Lighting Strategies to Enhance Artwork Visibility in Earth-Bermed Art Galleries

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Abstract
Earth-bermed art galleries, integrated into the natural environment, provide environmental and spatial advantages but present special challenges in providing adequate artwork illumination. This paper discusses integrated lighting approaches—both natural and artificial—to improve visibility, conserve artworks, and enhance visitor experience. It investigates advanced techniques including fiber-optic daylighting, solar tubes, tunable LEDs, and smart lighting systems. Drawing from international examples and current research in lighting design and conservation, the study proposes a sustainable and adaptable lighting framework suited for subterranean cultural environments.

Keywords: Artwork visibility, Earth-bermed architecture, Gallery daylighting strategies, Gallery exhibition lighting, Gallery lighting techniques, LED lighting systems

1. Introduction
Earth-bermed structures are gaining recognition in architecture for their eco-friendly design, thermal insulation, and natural integration into the landscape. However, their distinctive spatial form poses a unique set of challenges when converted for use as art galleries, especially when it comes to creating appropriate lighting conditions that guarantee the preservation of sensitive materials while also improving the visibility of artwork.
Lighting control in art galleries is crucial for curatorial planning, influencing the viewer's experience and the emotional tone of the space (Cuttle C. , 2015). The quality, intensity, and color temperature of light are essential, especially when showcasing various forms of art. Additionally, lighting must be carefully managed to prevent damage from UV rays and heat—issues that are more pronounced in earth-bermed galleries with limited natural sunlight.
This research explores artificial lighting techniques suited for gallery spaces and innovative daylighting strategies for earth-bermed structures. The study aims to develop an integrated lighting approach that enhances artwork visibility, supports conservation, and aligns with the sustainability goals of underground architecture.

2. Literature Study
1. Historical Context
The evolution of lighting in art galleries and museums reflects both technological progress and growing concern for artwork preservation. Initially, galleries depended on natural daylight, especially during the Renaissance. Museums like the Uffizi Gallery in Florence incorporated large windows and courtyards to

create a serene, well-lit atmosphere (Saunders, 2020). However, the inconsistency and damaging UV radiation of daylight led to the early use of blinds and tinted glass to control light exposure (Piana, 2020).

Figure 1 The Uffizi Gallery in Florence showing large windows and courtyard.

In the mid-19th century, artificial lighting marked a significant shift. Gas lamps extended viewing hours but posed fire and pollution risks. The introduction of electric incandescent bulbs offered more stable, safer lighting that mimicked daylight tones while allowing better control over light levels. Museums like the British Museum cautiously adopted this innovation (Gobbato, 2022).
During the 20th century, advancements continued with fluorescent lighting, which was energy-efficient but lacked color accuracy. The introduction of halogen and fibre optic lighting brought improved color rendering and conservation-friendly solutions, as fibre optics emit no UV or heat (Piana & Merli, 2020).
The most transformative development was the use of LED lighting from the 1990s onward. LEDs offer high color fidelity, Tunable brightness, long lifespan, and no UV radiation- making them ideal for conservation and display (Saunders, 2020).
Today, many museums adopt smart LED systems that adjust based on occupancy or daylight levels, balancing visitor experience, artwork preservation, and sustainability (Piana & Merli, 2020).

2. The Role and Effects of Lighting in Art Galleries

Lighting in art galleries is vital not only for making artworks visible but also for enhancing the emotional experience of visitors and ensuring long-term preservation. High Color Rendering Index (CRI) lighting—preferably above 90—is essential for accurate color perception, replicating the effect of natural daylight (CRI ~100) and maintaining the artwork's integrity (Piana & Merli, 2020). Similarly, Correlated Color Temperature (CCT), measured in Kelvin, shapes the gallery atmosphere: warmer tones (<3000K) work well for classical pieces, while cooler light (>4000K) enhances modern and contemporary art (Gao et al., 2020).

Figure 2 Illustration showing color temperatures of light

Lighting also directs visual flow and focus. Techniques like spotlighting isolate key works—such as the Mona Lisa at the Louvre—while wall-washing evenly lights large installations or murals, a method employed at the Getty Museum (Saunders, 2020). These approaches guide visitors through curated spatial narratives, influencing how they engage with the collection.

However, lighting is not only about aesthetics. It also directly affects the preservation of sensitive materials like pigments, paper, and textiles. Natural daylight, although visually rich, introduces ultraviolet (UV) and infrared (IR) radiation that can degrade artworks over time (Thomson, 2018). To address this, museums use UV-filtering glazing, skylight diffusers, and shaded orientations—such as the north-facing, UV-treated skylights at the Louisiana Museum of Modern Art (Varandani, 2021).

Figure 3 Louisiana Museum of modern art in Denmark showing Skylight

Artificial lighting, especially LED technology, offers better control over intensity, color temperature, and exposure. Modern LEDs are energy-efficient, low in heat and UV output, and available in Tunable systems that range from 2700K to 6500K (Scuello, 2004). These systems are favoured for their stability and ability to highlight detail without compromising conservation efforts.

Ultimately, neither natural nor artificial lighting alone is sufficient. Studies have shown that a hybrid approach, combining both—natural light for ambient effects and LEDs for controlled accent lighting—offers the best balance between visual comfort and material protection (Suleiman, 2024). Such strategies enable curators and architects to shape visitor experience while upholding conservation standards, proving that lighting is as much a narrative and preservation tool as it is a functional necessity.

3. Artificial Lighting Systems

Artificial lighting in galleries is essential for both visual presentation and artwork conservation. Key considerations—such as color temperature, CRI, UV/IR emissions, and heat—affect how art is seen and preserved. Hoke (1988) highlights the need to balance visual impact with preservation concerns when selecting lighting types. Lighting technologies have evolved from incandescent to advanced LEDs, each offering unique benefits.

3.1. Halogen Lamps: Traditionally used for their excellent CRI (~100) and warm tones (2700K–3000K) and are ideal for highlighting paintings and sculptures. They offer focused beam control but emit high heat and UV radiation, requiring protective measures. (John Ray Hoke, 1988)

3.2. Fluorescent lights: commonly used in back-of-house areas or for less-sensitive artifacts, offering color temperatures between 3000K and 6500K and CRI values of 80–90, they may not render colors accurately (CIBSE, 1999). They emit low heat, but their UV output can fade delicate materials like watercolors and textiles which can be reduced by triphosphor tubes and UV filters (Miller & Druzik, n.d.).

3.3. Metal halide lamps are used in large spaces needing strong general lighting. With a neutral-white tone (3500K–4200K) and CRI of 85–93, they are effective but not ideal for sensitive works due to high UV/IR emissions (Cuttle, 2007). Their use is best limited to robust objects or areas where exposure can be carefully timed.

3.4. LED (Light Emitting Diode) systems are now widely used in galleries due to their energy efficiency, low UV/IR emissions, and adaptability. Offering adjustable color temperatures (2700K–5000K) and CRI values above 90, they are suitable for all artwork types (Miller & Druzik, n.d.). LEDs enable dynamic control and work with various fixtures like track lights and wall washers. Their low heat output supports stable indoor conditions, crucial for conservation.

Figure 4 LED Lighting at Virginia Museum of Contemporary Art

Table 1: Comparative Overview of Artificial Lighting Systems in Art Galleries

Lighting Type	Color Temp (Kelvin)	CRI	UV/IR Emission	Heat Output	Best For
Halogen Lamps	2700K – 3000K	~100	High (requires filtering)	High	Oil paintings, metal sculptures
Fluorescent Lamps	2700K – 6500K	70 – 85	Moderate	Low	Ceramics, metals, general lighting
Metal Halide Lamps	3000K – 4200K	80 – 90	Moderate	Moderate	Large canvases, sculpture installations
LED Lighting	2700K – 6500K	90 – 98+	None	Very Low	Paintings, textiles, photography, sculptures

4. Artificial Lighting Techniques for Various Art Displays and Paintings

Different types of lighting are used depending on the medium, size, and location of the artwork. The key to selecting the right lighting system lies in balancing aesthetic presentation with conservation concerns such as UV radiation, heat, and color accuracy. Below are the various lighting techniques for distinct types of artwork:

4.1. Lighting Techniques for Paintings

4.1.1. Halogen Lamps

Halogen lamps offer a warm spectrum and high CRI (~100), emphasizing the rich color palette in oil and acrylic paintings. However, their high UV and IR output requires filters for conservation. Suitable for: Oil paintings, acrylics, traditional canvas works. Color Temp: 2700K–3000K, CRI: ~100, UV/IR: High (needs filtering), Example: National Gallery, London (Cuttle, 2007).

4.1.2. Tunable LED Lighting

Modern LED systems allow color temperature adjustments to suit different exhibitions. With no UV or IR emissions, they are ideal for long-term conservation and versatile applications. Suitable for: All types of paintings, especially contemporary or mixed media. Color Temp: 2700K–6500K, CRI: 90–98+, UV/IR: None, Example: Louvre, Paris (Naomi J. Miller, n.d.)

4.1.3. Fluorescent Lamps

Still used in some institutions due to energy efficiency, though less ideal for fine art due to lower CRI and moderate UV risk. Suitable for: Temporary displays, educational exhibits, less sensitive paintings. Color Temp: 2700K–6500K, CRI: 70–85 UV/IR: Moderate, Example: Metropolitan Museum of Art (McGlinchey, 1994).

4.1.4. Spotlighting (LED-based or Halogen)

Spotlighting allows controlled, focused illumination to emphasize detail or direct attention. It is especially effective in emphasizing brushwork and texture in impasto paintings or creating dramatic contrast. Suitable for: Oil paintings, textured canvases, featured exhibits. Color Temp: 3000K–4000K, CRI: 90–100, UV/IR: LED-based: None; Halogen: High, Example: Used in rotating exhibits at MoMA for key featured works (Cuttle, 2007).

Figure 5 LED Spotlighting

4.1.5. Cove Lighting (Indirect)

Cove lighting provides soft, ambient illumination often used in combination with direct lighting systems to reduce glare and provide even background brightness. This helps reduce eye strain and visual fatigue in gallery environments. Suitable for: Gallery-wide ambiance for oil and acrylic painting halls. Color Temp: 3000K–4000K, CRI: 85–95, UV/IR: None (with LED)**,** Example: Rijksmuseum, Amsterdam, employs cove lighting for background ambiance (Armas, Jan, 2011).

4.2. Lighting Techniques for Sculptures and Three-Dimensional Art

4.2.1. Track Lighting

Allows repositionable fixtures ideal for highlighting form, shadow, and volume in sculptures. Often LED-based for conservation and energy efficiency. Suitable for: Stone, metal, abstract modern sculptures. Color Temp: 3000K–4500K, CRI: 90–98, UV/IR: None, Example: Kimbell Art Museum (Khan, 2001).

Figure 6 Track lighting in Kimbell Art Museum's new Pavillion

4.2.2. Fiber Optic Lighting

Provides cool, safe illumination for fragile and valuable three-dimensional artifacts. Zero UV/IR transmission. Suitable for: Ancient statues, archaeological artifacts, Jewelry. Color Temp: 3000K–4000K, CRI: High (source dependent), UV/IR: None, Example: Getty Conservation Institute (Naomi J. Miller, n.d.).

4.2.3. Spotlighting

Spotlighting is used to highlight sculptures' dimensionality, shadows, and contours. Especially suitable in minimalistic or high-contrast gallery settings. Suitable for: Contemporary sculptures, central installations. Color Temp: 3200K–4200K, CRI: 90–98, UV/IR: LED = None, Example: Whitney Museum of American Art employs spotlighting for contemporary installations (Cuttle, 2007).

Figure 7 Whitney Museum of American Art spotlighting contemporary installations

4.3. Lighting Techniques for Textiles, Murals, and Decorative Art

4.3.1. LED Wall Washers

Uniformly light vertical surfaces such as murals or tapestries, preventing hot spots or uneven fading. Their wide beam spreads make fine details easier to see. Suitable for: Large wall-based art, tapestries, murals. Color Temp: 3500K–4500K, CRI: 90–95, UV/IR: None, Example: Smithsonian American Art Museum (Iordanidou, Sep 2017).

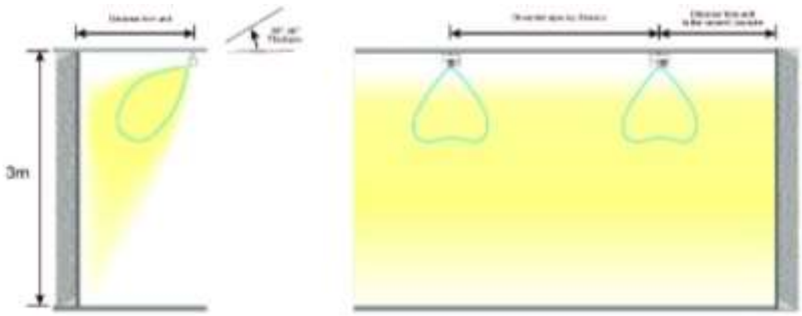

Figure 8 LED Wall Washers

4.3.2. UV-Free LED

Used in close-range textile or manuscript displays. These lights ensure full-spectrum visibility with no degradation risk to fibres or inks. Suitable for: Historic garments, paper art, embroidery. Color Temp: 3000K–3500K, CRI: 90–98, UV/IR: None, Example: Victoria and Albert Museum (Sylvania, 2015).

4.3.3. Cove Lighting (LED-based)

Provides gentle ambient lighting in textile exhibit rooms, helping to prevent direct light exposure and associated fading or discoloration. Suitable for: Fabric-based displays needing low lux conditions. Color Temp: 3000K–4000K, CRI: 85–95, UV/IR: None, Example: Textile Conservation Centre at Hampton Court Palace (Armas, Jan, 2011).

Table 2 Lighting Techniques by Artwork Type

Art Type	Lighting Technique	UV/IR Emission	Example Museum/Use Case
Oil & Acrylic Paintings	Halogen, LED (Tunable), Spotlighting, Cove	Halogen = High	National Gallery, MoMA, Louvre
Contemporary Art / Installations	LED (Tunable), Spotlighting	None	Louvre, MoMA
Metal / Stone Sculptures	Track Lighting, Spotlighting, Fiber Optic	None	Kimbell Art Museum
Ancient Artifacts & Jewelry	Fiber Optic, Track, UV-Free LED	None	Getty Institute
Murals, Wall-based Installations	LED Wall Washers, Cove Lighting	None	Smithsonian Museum
Textiles & Tapestries	Wall Washers, UV-Free LED, Cove Lighting	None	Victoria and Albert Museum
Paper Artworks / Manuscripts	UV-Free LED, Cove	None	British Library, Hampton Court

5. Natural Daylighting Systems

In the architectural design of earth-bermed museums and galleries, daylighting is a double-edged sword—an asset for experiential quality and sustainability, but a liability when unfiltered, uncontrolled, or poorly distributed. Thus, technical strategies for controlled daylighting are not optional but essential for creating a safe, visually optimized, and energy-efficient lighting environment. To achieve museum-grade lighting, natural light must be purposefully incorporated, filtered, redirected, and diffused.

5.1. Light Wells with Reflective Surfaces

Light wells are architectural features designed to channel natural daylight into deeper or underground spaces- especially useful in earth-bermed galleries where direct openings are limited. These vertical shafts guide sunlight from roof level into the interior, improving illumination in spaces otherwise reliant on artificial lighting. However, their efficiency depends on surface reflectance, shaft dimensions, and diffusion strategies.

Unmodified light wells often suffer from limited penetration due to the rapid light falloff. To improve performance, their interiors are finished with high-reflectance materials like white plaster, Aluminium, or mirrored glass, enhancing downward light transmission. As noted by Dubois & Blomsterberg (2011), reflective treatments can boost Daylight Factor (DF) by 20–35% compared to untreated wells.

An optimal depth-to-width ratio—typically between 1:1.5 and 1:2—is crucial for balancing light distribution, allowing adequate daylight to reach lower levels without excessive brightness near the top.

Kimbell Art Museum: A Benchmark Example

Figure 9 Light Well of The Kimbell Art Museum

The most often mentioned precedent is Louis Kahn's Kimbell Art Museum in Fort Worth, Texas, which opened its doors in 1972. Continuous linear light wells are located at the apex of each of the museum's long, cycloid-vaulted concrete roofs. Instead of exposing galleries to harsh direct sunlight, Kahn introduced curved aluminium reflectors beneath these skylights, bouncing diffused daylight laterally onto the walls and ceilings.

A field study by Seda Kacel (2013) measured average daylight illuminance in the Kimbell at 250–450 lux near the walls and 150–200 lux in central viewing zones—all within conservation-safe limits for most museum exhibits. The design successfully balances illumination uniformity and spatial drama, without requiring electric lighting during most daylight hours.

5.2. Skylights with UV-Filtering and Diffusing Glazing

Skylights have evolved from rudimentary roof openings to complex architectural systems that serve multiple functions in controlled daylighting—especially within conservation-sensitive spaces such as art galleries and museums. In contemporary practice, skylight systems are engineered not merely to admit light but to modulate intensity, eliminate UV radiation, and diffuse direct sunlight to achieve uniform ambient illumination.

According to (Chidi, 2022), modern museum skylights typically consist of multi-layered glazing assemblies. These systems incorporate:

1. **Laminated safety glass embedded** with UV-absorbing interlayers, which can block more than 99.9% of ultraviolet radiation (below 380 nm) that causes fading and chemical breakdown in organic materials.
2. **Low-emissivity (Low-E) coatings**, which reflect infrared (IR) heat while allowing visible light transmission, thereby preventing thermal gain.
3. **Fritted glass patterns, silkscreened ceramic coatings, or internal diffusers** that scatter incoming sunlight and prevent directional glare.

Figure 10 Image Shows Roof Glazed Skylight

The intent behind these interventions is to preserve artwork while maintaining visual comfort and aesthetic quality within exhibition spaces. (Thomson, 2018) emphasizes that even moderate exposure to unfiltered daylight can cause irreversible damage to sensitive media such as parchment, textiles, and pigment-based works. Therefore, filtering mechanisms are not optional but essential.

Louisiana Museum of Modern Art, Denmark

A practical application of this strategy can be observed at the Louisiana Museum of Modern Art in Humlebæk, Denmark. As noted by Chidi and Daminabo (2022), the museum's north-facing skylights are integrated into the roof structure to capture diffuse daylight while avoiding direct solar gain. These skylights utilize UV-filtered triple glazing, and the adjoining soffits and ceiling planes are angled and finished in light-reflective materials to bounce light deep into the gallery space without harsh shadows.

This carefully orchestrated lighting system allows the museum to maintain illuminance levels below conservation thresholds—often between 100 to 200 lux, depending on the exhibition. Furthermore, the daylighting design helps save energy by lowering the need for electric lighting during the day without sacrificing conservation objectives (Chidi, 2022).

5.3. Fiber-Optic Daylighting Systems

Fiber-optic daylighting is an advanced system in which sunlight is collected externally, usually via parabolic heliostats or rooftop solar collectors, and transmitted indoors via fibre-optic cables.

A major advantage of this system is its zero-UV, zero-heat light transmission, which is ideal for spaces that house highly sensitive artwork such as tapestries, manuscripts, and mixed media.

According to Mardaljevic et al. (2017), fibre-optic systems can achieve 50–70% daylight illumination levels indoors without any physical penetration between exterior and interior envelopes—critical for ea rth-bermed structures.

Figure 11 Fiber-Optic Daylighting Systems

These systems can be tailored for localized lighting, such as highlighting individual pedestals or showcases, and are currently in experimental use in sections of the Museo del Prado and National Gallery, London (Dubois, 2011).

5.4. Clerestory Windows

Clerestory windows are high-mounted, horizontally continuous window bands located just below the ceiling or roofline. They are typically oriented toward the north in the Northern Hemisphere to harvest diffuse natural light, which is more stable and less harmful than direct solar radiation.

In museums, clerestory windows serve dual functions: they bring in ambient daylight and define a visual break between structural elements, such as walls and ceilings. Their placement at eye-above height eliminates glare and enhances the perception of vertical volume.

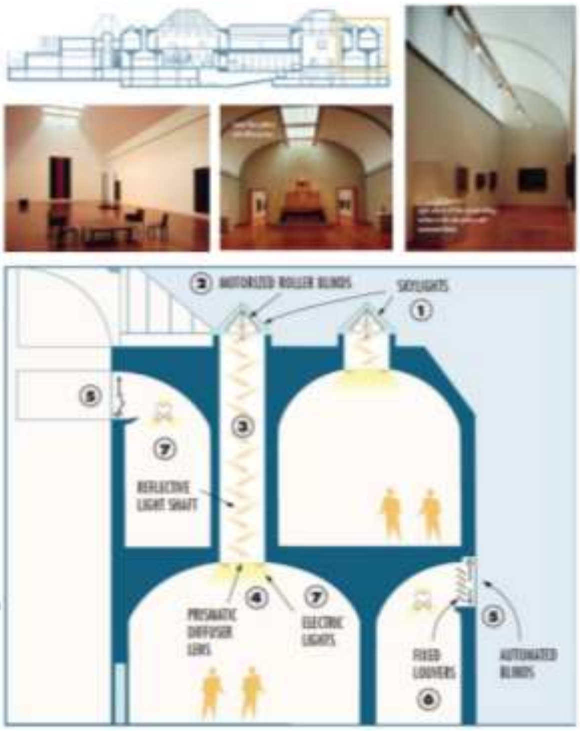

Figure 12 National Gallery of Ottawa, Canada

In the National Gallery of Canada, clerestory windows are paired with automated shading and motorized louver systems to maintain desired illuminance levels and prevent solar ingress during peak hours (Mardaljevic et al., 2017).

5.5. Tubular Daylighting Devices (Solar Tubes)

Tubular Daylighting Devices (TDDs), more commonly referred to as solar tubes, are one of the most compact and effective methods for channelling natural light into confined or earth-embedded interiors, such as subterranean museum galleries. Unlike traditional skylights or windows that require substantial roof area and direct line-of-sight, TDDs operate by capturing sunlight at roof level and transporting it through a highly reflective aluminium or polymer-lined tube into interior spaces. These systems provide diffused, low-glare daylight while minimizing UV radiation and heat gain—two of the principal threats to artwork preservation.

TDDs consist of three main components:

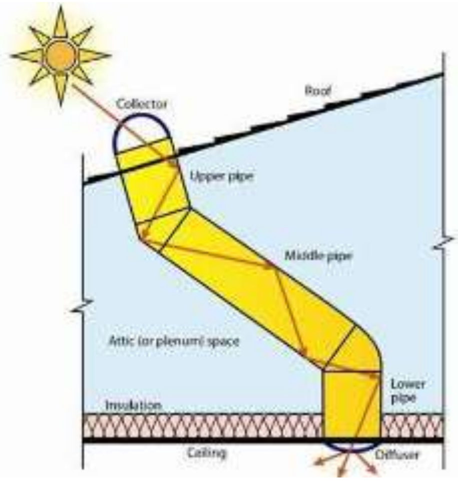

Figure 13 Solar Tubular Day Lighting System

1. **A dome-shaped rooftop collector**—often made of acrylic or polycarbonate, designed to capture sunlight from multiple angles, even in overcast conditions.
2. **An internal reflective tube**, usually with a reflectance value above 98%, ensuring minimal light loss during transmission.
3. **A diffuser lens or dome** at the tube's terminus, which spreads light uniformly across the interior ceiling or exhibit space.

This system allows light to travel horizontally or vertically, enabling architects to illuminate deep or otherwise inaccessible interior volumes, such as those commonly found in earth-bermed museums (Dalipi S., 2021).

Tubular Daylighting Devices (TDDs) deliver diffuse natural light with minimal heat or UV, making them highly suitable for preserving sensitive artifacts. According to Dalipi and Sadiki (2021), TDDs block over 95% of harmful UV wavelengths. When integrated with light sensors and dimmable LEDs, they enable consistent illumination within the safe range of 50–200 lux, reducing energy use while maintaining conservation standards and curatorial control.

National Museum of Western Art, Tokyo

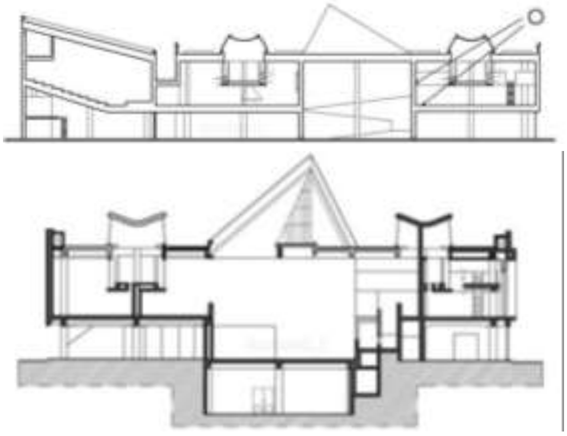

Figure 14 Sections of National Museum of Western Art, Tokyo

At the National Museum of Western Art in Tokyo, solar tubes are strategically employed to provide ambient daylight in semi-underground galleries. These are augmented with motorized shading devices and internal sensors that adjust artificial lighting based on the intensity of incoming daylight. According to Dubois & Blomsterberg (2011), this approach has led to an approximate 40% reduction in daytime electrical lighting load, making the solution both sustainable and contextually sensitive to conservation.

Conclusion

Lighting in art galleries plays a critical role in ensuring both **artwork visibility and conservation**. Given the limited access to daylight in subterranean environments, galleries must adopt innovative strategies that combine natural and artificial lighting systems. Techniques such as skylights, clerestory windows, fibre-optic daylighting, and solar tubes allow for controlled daylight integration, while advanced LED systems, Tunable lighting, and smart controls ensure precision, flexibility, and preservation.

The research shows that hybrid lighting strategies—merging the aesthetic benefits of natural light with the reliability of artificial systems—offer the most effective solution. When thoughtfully designed, these strategies enhance the visitor experience, support sustainability goals, and uphold conservation standards, making them essential in the architectural planning of modern earth-bermed art galleries.

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