provided within the glass to filter ultra violet radiation to within conservation limits. A custom white frit pattern is applied to the glass to provide diffusion and to reduce glazing transmission to within the required range.

Horizontal shading mesh

This additional shading layer consists of fixed aluminum louvers in an east-west and north-south orientation. The spacing of the mesh is designed to prevent sunlight from entering the galleries throughout the year and is required where there are no inclined panels to provide shading.

Gallery lighting and daylight linking

Track lighting with UV filters are integrated within the glazing mullions of the third floor gallery and installed to provide ambient light for circulation, to spotlight sculpture, and to supplement available natural lighting when appropriate. The majority of track mounted fixtures are daylight linked through the use of photocells connected to the electric lighting control systems.

As designed, the system is intended to adjust the level of electric lighting to the available natural light to maintain a given total illuminance. When natural light falls below a given threshold, the control system automatically adds the required amount of electric light to increase the total illuminance to the set level. Daylight linking ensures that energy consumption of track lighting is minimized when natural lighting levels within the gallery are sufficient and also provides for a gentle transition from daytime to night time lighting conditions.

Daylight predictions

During the design phase, a detailed annual illuminance exposure analysis was conducted to assess the performance of the roofing system. The light transmission through the roof system is a function of two factors referred to as the daylight factor and sun factor. The daylight factor is the ratio of the external horizontal illuminance from diffuse skylight to the internal illuminance. The sun factor is the ratio of the external horizontal illuminance from the sun to the internal illuminance.

Whereas the daylight factor can be assumed to be largely constant for all sky conditions (overcast, partly cloudy, or clear), the sun factor is a function of the position of the sun throughout the day and year and is thus variable. The analyses were conducted using a detailed three-dimensional computer modeling program created by Arup Lighting which made it possible to calculate the daylight and sun factors at various points on the walls of the third floor galleries.

Combining the daylight factor and sun factor analysis with measured weather data published for Los Angeles enables the annual variation of internal wall illuminance due to daylight to be predicted. From this data the annual exposure due to daylight can be calculated.

These analyses incorporate a wide range of data associated with the material characteristics of the roof and gallery construction including the percent transmission and reflectance of the glazing, internal walls and floors, roof structure, inclined shading panels, vertical roller blinds, and horizontal ceiling mesh. As expected these analyses also incorporate various assumptions associated with the operation of the museum including hours of operation, gallery cleaning and roof maintenance schedule, and roller shade operation.

The original design specifications called for a maximum of 30 ftc with the roller shades set at a fixed position for certain months of the year; thus, ensuring that the natural lighting remains within a given range throughout the year while maintaining some variability of natural light entering the third floor galleries.

The daylight linking system was programmed to add electric lighting when the daylight levels fell below 19 ftc, adding sufficient electric light to increase illumination due to daylight and electric light to 19 ftc when the museum is opened. When closed, the shades would be fully deployed and the electric lighting programmed to provide sufficient lighting for cleaning (19 ftc) and security (0.5 ftc).

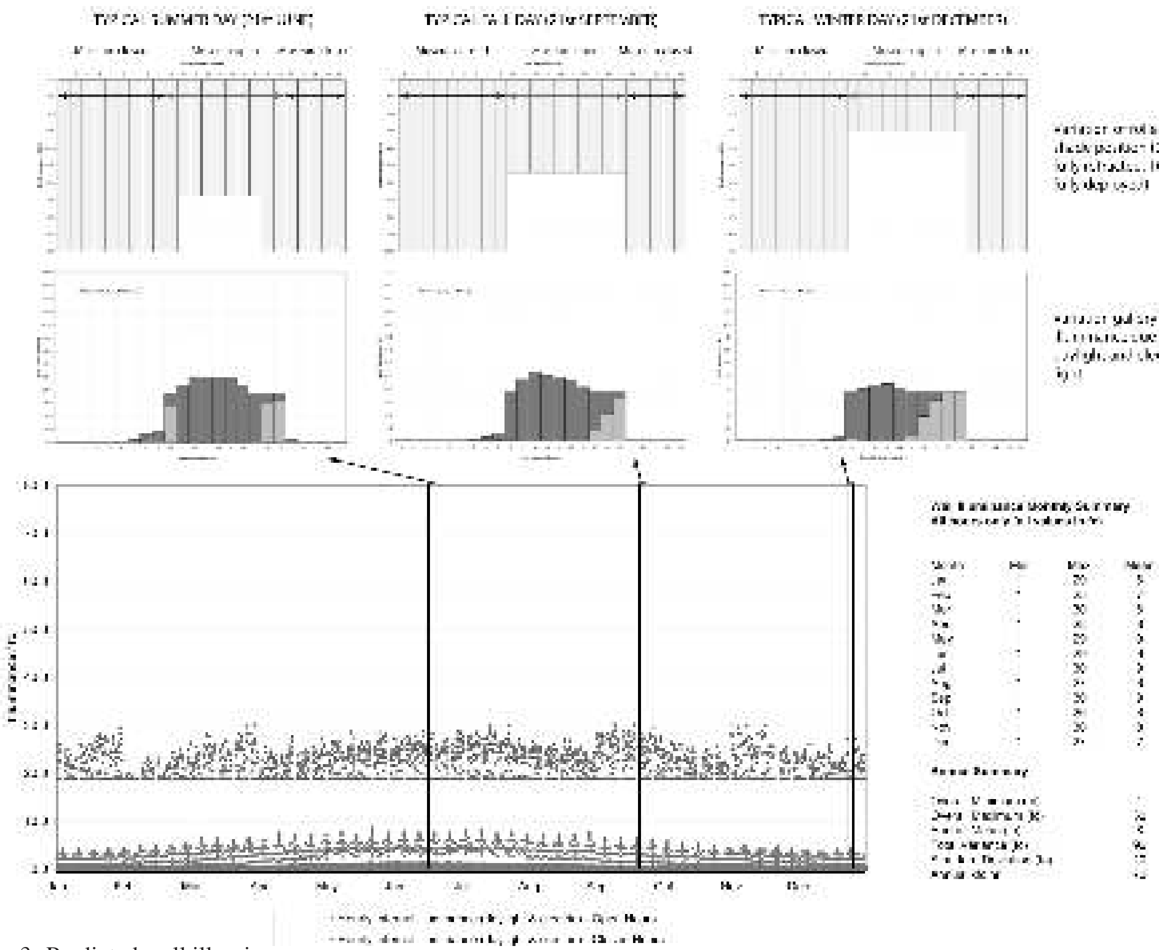


Figure 3 Predicted wall illuminance

The following series of diagrams illustrate the variation in wall illuminance at six feet above floor level due to natural and electric lighting within the third floor galleries predicted by the daylight and sun factor analysis incorporating the operational parameters discussed above (Figure 3). These diagrams illustrate how maximum natural light levels within the galleries can be controlled by partially deploying the roller shades. Predicted illuminance readings are illustrated for a typical summer, fall, and winter day.

Results and Discussion

Immediately following the opening of the museum it became readily apparent that the light levels in the galleries were far in excess of the predicted values. Even when the shades were fully deployed, the wall illuminances during the day were consistently above the predicted light exposure and reaching levels as high as 60 ftc. Given the magnitude of this discrepancy it was initially thought that the light transmission of the roller fabric was greater than anticipated. According to the manufacturer's specifications, the roller blind had a total visible light transmission of 14% (10% diffuse and 4 % direct). Testing of the roller fabric in-house as well as by an independent laboratory yielded a total visible light transmission of 16% (11% diffuse and 5% direct). Given that the test allows a 2% tolerance for error, the light transmission of the roller fabric was eliminated as one possible reason for the higher than predicted light levels in the galleries.

Attention soon focused on gaps in the design of the roofing system that allowed light to by-pass the roller blinds and enter the galleries. The original design specifications did not propose to provide 100% blackout to the galleries but that some daylight (5%) would pass between adjacent roller blinds. Hem bars that were supposed to be on the bottom of each roller shade were not installed due to a manufacturing problem. The absence of hem bars as well as gaps between the roller shade tube and the inclined roof panels also contributed to unfiltered light entering the third floor galleries and resulted in streaks of light moving across the gallery walls during certain hours of the day (Figure 4).

In order to estimate the amount of light infiltration into the galleries as a result of these gaps additional daylight factor analysis was conducted under total black-out conditions. The contribution due to hem bar gaps and the gaps between the roller shades was predicted to be 2% and 6.6% respec-

Figure 4 Unfiltered light entering third floor galleries

tively, yielding a total contribution of 8.6%. This amount was confirmed experimentally by comparing the light transmission of the roller blinds measured in-situ on the roof (15-17%) using an Elsec light meter with the gallery light readings obtained by measuring wall illuminances immediately before and after fully deploying the roller blinds (26%).

Even with the properly manufactured hem bars installed, it was not possible to eliminate the gaps between the roller blinds or the roller shade tube and the inclined roof. For this reason it was decided to replace the roller shades with a fabric possessing a lower visible light transmission to reduce the cumulative light exposure to an appropriate level. A roller blind was selected possessing a visible light transmission of 7% (6% diffuse and 1 % direct).

The light levels in the galleries were subsequently monitored using data-loggers placed at six foot levels from the floor facing in each of the four compass directions. The data-loggers were placed in the corners of the galleries beneath the horizontal shading mesh.

While this placement was not ideal, it was unavoidable given the location of installed artwork and temporary walls. Furthermore, it was necessary to move several of the data-loggers throughout the year to accommodate additional changes in art installation and the exhibition schedule. Nonetheless, concurrent measurements taken along the same wall using hand-held light meters confirmed that the locations chosen and the orientation of the data-loggers are representative of the visible light exposure of paintings in the galleries, although they will always be slightly higher in the afternoon due to the presence of the metal grating.

The results of the light level readings in the galleries from May to December are given in Figure 5 which shows a considerable variability in gallery wall illuminance and a maximum light exposure in excess of the desired 30 ftc.

While the high light levels on certain days can be attributed to on-going changes in the roller blind schedule involving the prolonged retraction of the roller blinds to accommodate roof maintenance and filming in the galleries, the overall trend line is well above 30 ftc during the summer months. This may be due to any number of factors including cumulative tolerance errors associated with measurement equipment, construction, and the daylight/sunlight factor analysis.

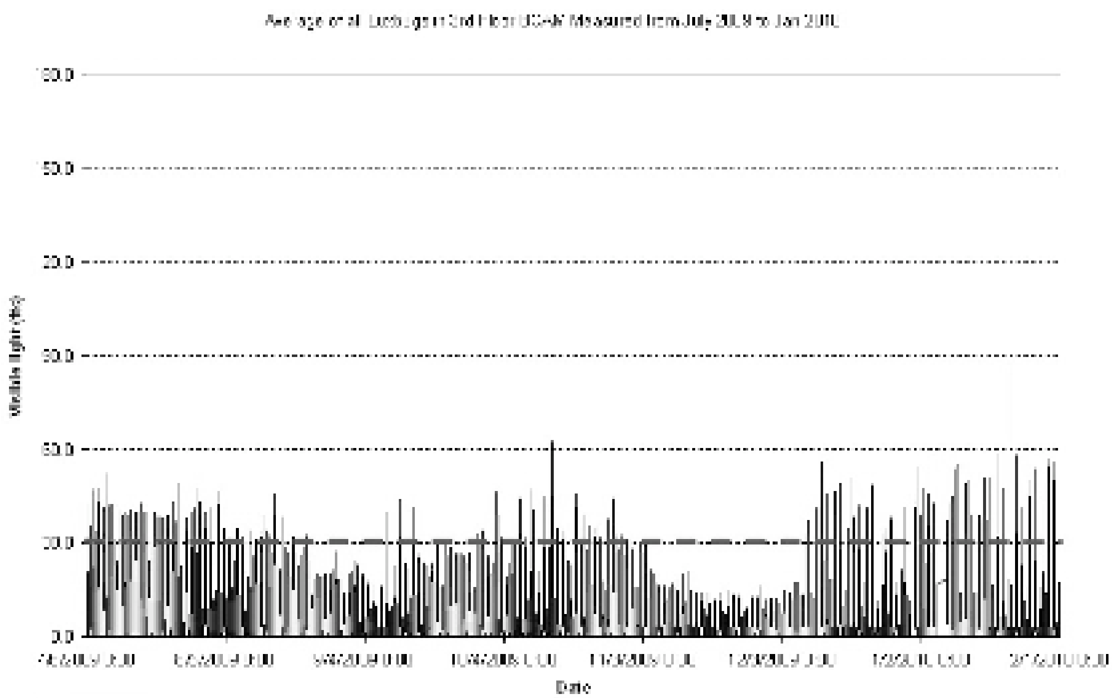


Figure 5 Measured wall illuminance

It also may be a reflection of how the analysis addresses the difference in transmission of diffuse and direct light through different roller blinds. The high reflectance (~92% reflectance) of the bright white walls in the third floor painted walls is certainly a contributing factor. When a new exhibition was installed in one of the galleries with a change in wall color from bright white to light grey (~56% reflectance), the wall illuminance dropped dramatically.

Figure 6 Measured wall illuminance for a typical summer day

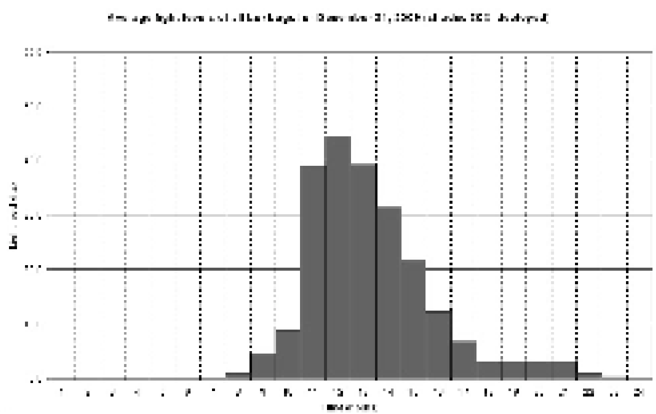


Figure 7 Measured wall illuminance for a typical fall day

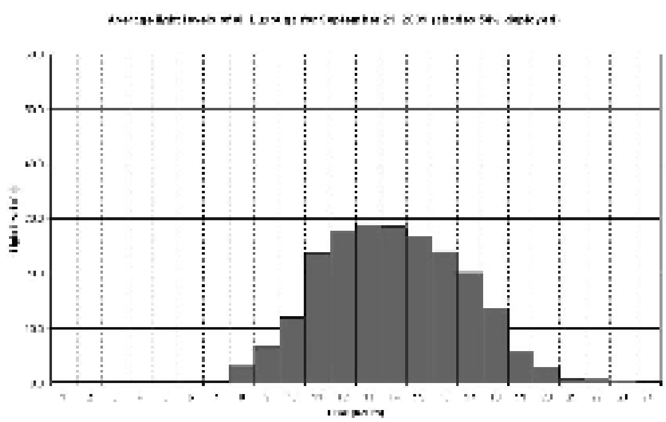
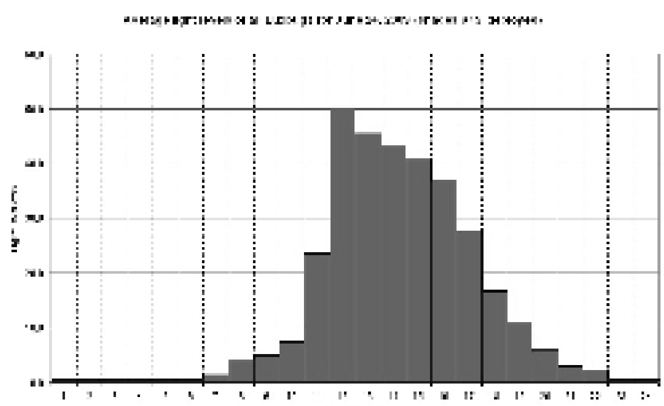


Figure 8 Measured wall illuminance for a typical winter day



Graphs of the variation in measured data representing the internal wall illuminance at six feet above the floor for a given day in summer, fall, and winter are illustrated in Figures 6, 7, and 8, respectively.

When compared with predicted values illustrated in Figure 3, it is readily apparent that the measured wall illuminance was not always greater than or equal to 19ftc as predicted for daylight linking for all museum open hours. The contribution to the gallery light levels provided by the gallery track lighting and the daylight linking system proved difficult to assess.

The track lighting was programmed to automatically turn on and off when the museum was open and closed to the public, respectively. The two track system was fully energized when the museum was open to spotlight specific works of art and to provide a gentle wash of the walls.

In general, the system failed to maintain the minimum 19 ftc of illumination in the galleries (as defined in the program) during the fall and winter months when the natural light levels fell below 19 ftc in the late afternoons and evening hours. This is probably a reflection of the number of gallery lights installed in the gallery which was not sufficient to generate the required wall illumination.

Table 1 Measured wall illuminance (monthly average)

Month	Roller Shade Control	Minimum (ftc)	Maximum (ftc)	Mean (ftc-hrs)
May	67% deployed	0	174	13
June	67% deployed	0	142	13
July	67% deployed	0	62	14
August	67% deployed	0	47	9
September	54% deployed	0	44	7
October	54% deployed	0	63	9
November	30% deployed	0	29	4
December	30% deployed	0	56	7
January	54% deployed	0	86	8
February	54% deployed	0	88	7

* Shades deployed when museum closed and when early morning and late summer sun shading is required in summer. Shades otherwise operate seasonally to limit maximum daylight illuminance to 30ftc. Gallery electric lighting controlled when museum is open to maintain 19ftc of illumination on the walls at 6 feet. Electric lighting off when natural lighting is greater than 19 ftc.

Table 2 Measured wall illuminance (annual summary)

Minimum	0	ftc
Maximum	174	ftc
Annual Mean	9	ftc
Total variance	164	ftc
Standard deviation	13	ftc
Annual kftc.hr (10months)	66	kftc-hr

The mean monthly wall illuminance calculated in ftc-hours over a 24 hour period from May through February is given in Table 1. An annual summary of the wall illuminance is given in Table 2. With the exception of the maximum monthly iluminances, these values are comparable to that predicted by the computer modeling simulations (Figure 3). The projected cumulative light exposure for the year is also within the predicted range originally identified for the display of oil paintings.

The higher maximum monthly wall illuminance can be attributed to a number of factors though it is primarily a function of the automated behavior of the roof shades. In order to protect the shades from wind damage, the shades will automatically retract if the wind speed exceeds 25mph. Under these conditions all the roof shades will fully retract and all other fully automated behavior and manual override capabilities will be disabled thus allowing direct light to enter the galleries.

Conclusions

The ramifications of adopting a daylight system for illuminating art galleries can be significant with respect to the display of light sensitive artwork. Not only is it critical that conservation be involved during the initial planning phase but conservators must stay involved throughout the commissioning process and after.

Despite everyone's good intentions and efforts, computer modeling is input-dependent and light level predictions and reality can diverge significantly due to small calculation errors or subsequent changes in operational parameters. Post monitoring and evaluation is critical but difficult to undertake given museum galleries generally open immediately after construction and the commissioning time is too short to properly evaluate a daylight system.

It must also be recognized that when using this approach to gallery illumination, daylight levels in the galleries will still vary appreciably throughout the year. Rather than targeting specific and constant illumination levels for the display of art, it is necessary to consider a range of light levels and study the total illumination exposure received by artworks over a given period of time as well as instantaneous light levels.

Such an approach is not compatible with current standards for the display of many works of art and thus may have a significant impact on negotiations with other museums. They may be hesitant to loan an artwork for an exhibition under these circumstances particularly if the light levels exceed the maximum permissible exposure during the loan period.

The complexity of such a system must also be taken into consideration when adopting a daylight system. Constant requests for manual overrides to accommodate maintenance, filming, and other marketing and development activities can have a significant impact on the total cumulative light exposure and require an additional degree of diligence in monitoring activities within the galleries.

While recent architectural approaches to gallery lighting have expressed a preference for natural light and describe its varying intensity and color as both pleasant and more enjoyable than conventional gallery track lighting, it is debatable whether or not this variability in natural light was achieved and indeed translated to the galleries in this case. Based on the experience with the BCAM building, changes were made in the design of a similar roofing system of the new Lynda and Stewart Resnick Exhibition Pavilion. Pre-opening light monitoring has been initiated and the results from the new building are pending.

Appendix: Instrumentation

Universal Light Monitor Type 774 and 764
Littlemore Scientific Engineering (ELSEC)
Gutchpool Farm, Gillingham, Dorset SP8 5QP, UK
International tel: +44 1747 835550
www.elsec.com

Luxbug Datalogger ML4701 and 2525
Hanwell Instruments Limited
Pendle House, Jubilee Road
Letchworth
Hertfordshire SG6 1SP
International tel: +44 1462 688078
www.hanwell.com

Micro-Tri-Gloss meter
BYK-Gardner USA
Rivers Park II
9104 Guilford Road
Columbia, MD 21046
Phone: 800-343-7721
www.byk.com