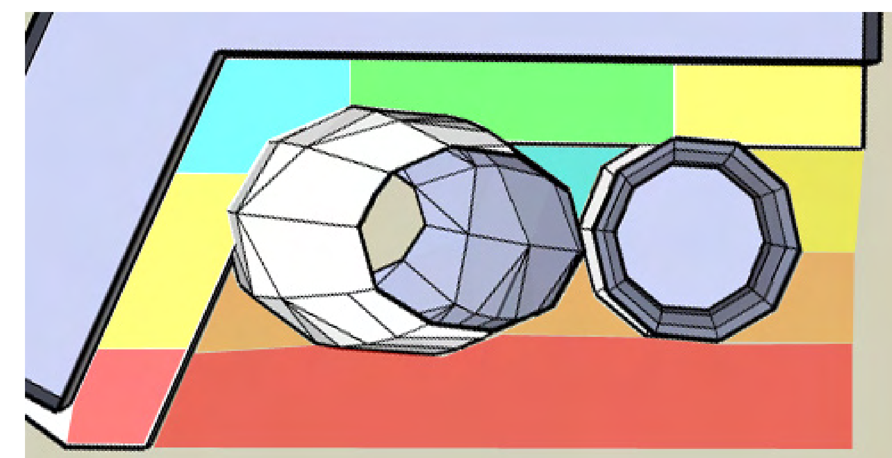
Miami Science Museum
DoE Modelling Grant

Light Planning

19 December 2008
Concept Design



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ArupLighting

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Background

This document presents the light planning studies undertaken as part of the DoE modelling grant for the Miami Science Museum. This work has informed the architectural concept design, and provides information useful to the ongoing design process.

Objectives

The DoE modelling grant was provided to ensure that the museum considers the energy savings that can be achieved through effective daylight design.

The work presented in this report was performed to achieve the following objectives:

- To understand the museum's planning and to identify a daylight strategy for each of daylit areas
- To review the proposed outdoor and indoor design concepts with regard to daylight performance and likely lighting energy savings
- To provide feedback to the design team in order to best utilize the available daylight resource, optimizing energy savings while ensuring visual comfort
- To provide daylight design guidance for the museum building's ongoing design process

Report Outline

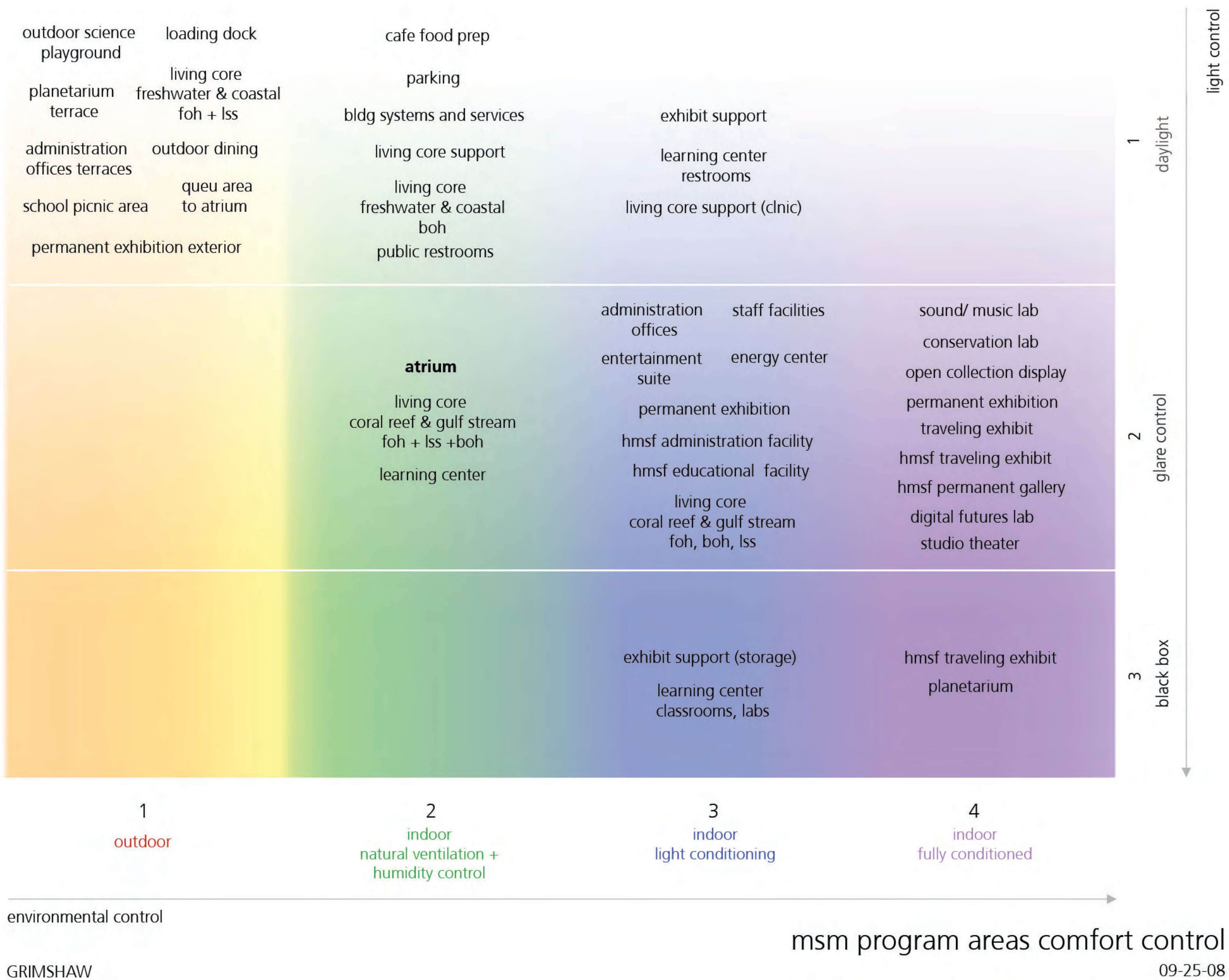
The following section of this report summarizes the museum building's daylight design objectives and relates these to each of the building's daylit areas.

The museum's sustainability objectives are then discussed and a range of sustainable design options are presented.

The outdoor program of the museum is discussed by characterizing the various identified outdoor space and identifying appropriate locations for each program element.

A study of the indoor program is presented, demonstrating daylight design improvements and estimating likely lighting energy savings.

A series of daylight design rules-of-thumb are also provided, assisting the design team in further development of the museum building's design.



Visible, Iconic, Sustainable

The MiaSci building aspires to be a 'prominent and iconic landmark poised at the City's waterfront gateway, representing a striking balance [of] aesthetics and energy efficient design' (Pre-design Report, October 2008).

Key amongst the building's design objectives is a high level of energy efficiency. This is evident in the provision of a modelling grant from the Department of Energy (DoE) to optimize the building's daylight design for maximum lighting energy savings.

Whilst daylight can provide important lighting energy savings, it is imperative that this is not provided at the expense of comfort and ambience. Daylight must be controlled for both maximum lighting energy savings and the creation of pleasing, visually interesting, comfortable internal and external lighting conditions.

The chart to the left shows the proposed comfort control requirements for the museum's various program elements, as defined by Grimshaw Architects. The following sections relate these control requirements to the different daylit elements of the museum's program.

Daylight Design Response

Recommendations for the daylight design of daylit spaces in the museum's outdoor and indoor program elements are provided below.

Entrance atrium:

- Largely glazed
- Some protection provided by surrounding structure
- Localized shading of work spaces
- Deliberate orientation of work spaces to minimize risk of glare

Cafe / dining:

- Largely outdoor experience
- Local protection to tables, counters

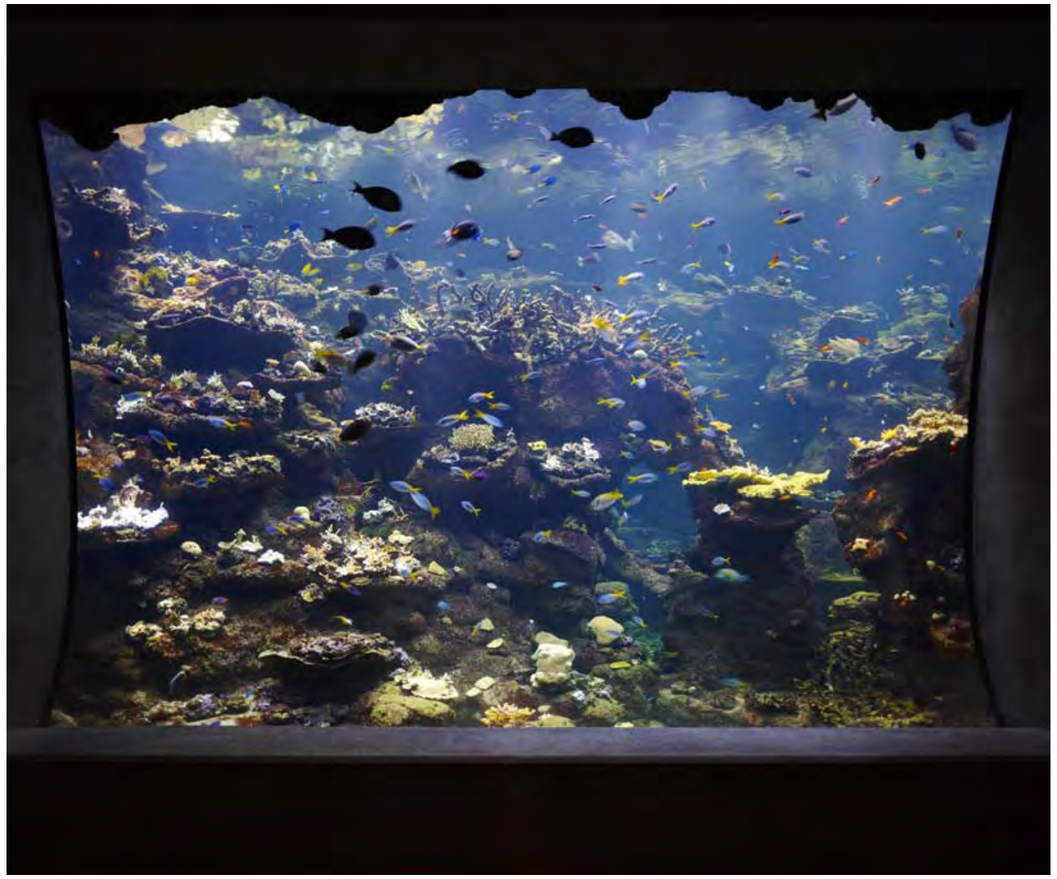
Queuing areas:

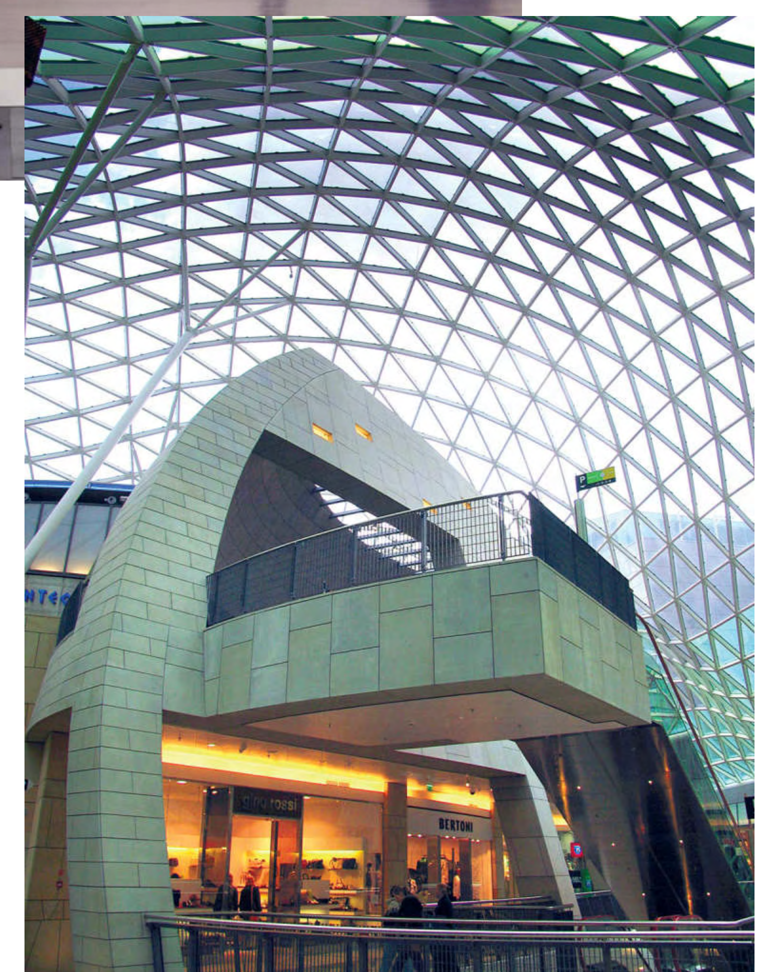
- Largely outdoor experience
- Some protection provided by surrounding structure
- Localized protection for ticket booths

Outdoor exhibits:

- More sensitive objects protected locally and/or by surrounding structure
- Vitrines oriented to avoid reflections that obscure view of exhibits

Daylight Design Objectives





Playground:

- Largely outdoor experience
- Some protection provided by surrounding structure

Terraces:

- Largely outdoor experience
- Some local cover

Entertainment suite / learning center:

- View windows
- Rooflights
- Black-out capability
- Patio cover to adjacent outdoor spaces

Living core:

- Some zones have greater daylight access than others
- Arrange on level and position by particular requirements

Exhibitions, history museum:

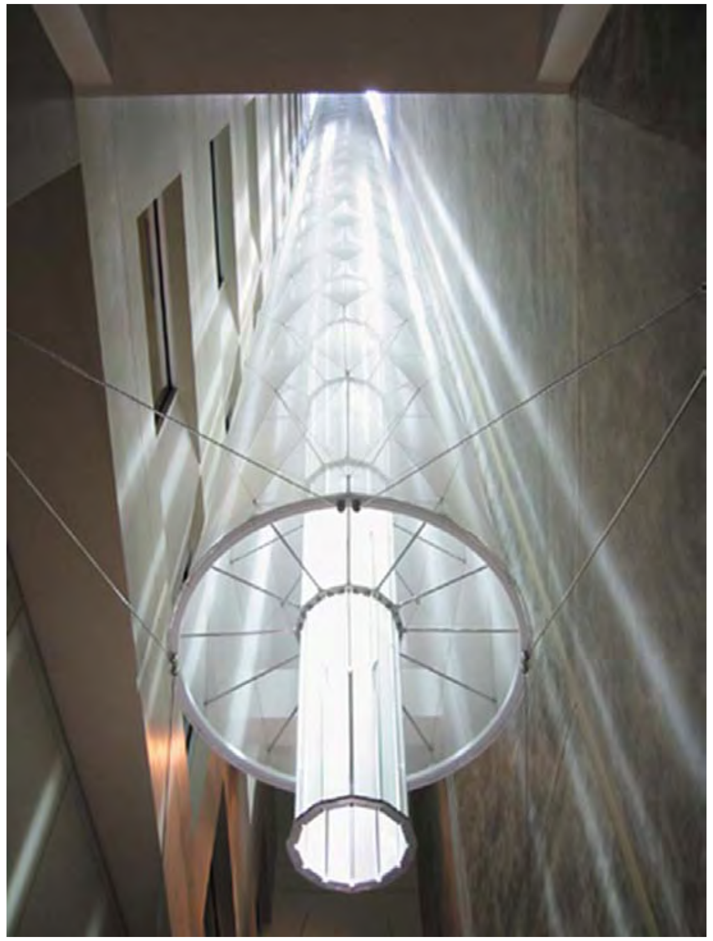
- High windows and/or rooflights
- Some view windows for external connection
- Protect from direct sunlight penetration
- Set window area / transmittance considering annual light exposure limits
- Consider adjacencies to outdoor spaces and risk of adaptation glare (temporary vision difficulty in moving from bright to dark spaces)
- Windows and rooflights arranged to avoid veiling glare (light reflected in vitrines that make encased exhibits difficult to see)

Offices:

- View windows
- Occupant operated glare control
- Orientation of office spaces and workplaces to reduce sun exposure and maximize access to view

Rest rooms, lockers, quiet rooms:

- Smaller windows
- Arrange and treat windows for privacy
- Lower daylight priority



Sustainability Objectives

The project aspires to be highly sustainable, with its sustainable design clearly visible both within the museum building and from a distance.

Several elements of sustainable design are briefly listed below.

Externally Visible Elements

Daylight collection and transport elements:

- Heliostats - a system of mirrors that track and capture sunlight and redirect it into the building
- Light pipes - transporting daylight from roof or facade mounted daylight capturing elements to deep within the building
- Solid state light transport - thin glass and plastic elements, such as fibre optics, used to transport daylight deep within the building

Solar energy collectors:

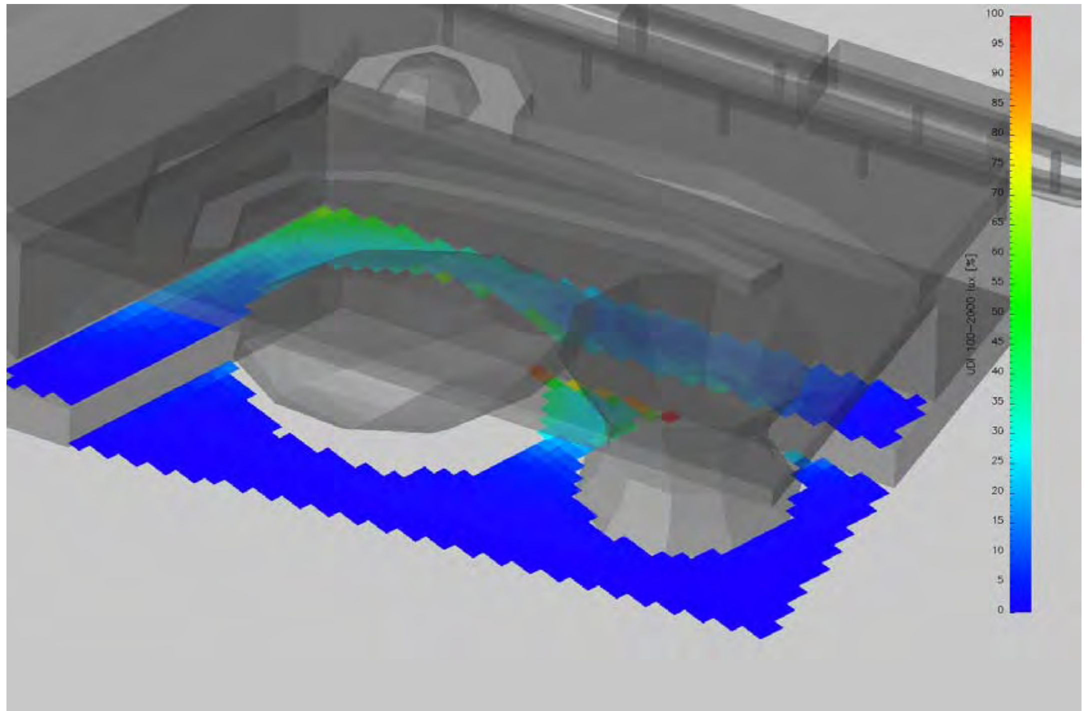
- Photovoltaics - capture sunlight and convert it into electricity that can be used immediately, stored for use later or exported to the power grid
- Solar thermal - convert sunlight into heat, used for hot water or building heating or cooling requirements

Wind and water:

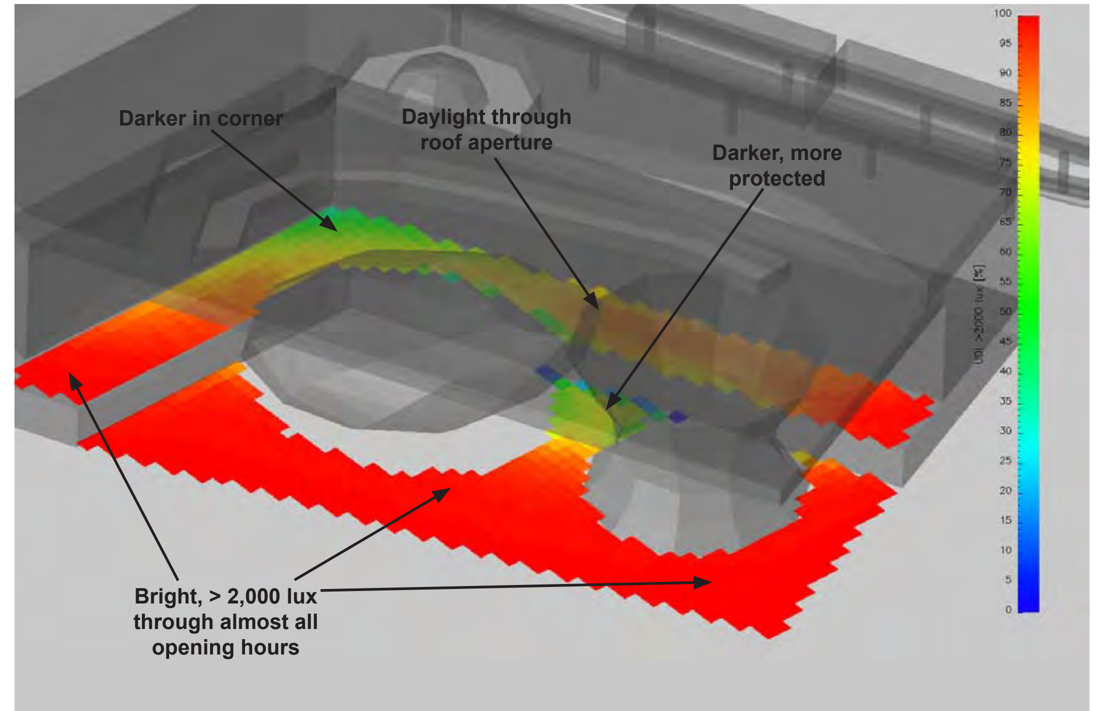
- Natural / mixed-mode ventilation - use natural air flow for cooling, reducing the need for artificial space cooling
- Forced ventilation - fans, jets and similar to increase air movement for physiological cooling, without the need for artificial space cooling
- Evaporative cooling - air flow across water reduces air temperature and assists physiological cooling
- Wind turbines - generate electricity from air movement
- Rainwater collection - store rainwater for use in irrigation and other uses, reducing mains water consumption

Internal Demonstration

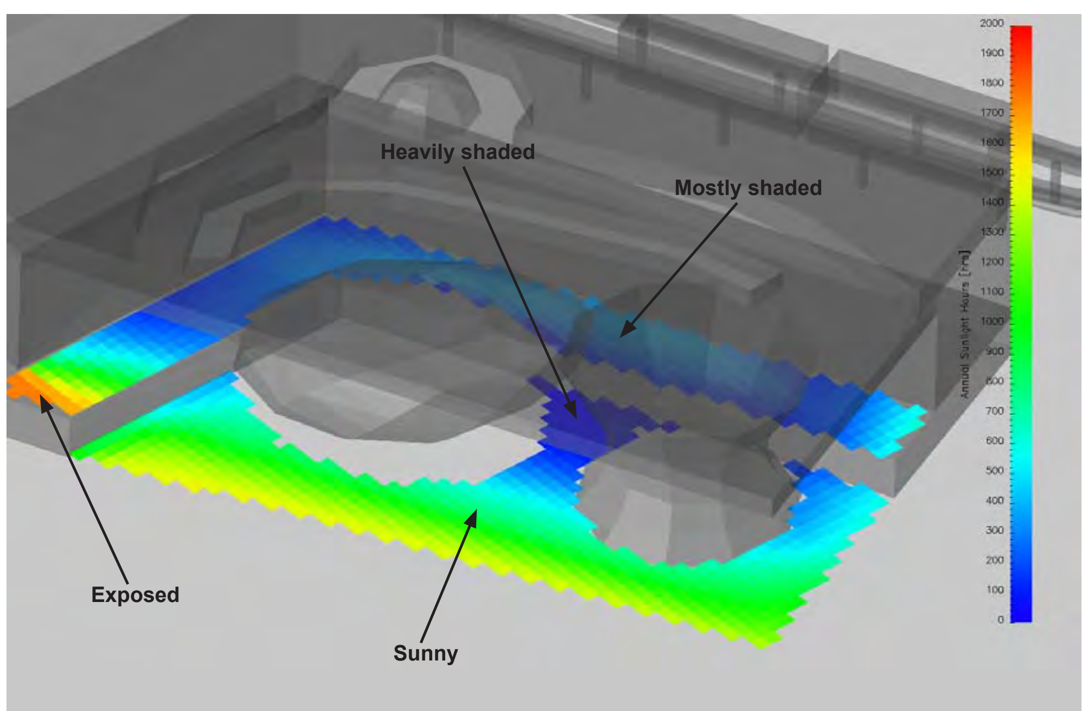
- Ambient lighting dimmed in response to available daylight - demonstrate the dimming level and lighting energy saved
- External lighting switched by sensors and/or time clock - demonstrate lighting energy saved
- Active shading systems to reduce solar load - demonstrate reduced solar loads, link to cooling energy savings
- Building integrated photovoltaics - display current power output and energy stored for re-use



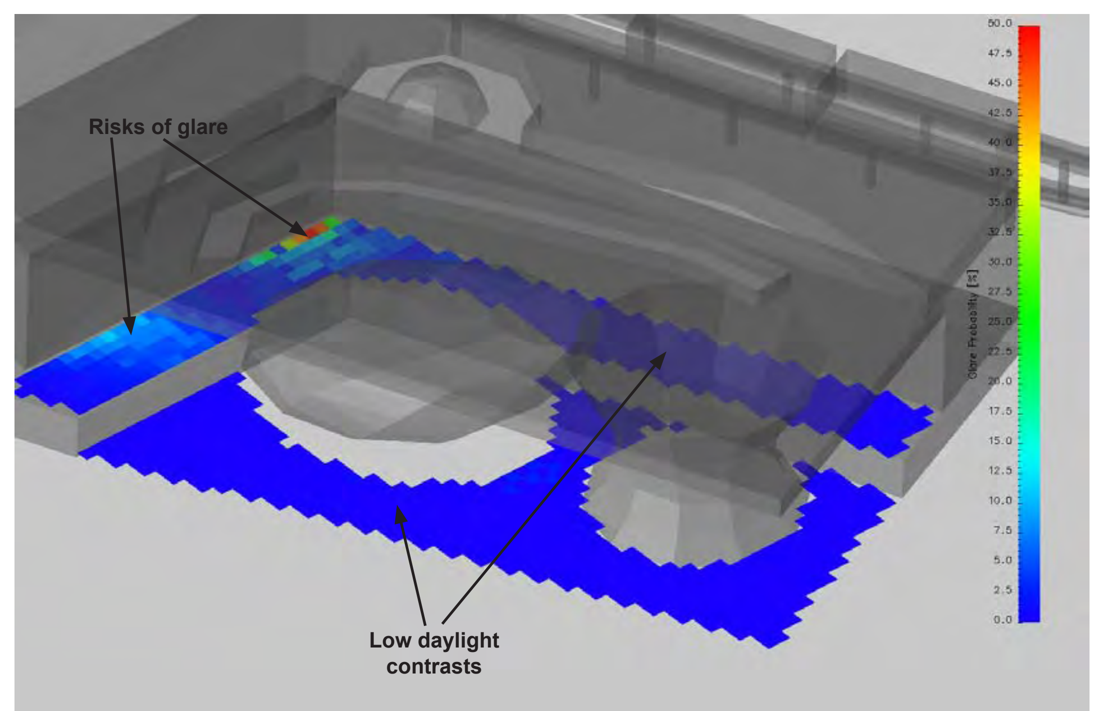
Daylight Penetration to Outdoor Program Space - Proportion of Hours Receiving 100-2,000 lux Daylight



Daylight Penetration to Outdoor Program Space - Proportion of Hours Receiving >2,000 lux Daylight



Sunlight Penetration to Outdoor Program Space - Sunlight Hours



Risk of Daylight Glare - Proportion of Hours Receiving Strong Visual Contrasts

Daylight Assessment Approach

The investigation of the outdoor program space commenced by reviewing a generic building design and characterizing the daylight conditions in various parts of the outdoor program space. The more difficult outdoor space areas were identified and design responses to these areas were recommended. Following the proposed mitigations, space planning recommendations were provided, matching identified daylight conditions with outdoor program elements.

The majority of this discussion is based on a model provided by Grimshaw Architects on 24 October 2008. This assessment was used to understand daylight and glare issues prior to investigation of the internal floor plates. Comments on the current concept design are presented at the end of this section.

Daylight Characterization

Daylight conditions in the outdoor program space are characterized by generic descriptors of brightness, 'sunniness' and risk of glare. Different daylight metrics are referred to for each of these generic descriptors. The three metrics are then combined to a more complete understanding of daylight conditions in each region.

The result of this assessment are descriptors of the following forms:

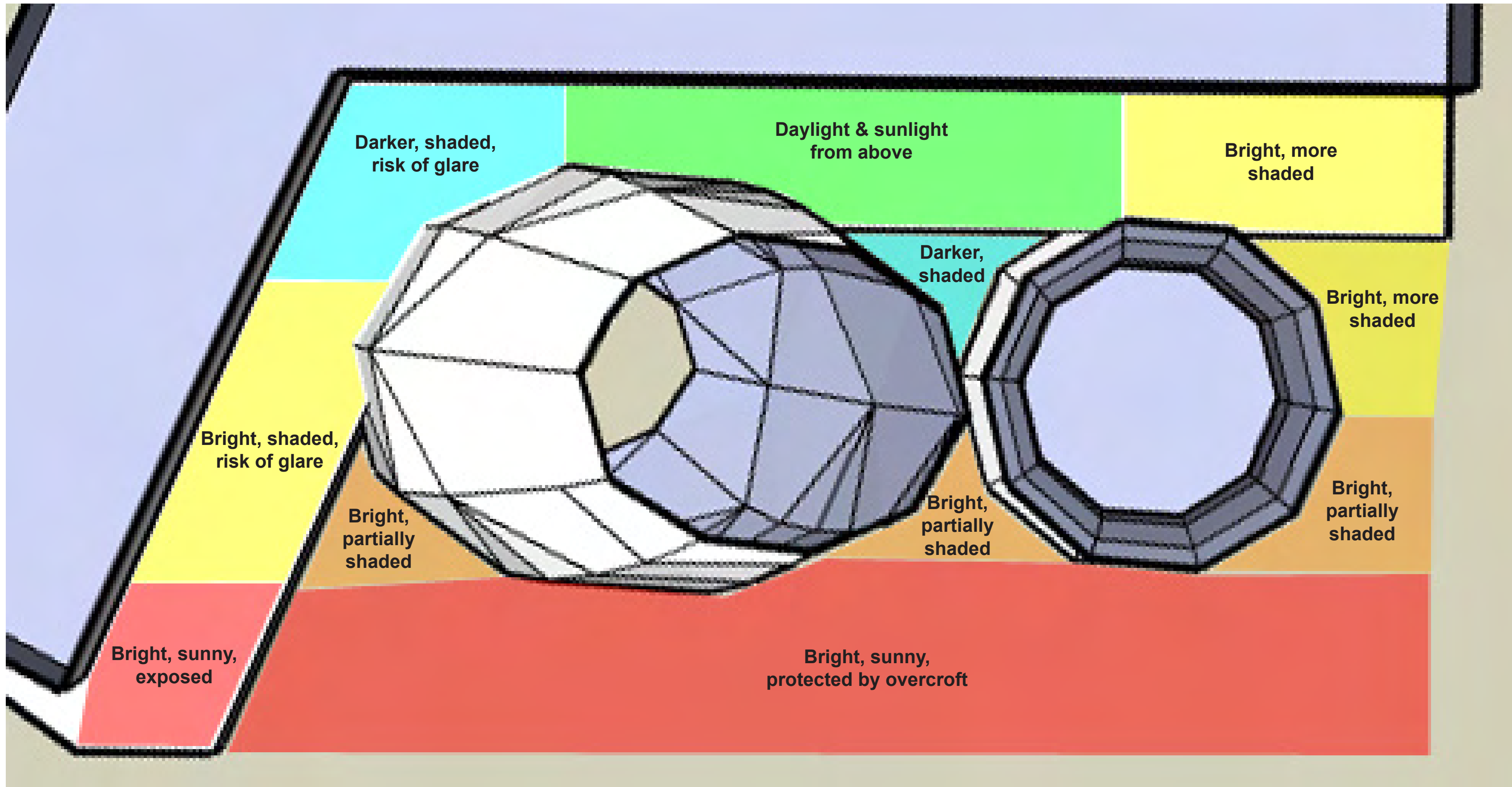
- 'Bright and sunny' - high daylight autonomy, high sunlight hours
- 'Bright and shaded' - high daylight autonomy, low sunlight hours
- 'Darker and sunny' - low daylight autonomy, high sunlight hours
- 'Darker and shaded' - low daylight autonomy, low sunlight hours

Useful Daylight Illuminance (aka UDI)

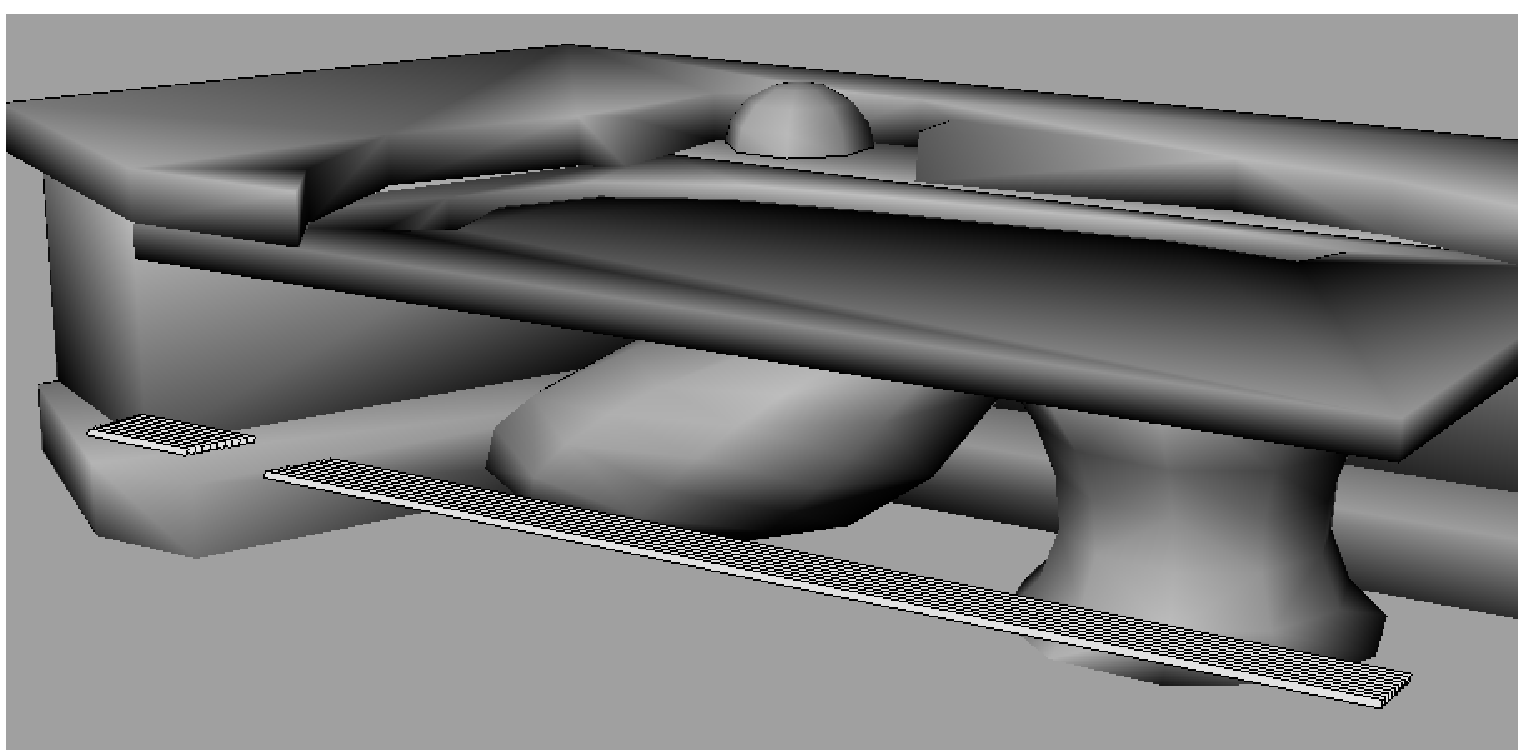
UDI is an indicator of general daylight brightness.

The assessment is performed by predicting through what proportion of museum opening hours is 'useful' daylight, or too much daylight, received.

Daylight illuminance distributions are calculated throughout the outdoor program space for every 10 minutes through opening hours throughout the year. The predicted daylight illuminance levels are compared with 'useful' daylight targets. The proportion of hours through the year that each position receives 'useful' daylight are then predicted.



Daylight Characterization of Outdoor Program Space



Localized Shades to Reduce Solar Exposure at Southern Edge of Outdoor Space

The 'useful' daylight illuminance benchmark is based on an extrapolation of internal conditions for the outdoor environment. This suggests that daylight illuminances up to 2,000 lux (~200 fc) are considered 'useful', and higher daylight illuminances are brighter. However, it should be considered that this is an outdoor environment, and so higher daylight levels are acceptable.

The two upper charts shown on the previous page show 'useful' and bright UDI conditions throughout the outdoor program space. Regions are identified by the degree of daylight brightness expected in the region.

Sunlight Hours

Sunlight hours is an indicator of visual and thermal discomfort and 'outdoorness'.

The assessment is performed by predicting how many hours of sunlight are received over the course of the year through museum opening hours. Seasonal cloudiness is considered, using regional climatic data and average monthly sunshine probability.

The maximum possible sunlight hours for Miami, from 10am to 6pm, is around 2,070 sunshine hours in a fully exposed position.

The lower left chart on the previous page shows the sunlight hour distribution over the outdoor program space. Regions are identified by the degree of 'sunniness' or shade provided to the region.

Daylight Contrast

Daylight contrast is an indicator of the risk of visual discomfort.

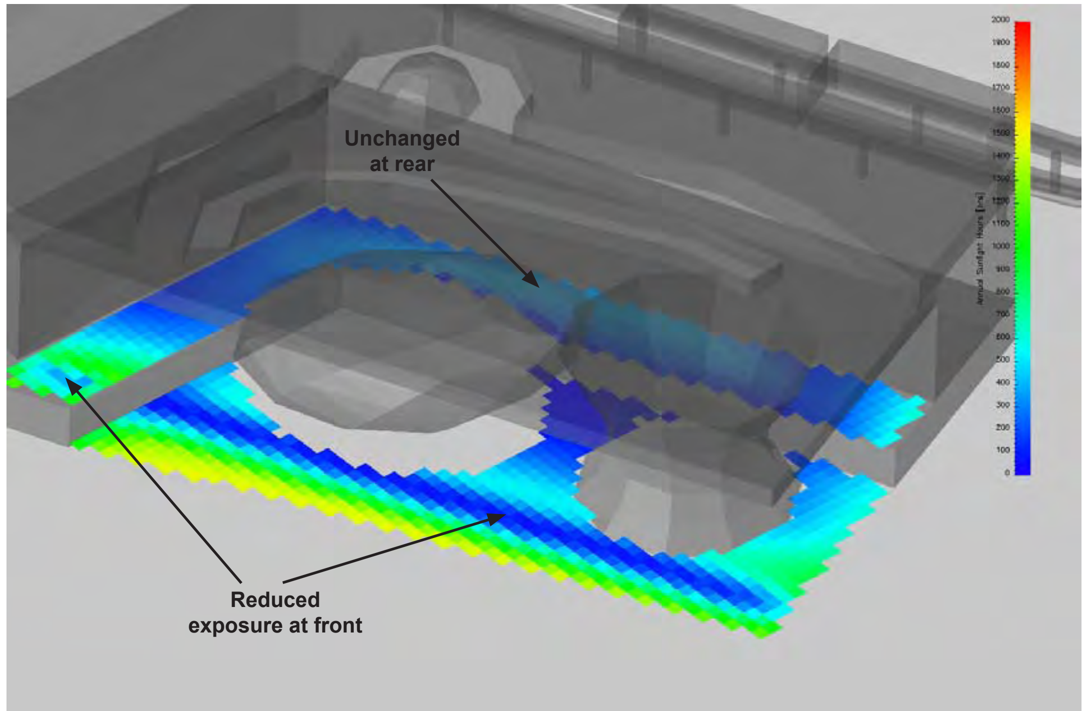
The assessment is performed by predicting brightness contrast ratios for viewers in the same position looking in different directions.

Daylight illuminances are calculated for four cardinal directions for every 10 minutes through opening hours throughout the year. For each position at each time step, maximum / minimum illuminance ratios are calculated and compared with the contrast benchmark. The proportion of hours through the year that each position may experience excessive visual contrasts are then predicted.

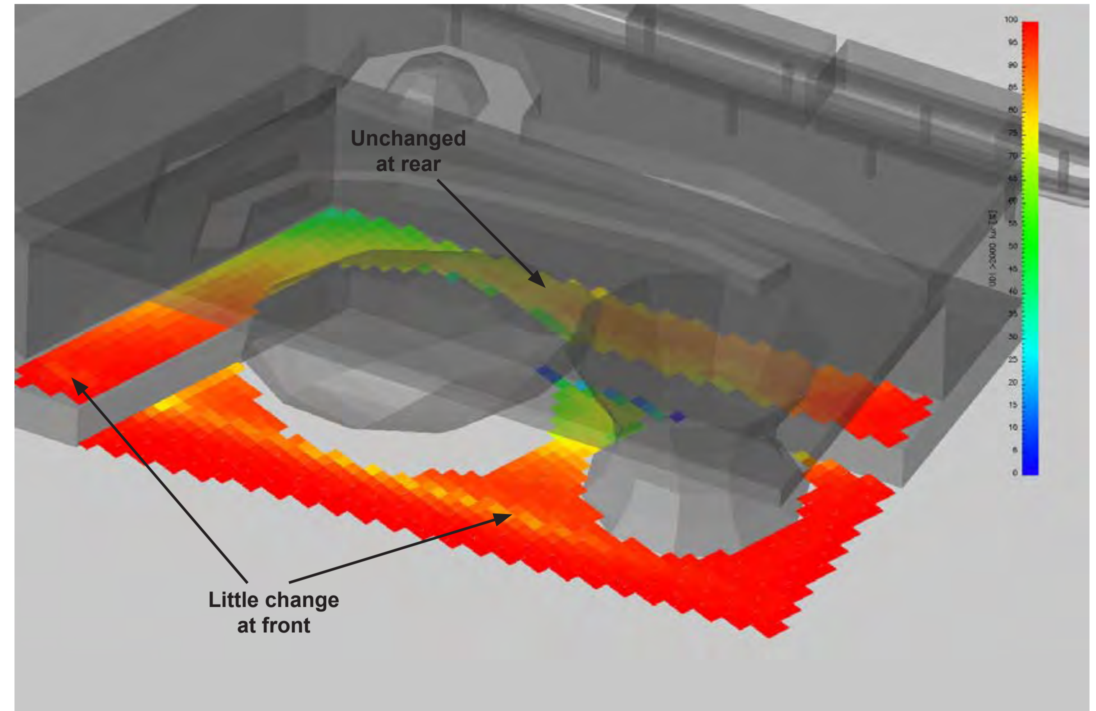
It should be noted that this initial assessment is based on a simplified material palette of medium reflectance, grey, matte finish surfaces. This assessment relates only to brightness contrasts, and does not consider sun reflections of shiny surfaces.

For the outdoor environment, visual contrasts up to 20:1 are considered acceptable.

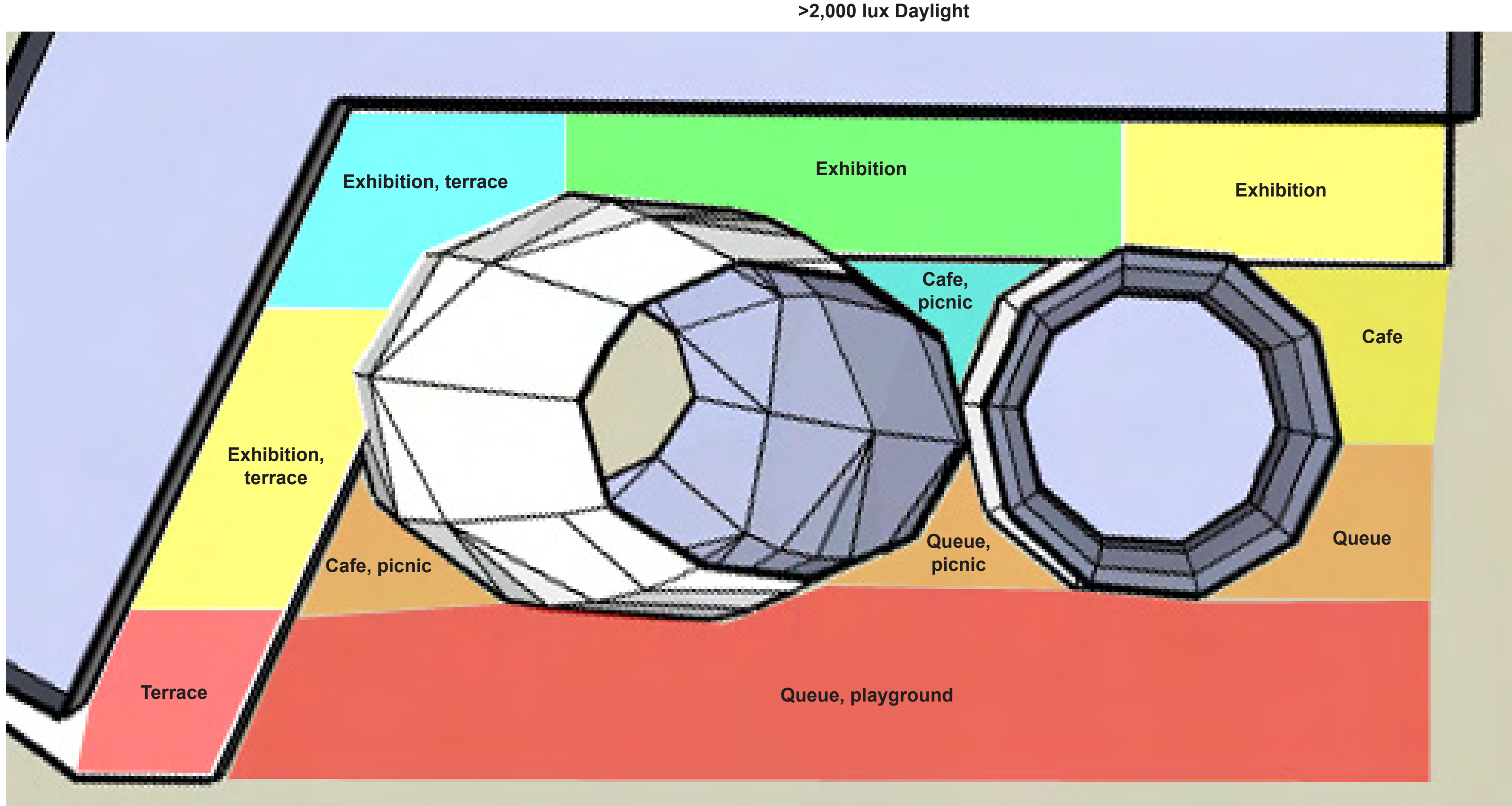
The lower right chart on the previous page shows the probability of daylight glare due to brightness contrasts throughout the outdoor program space. In general there is little to no occurrence of excessive visual contrasts. Only in two regions were strong visual contrasts predicted for generally small proportions of opening hours.



Sunlight Penetration to Outdoor Program Space with Localized Shading - Sun Hours



Daylight Penetration to Outdoor Program Space with Localized Shading - Proportion of Hours Receiving >2,000 lux Daylight



Proposed Outdoor Program Layout

Outdoor Space Characterization

The three daylight metrics are combined to form an overall impression of the daylight character of the outdoor program space, as shown on the previous page.

The color coding shown on the diagram corresponds roughly to degree of daylight exposure. Red areas are bright and sunny, while blue areas are darker and shaded.

Difficult Outdoor Areas

Of all the identified outdoor areas, the two red areas were the most exposed to sunlight. Visitors in these spaces would experience little protection from sun and rain and are most likely to experience thermal and visual discomfort.

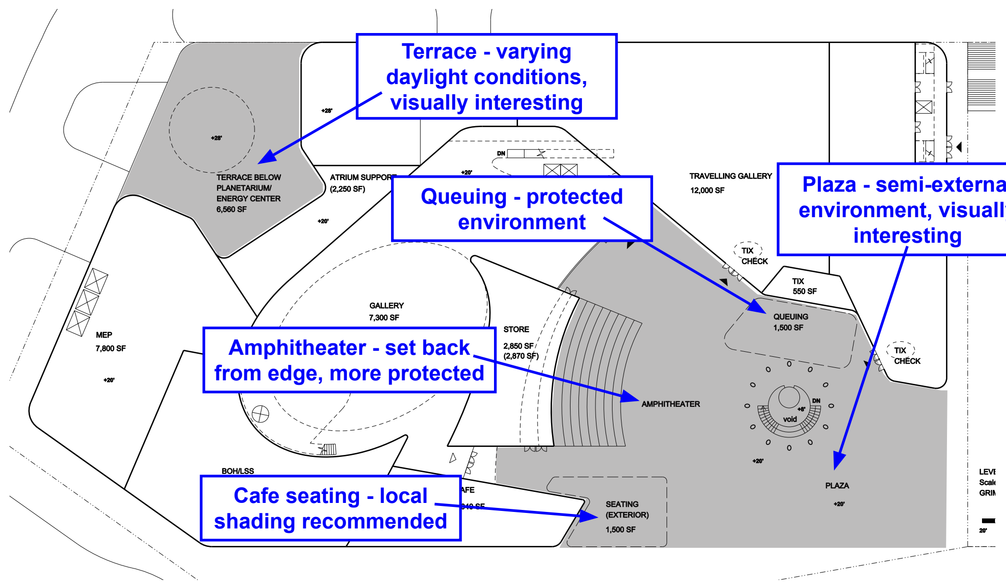
Localized shading systems of some form are recommended for these areas. These shading systems can take various forms, and can vary according to season and/or time of day. They could also be integrated with light and/or solar collectors.

The expected impact of such localized shading systems was investigated in terms of sunlight hours and UDI. The modelled shading system and the revised sunlight and daylight penetration results are shown to the left. It should be noted that the modelled system is illustrative only. Details of this system have developed further following these studies.

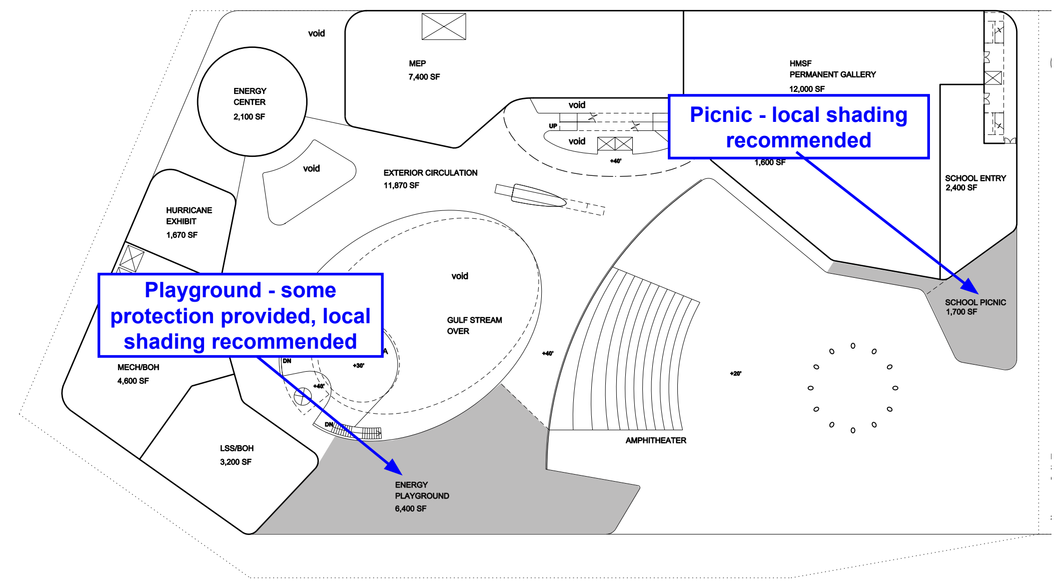
These results have shown that localized shading systems can be very effective in reducing unwanted solar exposure while still maintaining excellent daylight access.

Outdoor Program

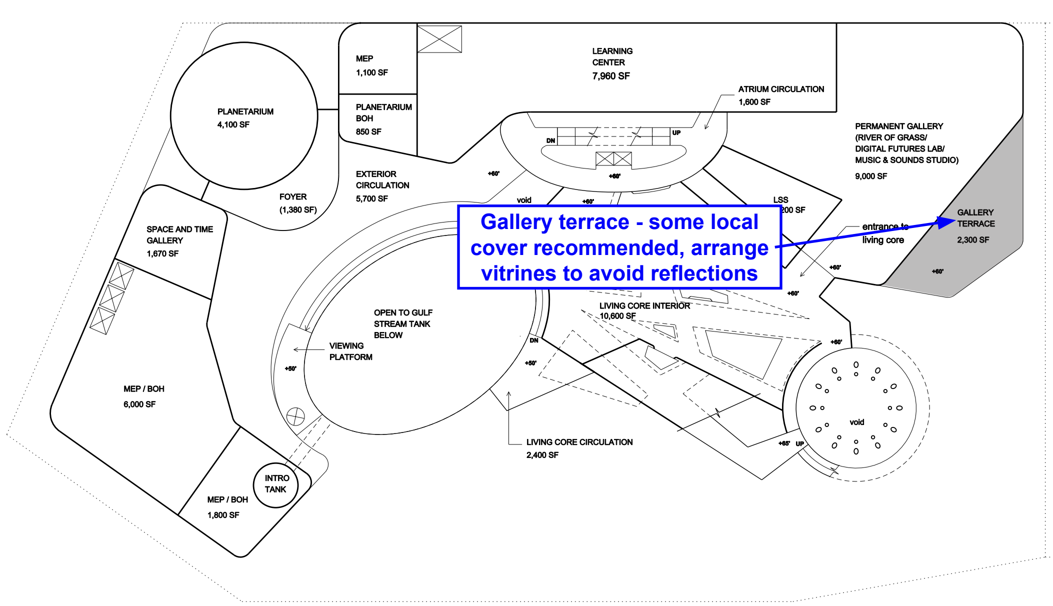
For the modelled configuration of the outdoor program area, the diagram to the left presents a suggested layout of the outdoor program elements.



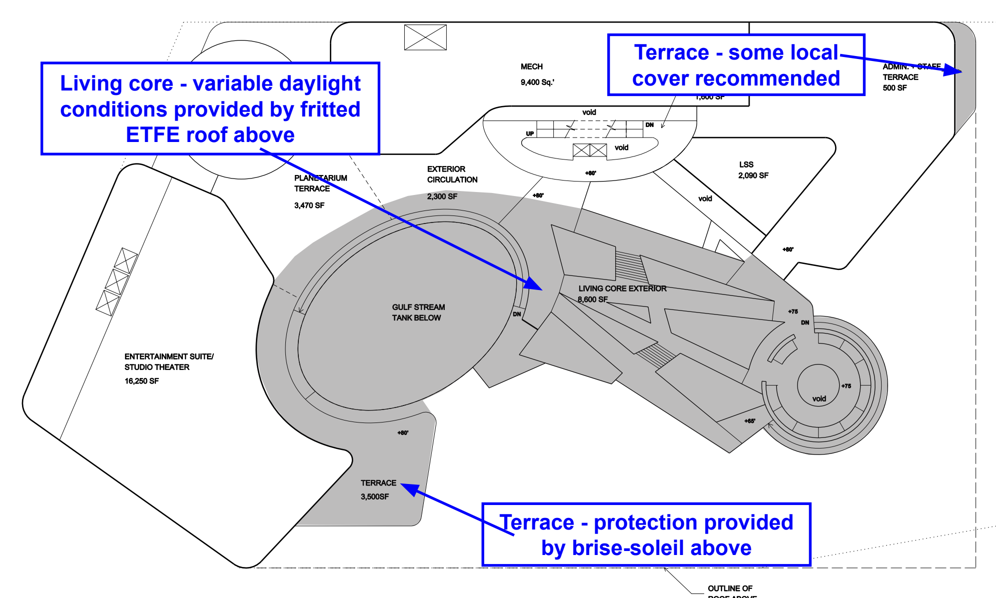
Concept Design Outdoor Program - Level 1



Concept Design Outdoor Program - Level 2



Concept Design Outdoor Program - Level 3



Concept Design Outdoor Program - Level 4

Outdoor Program - Concept Design

The diagrams shown to the left illustrate the concept design for the outdoor program space. The daylit outdoor program areas are highlighted and comments provided for the design team. These comments are based on the work presented on the preceding pages:

- The outdoor program has been spread over all levels, and generally greater solar protection has been provided.
- The level 1 outdoor space is now generally more protected for improved comfort.
- A range of daylight conditions, from more to less covered, is provided in various areas, creating lively and visually interesting spaces.
- The proposed ETFE roof over the living core provides the ability to vary daylight conditions over the different areas using different degrees of frit coverage or similar.
- Some localized shading is recommended for the cafe seating, picnic area, energy playground and terraces.

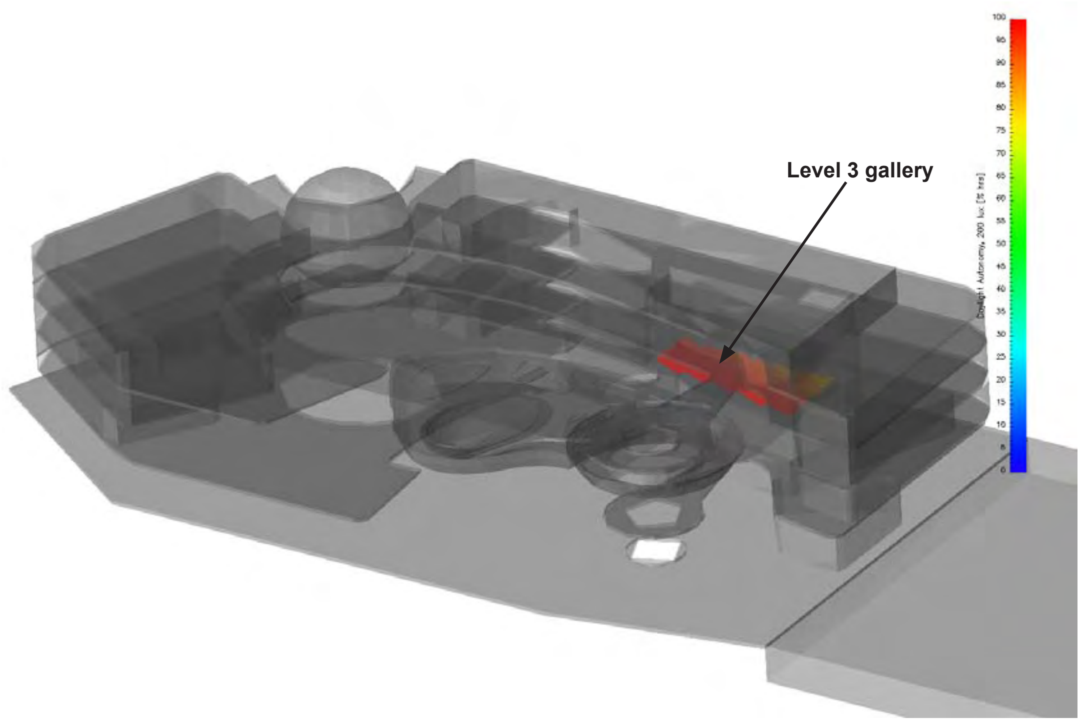
Energy Savings

Substantial lighting energy savings can be provided by placing much of the museum's program outdoors. This adds to the visitor's experience while reducing the museum's energy consumption.

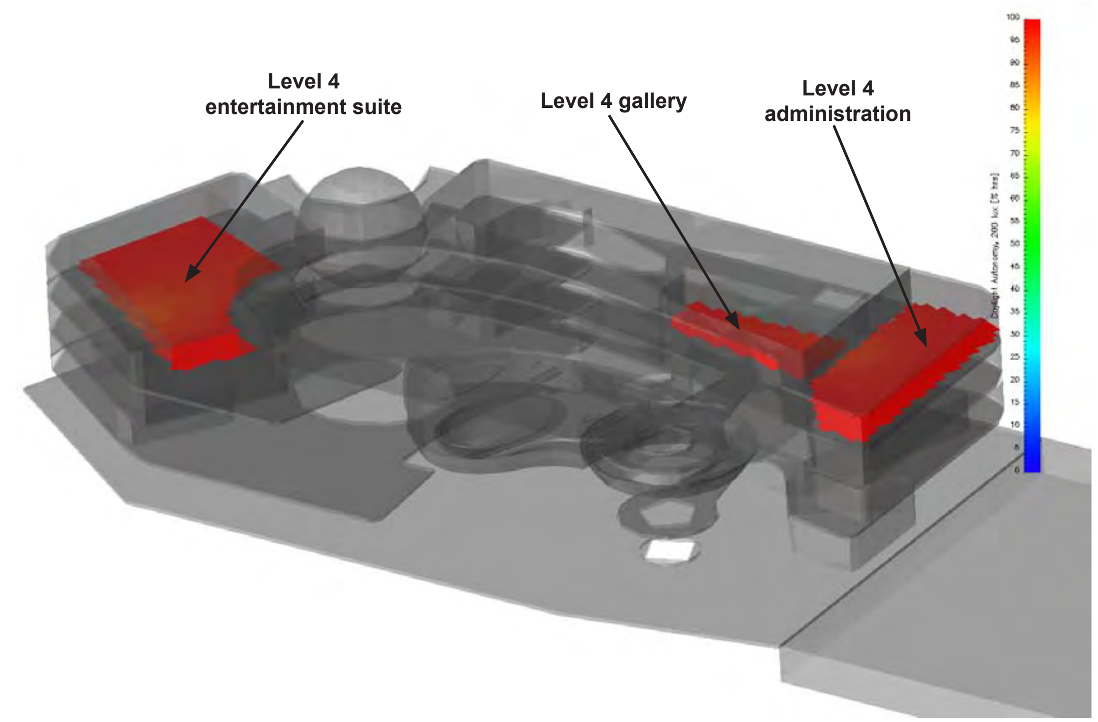
Lighting of the outdoor spaces should be linked to available daylight through either daylight sensors or timeclocks, ensuring that the outdoor lighting is only on when required.

Those areas requiring greater light levels, including the cafe seating, gallery terrace and living core, have all been placed in positions with high potential for daylight, and therefore high potential for lighting energy savings.

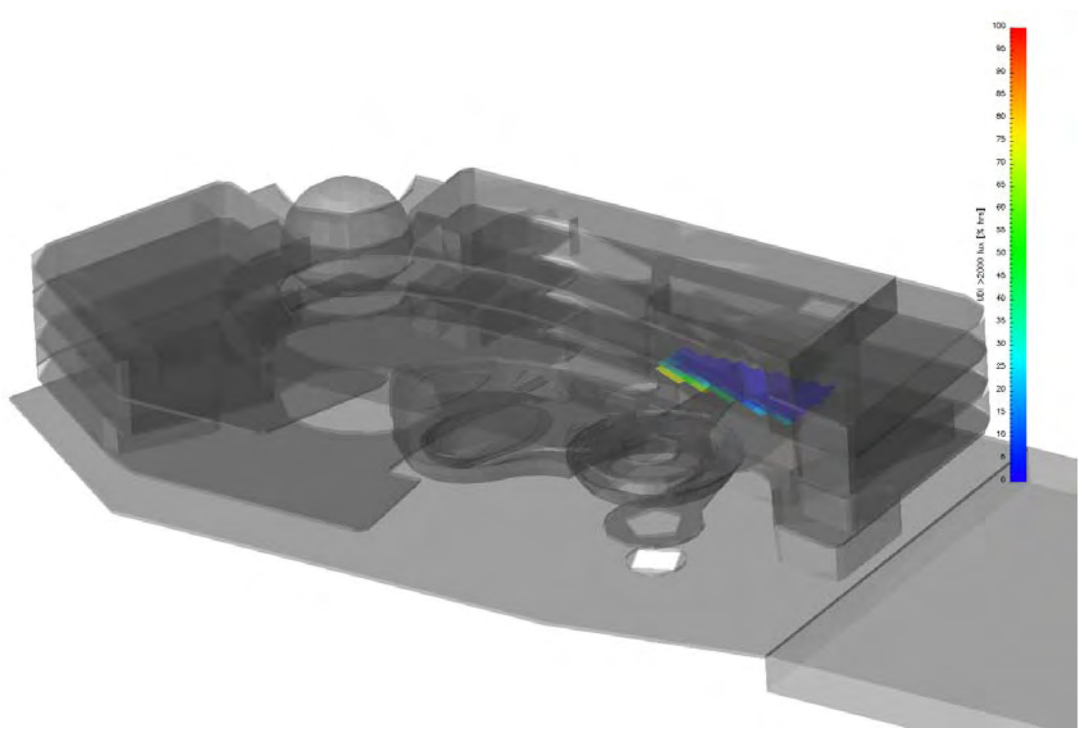
Areas requiring lower light levels or greater control over illumination, including the amphitheater and exterior circulation, are more enclosed, improving daylight control while still providing access to daylight for lighting energy savings.



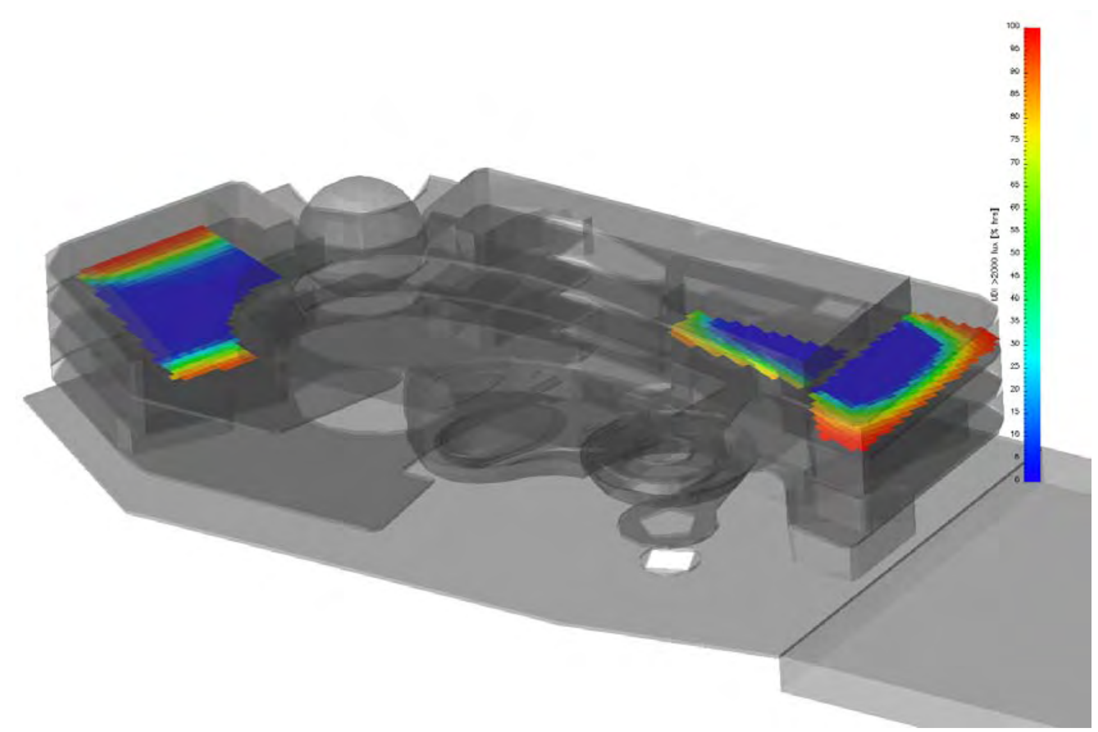
Level 3 Base Case Daylight Autonomy - Ability to Switch off Ambient Lighting above 200 lux Daylight



Level 4 Base Case Daylight Autonomy - Ability to Switch off Ambient Lighting above 200 lux Daylight



Level 3 Base Case UDI > 2,000 lux - Likelihood of Visual Discomfort



Level 4 Base Case UDI > 2,000 lux - Likelihood of Visual Discomfort

Daylight Assessment Approach

Four internal spaces within the museum building were selected for daylight assessment. These spaces were modelled for potential lighting energy savings and visual comfort. A base case assessment considered the design proposed by Grimshaw Architects on 3 December 2008. The initial assessment provided a series of design recommendations for improved daylight performance. A second assessment of the same spaces following implementation of the design recommendations displayed the improvements made as a result of the initial assessment.

Modelled Spaces

Four representative spaces were selected for daylight assessment. These spaces cover various program uses and different levels of the building.

The four modelled spaces, shown to the left, include the following:

- Level 4 administration
- Level 4 entertainment suite
- Level 4 gallery
- Level 3 gallery

The base case model was based on a model provided by Grimshaw Architects on 3 December 2008. Key material assumptions used with this model are listed below.

- 60% glass light transmittance
- 67% ETFE light transmittance (as clear ETFE with 40% dot frit coverage)
- Floor, wall, ceiling have 15%, 50%, 70% reflectance respectively

Changes made to the model for the second assessment are described in that section.

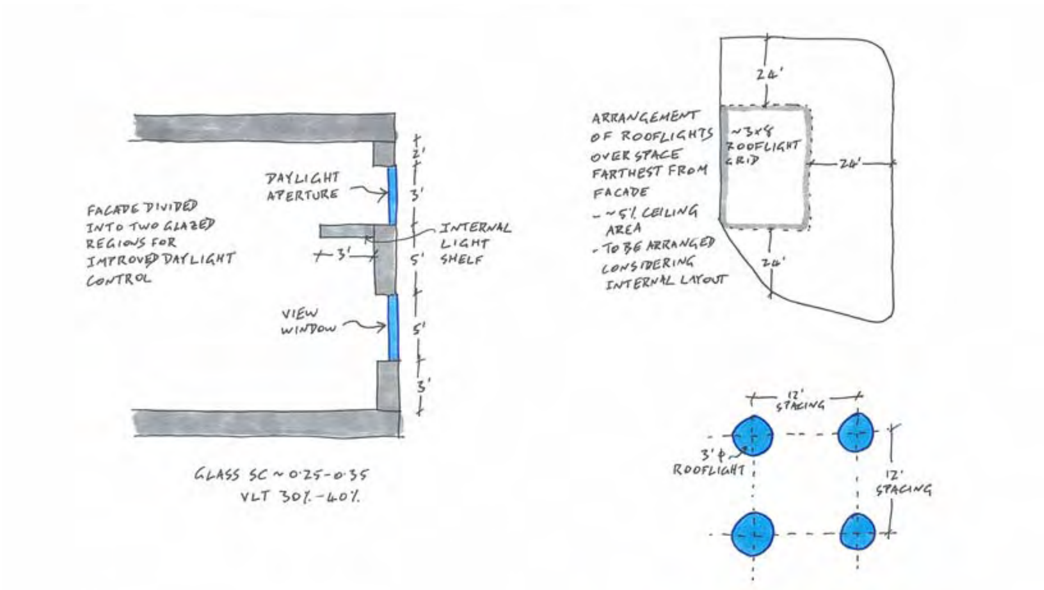
Performance Criteria

Internal daylight performance was assessed in terms of potential for lighting energy savings and the likelihood of visual discomfort.

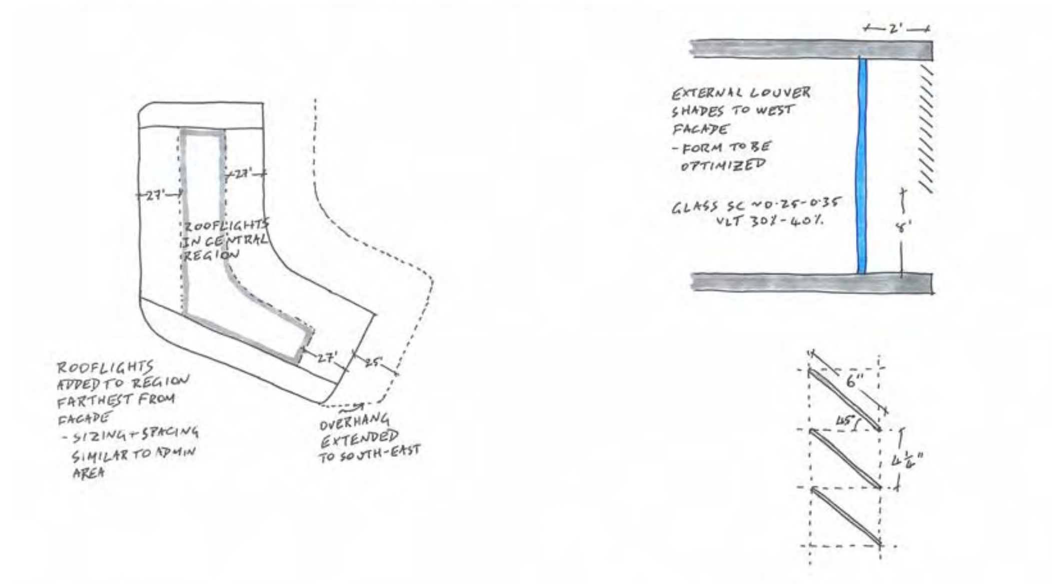
Potential for lighting energy savings is assessed using daylight autonomy. This daylight metric presents the proportion of opening hours through which daylight provides more than a set level of illuminance.

The target illuminance level was set at 200 lux - this is considered sufficient for ambient illumination of all the space types under assessment.

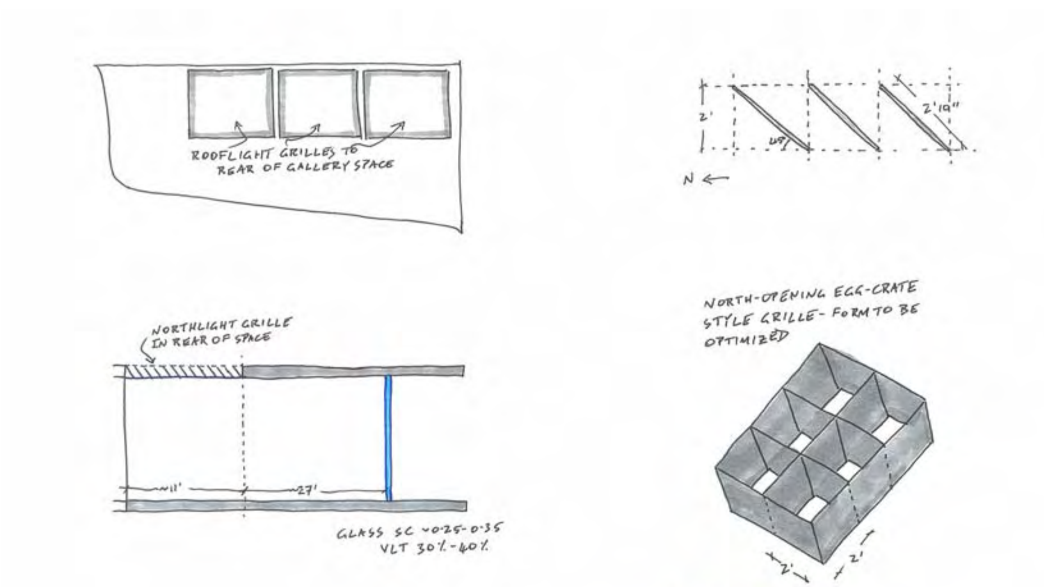
High daylight autonomies indicate high potential for turning off electric lighting in response to available daylight.



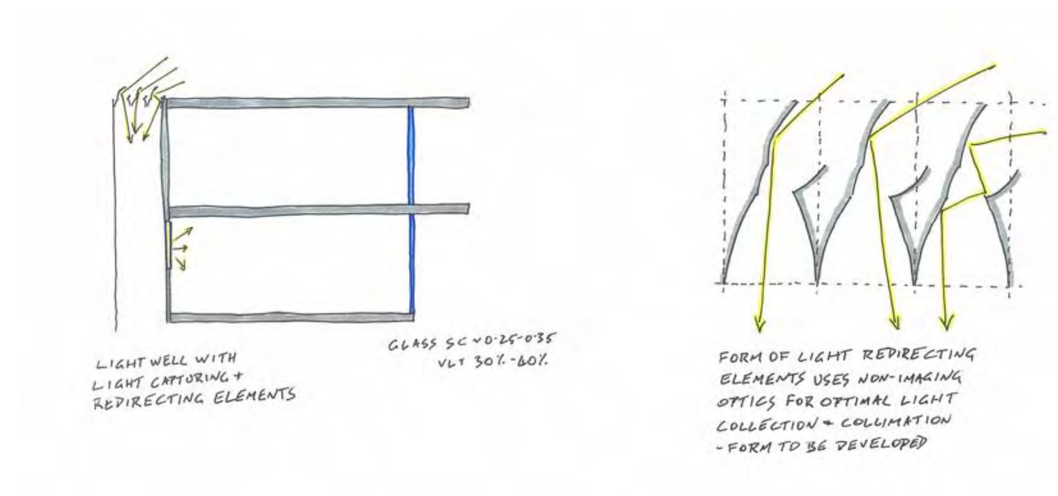
Daylight Design Recommendations - Level 4 Administration



Daylight Design Recommendations - Level 4 Entertainment Suite



Daylight Design Recommendations - Level 4 Gallery



Daylight Design Recommendations - Level 3 Gallery

Visual comfort was assessed using the UDI metric discussed previously. Where daylight provides more than 2,000 lux it is likely that occupants will lower internal blinds for visual comfort control. This metric presents the proportion of opening hours through which 2,000 lux of daylight illumination is exceeded.

Lower occurrences of more than 2,000 lux daylight illumination indicates lower chance of visual discomfort.

Base Case Findings

The base case assessment results are presented on the previous page.

All of the investigated spaces have high levels of daylight access, with all areas receiving daylight autonomies greater than 75%. This indicates that ambient electric lighting can be switched off for more than 75% of opening hours between 10am and 6pm.

The results also reveal high levels of excessive daylight illumination. This implies frequent occurrence of visual discomfort, particularly on level 4. Areas near the facades of the administration and entertainment suite spaces receive more than 2,000 lux daylight illumination through more than 75% of opening hours.

The base case design provides plenty of daylight due to large glazed areas and tall spaces. However, this daylight illumination is generally asymmetric and there is a high probability of daylight glare in regions near to the facade.

Design Recommendations

The base case findings indicated a need for improved control of daylight penetration and distribution. However, it is also desired to maintain the high levels of potential lighting energy savings.

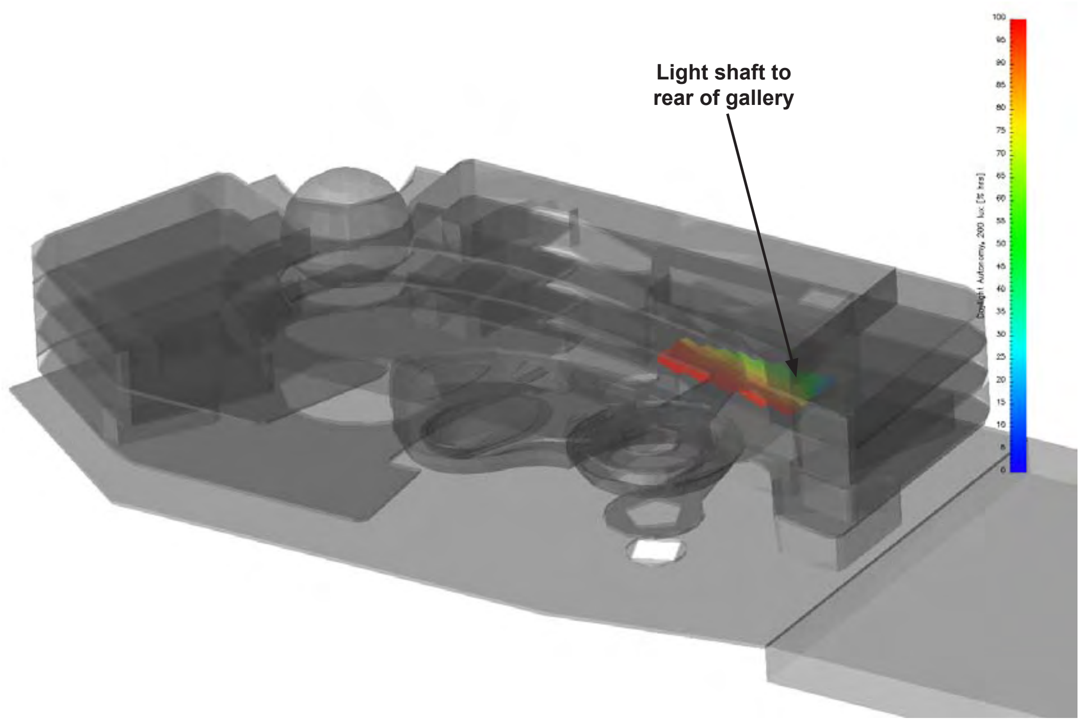
A series of design recommendations were provided to the design team to improve the daylight performance of the four selected spaces. These design recommendations are illustrated to the left.

It should be noted that these designs are indicative at present, and are used to demonstrate achievable improvements in daylight performance. The precise forms of these elements are to be further developed through the Schematic Design phase.

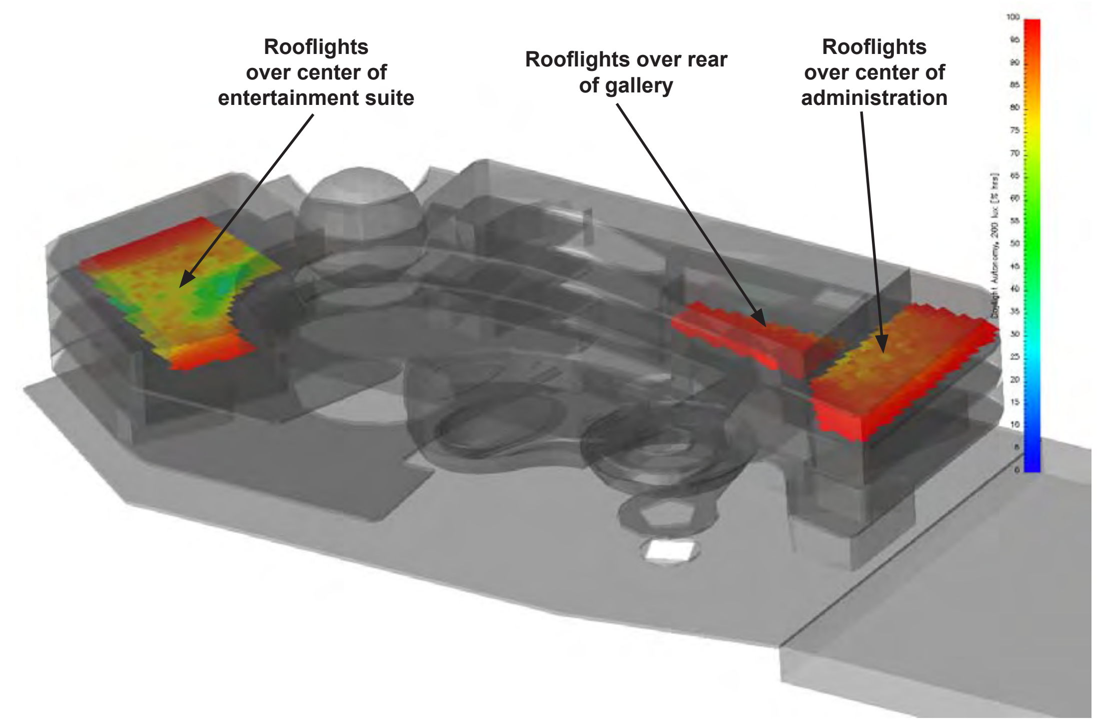
Care must be taken to balance the additional daylight input provided by the recommended rooflights and the potential for increased thermal loads. This can be addressed through appropriate glass selection and shading systems.

Developed Design

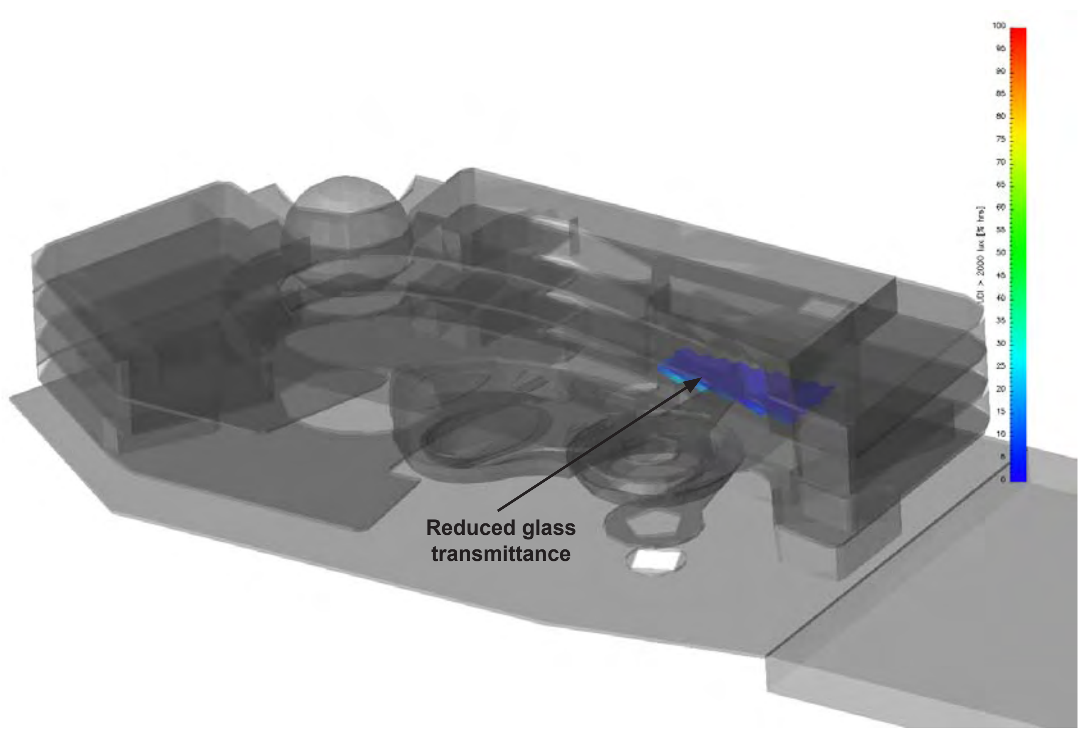
The design recommendations discussed above were all implemented and the daylight modelling completed for the developed design. The findings for this design should be contrasted with those from the base case, demonstrating improvements in the building's daylight design.



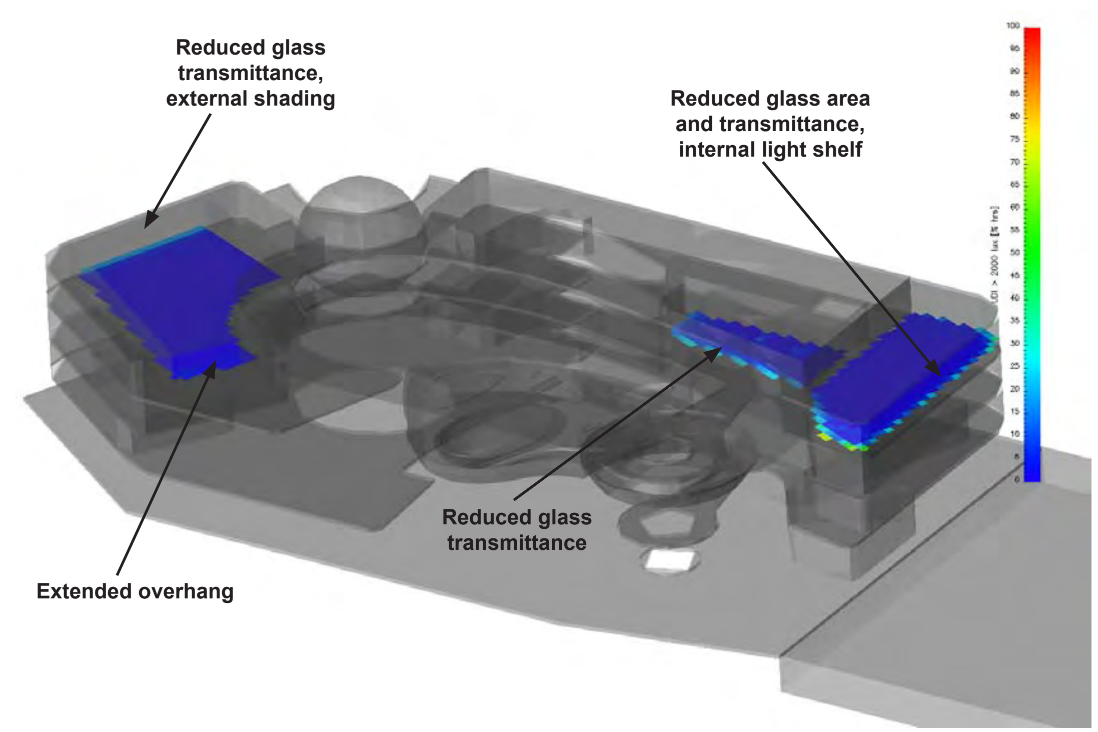
Level 3 Developed Design Daylight Autonomy - Ability to Switch off Ambient Lighting above 200 lux Daylight



Level 4 Developed Design Daylight Autonomy - Ability to Switch off Ambient Lighting above 200 lux Daylight



Level 3 Base Case UDI > 2,000 lux - Likelihood of Visual Discomfort



Level 4 Base Case UDI > 2,000 lux - Likelihood of Visual Discomfort

The findings for the developed design are presented to the left.

The applied design changes, particularly the much reduced glass light transmittance, provided some reduction in daylight autonomy, and therefore potential lighting energy savings. However, lighting energy savings greater than 50% are still possible in all areas, with many areas still achieving greater than 75% energy savings.

The table below provides estimates of potential lighting energy savings. This is based on the daylight autonomies presented to the left and a series of assumptions regarding lighting power densities, room areas and occupancy hours. The assumptions made are noted therewith.

For the four investigated spaces, lighting energy savings up to 80% are available. This amounts to 40,600 kWh savings per year just for these four spaces.

Significant improvements in visual comfort conditions were provided by the design recommendations. Only small parts of the spaces close to the facade receive more than 2,000 lux daylight, generally for less than 25% of museum hours.

These results indicate significant improvements in internal daylight conditions whilst maintaining excellent potential for lighting energy savings.

There is room for further improvement in these results. The design elements described above will be further developed in the Schematic Design phase.

Space	Area (ft^2)	Installed load density (W/ft^2)	Annual load [1] (kWh)	Daylight autonomy (%)	Energy savings (kWh)
Level 4 administration	6,500	1.1	14,900	85	12,700
Level 4 entertainment suite	8,400	1.3	22,700	75	17,000
Level 4 gallery	2,900	1.0	6,200	95	5,900
Level 3 gallery	2,900	1.0	6,200	80	5,000
Total	**20,700**	**1.15**	**50,000**	**81**	**40,600**

Note 1: Assumes 8 hours occupancy, 5 days a week

Estimated Lighting Energy Savings due to Available Daylight