NATIONAL BUILDING MUSEUM

Learning to breathe again

Credits
The project team would like to extend our gratitude to the many people and organizations who went out of their way to support this effort. This report would not have been possible without you.

General Services Administration
Jackie Boyd
Zaziouxe Zadora

National Building Museum
Betzy May-Salazar
Hank Griffith
Sarah Kabakoff
Chase Rynd
Bryna Lipper

Autodesk
Carol Lettieri
Robert Middlebrooks
Phil Bernstein
Justine Crosby

Project Team
BNIM Architects
Heitman Architects
Metco Services
Super Symmetry

Imagery
Courtesy of National Building Museum: pages 8, 28
Montgomery C. Meigs and the Building of the Nation's Capital: pages 11, 13, 15, 16-17, 18
Flickr: pages 2, 5, 32-33, 43, 45, 63-64, 78-79, 94-95, 110, 112-113
John J Young: page 110 and Kyle Walton: page 65 (from Flickr)
BNIM: all others

NATIONAL BUILDING MUSEUM

Learning to Breathe Again

The following information documents the process and results of an effort funded by **Autodesk** to create a map for the future that will transform existing buildings into high performance buildings.

Autodesk + BNIM

Contents

The fluttering of a butterfly’s wings can effect climate changes on the other side of the planet.

PAUL ERLICH

SECTION 1

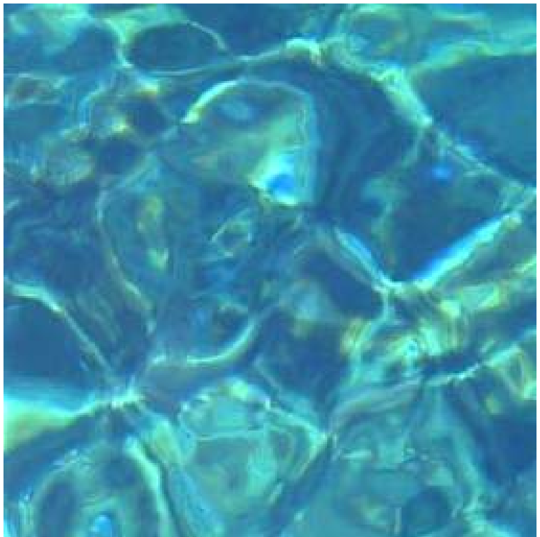
Introduction

The research that is outlined in this document was initiated in response to the large number of existing buildings in the United States that could benefit from significant building performance improvements. Creating an accurate virtual representation of the building and analyzing it for performance issues allows building owners and designers to make key decisions about how to improve their buildings.








EXECUTIVE ORDER 13423 GOAL

To reduce facility energy use per square foot by 3% per year through the end of 2015 or by 30% by the end of fiscal year 2015, relative to a 2003 baseline.

The Mandate

The National Building Museum (NBM) is a not-for-profit entity managed and operated by a team of professionals dedicated to teaching the public about the built environment. The building facility itself is managed by the U.S. General Services Administration (GSA). As a governmental body, the GSA and its facilities are required to meet a number of energy and water management goals mandated through executive orders, legislation, and other programs that address energy conservation. One such mandate is Executive Order 13423, which is a national initiative to reduce the average annual energy consumption of the GSA's entire building inventory. **Specifically, its goal is to reduce facility energy use per square foot (including industrial and laboratory facilities) by 3 percent per year through the end of 2015 or by 30 percent by the end of fiscal year 2015, relative to a 2003 baseline.**

To achieve this goal, GSA's inventory must reach a metered annual energy consumption of approximately 55,000 BTU/GSF. The Energy Policy Act of 2005 (EPACT 2005) is another directive that requires that federal buildings be designed to use 30% less energy than they typically would by complying with the industry standard - ASHRAE Standard 90.1, and to increase the renewable electricity consumption by the federal government to at least 3 percent in fiscal year 2007-2009; 5% percent in fiscal year 2010-2012; and 7.5% in fiscal year 2013 and each fiscal year thereafter. In addition, The Energy Independence and Security Act of 2007 (EISA 2007) also requires the GSA to reduce its designed energy consumption with respect to the average commercial building energy usage as determined by the Department of Energy's Energy Information Agency. As such, in 2010 the GSA must use 55% less energy than the average commercial building and continue with incremental decreases every five years. By 2030, GSA must construct all new facilities to be net zero energy buildings. Finally, EISA 2007 stipulates that every 5 years, GSA must select a third-party green building certification system, with corresponding level of certification, to document the overall sustainable performance goals of GSA's new and modernized buildings.

BNIM and Autodesk teamed to deliver a comprehensive report using state of the art software and technology. That exercise, documented here, endeavors to not only meet the mandates stated above, but to enhance the museum experience for NBM guests and to improve the working environment for both NBM and GSA employees in the building.

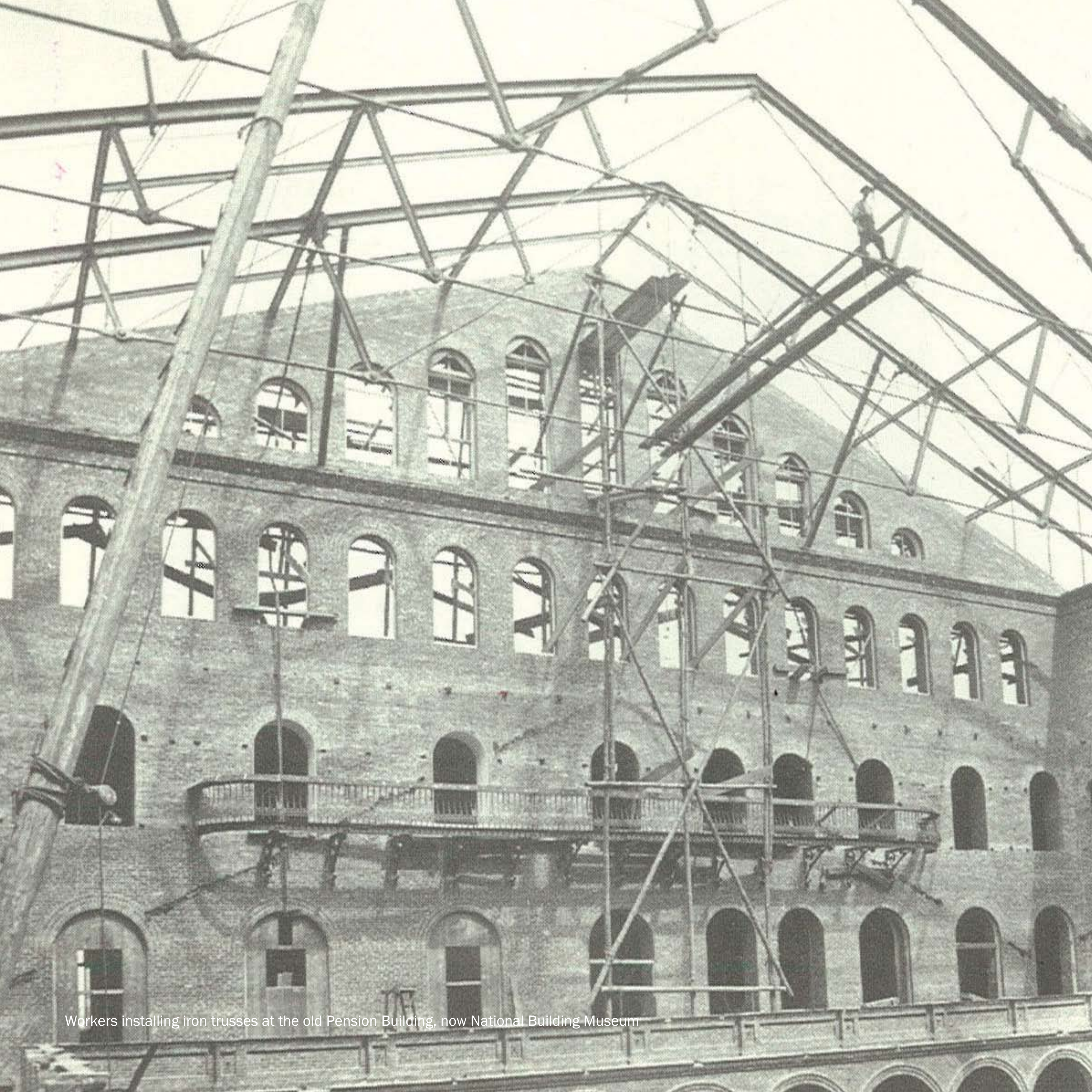
From our findings, it became obvious that implementing energy efficiency strategies, such as daylighting and natural ventilation, to meet the goals Executive Order 13423 would not only enhance the internal building environment, it would also take a dramatic step towards once again utilizing innovative natural systems – just as the original design of the building had done.

The future belongs to those who understand that doing more with less is compassionate, prosperous and enduring and thus more intelligent, even competitive.

PAUL HAWKEN

SECTION 2

The National Building Museum



Workers installing iron trusses at the old Pension Building, now National Building Museum

The historic home of the National Building Museum stands today as one of the great American buildings of the nineteenth century and one of Washington, D.C.'s most spectacular works of public architecture.

(Quote - National Building Museum, http://www.nbm.org/about-us/historic-building)

History of the Pension Building

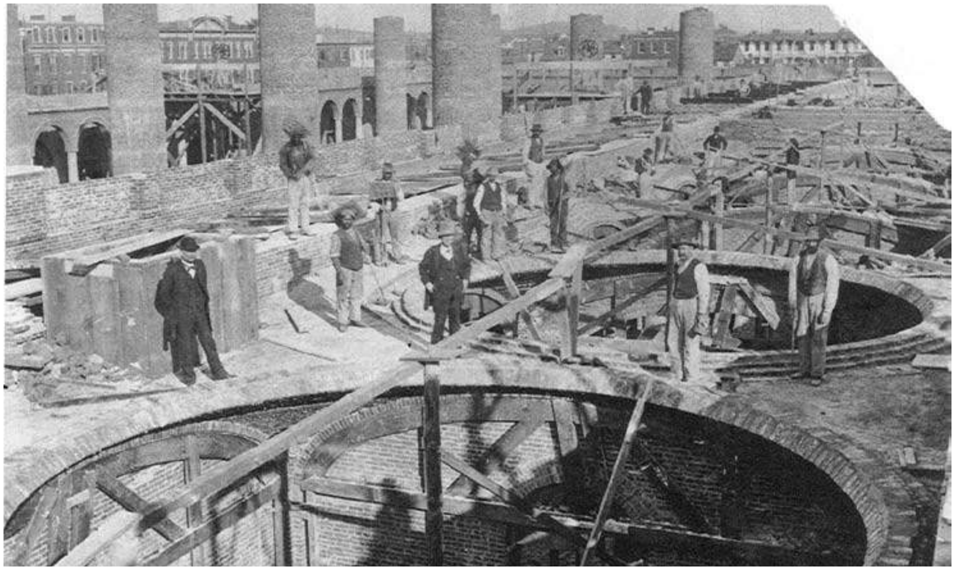
The historic home of the National Building Museum stands today as one of the great American buildings of the nineteenth century and one of Washington, DC's most spectacular works of public architecture. Originally termed the Pension Building, the project was constructed between 1882 and 1887 as a fireproof building for the US Pension Bureau's headquarters. U.S. Army Quartermaster General Montgomery C. Meigs was appointed as both the architect and engineer for the building.

The Pension Building not only originally housed the Pension Bureau, but it also provided a grand space for Washington's social and political functions. The tradition of holding the Inaugural Ball at the National Building Museum continues to the present day.

General Meigs drew inspiration from traditional Renaissance Roman palaces; the exterior design of the Pension Building from the Palazzo Farnese and the interior arcaded galleries from the Palazzo della Cancelleria. Brick was the primary building material throughout, a choice largely driven by affordability and brick's fireproof properties. The decorative elements of the building were also accomplished in an "economic" fashion with ornamental terra cotta and painted plaster on brick surfaces rather than expensive building materials such as carved stone or fine marble.

The original design of the Pension Building was innovative even by today's standards. Meigs careful attention to light and ventilation is evident throughout. As originally designed, fresh air would enter the buiding through large casement windows along the permieter. The air would be drawn through the large central atrium and the warm air would rise up and exit the building through the Great Hall's operable clerestory windows. In addition, vents were provided under each of the building's exterior windows. The vents were situated behind the steam radiators so that the fresh air could be warmed to room temperature. The windows, archways, and numerous clerestory windows also provided generous levels of natural light. The ingenious system of the windows, vents, and open archways allowed the Great Hall to function as a reservoir for light and air.

The Pension Building continued to serve as office space for a variety of government tenants through the 1960s. The government began to consider demolishing the building as it was badly in need of repair, but they came under pressure from preservationists and commissioned architect Chloethiel Woodard Smith to explore other possibilities for its use. In her 1967 report, “The Pension Building: A Building in Search of a Client,” Smith introduced the idea that the building be converted to a museum of the building arts. In 1969, the Pension Building was listed on the National Register of Historic Places. Congress passed a resolution in 1978 calling for the preservation of the building as a national treasure, and a 1980 Act of Congress mandated the creation of the National Building Museum as a private, non-profit educational institution.



(Source: National Building Museum, http://www.nbm.org/about-us/historic-building)

Meigs stated that the building he was planning "will have no dark corridors, passages, or corners. Every foot of its floors will be well lighted and fit for the site of desks at which to examine and prepare papers. It will be thoroughly ventilated, every room having windows on two sides, one opening to the outer air, the other into a central court covered from the weather by a non-conducting fire-proof roof, with ample windows above for escape of warm and foul air, and for the free admission of light."

Annual Report of the Quartermaster General (1881) p. 236, photocopy in reference files of National Building Museum (NBM), Washington, D.C.

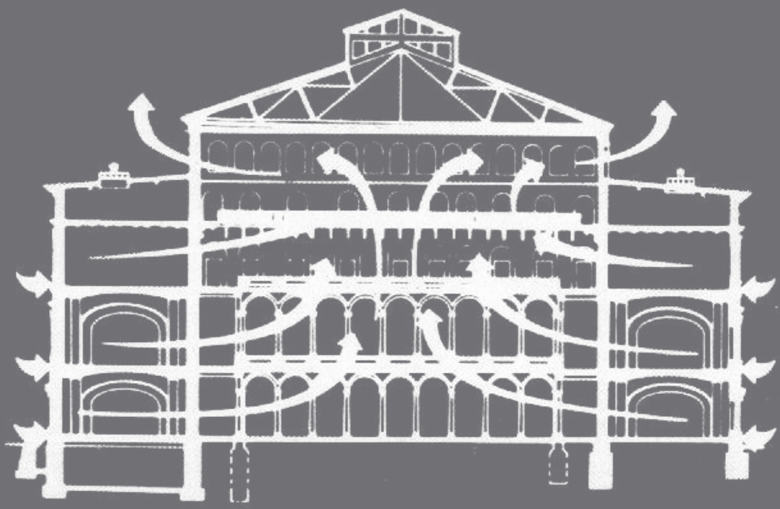
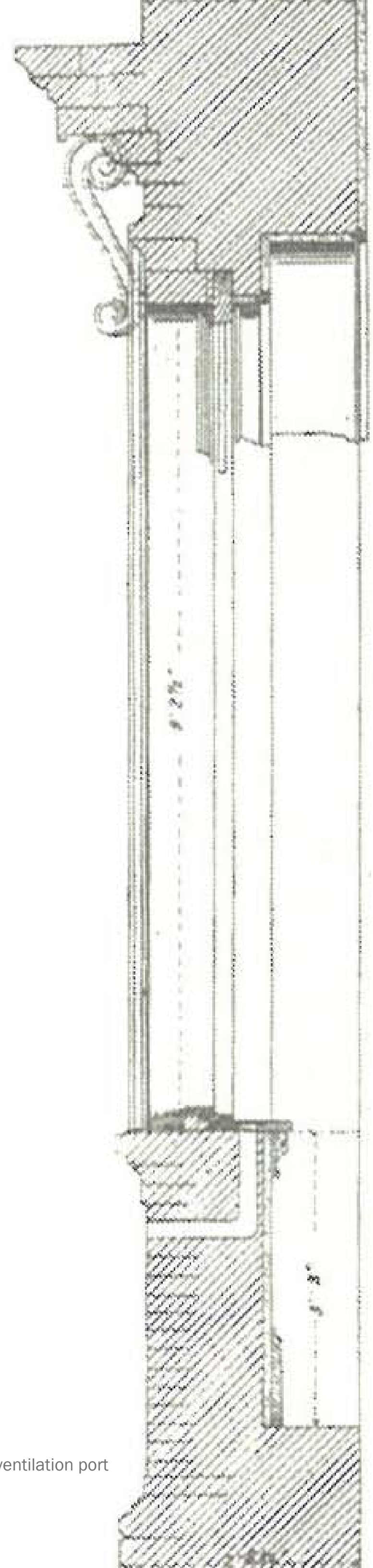


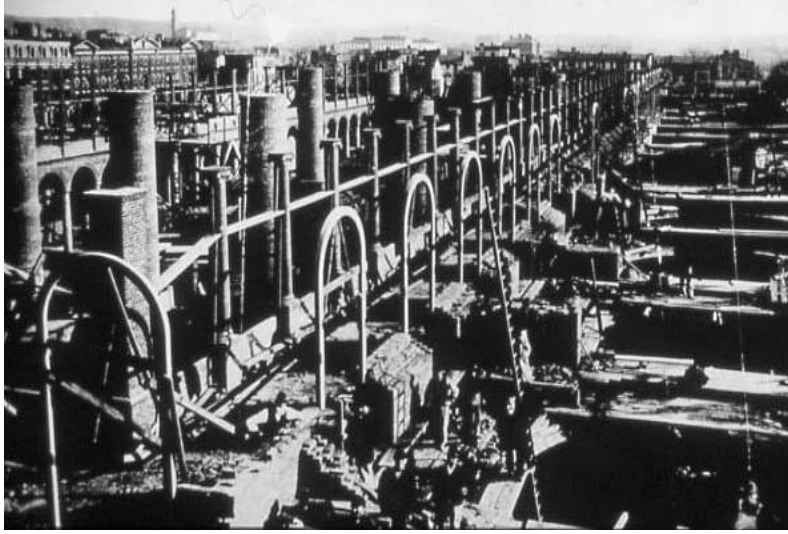
FIG. 4. Diagram of planned airflow through Pension Building. *(Courtesy National Building Museum.)*

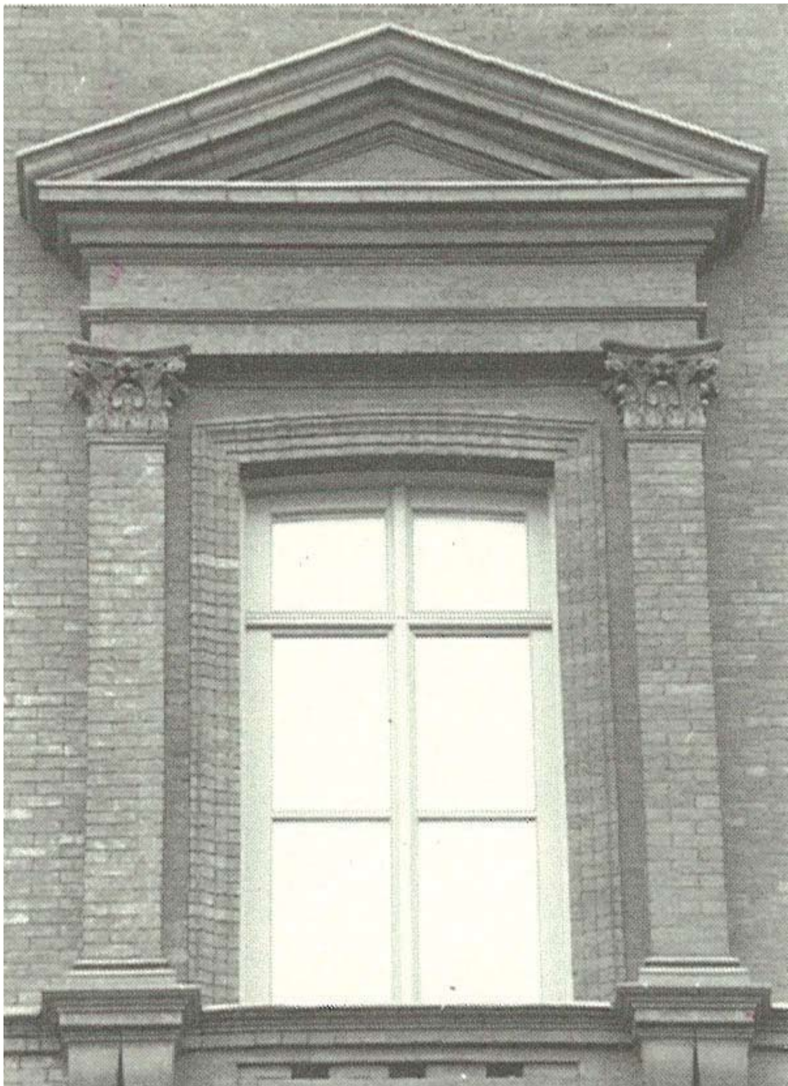
NATIONAL BUILDING MUSEUM FACTS

Architect/Engineer Montgomery C. Meigs (1816-1892), Quartermaster General in charge of provisions during the Civil War *Construction Dates* 1882-1887 *Original Cost* $886,614.04 *Exterior Dimensions* 400 feet by 200 feet, 75 feet to cornice level *Materials* 15,500,000 bricks with brick and terra cotta ornament *Exterior Frieze* 1,200 feet long, 3 feet high, made of terra cotta. Features a continuous parade of Civil War military units designed by Caspar Buberl (1834-1899) *Great Hall* 316 feet by 116 feet, 159 feet (approximately 15 stories) at its highest point *Corinthian Columns* 75 feet high, 8 feet in diameter, 25 feet in circumference. Each built with 70,000 bricks and originally painted to resemble marble in 1895 *Busts* 234 busts designed by Gretta Bader in 1984 *Arcade* 72 Doric-style columns on the ground floor and 72 Ionic-style columns on the second floor *Inaugural Balls* First Inaugural Ball at the National Building Museum was held by Grover Cleveland in 1885, the tradition continues to the present day

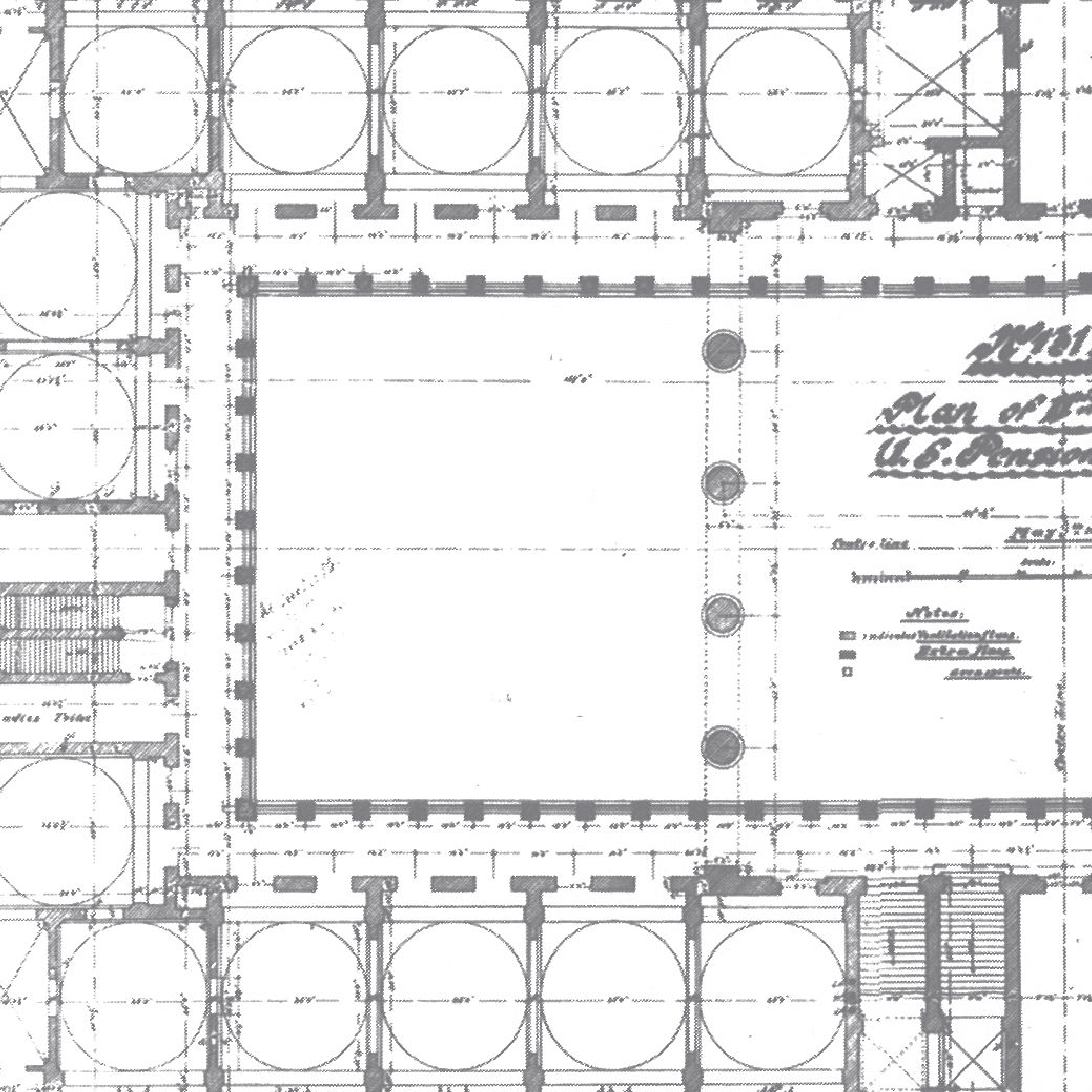
(Source: National Building Museum, http://www.nbm.org/about-us/historic-building/nbm-quick-facts.html)

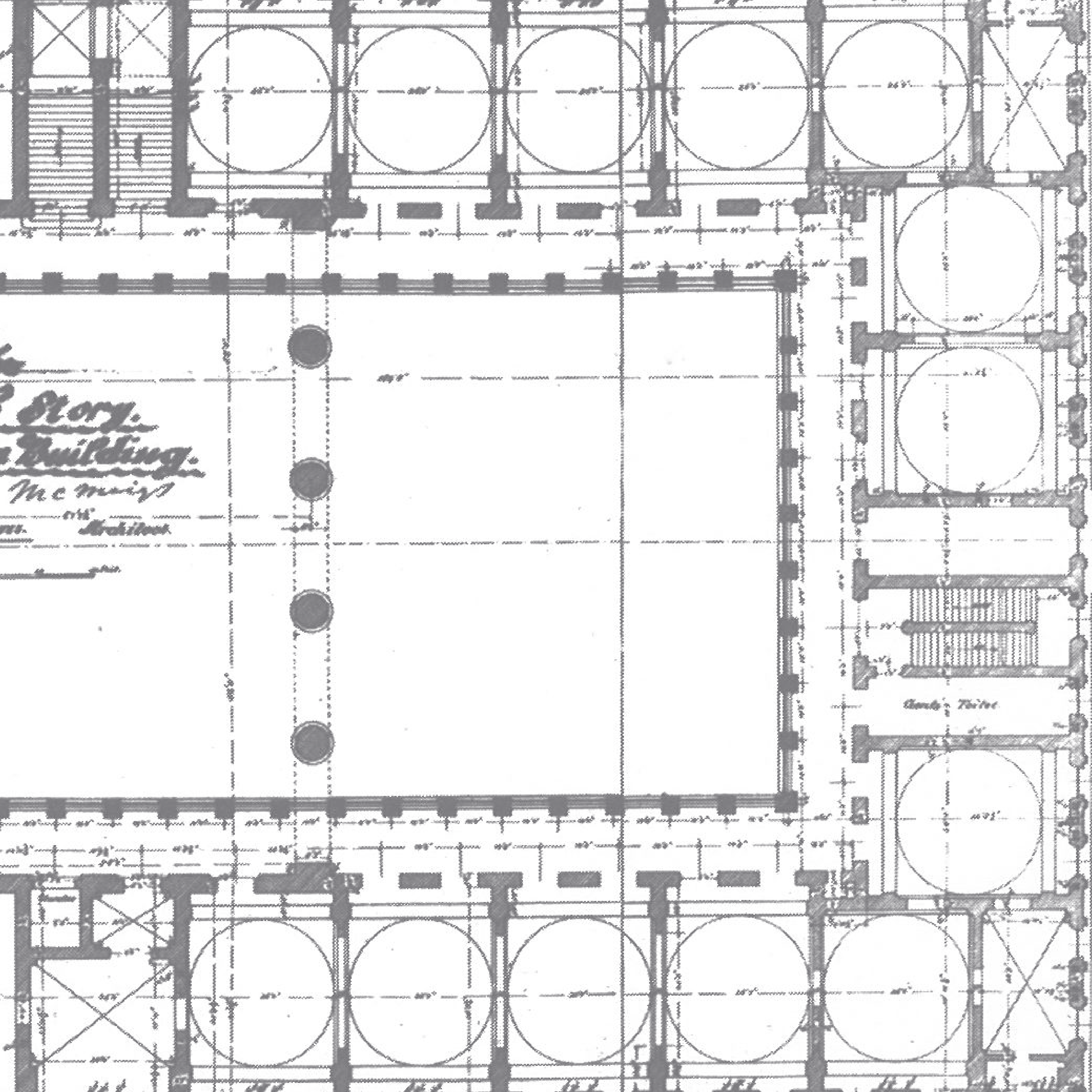






Meigs' window section and window showing ventilation port


No 181
Plan of
U.S. Pension
Centre line
Notes;
Extra flues



Story.
Building.
M C Meigs
Architect

The National Building Museum Today

The historic Pension Building now serves as home to The National Building Museum. The National Building Museum was created by an act of Congress in 1980 and has become one of the world's most prominent and vital venues for informed, reasoned debate about the built environment and its impact on people's lives. The exhibitions, educational programs, and publications offered by the museum and frequented by visitors throughout the world are well regarded not only for their capacity to enlighten and entertain, but also to serve as vehicles to foster lively discussion about a wide range of topics related to development, architecture, construction and engineering, interior design, landscape architecture, and urban planning. In a time of unprecedented concern about how our actions affect the environment, it seems only appropriate that the National Building Museum is taking a look at their own facility and operations and assessing ways to reduce their demand on our earth's natural resources.

The glorious building that you visit today is the result of years of careful renovation and restoration. In 1997, the historic building was officially renamed the National Building Museum.

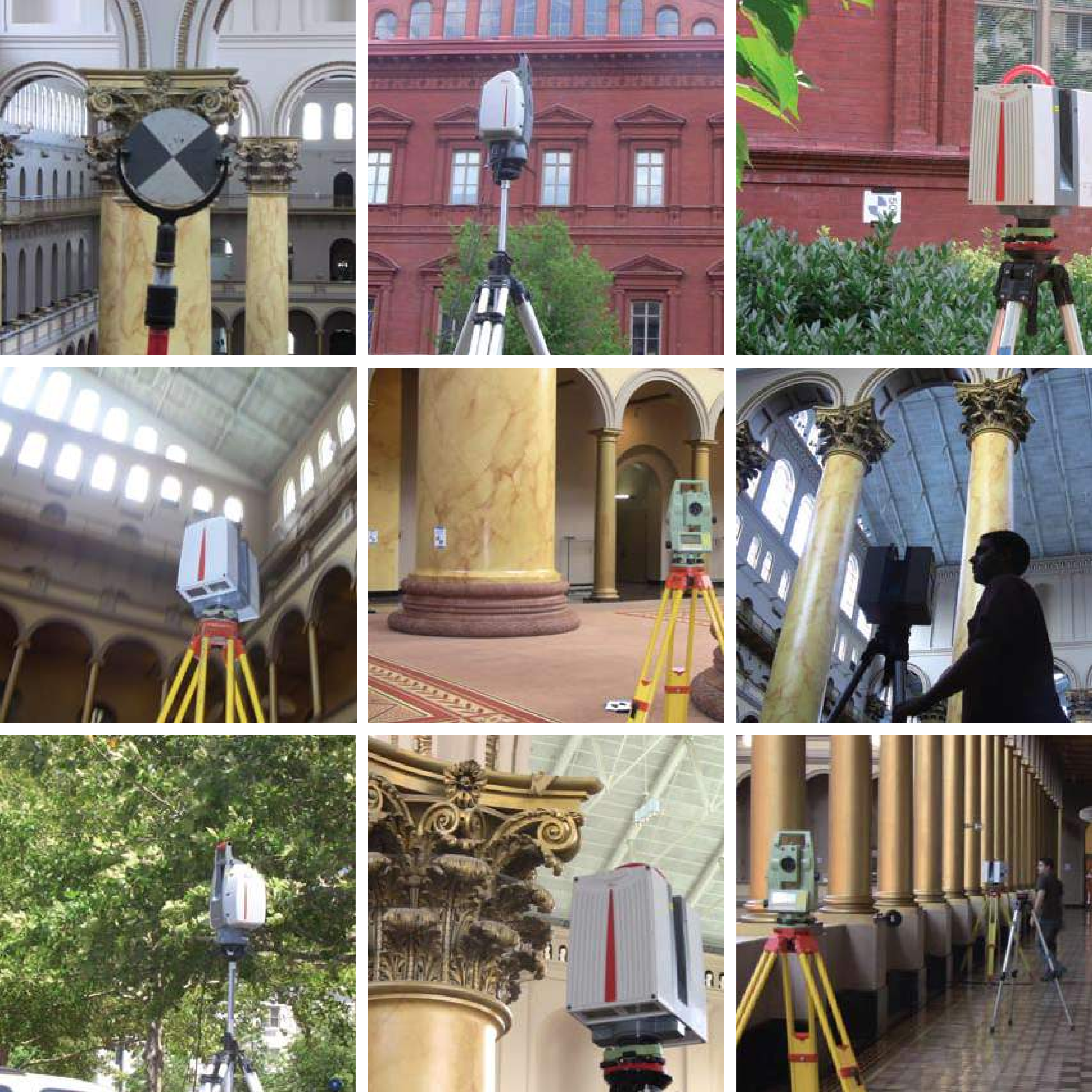
(Quote - National Building Museum, http://www.nbm.org/about-us/historic-building)

An ingenious system of windows, vents, and open archways allows the Great Hall to function as a reservoir for light and air.

National Building Museum, http://www.nbm.org/about-us/historic-building

SECTION 3

Current Building



You don’t know what you don’t measure.

To understand existing buildings it is important to first measure how the building is currently performing and the conditions that are creating those results. Only then can you understand the opportunities that are hidden within the building.

Gathering Data

Current building information was compiled through various means including scanning, studying historical drawings and photographs provided by the National Building Museum, a site visit, a comprehensive tour of the facility and conversations with facility and operations personnel. Included here is a summary of the findings.

Structure / Envelope

- Load bearing brick construction
- Exterior Walls are 1.5 - 3ft thick, uninsulated, with interior plaster coat.
- Interior Walls are brick with plaster coat on each side.
- Floating wood floor structure supported by brick superstructure.

Roof

- Great Hall: Iron trusses supporting lightweight concrete tiles, wood decking, and metal roof.
- Main Building (lower roof): fireproofed iron supporting masonry deck with a lightly colored membrane.
- Drawings from the 1986 renovation of the building indicate that the roofs were not insulated during the renovation.
- Basement: Fourth floor windows were replaced around 1986 with inoperable double glazed units.
- Great Hall clerestory windows are single glazed.
- Ventilation ports under windows have been sealed shut, though noticeable infiltration was observed at surveyed portals.

TRANSFORMATION PROCESS KEY

Data Gathering > Laser Scanning > Building Information Model > Big Picture Analysis > Detailed Analysis > Design Solutions > Analyze Solutions > Implement > Maintain

Water

- Toilets and faucets are standard flow and single flush.

HVAC

- Museum climate control is required in galleries to insure the well being of artifacts; gallery spaces are maintained at 70 degree F and 50% humidity.
- Spaces other than galleries and museum storage are maintained within normal comfort bands.
- Building make-up air and air changes are not tied to actual demand via CO_2 censors, etc.
- Central district steam is converted to hot water at the building for heat.
- Building is conditioned by central chillers with 2 outside cooling towers. These chillers are rotary screw chillers with a performance of 0.61 kW/ton. (The most efficient chillers available of this size are centrifugal type and operate at 0.48 kW/ton)
- Dedicated air handlers serve each gallery. Zoned air handlers serve the remainder of the building spaces.
- The dehumidification system sub-cools supply air to remove humidity and then reheats it to the desired temperature. The excess steam is converted into hot water for space heating and dehumidification re-heat.

Lighting

- The Great Hall uses incandescent lighting fixtures. During the site visit, however, artificial lighting was not used and the space was adequately daylit for general usage of approximately 30.5 foot candles.
- Office spaces use a mix of florescent and incandescent lighting. Natural ambient light levels at southern bays were observed to be in the range of 15 to 25 foot candles at the center of the bays.
- Galleries use a mixture of incandescent and LED point sources. The NBM stated they are gradually shifting towards LED lighting where possible although some exhibit features require infrared light which is not produced by LEDs.
- MEP and Support Spaces also use a mixture of fluorescent and incandescent lighting sources that operate on occupancy sensors.

Energy Use

- Annual energy use from steam was stated at around 75,000 therms (2,197,500 kWh). This includes potable hot water and miscellaneous uses.*
- Annual electric energy use was stated to be around 3,533,225 kWh with a peak demand of about 800 kWh.*
- Combined annual building energy use is calculated at around 5,476,313 kWh.

Beyond space heating and cooling, miscellaneous equipment loads and lighting comprise the next highest energy demands. While the Great Hall is successfully daylit, many galleries, offices, and other use spaces block out natural light from windows in favor of more controlled artificial lighting. It is likely that offices have minimized daylight in order to control glare and the galleries have minimized daylit out of the need to protect artifacts from UV exposure and allow exhibit designers control over theatrical lighting of installations.

* Note: Autodesk Green Building Studio was used to compute average existing energy use shown here. These results used to calibrate each energy model for testing of individual solutions.

Dehumidification plays a major role in the inefficiencies of the current HVAC system and appears to be a year round necessity. The constant flow of visitors to the museum, atrium fountain, and natural moisture movement of the historic masonry building combine to produce excess humidity in this already humid climate.

Mechanical room/equipment currently in use at the NBM

The high thermal mass of the load bearing brick construction makes for a building with a lot of thermal momentum which can be problematic during transitional seasons, but beneficial most of the year. The 15,500,000 bricks used in construction, equate to roughly

765,527

cubic feet of thermal mass.

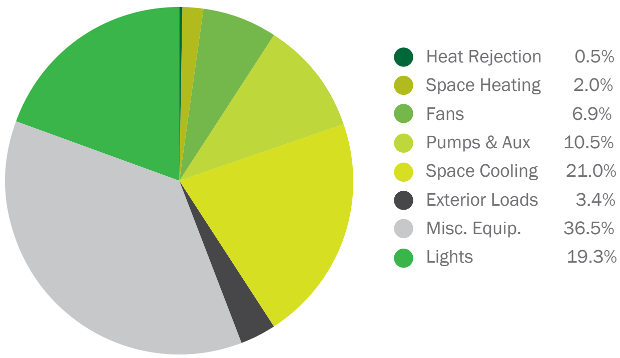


Figure 01. **Breakdown of electric energy use by category**

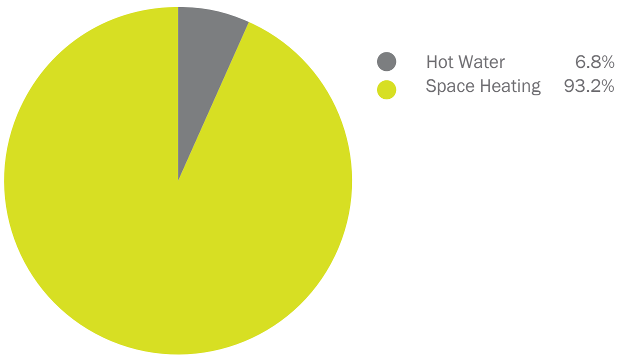


Figure 02. **Breakdown of fuel source (steam) use by category**

Climate is what we expect,
weather is what we get.

MARK TWAIN

SECTION 4

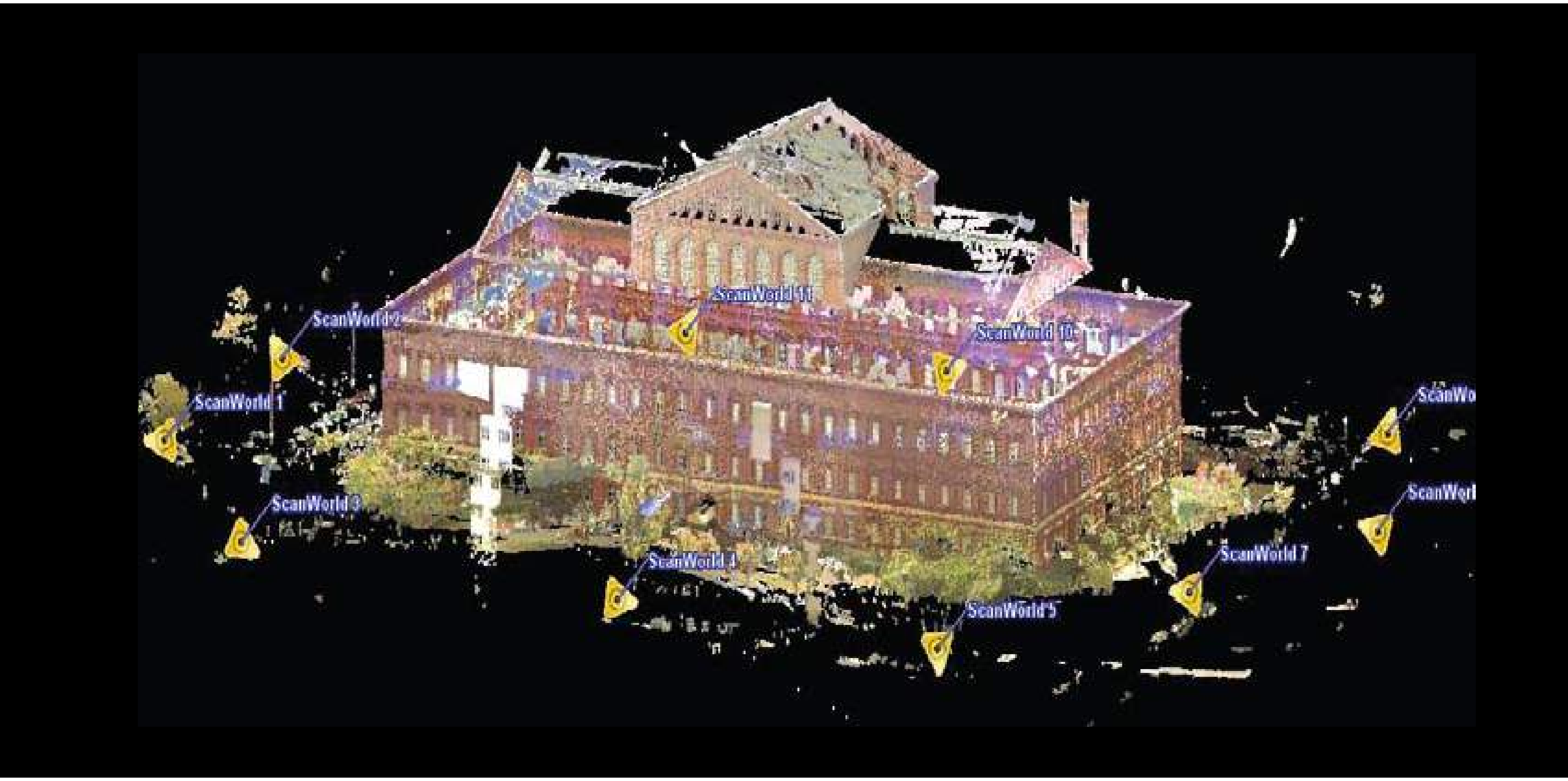
Process of Analysis

If buildings could speak,


what would they tell us?

Laser Scanning

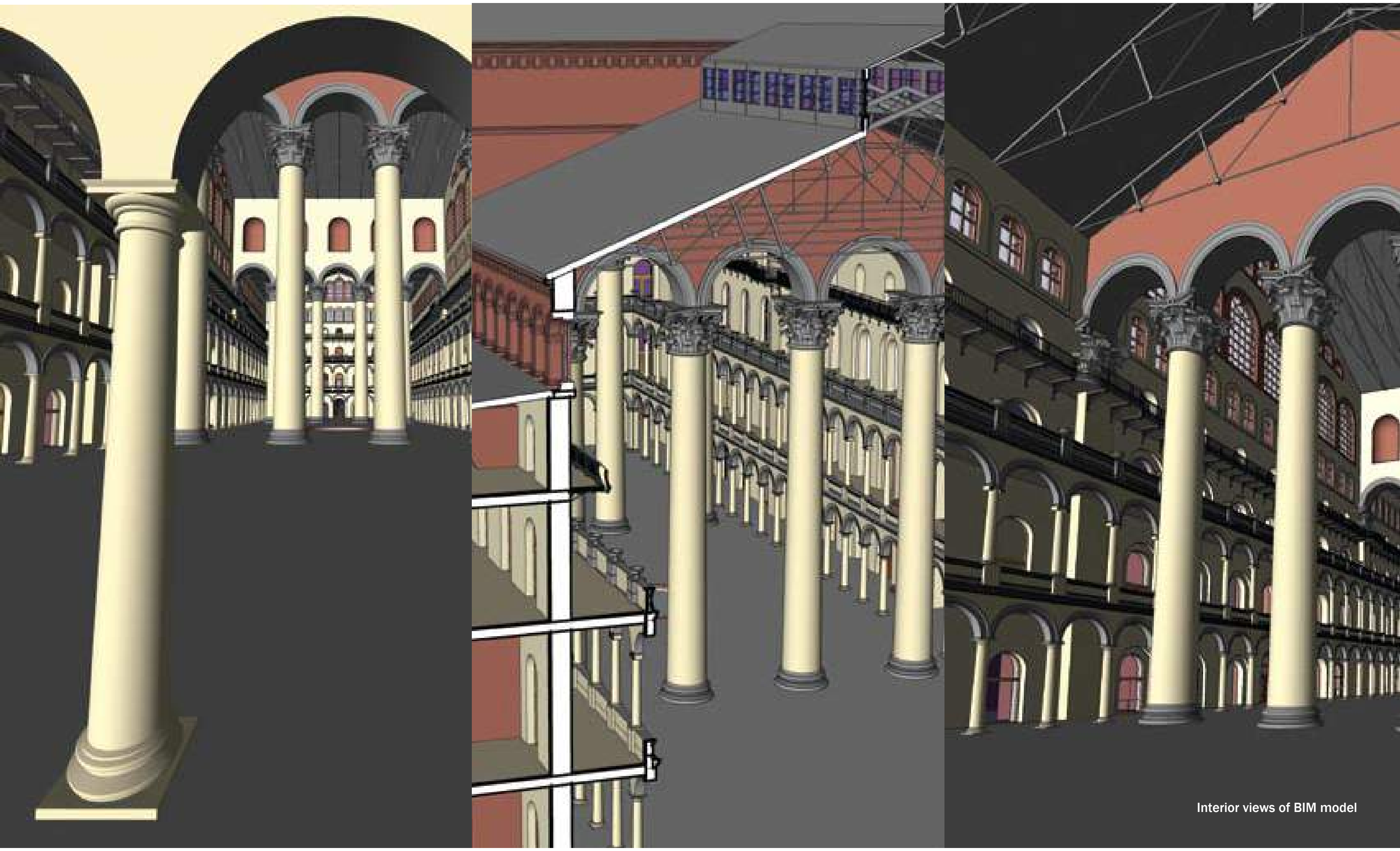
Along with information from historical photographs, construction drawings, and field observation, High Definition Laser Scanning was used to collect accurate three-dimensional physical and spatial information. The laser scanning process creates a three-dimensional point cloud of the surfaces that it measures. Using high definition scanning, a accurate building model can be created in a fraction of the time that it would take to perform field measurements or interpret the design from existing drawings.



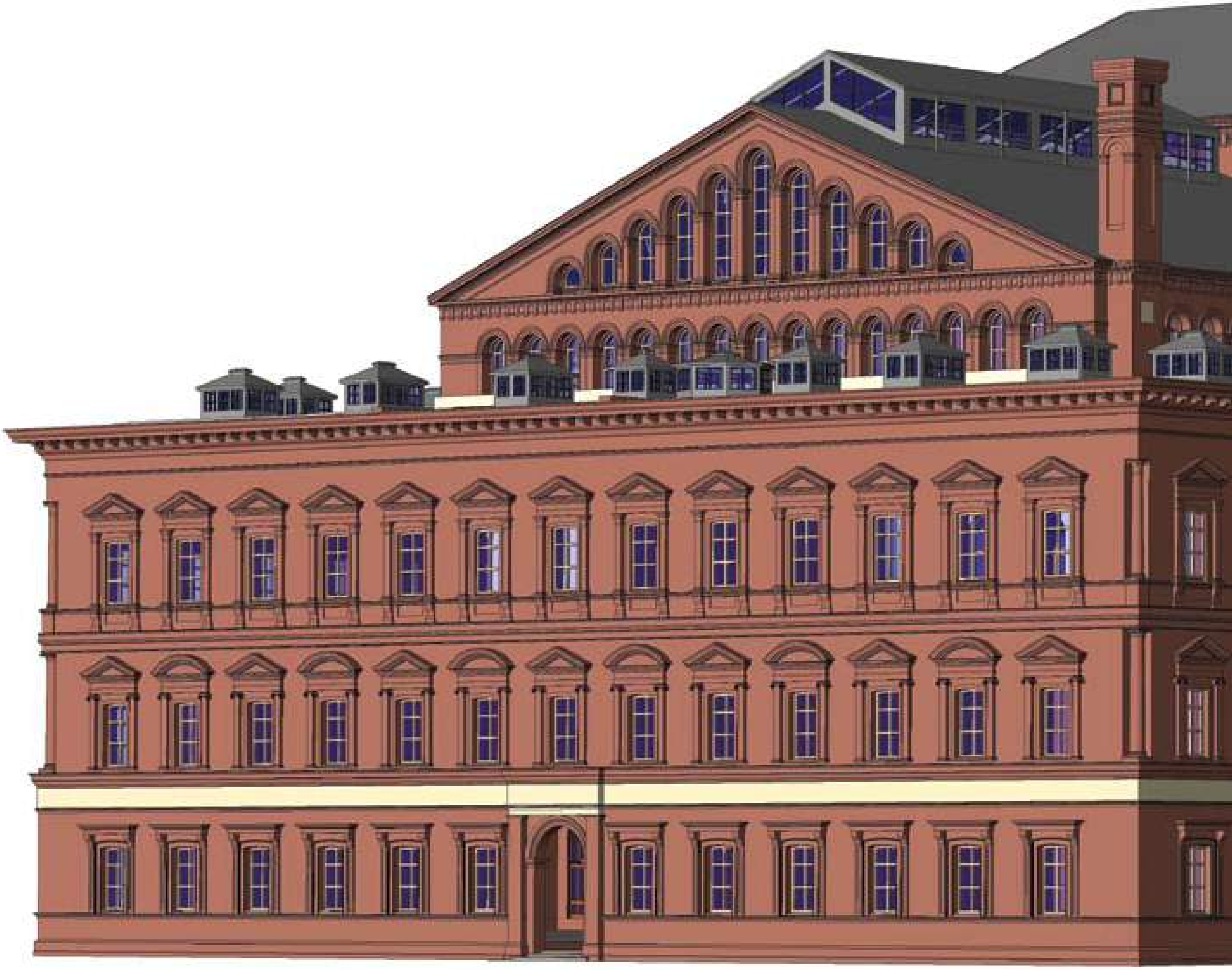
Point cloud of building components (above) and building exterior, showing registration points

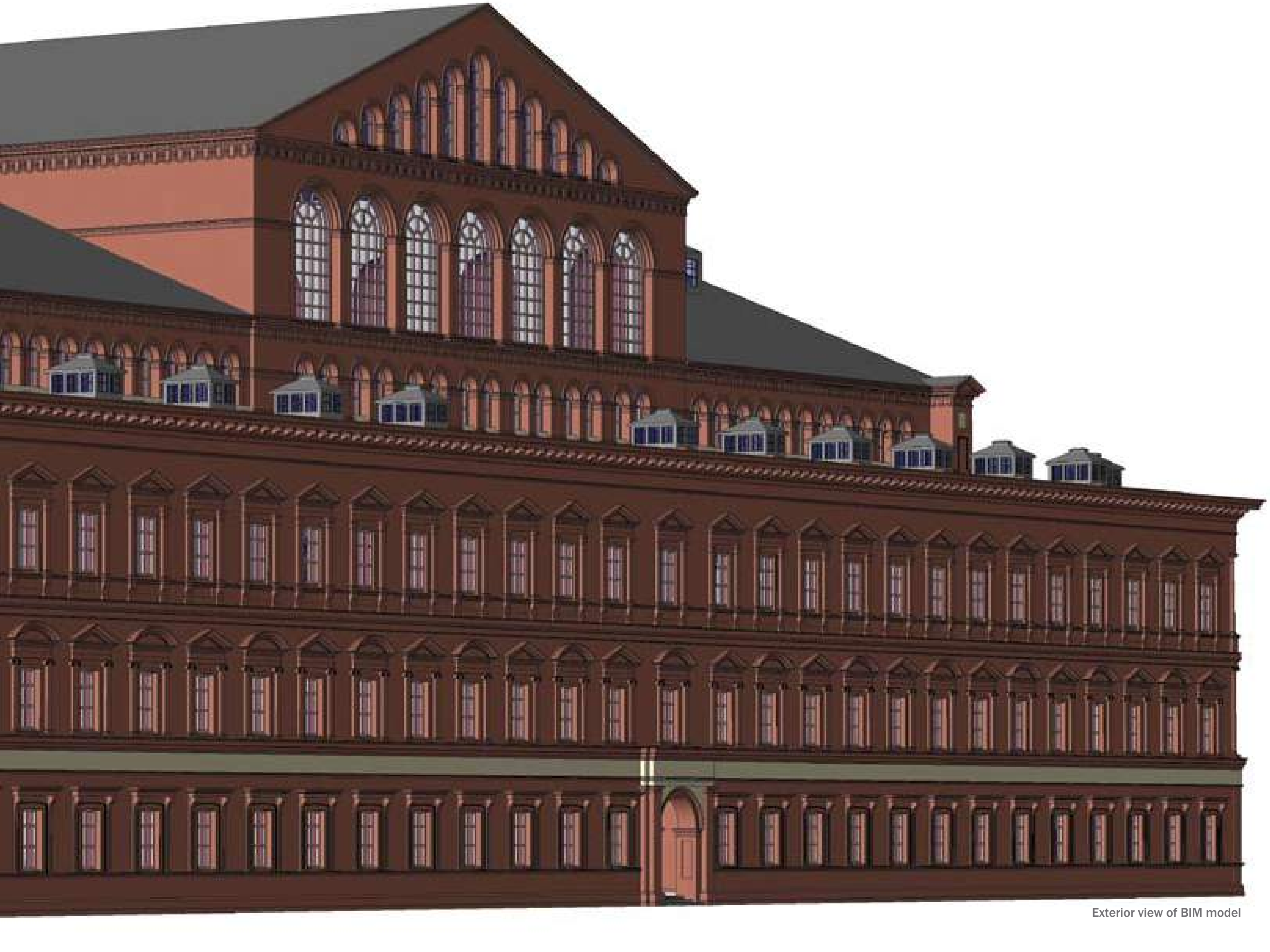
Conversion to BIM

From the three-dimensional point cloud, a dimensionally accurate building model is created, which acts as a coordinated repository of what is known about the building. Called a Building Information Model (BIM), this model can contain any information that is required about a building. In this case, the team input information which would impact the performance of the building such as glazing types, material properties, HVAC zones, occupancy and even the type of attire a worker or visitor might wear.



Interior views of BIM model




Exterior view of BIM model

Big Picture Analysis

With geometry and necessary information collected into a BIM, it is loaded into Autodesk Green Building Studio (GBS). GBS runs calculations against the Building Information Model and, within minutes, is able to return a big picture assessment of how the building will perform in its climate, which helps to identify particular areas for more detailed study and allows the team to generate a working hypothesis about the building's behavior and possible performance solutions.

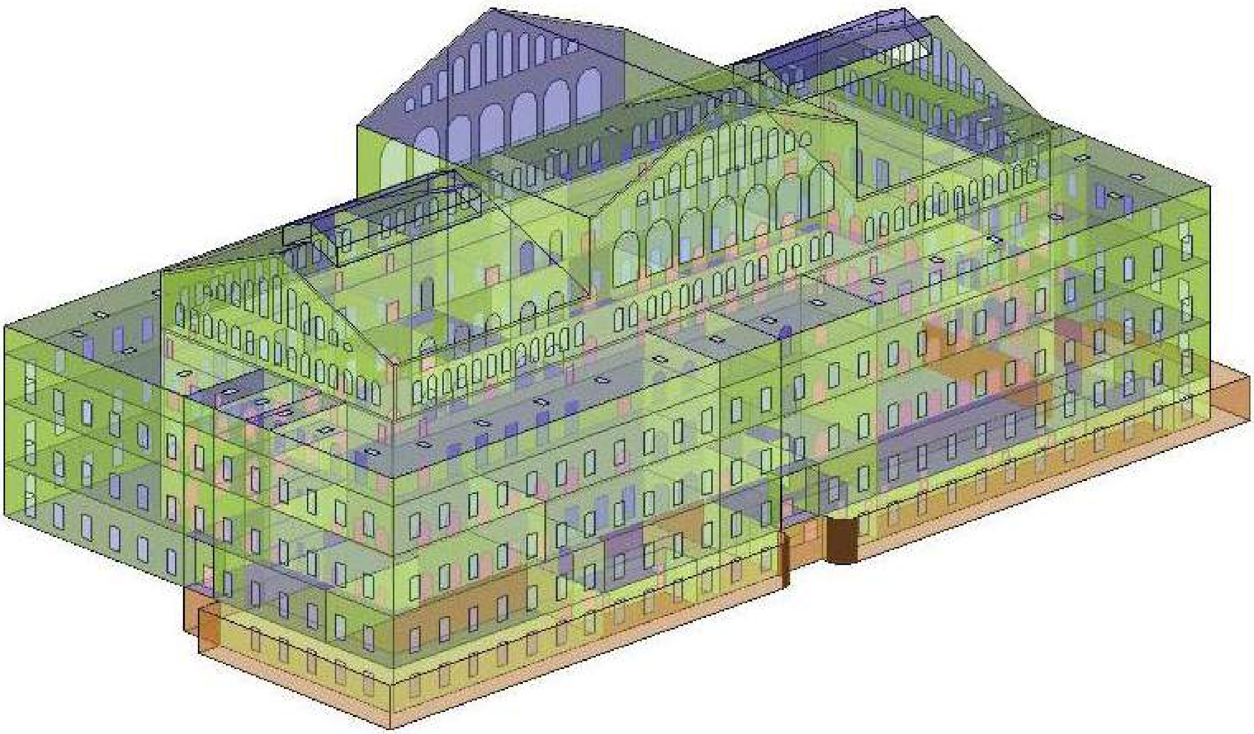
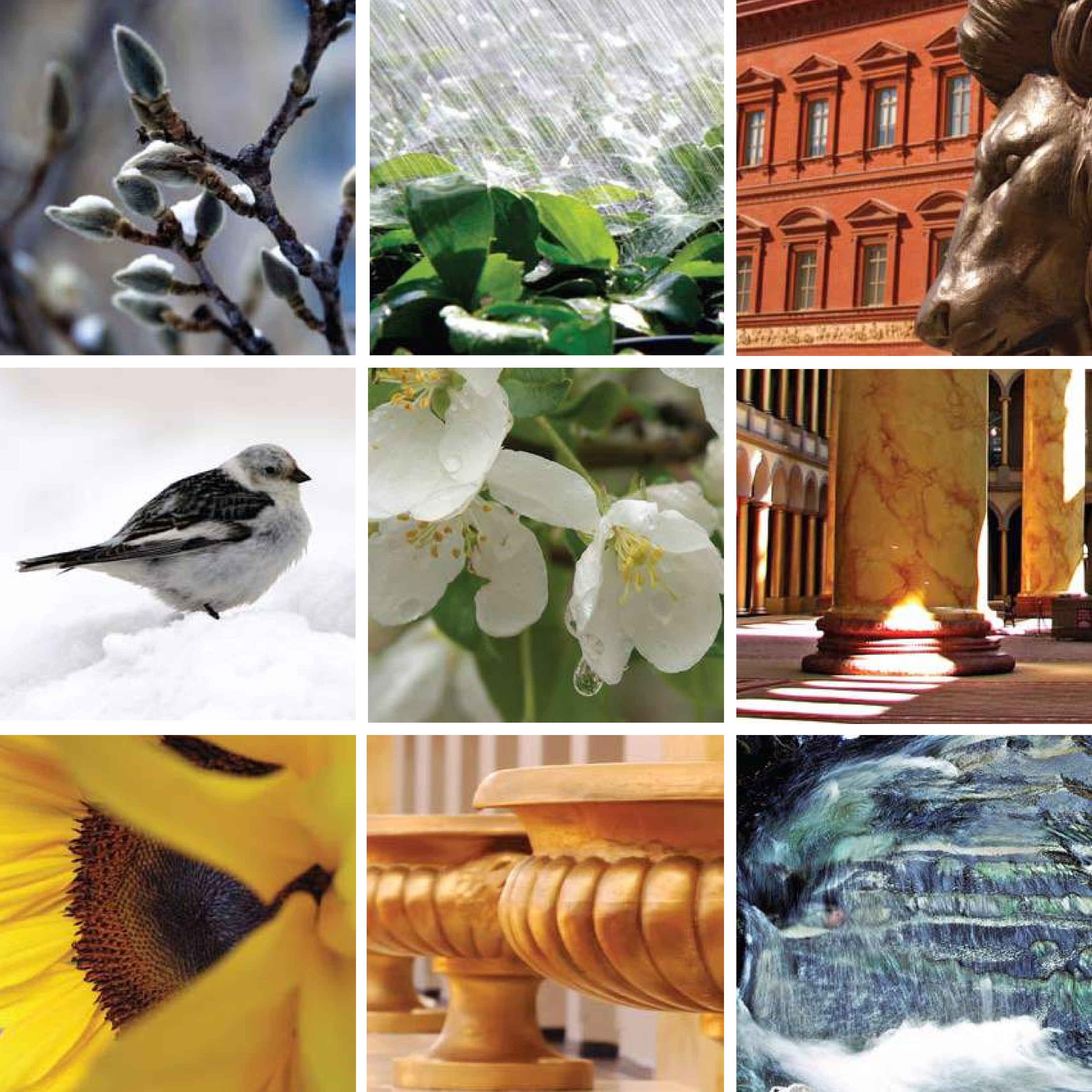


Figure 03. **GBXML model (ready to upload to Green Building Studio)**

Figure 04. **Results of analysis using simple envelope upgrades**

Climate Data

Understanding the climate where the building is located is paramount to understanding its current behavior and to identify opportunities for improving performance.



Solar

Sun Extremes: Washington, D.C.'s, high summer sun angles suggest that minimal shading devices can be effective while allowing winter sun penetration. Internal solar controls such as light shelves should also be considered to prevent glare.

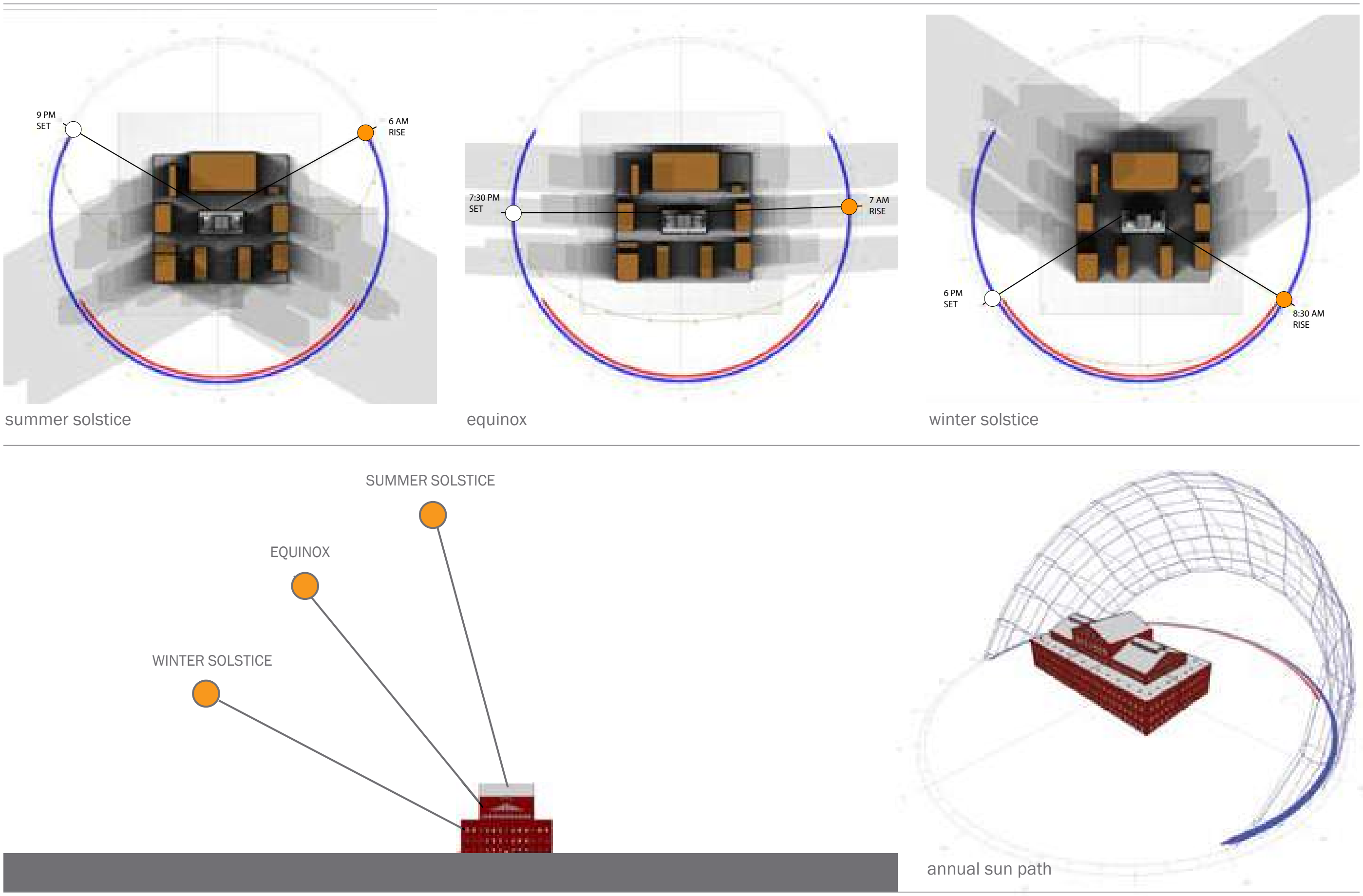


Figure 05. **Sun path diagrams**

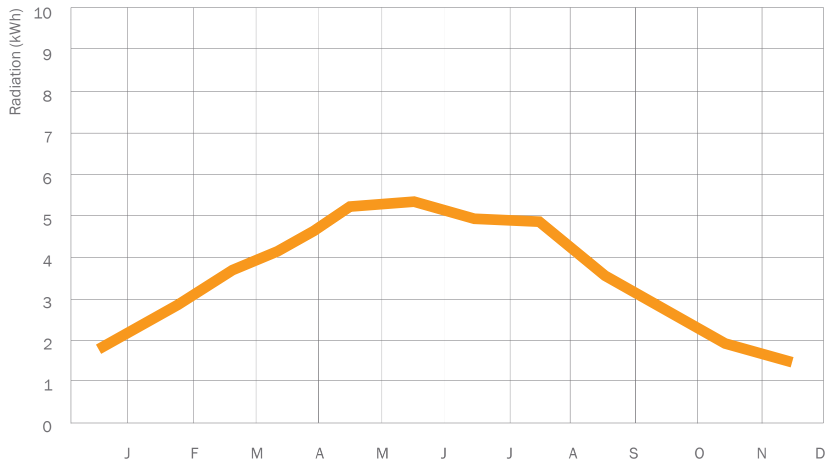
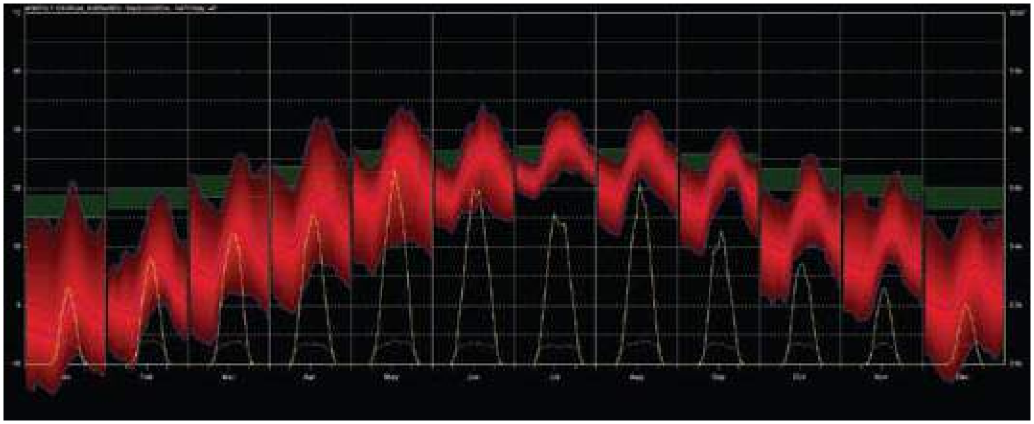


Figure 06. **Monthly average incident solar radiation** (also referred to as insolation): In Washington D.C., April through August are the best months for effective solar collection. The yearly average insolation is 3.6 kW/h.

Temperature

Washington, D.C. weather is characterized by four distinct seasons with relatively mild temperatures in the summer and winter. The hottest average summer is around 92 degrees F, while the coldest average winter day is around 0 degrees F.



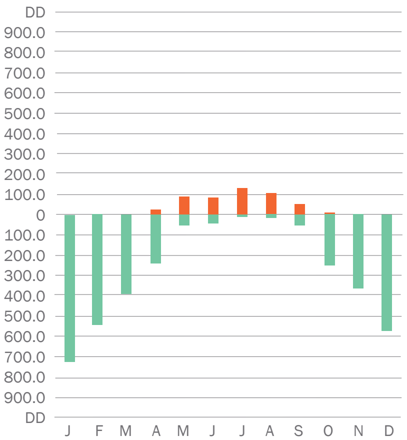


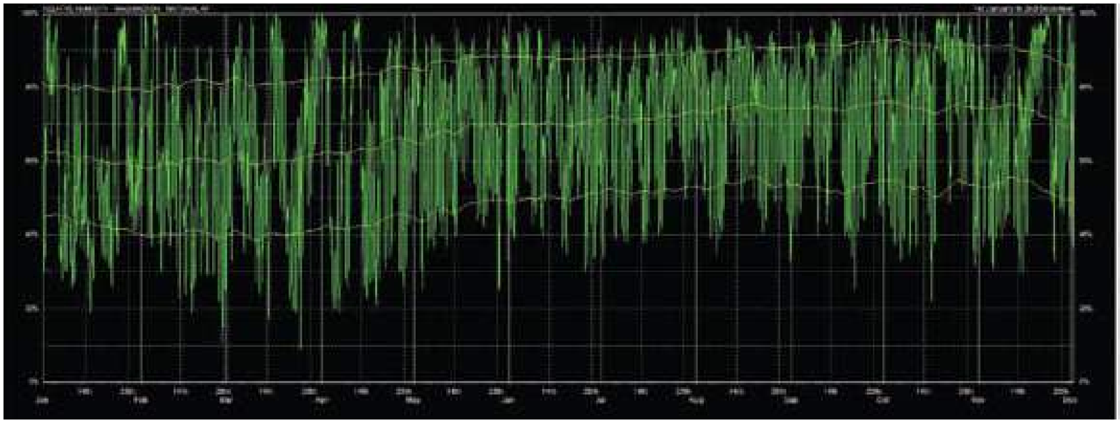
Figure 07. **Daily temperature range (red) and comfort range (green)**

Figure 08. **Heating degree days (green), cooling degree days (orange)**

Heating and Cooling Degree Days are a representation of the amount of time the ambient outside temperature is above (requiring cooling) or below (requiring heating) a given comfort range. At the National Building Musuem, this comfort range is represented by 69 to 71 degree F for the galleries and artifact storage and a broader 65 to 78 degree range for the rest of the building.

Moisture

Washington, D.C. has a high average Relative Humidity ranging from 60% in the winter months to 75% in the summer months. Dehumidification of spaces dealing with sensitive artifacts requires year-round consideration, in addition to consideration for human comfort in occupied spaces.



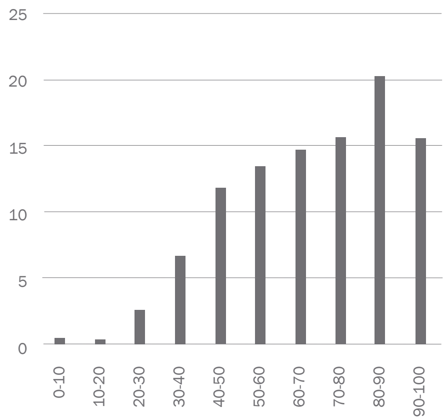


Figure 09. **Daily relative humidity**

Figure 10. **Relative humidity frequency distribution (annual)**

Wind

Average wind speeds throughout the year are generally mild, ranging from 0 to 11 km/h over 75% of the time. Winter months (Jan-Mar) see the strongest winds out of the north-west and west-north-west directions at speeds up to 30.6 km/h. Summer months (Jul-Sept) see more distributed wind direction, but predominantly between south and west.

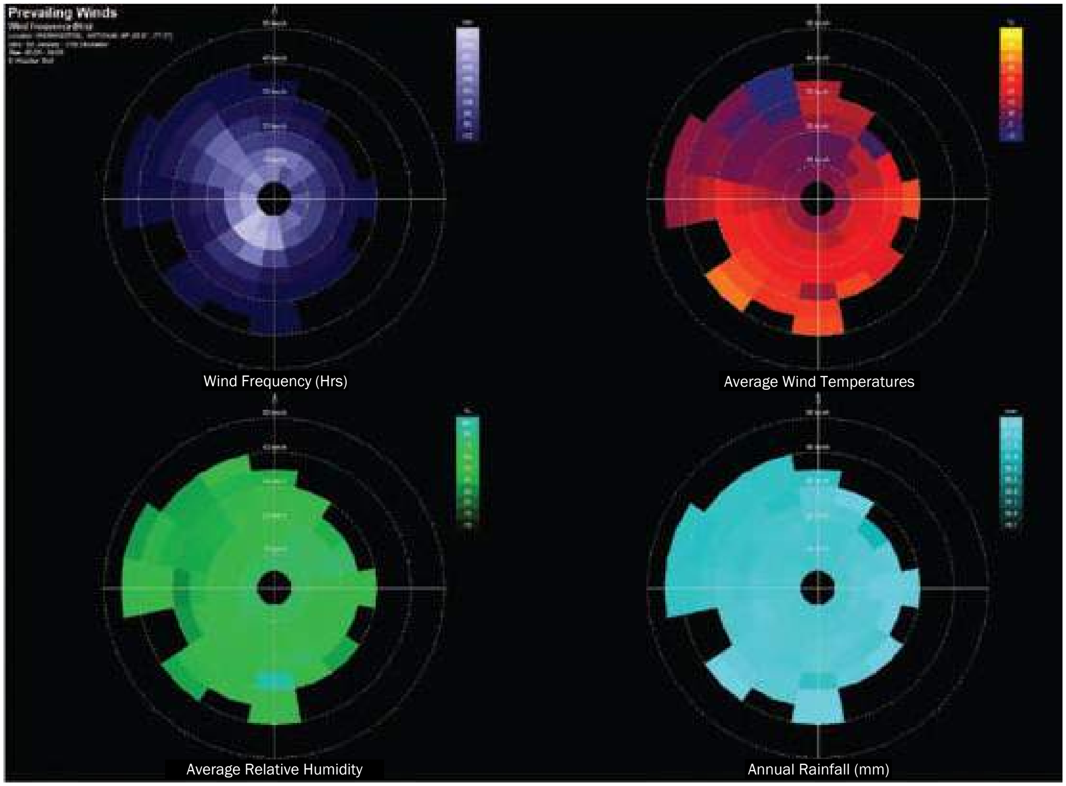


Figure 11. **Wind charts**

Psychrometric Data

In addition to air temperature, human comfort is effected by many environmental factors such as air movement/ wind, humidity, and radiant energy. The yellow “window” represents a range of conditions at which most people can be comfortable.

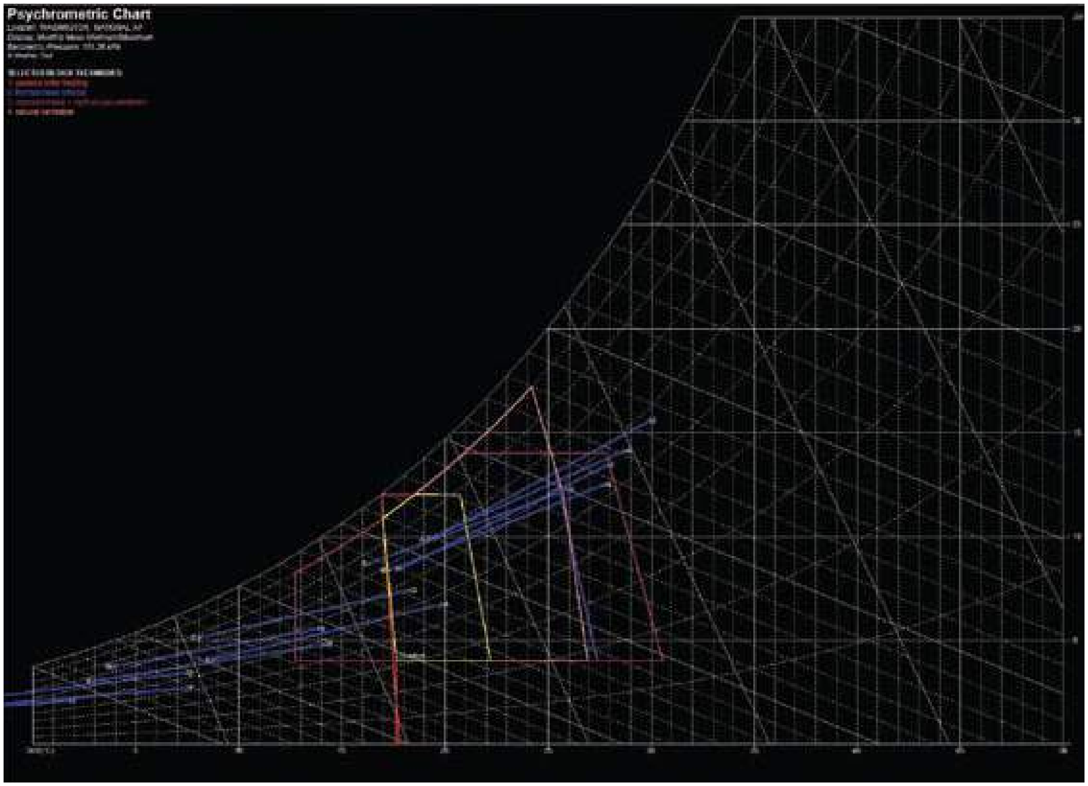


Figure 12. **Psychrometric charts**

Detailed Analysis

The Big Picture Analysis provided clues about the aspects of the building that need more detailed analysis. Working again from the base Building Information model, the geometry and data was loaded it into Autodesk Ecotect. This allowed the team to look at discrete areas of the building and to set up experiments to test hypothesis about the function and performance of the building. The following pages are the results of some these studies and experiments.

The average daily absorbed/transmitted solar radiation tells us how much heat energy the skin contributes to the load of building spaces adjacent to the exterior walls.

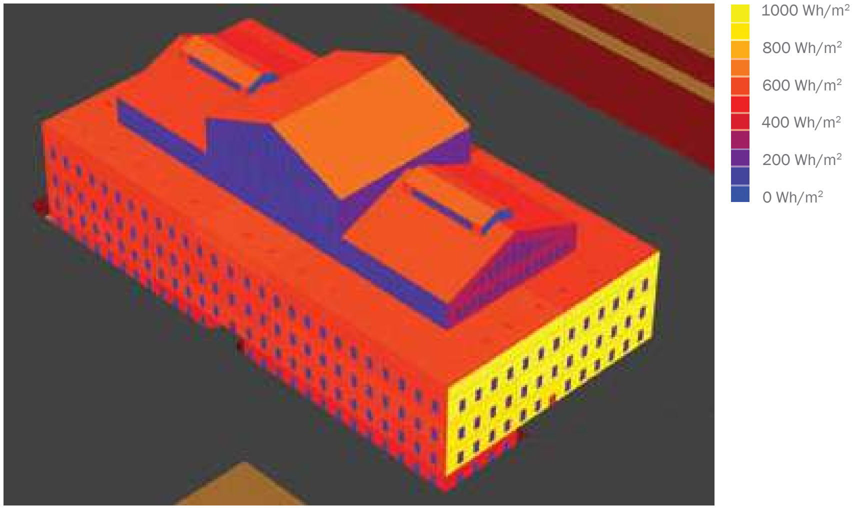


Figure 13. **Average daily absorbed/transmitted solar radiation, December - February**

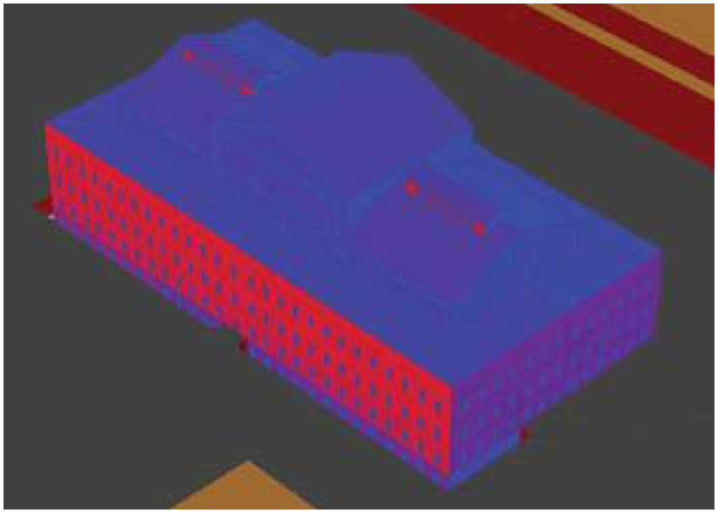


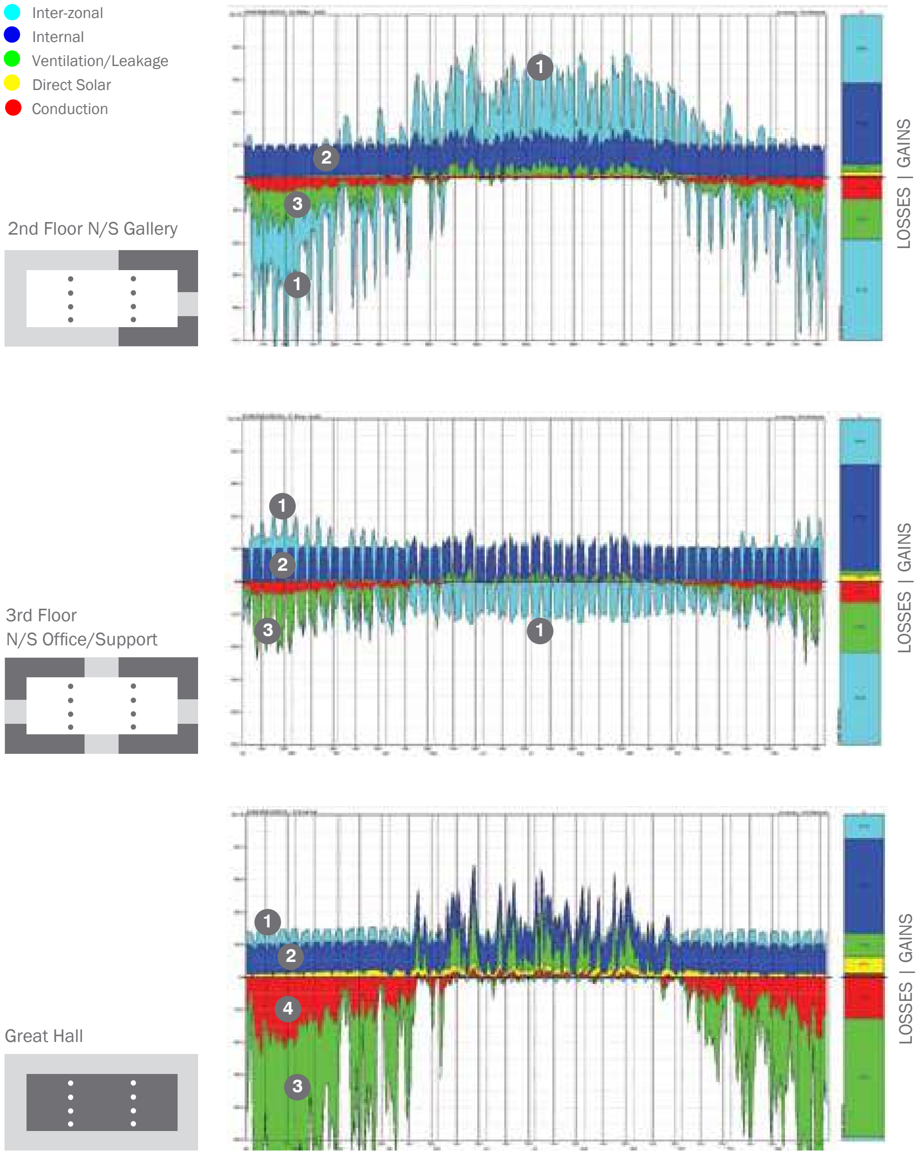
Figure 14. **Average daily absorbed/transmitted solar radiation, June - August**

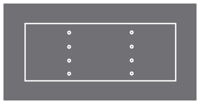
Considerations

Based on initial investigations of building loads, the Great Hall and gallery spaces proved to be a significant factor in the overall energy use of the building. To understand the conservation opportunities for these spaces, the analysis team used the base building model in Ecotect to plot passive heat gains and losses throughout the year in two representative galleries, office/support spaces, and the Great Hall. Comparing these plots, the following observations can be made:

1. In the winter months, the galleries are losing energy to the rest of the building while gaining energy from the office/support spaces during the summer. Due to the higher degree of conditioning — Temperature and humidity — of the gallery air, this uses more energy than necessary and should be minimized.
2. Internal gains from lighting, projectors, and visitors and office workers are the next highest source of energy movement. This "free" heat is desirable during the winter, but adds to cooling loads during summer months.
3. During the team's site visit, we observed significant air leakage around doors and through the abandoned ventilation ports. We assumed "average" air leakage through the envelope for analysis purposes, although above average air leakage is more likely. In either case, coupled with necessary ventilation air, this is a significant and unnecessary source of heat loss and gain. In the Great Hall, this is more pronounced due to the ratio of volume and skin area to the floor area.
4. Throughout the building, conduction through the skin is more pronounced during winter months than summers due to higher indoor/outdoor temperature differentials in the cold season. This is even more pronounced in the Great Hall where warm air pools at the top of the volume. Single pane windows at the clerestories and an uninsulated roof provide for high conduction between indoors and outdoors.

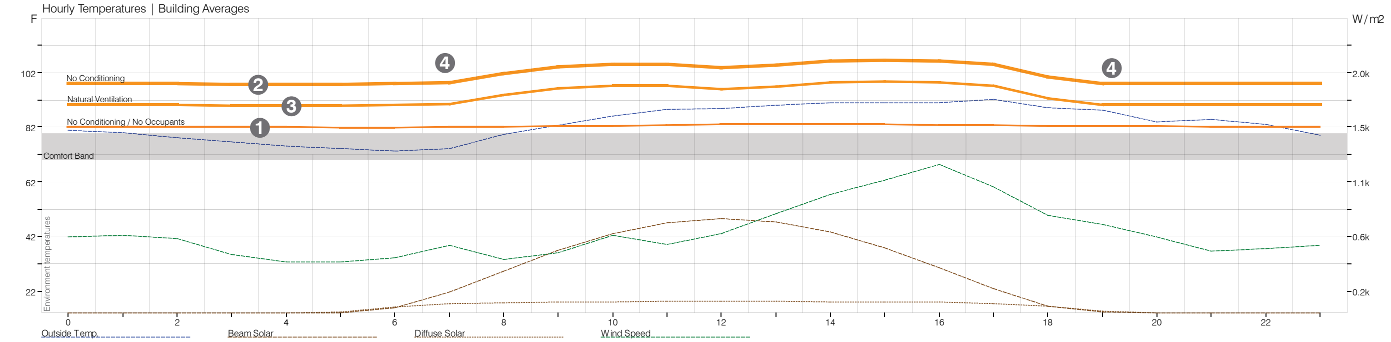
Figure 15. **Passive gains & losses**





HOTTEST AVERAGE DAY: MAY 24

BUILDING AVERAGES



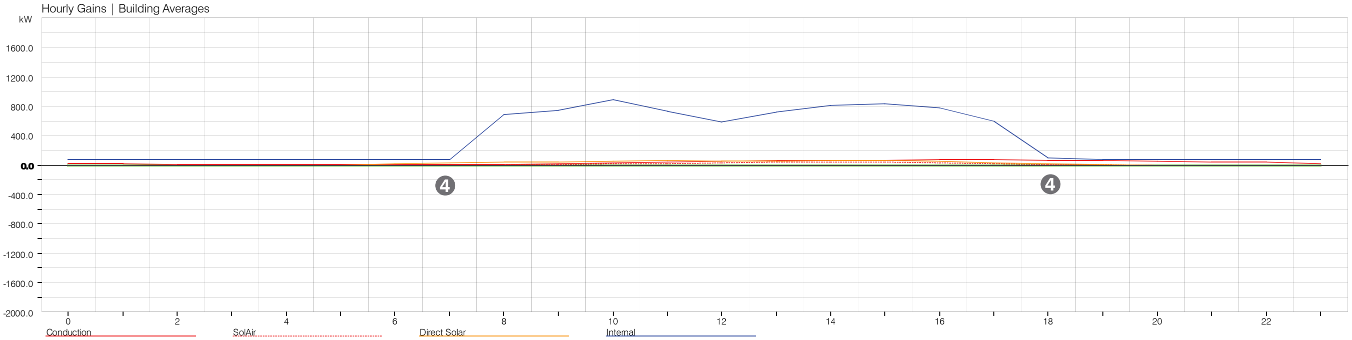
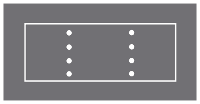


Figure 16. **Building performance on a normal extreme cooling day**

1. When internal loads (people, lighting, equipment, etc.) are removed, due to the high thermal mass, the inside temperature tends to be a stable average of outside temperature. Without the high thermal mass, this line would track along with outside temperatures.
2. When internal loads are added, heat energy accumulates in the building mass and is radiated back into the space.
3. Natural ventilation strategies - and mechanically pre-conditioning of the building when necessary - will help to remove this additional burden on the mechanical system during the high load times of the day.
4. Internal gains rise as visitors and workers begin arriving at the building, this is reflected by the inside temperatures



COLDEST AVERAGE DAY: JANUARY 10

BUILDING AVERAGES

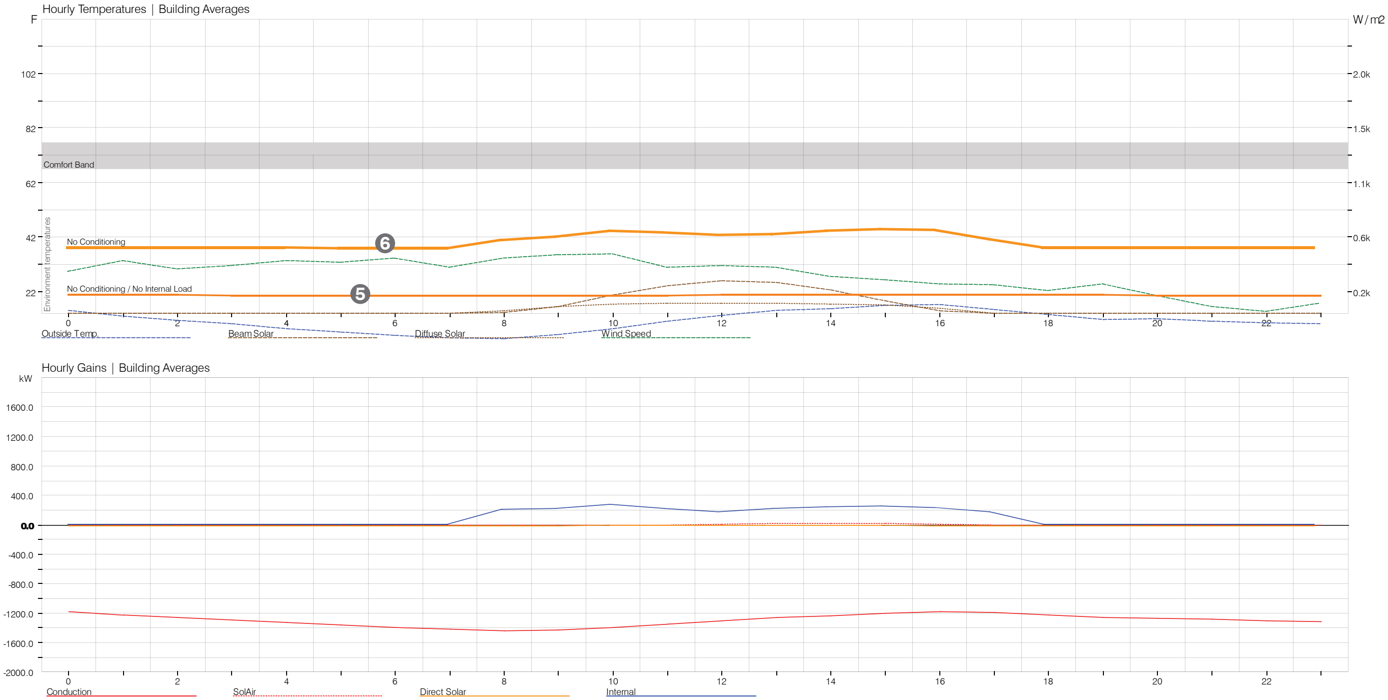
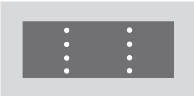


Figure 17. **Building performance on coldest day of the year (based on averages) with no mechanical heating**

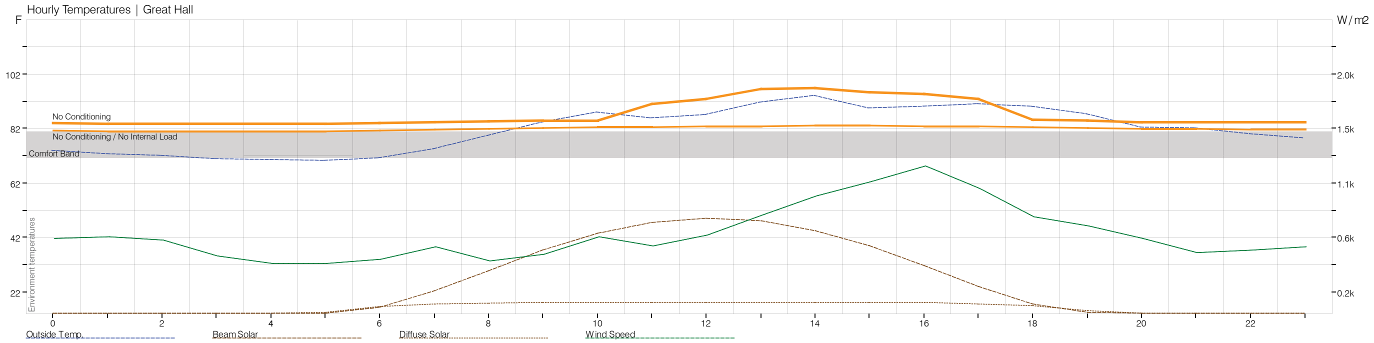
5. When internal loads (people, lighting, equipment, etc.) are removed, the inside temperature tends to be stable but higher than the outside temperature. This shows that the building mass is slowly releasing stored energy from solar gain and warmer days.

6. When internal loads are added, heat energy accumulates in the building mass and is radiated back into the space. This reduces the amount of heating required to move inside the inside temperature into the comfort zone.



HOTTEST AVERAGE DAY: MAY 24

GREAT HALL



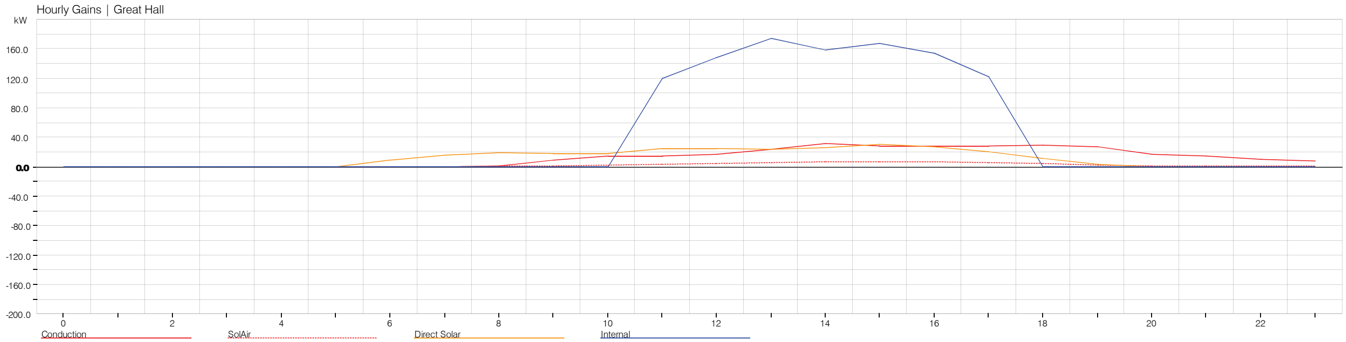
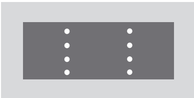


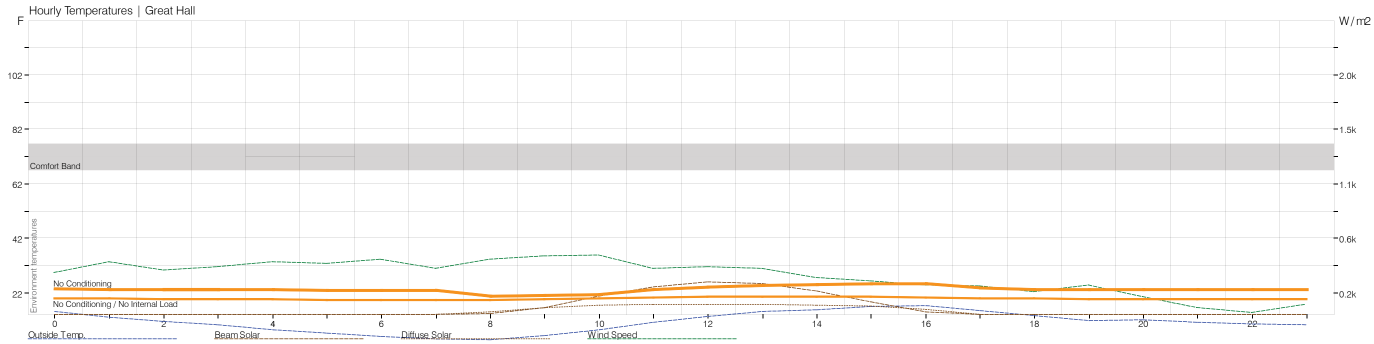
Figure 18. **Great hall performance on a normal extreme cooling day**

The Great Hall generally follows the same trends as the building averages, however due to the mostly internal nature of this space and the large volume to floor area ration, this space stays relatively comfortable.



COLDEST AVERAGE DAY: JANUARY 10

GREAT HALL



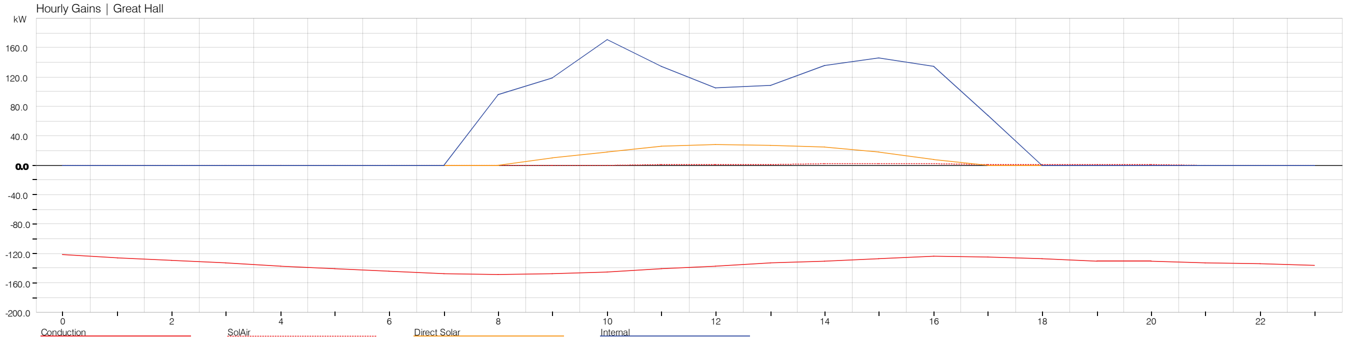
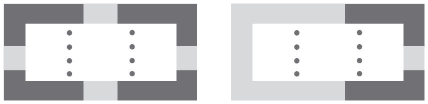


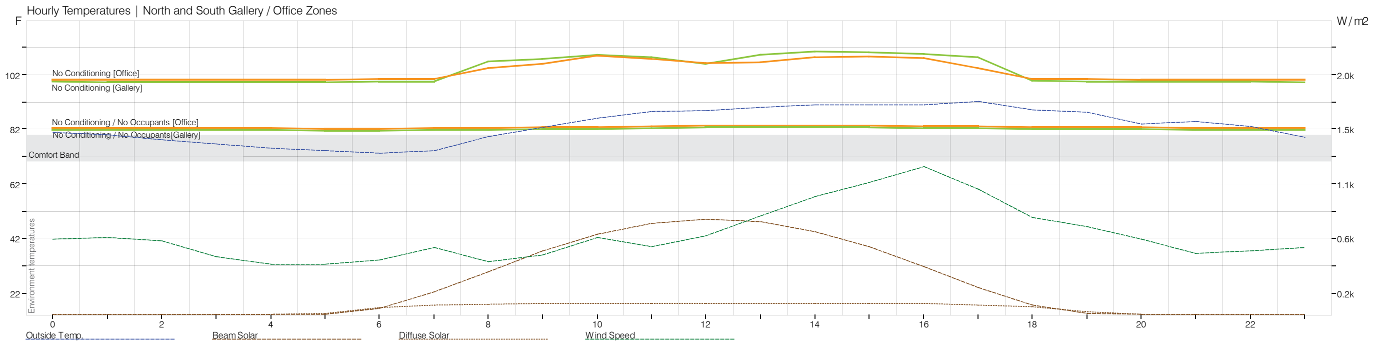
Figure 19. **Great hall performance on coldest day of the year (based on averages)**

On the coldest day, the Great Hall again generally parallels the building average conditions previously studied. In contrast to the summer months, however, the high volume coupled with an un-insulated roof and single pane glazing at the clerestories work against maintaining thermal comfort in the occupied portion of the volume. The mechanical systems must add over 43 degrees F to the environment to attain reasonable comfort levels.



HOTTEST AVERAGE DAY: MAY 24

NORTH AND SOUTH GALLERY / OFFICE ZONES



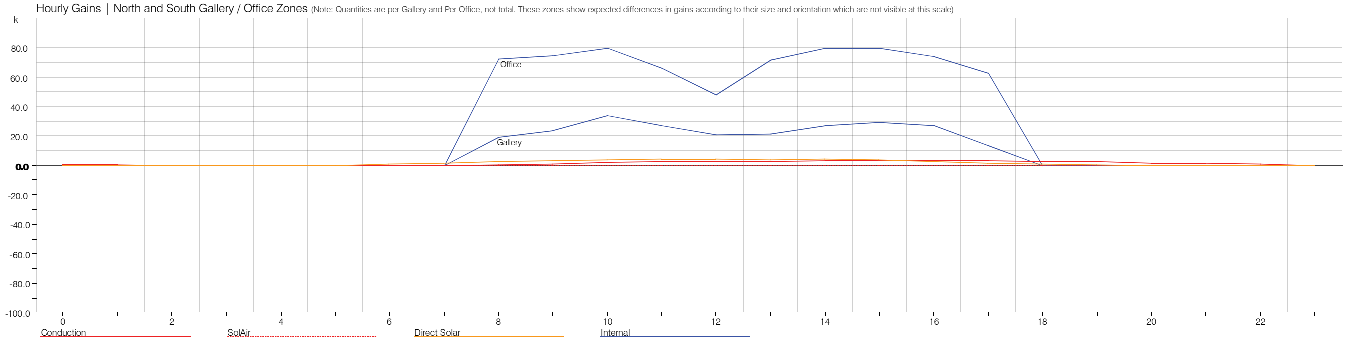
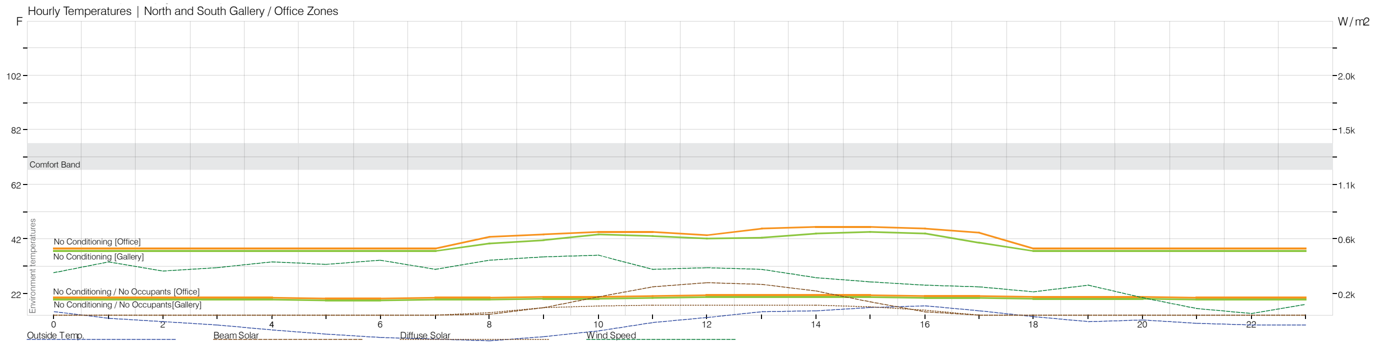


Figure 20. **Performance of north and south gallery/office zones on a normal extreme cooling day**

These spaces very closely parallel the building average conditions previously studied. Here, again, natural ventilation strategies and mechanical pre-conditioning of the space when necessary, will help to purge heat built up in the thermal mass throughout the day. This in turn will reduce mechanical cooling requirements during peak load conditions.

COLDEST AVERAGE DAY: JANUARY 10

NORTH AND SOUTH GALLERY / OFFICE ZONES



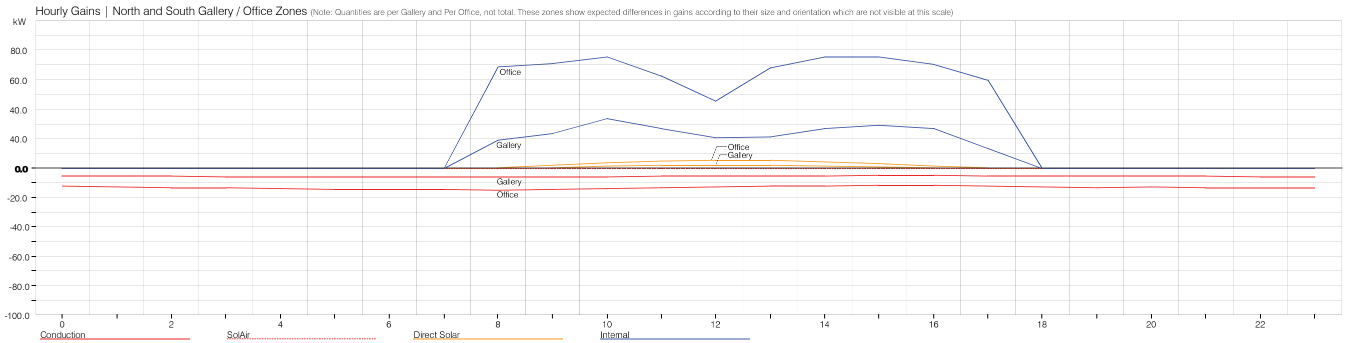


Figure 21. **Performance of the north and south gallery/office zones on coldest day of the year (based on averages)**

On the coldest average day, these spaces again closely parallel the building averages.

When one tugs at a single thing in nature;
he finds it attached to the rest of the world.

JOHN MUIR

SECTION 5

Concepts/Solutions

Universal Strategies

While the National Building Museum enjoyed high levels of comfort at the time of construction, evolving standards and the specific gallery needs of the museum have produced a situation in which the building can no longer perform as it was designed. Assessment of the building's energy use took into account the historic nature and significance of the structure.

The following strategies for reducing the building's energy consumption are relatively easily achieved and should be considered universal strategies that can be applied in conjunction with or separate from the other, more far-reaching NBM-specific schemes that are outlined.

UNIVERSAL STRATEGY 1

Water

Water is the vehicle of nature. LEONARDO DA VINCI

POTENTIAL STRATEGIES

- Replace existing plumbing fixtures with low-flow, waterless, and hands-free fixtures
- Utilize grey water recovery
- Utilize rain water cisterns to collect roof runoff for building use
- Emply native landscaping and rain gardens on site to reduce water usage
- An Eco Machine (a contained biological wastewater treatment system) could be an educational addition to the building space

Eco Machine

Rainwater cistern

Raingarden / native planting

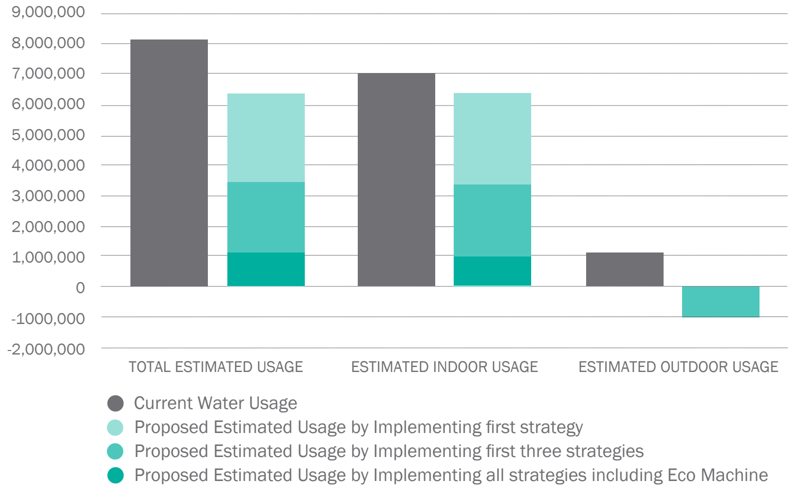


Figure 22. **Water usage in gallons/year**

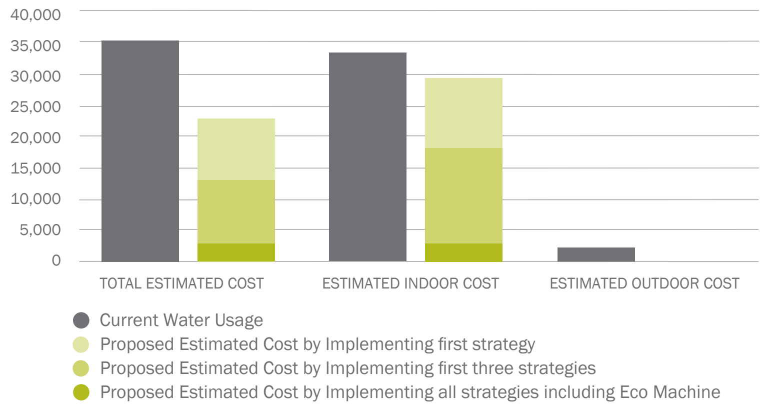


Figure 23. **Water cost in dollars/year**

UNIVERSAL STRATEGY 2

Daylighting / Efficient Lighting

Studies show that access to abundant natural daylight dramatically improves occupants' mental alertness, productivity and psychological well-being.

DAYLIGHTING STRATEGIES can reduce glare and shadowing and protect exhibits from UV exposure.

- Internal vertical light reflectors for use at east, south and west gallery exposures
- Internal light shelves can improve the quality and distribution of daylight for east, south and west office exposures

EFFICIENT LIGHTING STRATEGIES

- Use more efficient fixtures
- Dimmable fixtures tied to occupancy sensors and light meters can maintain appropriate light levels when daylight is not available

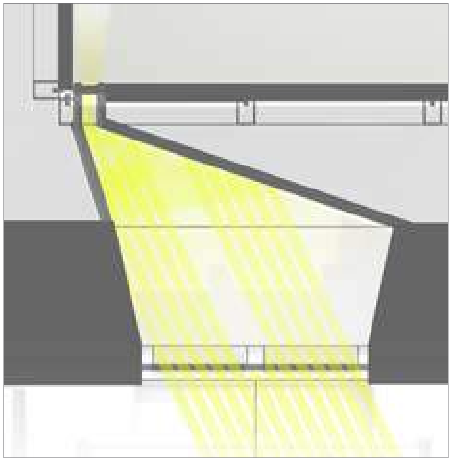


Figure 24 (left): **Plan of vertical light reflectors - appropriate for free standing exhibits.**

Figure 25 (right): **Section of horizontal light shelf - offices and wall mounted exhibits.**

DAYLIGHTING ANALYSIS

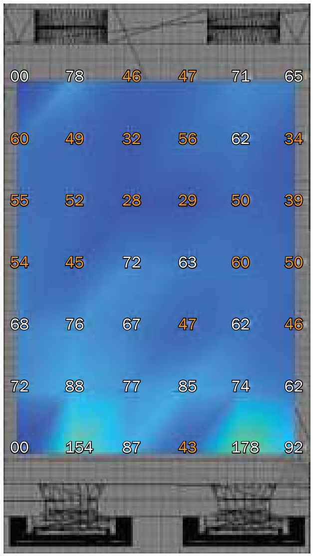
Based on lighting measurements gathered during a site visit, summer daylight in the office and gallery spaces is adequate for most uses. Although daylight conditions in the winter, when the sun is lower in the sky, were not measurable, they were simulated.

From the Revit BIM, we extracted accurate geometrical data along with material properties, such as visible light transmittance and reflectance of glazing and surfaces, into a 3d Studio Max model to perform accurate daylight calculations.

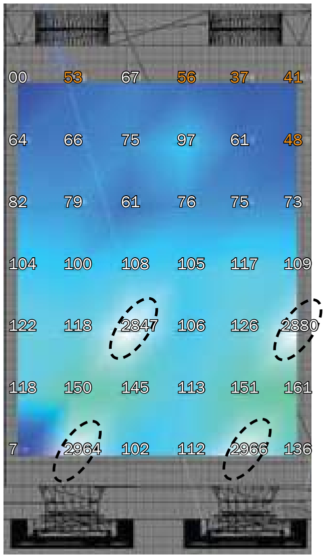
We performed two sets of light level calculations at an imaginary 3ft high work surface. One set of the existing conditions, without blinds, and one set with an internal light shelf fitted within the window opening.

Public spaces with dark surroundings.	2-5 fc
Simple orientation for short temporary visits.	5-10 fc
Working spaces where visual tasks are only occasionally performed.	10-20 fc
Performance of visual task of high contrast or large size (Typical Office / Target Range).	**20-60 fc**
Performance of visual tasks of medium contrast or small size.	60-100 fc
Performance of visual tasks of low contrast or very small size.	100-200 fc

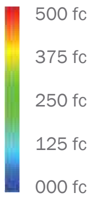
Figure 26. **Daylighting**

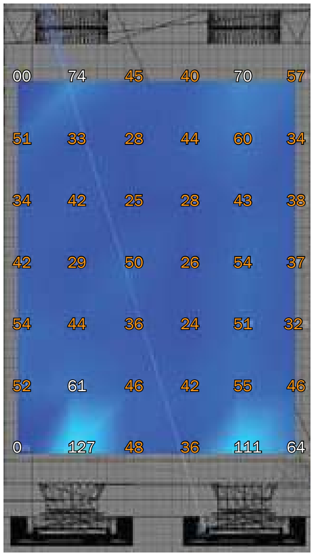


Existing Daylighting - June 21st @ 1:00

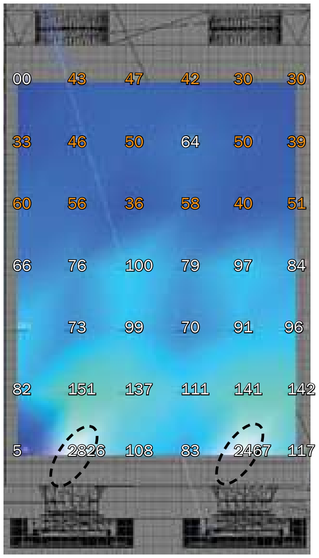


Existing Daylighting - Dec. 21st @ 1:00

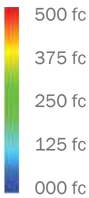




Light Shelf - June 21st @ 1:00



Light Shelf - Dec. 21st @ 1:00



Daylighting in the National Building Museum

1. At winter solstice, windows allow passive solar heat gain into the main hall. Glare from the direct sun within the great hall is at its greatest.

2. Spring and fall solar angles still allow for some solar radiation but total capacity has been reduced.

3. At summer solstice, the existing building and its ornamentation has shaded the south side glass but additional shading is required on the east and west elevations. Automated solar window shades are anticipated on the larger openings in the great hall.

4. Photovoltaic panels integrated into the standing seam metal roofing reduce overall power consumption of the building.

5. At summer solstice, the existing building and its ornamentation has shaded the south side glass but additional shading is required on the east and west elevations through manual solar shades.

6. Sunlight is directed into the building using directional solar shade louvers.

7. Sunlight is bounced indirectly into the galley spaces so that the light does not contain UV rays.

8. Lighting in the offices is revised to allow daylight sensors to dim or turn off perimeter lighting. Light fixtures are changed to super T-8 fixtures or T-5HO fixtures to minimize overall watts used for lighting.

9. Occupancy sensors have already been installed and are used to dictate on/off lighting controls within most areas in the building. Continue providing sensors at additional locations.

10. LED lighting program, which has been started in the gallery spaces, is continued through all the gallery spaces.

11. Replace the existing halogen lamps in the great hall with LED spot-lights that allow dimming, which provide daylighting controls to moderate the amount of light that is needed.

12. Replace incandescent light fixtures with CFL’s or LED fixtures in the public spaces.

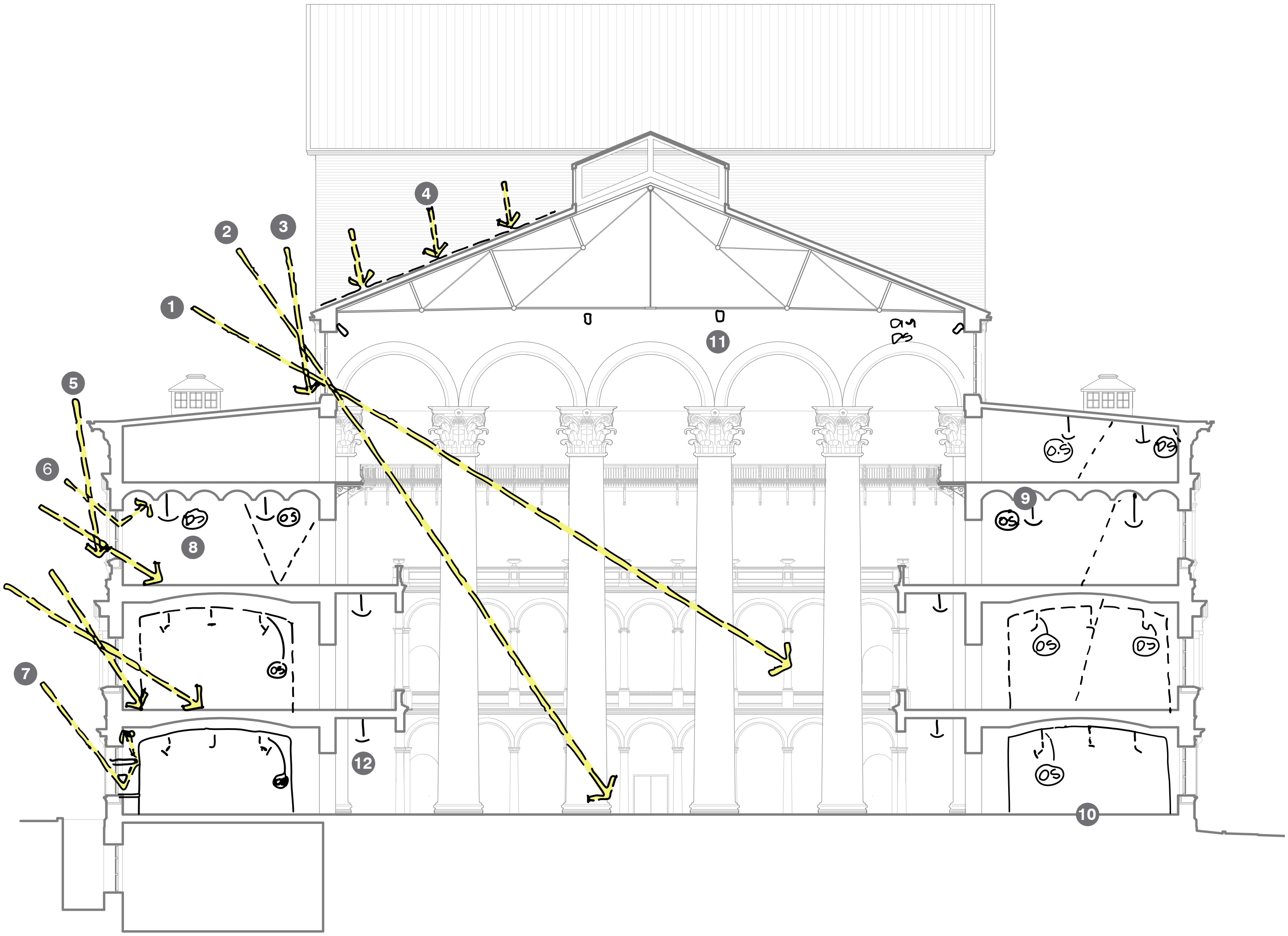


Figure 27. **Building section showing daylighting**

UNIVERSAL STRATEGY 3

Energy Production

Photovoltaic panels covering the optimal areas (indicated as in figure 28) which total 53,500 square feet, can collect around 395,500 kWh of solar energy per year.

POTENTIAL STRATEGIES

- Install photovoltaic panels (PV) for energy production at strategic locations on the roof.
- Solar hot water collectors use solar energy more efficiently than PV and can provide hot or preheated water for domestic hot water uses in addition to space heating needs.

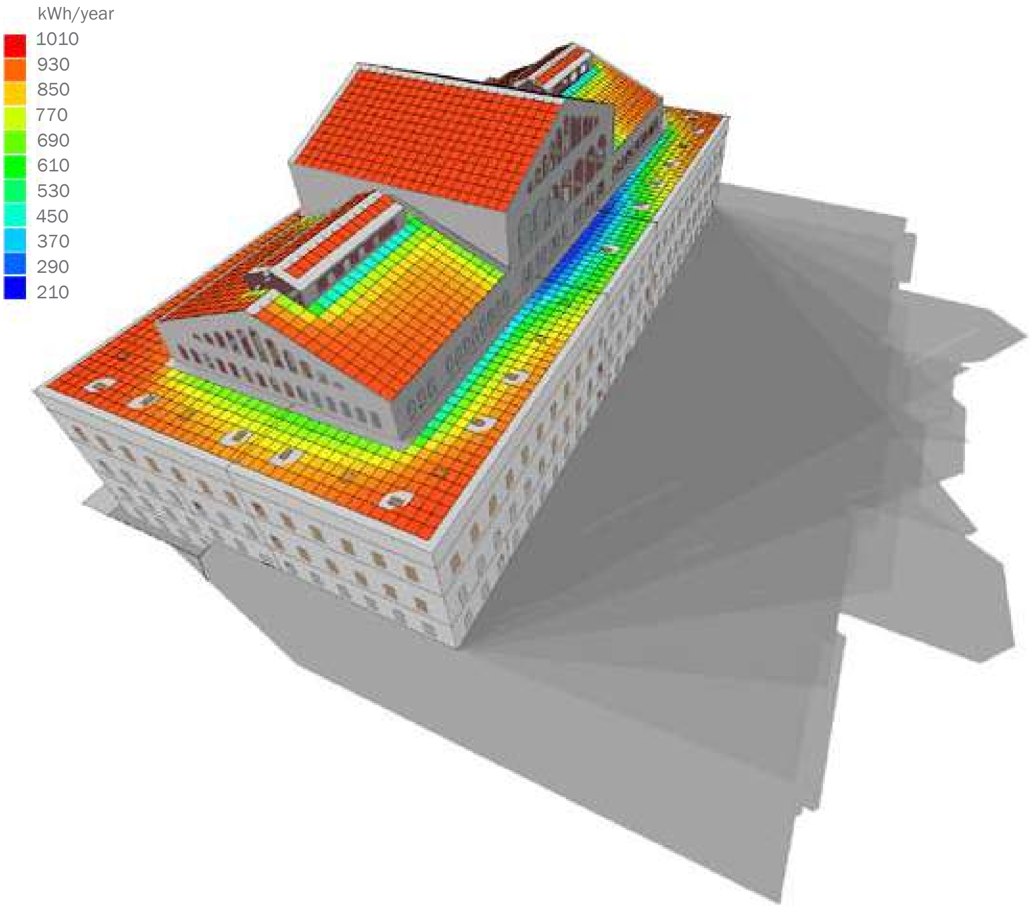


Figure 28. **Incident solar radiation**
Using the base Ecotect analysis model with average yearly incident solar radiation (insolation) data from Washington D.C., we plotted incident solar radiation levels across a grid on the roof surfaces. Red and orange squares indicate the highest energy production potential.

UNIVERSAL STRATEGY 4

Mechanical Waste

While the building enjoyed high levels of comfort at the time of construction, evolving standards and the specific gallery needs have produced a situation in which the building can no longer perform exactly as it was designed.

POTENTIAL STRATEGIES - LOWERING THE BUILDING LOAD

- Eliminate simultaneous heating and cooling. The current building load indicates simultaneous heating and cooling which is responsible for about 1/3 of the building load. This parasitic load is unnecessary and should be reduced or eliminated.
- Eliminate reheat for dehumidification, use existing internal loads and free heat sources. Dehumidification does not require sub cooling and re-heating to maintain 50% relative humidity (RH). When the cooling load is light in the space there is little need for dehumidification and when the load is high, the load in the space is sufficient to re-heat the supply air.
- Reduce/eliminate pre-heat for humidification and/or steam humidification. Once the vapor barrier is in place for the gallery, very little moisture will have to be introduced into the space in the winter. Stand-alone humidity control devices can serve the area without adding additional heat for vaporization.
- Demand-Controlled Ventilation. System designed to introduce outside air into the building to ensure fresh, conditioned air purges the CO_2, other “bio effluents,” and building materials’ off-gassing pollutants. In this building, the occupancy is highly variable depending on the number of visitors at any given time. A constant volume ventilation air (outside air) system wastes energy during low occupancy by conditioning and then exhausting the air. One way to reduce this waste is to use CO_2 sensors to monitor indoor and outdoor concentrations and modulate the volume of ventilation air maintaining a differential of 800 parts per million (ppm) of CO_2. The ventilation load represents about 6% of the total energy use for the building and use of a Demand-Controlled Ventilation strategy could save more than half of this energy.

Figure 29. **Existing dehumidification: Cooling mode**

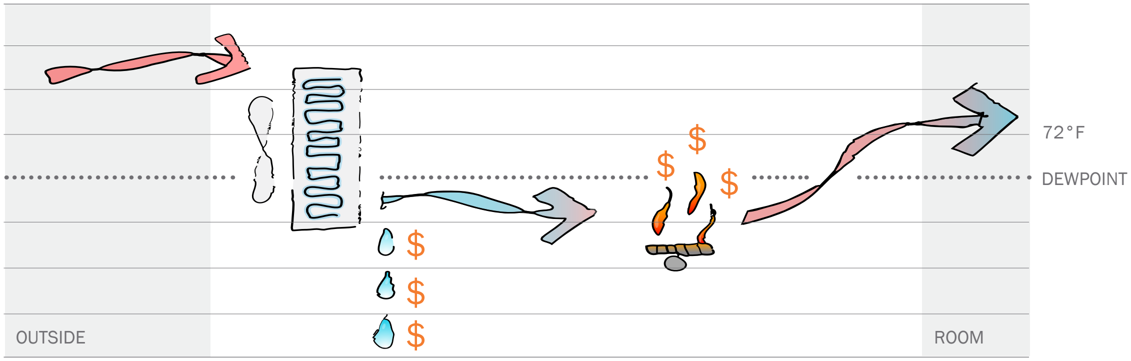
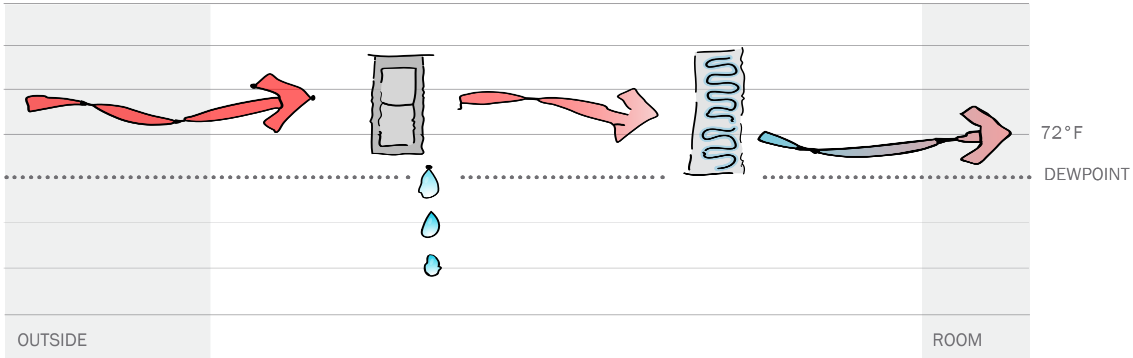


Figure 30. **Efficient dehumidification: Cooling mode**



Mechanical Efficiency

Space heating and cooling loads are by far the greatest energy uses for the National Building Museum.

POTENTIAL STRATEGIES - IMPROVE EFFICIENCY

Once the building load has been lowered, we can then concentrate on how to improve equipment efficiency and reduce run time. Measures designed to increase heating and cooling efficiency include:

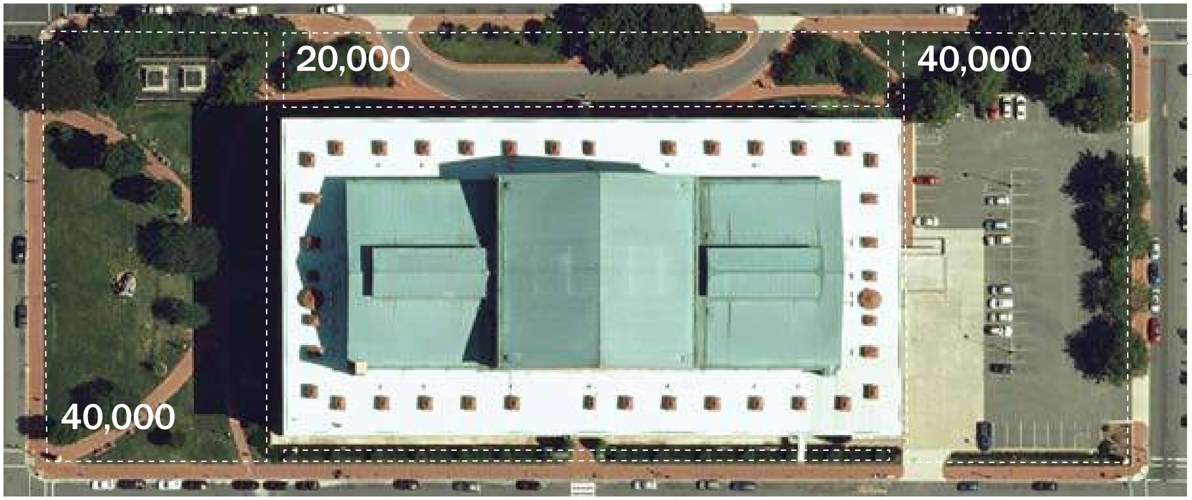
- **Improve efficiency of cooling equipment.** Eliminate the use of hot gas by-pass on the screw chillers. This can be achieved by using outside air economizers or waterside economizers to allow chillers to cycle off during low load conditions. The chiller plant equipment can be improved to operate almost twice as efficiently as the existing equipment selections. See chart below.

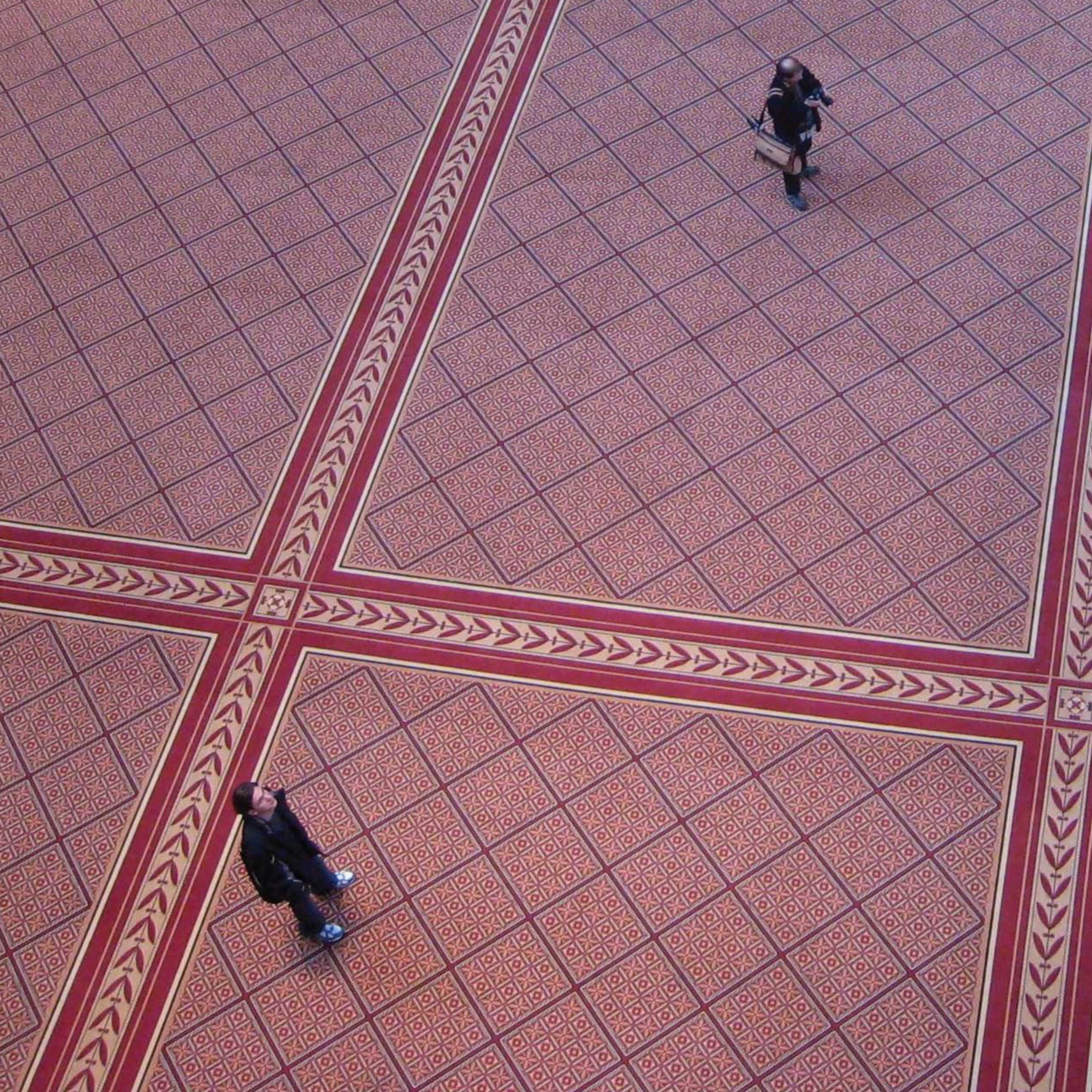
Equipment Efficiency Opportunities

Equipment	*Base kW/ton*	*Best Practice*	*Delta*	*Avg. Tons Ann*	*kWh Opp*
Chiller	0.61	0.48	0.13	351.5	400,288
CWP	0.094	0.021	0.073	351.5	224,777
CHWP	0.16	0.026	0.134	351.5	412,605
CT	0.06	0.012	0.048	351.5	147,799
Total System	0.924	0.539	0.385		1,185,469

- **Install radiant heating and cooling devices at building perimeter.** Radiant heating and cooling uses no fan energy and can increase comfort levels. Radiant devices can be located on walls below windows and can be incorporated into other wall hanging equipment such as white board panels.
- **Replace steam boiler with hot water boiler to reduce lift.** Using hot water instead of steam as the primary heat source can increase the efficiency of the heating system. Generating steam and using this energy to heat water wastes energy.
- **Improve ventilation strategies.** Install a Variable Frequency Drive central make-up air handler that is served by an earth tube system and a Demand Controlled Ventilation system. In the new isolated gallery area use stand alone humidification and de-humidification equipment to maintain a relative humidity set point.
- **Use hot gas or other free heat sources to re-heat air when necessary.** It is unnecessary to add energy for re-heat during de-humidification.
- Use pressurized spray or wetted media to add moisture to air - not steam or electrical heat evaporation.
- **Earth Tube make-up air tempering system.** The temperature of the earth below 4' depth is constant year around. This resource can be used to temper air from 17˚ F in the winter and 91˚ F in the summer to 55˚ F as it enters the building. This air can be used for ventilation and to lower the cooling/heating load of the building. Since this air can contain mold and other moisture-hosted microbes, Titanium dioxide loaded (TiO_2) filters with UV lamps will sterilize this air prior to introducing it into the building systems (Lennox "pure air" system). Earth tubes that capture the air consist of a network of buried corrugated steel or concrete pipes with a remote screened entry feature.

Figure 31. **Area available for earth air tubes**





NBM Opportunities

The following are opportunities which are unique to the National Building Museum. Strategies that leverage the existing heating and cooling conditions and the climate have been studied to maximize the building's energy and cost saving potential.

NBM OPPORTUNITY 1

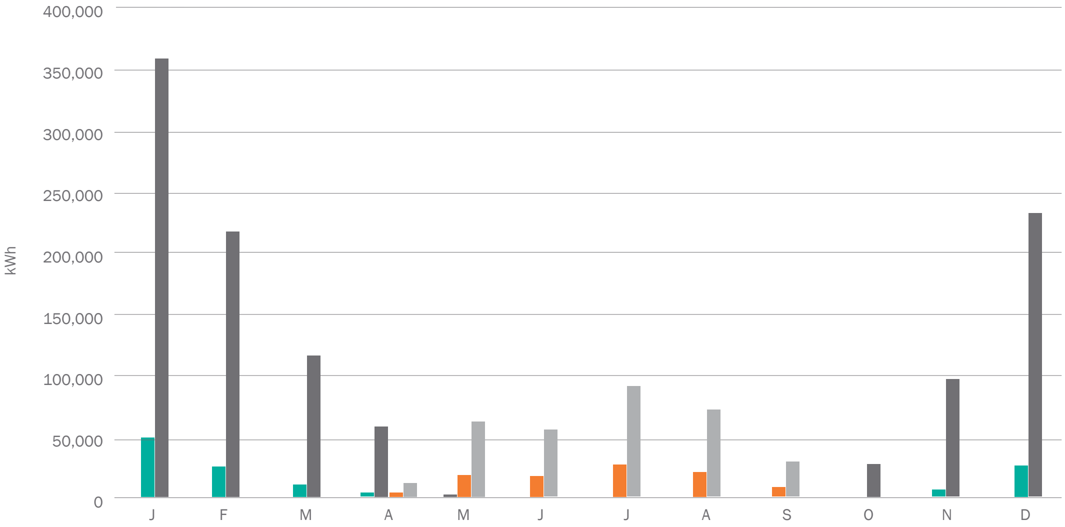
Zone and Naturally Ventilate Great Hall

Our initial analysis of the Great Hall revealed a couple of key opportunities for energy savings:

- The entire volume of this space is being conditioned while the ground floor area and walkways are the only portion of the volume that will ever be occupied regularly
- During the summer months, under normal occupancy conditions, the space can remain fairly close to a desired comfort range passively, without supplemental mechanical cooling

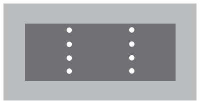
Based on this understanding, one key opportunity is to open the space up to natural ventilation and night flushing of the thermal mass to release heat built up during the day. The second opportunity is to reduce the volume of space being conditioned to only what is regularly occupied. This would involve converting the existing HVAC system to provide supply air through a displacement system at, or close to, the floor level.

These strategies will understandably create deferring conditions as one moves higher in the volume on the balconies. While further investigation would be required, our initial investigations show that the balcony zones are able to remain relatively comfortable during both summer and winter. For the purposes of this analysis we assumed the balconies would be used only when transitioning from space to space and an expanded comfort range would be appropriate.



(kWh)	J	F	M	A	M	J	J	A	S	O	N	D
ZONED + NV	48751.766	26092.285	11300.363	4555.820	0	0	0	0	0	810.872	6972.331	26862.164
BASE	358506.125	218290.234	117014.375	58400.707	2629.515	0	0	0	0	27775.434	97467.797	233300.203
ZONED + NV	0	0	98.878	4158.936	18878.725	17887.912	27346.420	21193.135	8770.656	0	0	0
BASE	0	0	0	11755.020	62478.617	56224.102	91539.336	72407.703	30155.238	0	0	0

Figure 32. **Base/existing vs. NBM Opportunity 1 energy use**



GREAT HALL

USING ECOTECT, THE GREAT HALL IS ZONED INTO A MIXED-MODE CONDITIONED VOLUME AT THE FIRST FLOOR, WHILE THE REST OF THE VOLUME IS NATURALLY VENTILATED.

38 KWH/SF - 6 KWH/SF

84%

LESS ENERGY

NBM OPPORTUNITY 2

Thermally Decouple Gallery Spaces for Natural Ventilation to Occur

In the analysis of the gallery spaces as they are today, we found they have very different environmental needs -- for the artifacts and occupants or resulting from the occupants -- than most of the rest of the building. Not only do these different needs limit the use of strategies such as natural ventilation for the rest of the building, they also require large amounts of energy to overcome liabilities inherint in historic buildings and this building type. *NBM Opportunity 4* explores the use of an internal gallery shell to decouple these spaces envrionmentally from the rest of the building.

1. **Lighting**
   By moving some of the lighting fixtures into the cavity, the heat they generate can be dealt with more economically via high mass absorption and night flush ventilation.
2. **Natural Ventilation**
   After reopening the original ventilation ports (with a new damper system) and operable windows, air is allowed to circulate around the galleries and through the original doorways.
3. **Daylighting**
   A light shelf and deep window surround reflects light deeper into the spaces. Reflecting sunlight into the space decreases UV.
4. **Ceiling**
   Transparent ceiling panels allow visitors to see the original building structure. The supporting frame creates attachment points for lighting and exhibits.
5. **Supply Air**
   Conditions only the portion of the spaces that is inhabited.
6. **Return Air**
   Hot air is allowed to escape at the top of the gallery into the cavity space.
7. **Vestibule**
   An airlock between gallery and building spaces allows more measured control of air, moisture, and thermal movement.
8. **Modular Walls**
   Modular wall panels act as an air and vapor barrier between the galleries and the rest of the building. The panels can be switched out at, for example, window openings to tune daylighting as required by the exhibit.

Figure 33. Cutaway axonometric of proposed gallery shell and existing building

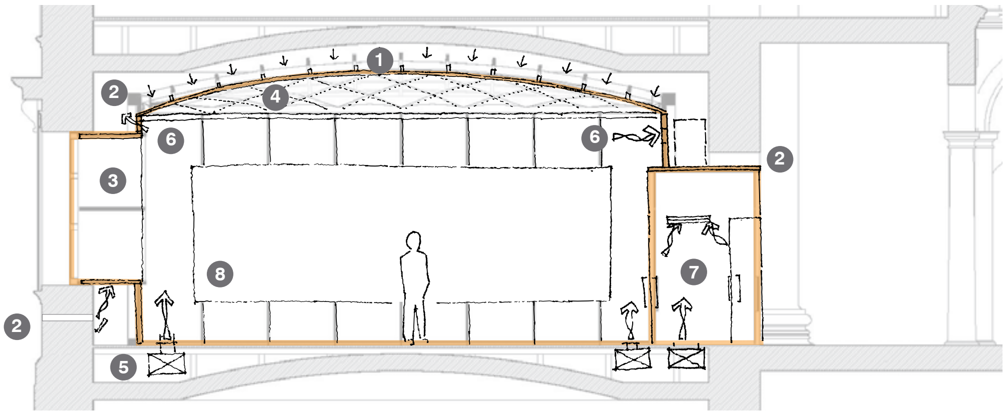
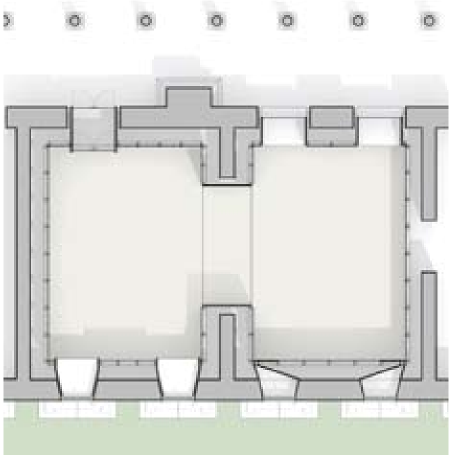


Figure 34. Section through proposed gallery shell and existing building



left to right:

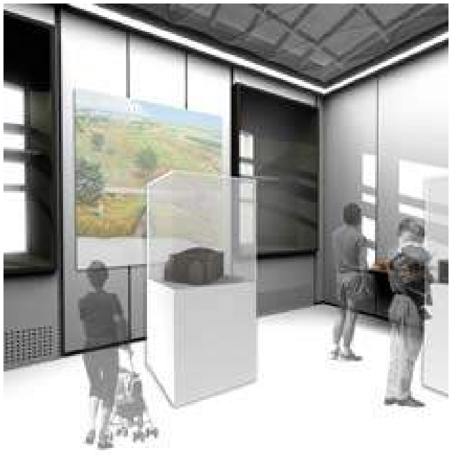
Figure 35. **Plan of typical gallery bays configured for free standing (left) and wall hung (right) exhibit.**

Figure 36. **Section axon of a typical bay showing glazed ceiling.**

Figure 37. **View of entrance vestibule.**

Figure 38. **Gallery configured for wall hung media showing vertical wall wash daylighting.**

Figure 39. **Gallery configured for a mix of free standing and wall hung media using deep window boxes and light shelf.**



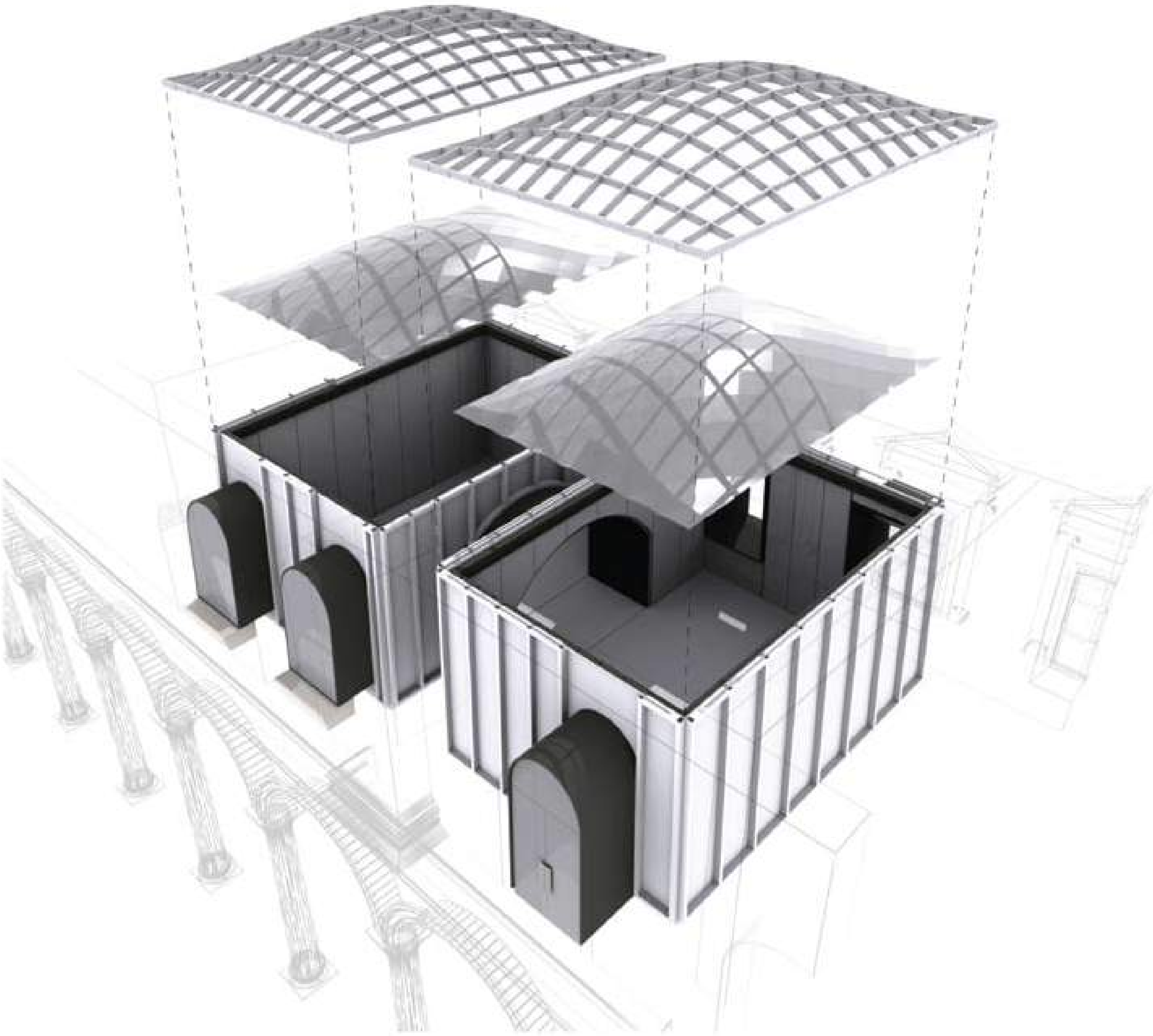
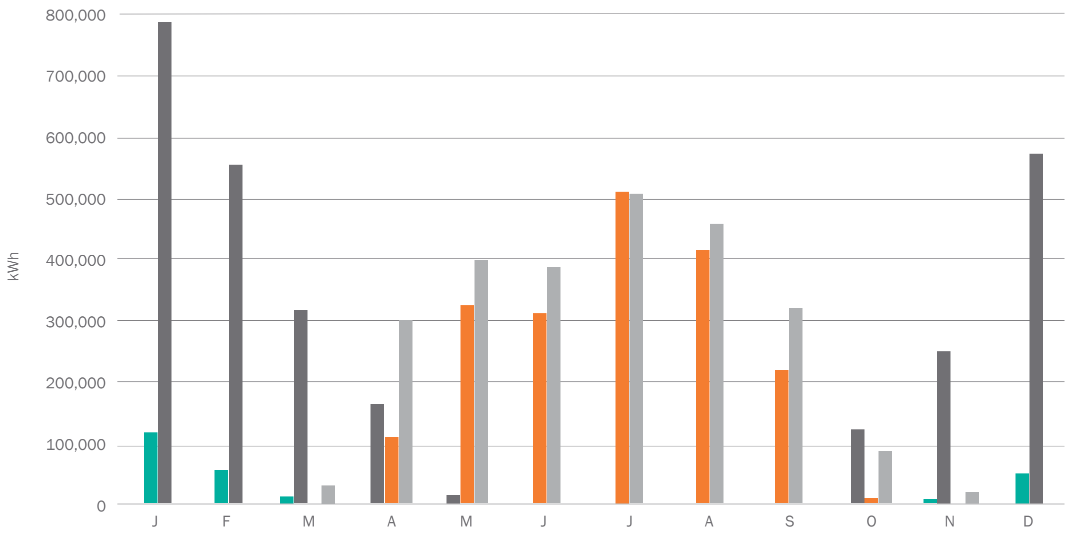
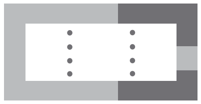


Figure 40. **Exploded axonometric of a typical bay**



	J	F	M	A	M	J	J	A	S	O	N	D
SCHEME 1 GALLERIES (teal)	11677.608	5467.270	1207.193	110.146	0	0	0	0	0	1.192	508.891	5044.633
BASE GALLERIES (dark grey)	79267.240	55815.334	31840.419	16320.159	1338.875	0	0	0	0	12250.638	24918.708	57345.860
SCHEME 1 GALLERIES (orange)	2.033	0.568	100.035	5447.299	32577.323	31290.417	51284.772	41740.782	21950.962	842.821	116.314	0
BASE GALLERIES (light grey)	151.382	0	3120.731	12936.293	40066.393	38816.686	51017.262	46038.955	32219.994	8716.793	1792.937	0
(kWh)												

Figure 41: **Base/existing vs. NBM Opportunity 2 energy use**



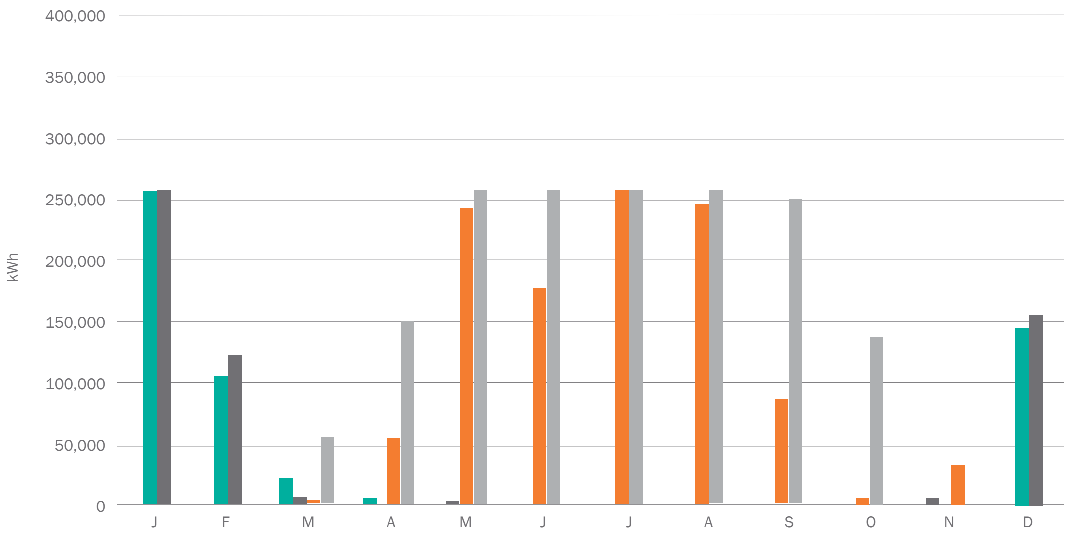
DECOUPLED GALLERIES

TO UNDERSTAND THE POTENTIAL SAVINGS FOR THIS STRATEGY, WE ISOLATED 2 REPRESENTATIVE GALLERY SPACES ON THE NORTH AND SOUTH SIDES OF THE 2ND FLOOR.

33 KWH/SF - 13 KWH/SF

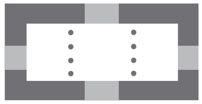
61%

LESS ENERGY



(kWh)	J	F	M	A	M	J	J	A	S	O	N	D
OFFICE / SUPPORT (teal)	30228.501	10473.556	2054.967	257.836	0	0	0	0	0	0	500.238	14472.117
BASE O/S (dark grey)	32424.559	12159.229	262.344	0	0	0	0	0	0	0	49.416	15562.209
OFFICE / SUPPORT (orange)	0	0	158.166	5293.524	24091.097	17501.978	29590.971	24512.362	8445.193	548.139	77.546	0
BASE O/S (light grey)	182.320	0	5558.729	14758.625	33057.653	28536.999	34959.059	34536.836	24885.438	13862.730	3173.33	0

Figure 42: **Base/existing vs. NBM Opportunity 2 energy use**



MIXED MODE OFFICES/ SUPPORT SPACE

WITH THE GALLERIES THERMALLY DECOUPLED FROM THE REST OF THE BUILDING, A "MIXED MODE" SYSTEM CAN BE UTILIZED FOR THE REMAINING BUILDING SPACE. TO UNDERSTAND POTENTIAL SAVINGS, WE ISOLATED THE NORTH AND SOUTH OFFICES/ SUPPORT SPACES ON LEVEL 3.

6 KWH/SF - 4 KWH/SF

33%

LESS ENERGY

NBM OPPORTUNITY 3

Double Skin

The climate data and analysis of the building performance referenced earlier suggests that high thermal mass in conjunction with natural ventilation are ideal passive design techniques in Washington, D.C. These are techniques Montgomery Meigs clearly understood when considering the design of the building.

NBM Oppotunity 3 explores the possibility of utilizing the mass available in the exterior walls of the building using advanced glazing systems unimaginable when the building was originally designed. In essence, this strategy uses the building as a solar collector for thermal storage.

While further exploration of the thermal and fluid dynamics at play would be necessary to optimize and understand this solution, our results from this analysis show that this would be an effective energy saving strategy.

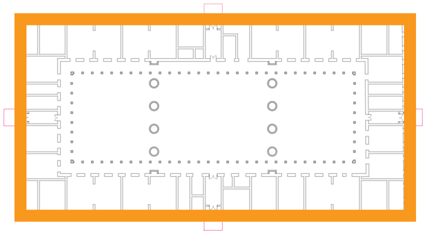


Figure 43. Conceptual plan of secondary skin (orange)

Figure 44. **Concept rendering showing a portion of facade**

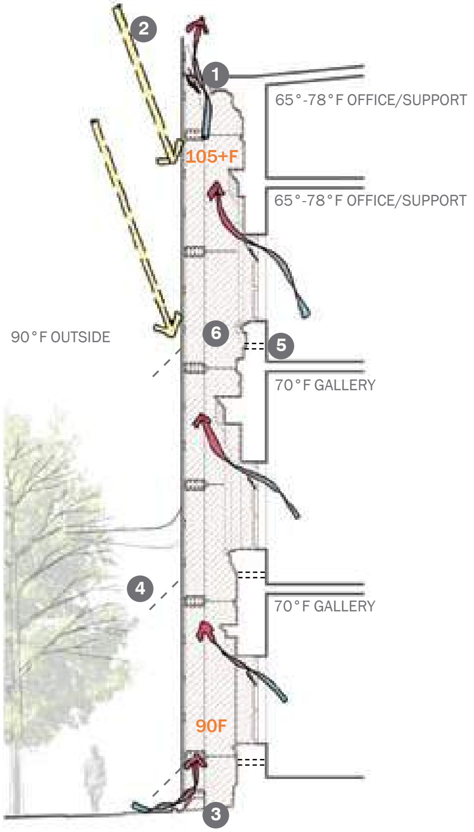


Figure 45. **Wall section showing summer operation**

1. A damper allows rising hot air to escape the cavity.
2. Due to the high incident angle of the summer sun, the glass skin reflects a large portion of the solar radiation that would otherwise be absorbed and then transmitted through the brick wall.
3. Air is drawn into the cavity through an open vent at the bottom of the wall.
4. Vent windows at each level provide for cross ventilation when appropriate.
5. Dampered ventilation ports and operable windows allow for ventilation of office and support spaces.
6. Solar radiation from the glass and brick heats the cavity air inducing stack ventilation effect.

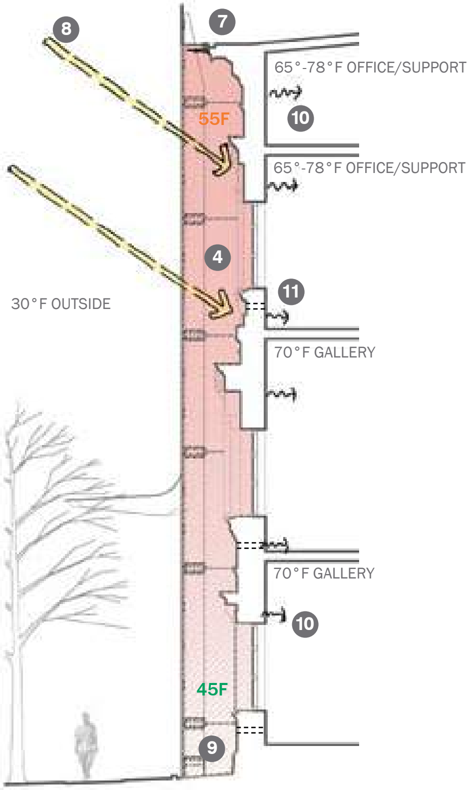
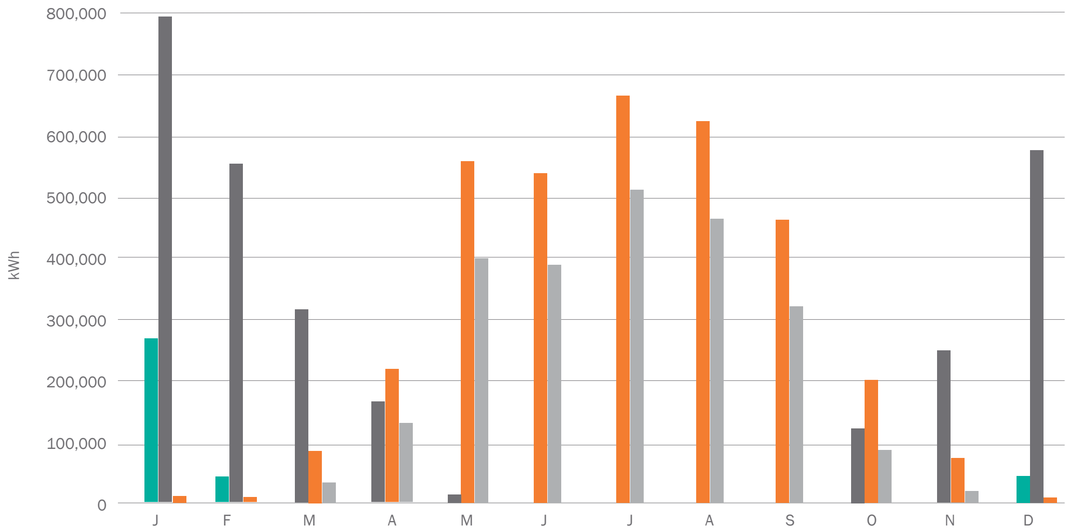


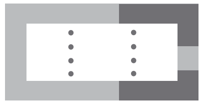
Figure 46. **Wall section showing winter operation**

7. A damper closes trapping air in cavity.
8. Because of it's lower angle of incidence, more of the winter sun is able to penetrate the glass and be absorbed by the brick building.
9. The lower damper is closed.
10. Heat from solar radiation is conducted through the brick mass wall and is radiated into the spaces.
11. Building air is warmed as it circulates through the cavity space.



(kWh)	J	F	M	A	M	J	J	A	S	O	N	D
SCHEME 2 GALLERIES	26840.586	4457.851	0	0	0	0	0	0	0	0	0	4221.932
BASE GALLERIES	79267.24	55815.334	31840.419	1630.159	1338.875	0	0	0	0	12250.638	24918.708	57345.860
SCHEME 2 GALLERIES	952.105	619.736	8745.647	21721.968	56018.616	53648.428	66292.420	62069.74	46257.394	20195.087	7213.118	703.643
BASE GALLERIES	151.382	0	3120.731	12936.293	40066.393	38816.686	51017.262	46038.955	32219.994	8716.793	1792.937	0

Figure 47: **Base/existing vs. NBM Opportunity 3 energy use**



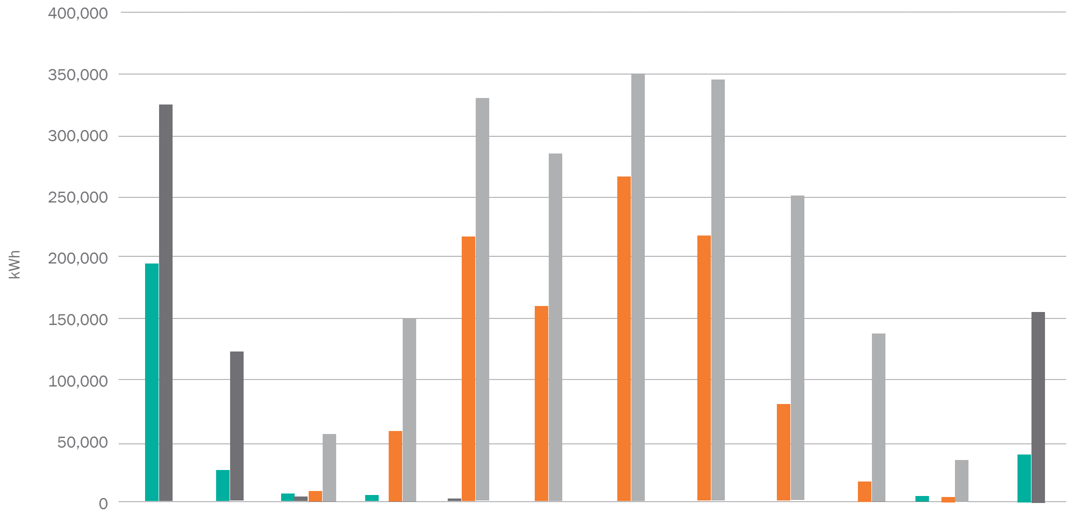
GALLERIES WITH DOUBLE SKIN

TO UNDERSTAND THE POTENTIAL SAVINGS FOR THIS STRATEGY, WE ISOLATED 2 REPRESENTATIVE GALLERY SPACES ON THE SECOND FLOOR, ONE NORTH AND ONE ON THE SOUTH SIDES OF THE BUILDING.

33 KWH/SF - 24 KWH/SF

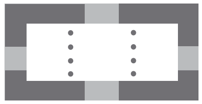
27%

LESS ENERGY



(kWh)	J	F	M	A	M	J	J	A	S	O	N	D
OFFICE / SUPPORT ● (teal)	19456.323	2521.399	727.564	453.519	0	0	0	0	0	0	460.181	3975.184
BASE O/S ● (dark grey)	32424.559	12159.229	262.344	0	0	0	0	0	0	0	49.416	15562.209
OFFICE / SUPPORT ● (orange)	0	0	926.898	5688.153	21753.834	16092.307	26598.229	21850.408	7746.053	358.384	358.383	0
BASE O/S ● (light grey)	183.32	0	5558.729	14758.625	33057.653	28536.999	34959.059	34536.836	13862.730	3173.33	3173.330	0

Figure 48: **Base/existing vs. NBM Opportunity 3 energy use**



OFFICE/SUPPORT WITH DOUBLE SKIN

DECOUPLING THE GALLERIES FROM THE REMAINDER OF THE BUILDING ALLOWS US TO LOOK AT REINTRODUCING NATURAL VENTILATION FOR THE REST OF THE BUILDING.

6 KWH/SF - 3 KWH/SF

50%

LESS ENERGY

I live on Earth at present, and I don’t know what I am. I know that I am not a category. I am not a thing - a noun. I seem to be a verb, an evolutionary process - an integral function of the universe.

BUCKMINISTER FULLER

SECTION 6

Conclusion

Closing Thoughts on the Process

The process used for this project — which utilized High Definition Laser Scanning that was converted into a Building Information Model used to conduct various design and energy analysis scenarios — proved to be a highly efficient and precise way to understand what opportunities existed for improvement of the National Building Museum's operation. The seamless exchange of information between programs improved the accuracy of the process and its results, while reducing the amount of time required. In the past a process to provide similar analysis would have required multiple models to be made in different programs by different individuals with less accurate information.

Creating and testing new strategies for the building was also simplified because modifications could be made easily to the existing BIM model. Therefore, information generated in subsequent modifications added to and augmented information generated in previous phases of the process. We believe the accurate representation of the National Building Museum captured in the BIM can help realize savings through maintenance operations and future renovations of the facility.

Testing Alternative Paths:
Two ways of addressing the building

It quickly became clear to the team that the existing assets of the building – Meig's innovative ventilation and day lighting strategies, along with thermal storage of the brick structure– provided opportunities for reducing the energy use of the building beyond the common mechanical strategies. Reestablishing these passive comfort solutions will, in addition to conserving resources, act as an educational component of the National Building Museum.

The two paths outlined in the following pages take the building beyond universal strategies (outlined in section 3, these are water, daylighting/efficient lighting, energy production and mechanical solutions) are different in their approach in order to understand how the building would react in two distinct modes of operation.

This process approached the building as a set of complimentary systems, rather than a collection of individual and discreet components. For example, installing operable windows would not, in and of itself, generate a significant cost payback or reduction in energy use. However, by utilizing operable windows with mass thermal storage and earth air tubes, the value of saving from this whole system is greater than sum of each part. Likewise when implementing these strategies, it is important to consider the building as a whole rather than a series of discreet parts.

Path 1

Path 1 looks at reinstating Miegs' original passive strategies and combining them with newer controls and systems. This path integrates Universal Strategy 4 (mechanical efficiency) and two NBM Opportunities listed below. When these approaches are combined, Path 1 becomes the *most efficient approach* that was explored for the building.

- **NBM OPPORTUNITY 1**
  Provides displacement air as a strategy to reduce the overall conditioning of the great hall. The great hall, by volume, is the greatest contributor to the overall performance of the building.
- **NBM OPPORTUNITY 2**
  Decouples the galleries from the thermal mass of the building allowing for natural ventilation and thermal mass fluctuation. It creates a vapor barrier between the galleries and the rest of the building spaces.

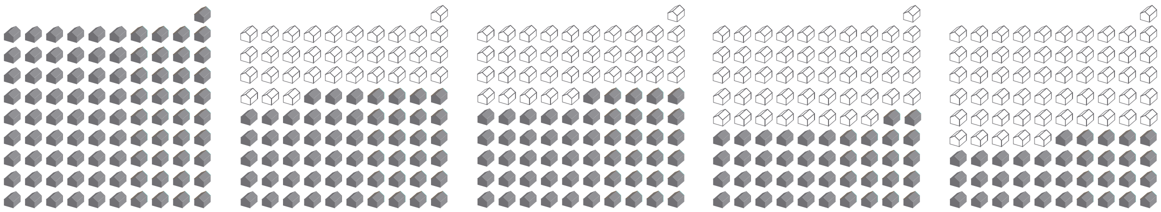
NBM EXISTING ENERGY CONSUMPTION
5,524,381.09 KWH/YEAR
ENERGY COST
$771,062/YEAR

APPLY
NBM STRATEGY 01
4,313,782.71 KWH +
NBM STRATEG**Y 02**
3,431,094.65 KWH

APPLY
UNIVERSAL STRATEGY 05
UPGRADE MECHANICAL EFFICIENCY
3,296,798.68 KWH

ADD
EARTH AIR TUBES
2,813,333.20 KWH +
LIGHTING/DAYLIGHTING
2,529,203.20 KWH

USE SOLAR COLLECTION
SAVES 395,477.81 KWH



182 | - 67 = 113 | - 4 = 109 | - 26 = 83 | - 7 = 70

NEW ESTIMATED ENERGY CONSUMPTION
2,133,725 KWH/YEAR
ENERGY COST
$300,714/YEAR**

= energy consumed by 2 households

EXCEEDS EXECUTIVE ORDER 13423 GOAL
TO REDUCE FACILITY ENERGY USE PER SQUARE FOOT BY 3% PER YEAR THROUGH THE END OF 2015 OR **BY 30% BY THE END OF FISCAL YEAR 2015**, RELATIVE TO A 2003 BASELINE.

By utilizing and improving upon the natural systems that Meigs had original designed in the building, the National Building Museum can become a example of how existing buildings can be high performance buildings. The strategies that are outlined in this integrated path not only exceed the mandate of 30% reduction by 2015, but doubles that mandate to a 60% reduction. This will allow this building to be operated at efficiencies that are above and beyond our current vision.

5,524,381 > 2,133,725 KWH

61%

LESS ENERGY PER YEAR

$771,062 > $**$300,714**

$470,348

SAVED PER YEAR

** 1 household uses 30,300 kWh of energy per year, Energy Information Admin (DOE) 1993*
*** Assumes maintaining energy rates. $0.14/kWh for electricity. $40.95/MMBtu for steam.*

Path 1: Cooling Mode

1. Solar radiation is used to heat hot water for domestic water and any make up heat for the building.

2. Vertical stack ventilation is allowed to remove the excess heat from the building. Windows would be activated on control sensors to regulate outside air.

3. Energy recovery wheels would be used in locations where solar radiation is not possible to provide any make up heat requirements.

4. Openings at the interior wall locations would regulate natural ventilation for individual spaces.

5. At the fourth floor, overhead air distribution would remain.

6. The exterior national ventilation ports that have been previously blocked, will be opened and controlled with automated dampers. The exterior ports will be opened during the expectable outside air temperatures and at night to pre- cool the building's thermal mass.

7. Displacement air distribution will allow galleries and some office spaces to only cool the lower occupied zones of the spaces.

8. Thermostats and CO_2 sensors will notify the outside exterior ventilation ports that conditions are right for additional ventilation.

9. Earth tubes, buried under the ground, take in exterior air and temper the air prior to entering the building allow for longer sessions of 100% natural ventilation for the building and pre-tempers the air when additional cooling is required to meet demand.

10. The central chillers are greatly reduced and replaced with higher efficiency units with a more efficient pumping strategy.

11. The central space is cooled using a displacement air system that reduces the required load for the space by 60%.

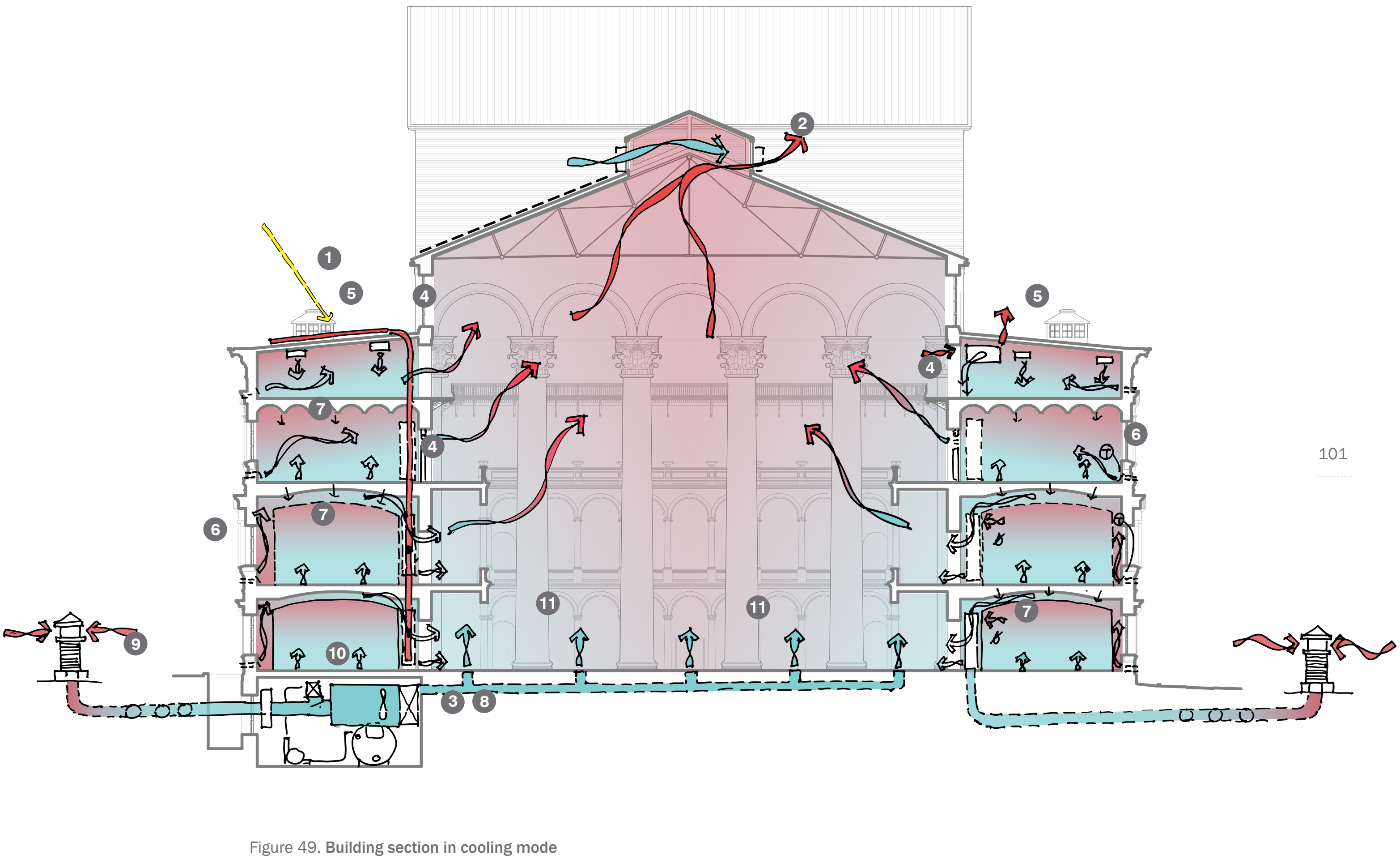


Figure 49. **Building section in cooling mode**

Path 1: Heating Mode

1. Solar radiation is used to heat hot water for domestic water and make up heat for the building.

2. Vertical stack ventilation is automatically closed in heating conditions.

3. Energy recovery wheels would be used in heating mode to capture any excess heat at relief air locations.

4. At the fourth floor, overhead air distribution would remain.

5. Displacement air distribution will allow galleries and some office spaces to have more efficient heating and/or cooling as required in the lower occupied zones of the spaces.

6. Humidification will be added to enclosed gallery spaces to maintain 50% relative humidity.

7. Radiant heating is provided at the exterior wall locations to provide minimal heat at windows and non occupied spaces.

8. The central chillers are greatly reduced and replaced with higher efficiency units with a more efficient pumping strategy.

9. Earth tubes, buried under the ground, take in exterior air and temper the air prior to entering the building allowing for longer sessions of 100% natural ventilation for the building and pre-tempers the air when additional heating is required to meet demand.

10. The central plant is turned off in heating mode and only supplemental steam heat to the solar hot water system is required.

11. The central space is tempered using a displacement air system that reduces the required load for the space by 60%.

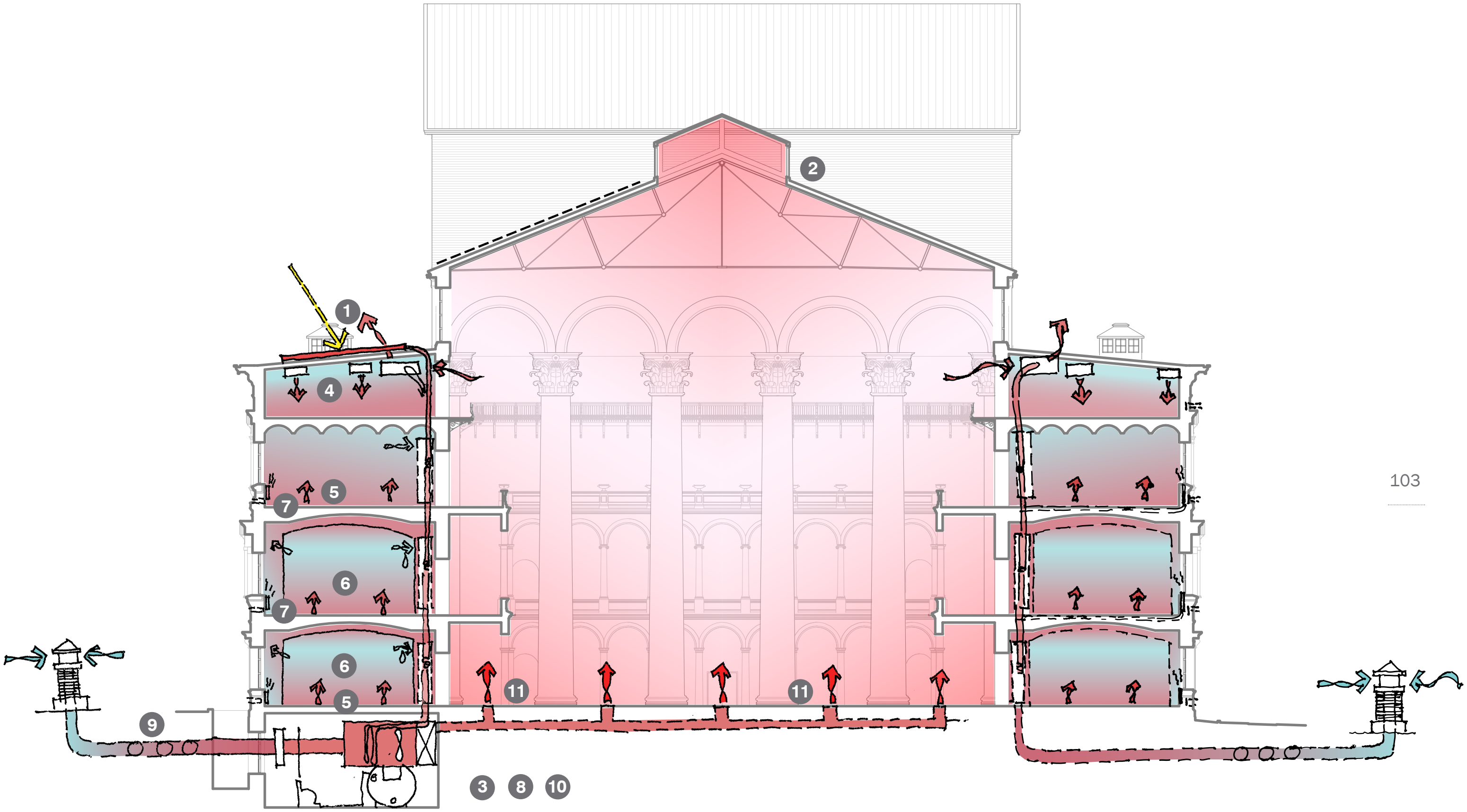


figure 50. **Building section in heating mode**

Path 2

Path 2 represents a *more radical approach* that modifies Meigs' original ventilation methods and also employs the use of the building's thermal mass in a different way. This scenario integrates the Universal Strategy 04 (mechanical efficiency) with two NBM Opportunities (listed below) that help reduce the building's overall resource consumption.

- **NBM OPPORTUNITY 1**
  Provides displacement air as a strategy to reduce the overall conditioning of the Great Hall. The Great Hall, by volume, is the greatest contributor to the overall performance of the building.
- **NBM OPPORTUNITY 3**
  Provides for a second skin on the building that allows for the existing mass of the building to be used as a heat sink for thermally heating the building in the winter, since heating is the highest energy requirement. This path also allows for additional ventilation at the perimeter of the building in the summer by using the vertical stack effect to convey hot air upwards between the two walls.

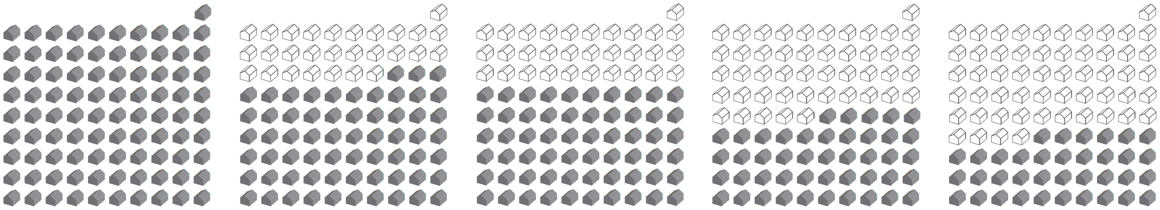
NBM EXISTING ENERGY CONSUMPTION
5,524,381.09 KWH/YEAR
ENERGY COST
$771,062/YEAR

APPLY
NBM STRATEGY 01
4,313,782.71 KWH
NBM STRATEGY 03
3,816,691.65 KWH

APPLY
UNIVERSAL STRATEGY 05
UPGRADE MECHANICAL EFFICIENCY
3,643,835.98 KWH

ADD
EARTH AIR TUBES
3,021,555.58 KWH
LIGHTING/DAYLIGHTING
2,737,425.58 KWH

USE
SOLAR COLLECTION
SAVES 395,477.81 KWH



182 households → - 56 = 126 → - 6 = 120 → - 30 = 90 → - 13 = 77

NEW ESTIMATED ENERGY CONSUMPTION
2,341,948 KWH/YEAR
ENERGY COST
$323, 846/YEAR**

= energy consumed by 2 households

MEETS EXECUTIVE ORDER 13423 GOAL
TO REDUCE FACILITY ENERGY USE PER SQUARE FOOT BY 3% PER YEAR THROUGH THE END OF 2015 OR **BY 30% BY THE END OF FISCAL YEAR 2015**, RELATIVE TO A 2003 BASELINE.

Although this option does not create the most efficient option presented in this study, it does show that there are a number of different ways to achieve a high performance, energy efficient building. The strategies that are outlined in this path not only meet the mandate of 30% reduction by 2015 but exceed it by a estimated 28%.

5,524,381 > 2,341,948 KWH

58%

LESS ENERGY PER YEAR

$771,062 > $323, 846

$447,216

SAVED PER YEAR

** 1 household uses 30,300 kWh of energy per year, Energy Information Admin (DOE) 1993*
*** Assumes maintaining energy rates. $0.14/kWh for electricity. $40.95/MMBtu for steam.*

Path 2: Cooling Mode

1. Solar radiation is used to heat hot water for domestic water and any make up heat for the building.

2. Vertical stack ventilation is allowed to remove the excess heat from the building. Windows would be actuated on control sensors to regulate outside air.

3. A variable double skin glass box is created around the existing building to allow the building to provide additional heating or ventilation strategies.

4. The internal space of the double skin façade is used to create a stack ventilation effect using the rising heat in the space.

5. Openings at the interior wall locations would regulate natural ventilation for individual spaces.

6. Earth tubes, buried under the ground, take in exterior air and temper the air prior to entering the building allow for longer sessions of 100% natural ventilation for the building and pre tempers the air when additional cooling is required to meet demand.

7. The central chillers are greatly reduced and replaced with higher efficiency units with a more efficient pumping strategy.

8. The central space is cooled using a displacement air system that reduces the required load for the space by 60%.

9. Relief air is provided to the internal space of the double skin wall to reduce heat build up in the summer.

10. The top relief vent is automatically controlled to provide relief air to the double skin internal space and the building.

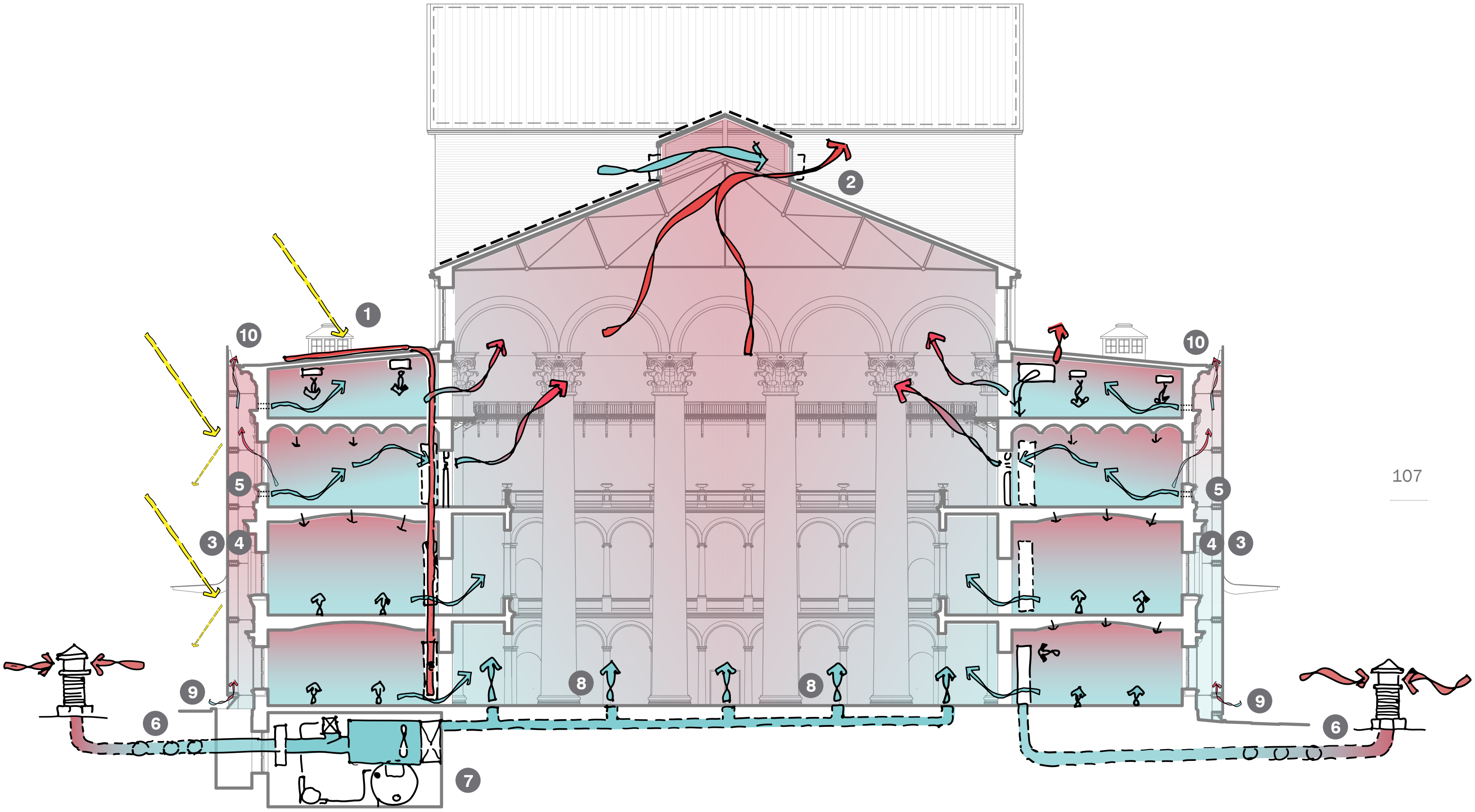


Figure 51. **Building section in cooling mode**

Path 2: Heating Mode

1. Solar radiation is used to heat hot water for domestic water and any make up heat for the building.

2. Vertical stack ventilation is automatically closed in heating conditions.

3. A variable double skin glass box is created around the existing building to allow the building to reduce heating requirement of the mass of the building.

4. The internal space of the double skin façade is heated during the daytime by the solar radiation to provide a thermal trome wall that sinks heat during the day and provides additional insulation at night.

5. Openings at the interior wall locations would regulate to all heated air in and out of the spaces.

6. Earth tubes, buried under the ground, take in exterior air and temper the air prior to entering the building allow for longer sessions of 100% natural ventilation for the building and pre tempers the air when additional heating is required to meet demand.

7. The central plant is turned off in heating mode and only supplemental steam heat to the solar hot water system is required.

8. The central space is tempered using a displacement air system that reduces the required load for the space by 60%.

9. Relief air is limited in the heating mode to allow the internal space of the double skin wall to create heat buildup in the winter.

10. The top relief vent is automatically controlled to provide relief air to the double skin internal space and the building when required.

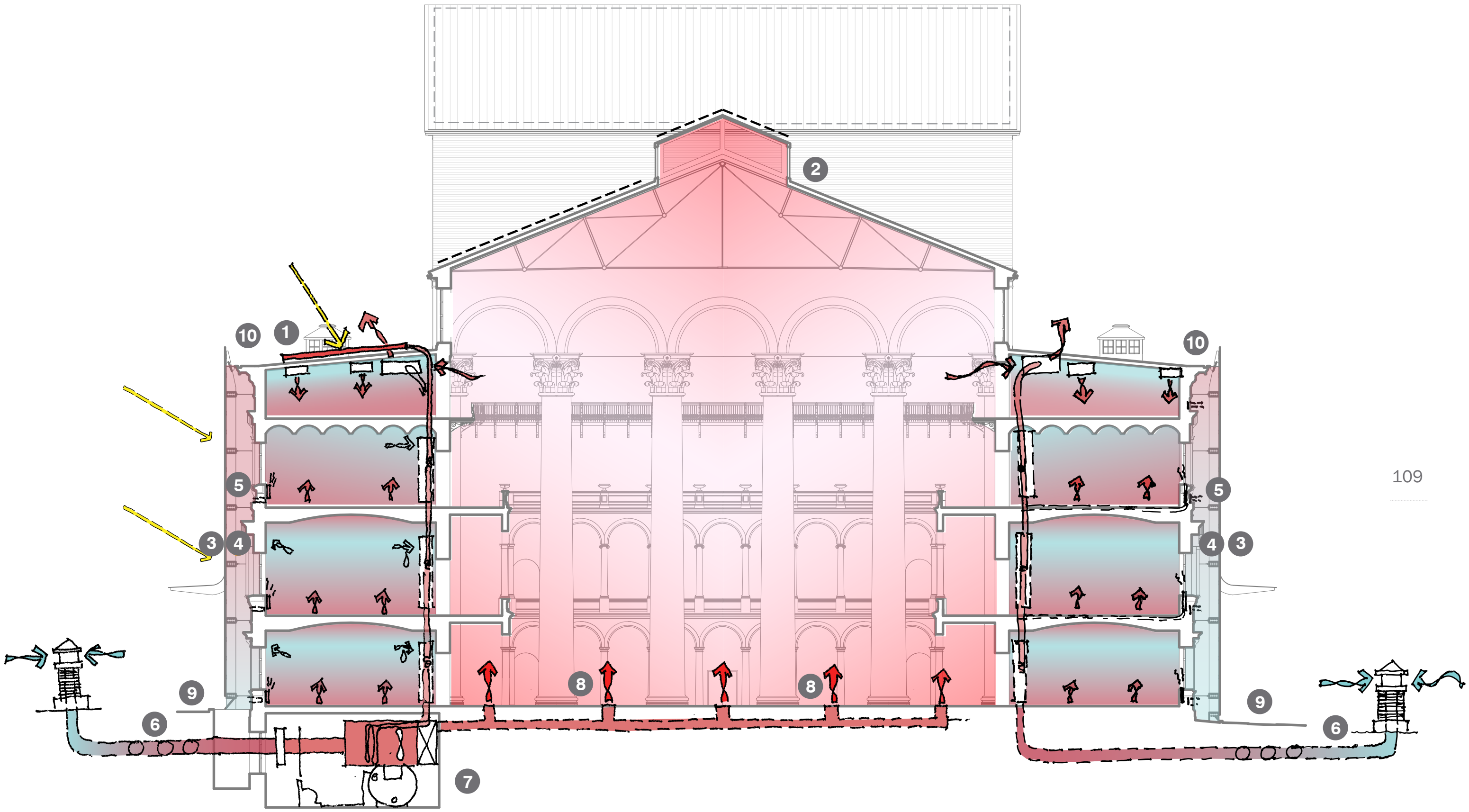


Figure 52. **Building section in heating mode**









Recommendations
for Implementation

Given the national prominence of the National Building Museum and its ability to set the stage for future strategies to be adopted within the design profession, we suggest that the NBM avoid using traditional mechanical systems upgrades to enhance energy efficiency. Instead, we recommend an integrated design solutions similar to those explored in this report. The analysis performed in this report indicates the potential of the strategies studied within, however, a holistic Life Cycle Cost Analysis should be preformed to further refine the most efficient approaches for the building.

The following strategies are the ones that, based on this study, deserve additional consideration for creating the most energy efficient building possible.

1. Decouple the galleries from the rest of the building mass and allow automated natural ventilation to occur within the building.
2. Displacement air system in the great hall to reduce the amount of conditioned air required in the building.
3. Allow the building to return to mixed mode operation in all areas except for the galleries.
4. Install additional daylighting and advanced lighting systems to reduce the lighting load in the building.
5. Reduce water consumption in the building by installing low flow fixtures and through implementing additional strategies outlined in this study. *Note: although water is currently highly undervalued from a cost standpoint, its overall effect on infrastructure and our long term ability to allow for population increase makes it a higher priority.*
6. Reduce mechanical waste through advanced humidification and dehumidification systems for the building's galleries.
7. Create mechanical efficiency by upgrading equipment, utilizing radiant heating and employing improved mechanical ventilation strategies.
8. Pre-temper air through earth tube air system to allow longer natural ventilation periods and reduce the load on mechanical systems.
9. After reducing the building loads through efficacy measures, introduce solar hot water heating along with renewable systems via Photovoltaic panels.

Index: Figures

BNIM people. innovation. design.

BNIM

Kansas City | Houston | Des Moines | Los Angeles | San Diego | bnim.com